












Handbook for Analyzing Greenhouse Gas Emission Reductions in Western States

Designed to Support Planning Analyses in AZ, CO, NM, OR, and WA

AUGUST 2025

Prepared by ICF in collaboration with the Western States of Arizona, Colorado, New Mexico, Oregon, and Washington

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Final

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Acknowledgements

Portions of this Handbook have been derived from the California Air Pollution Control Officers Association (CAPCOA) *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity*, available at CalEEMod.com. This Handbook also retains some text and images from the CAPCOA *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity,* which are reused here as appropriate under the permissions granted by CAPCOA.

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The CAPCOA *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity* is hosted at CalEEMod.com

ICF has adapted that document here, under permission granted by CAPCOA, to apply to the five western states that contributed to its development. We thank the staff at CAPCOA and the five states: Arizona, Colorado, New Mexico, Oregon, and Washington. Most of the measures and calculation methodologies included herein are consistent with the CAPCOA Handbook, with inputs customized for these five states. Exceptions are noted.

We appreciate the support and understanding for this project provided by CAPCOA and the Sacramento Metropolitan Air Quality Management District.

We also thank western state departments for submitting photos for use in this Handbook. Images were received directly from departments in Colorado, Oregon, and Washington and pulled from state government websites for Arizona and New Mexico.

This project was completed with support from the U.S. Climate Alliance.

Authors

This Handbook was written by ICF Incorporated, LLC (hereafter referred to as ICF).

Release Version

This is the final version of this Handbook, version 1. Released August 28, 2025.

An Important Consideration

ICF prepared this Handbook to provide a common platform of information and tools for evaluating greenhouse gas reduction measures in land use planning and project design. It was prepared in collaboration with representatives of multiple departments, local agencies, and academics in the five states and hews closely to the research conducted to develop the CAPCOA Handbook, adapted for these states. The quantification methods, tools, and recommendations provided in this Handbook were developed based on the latest science and literature available at the time of publication.

Our understanding of climate science can and should be addressed in land use planning as it continues to evolve. Regulations, policies, and government programs to reduce greenhouse gas emissions are likewise dynamic. Future legislation, litigation, public opinion, and scientific research will influence how climate change is addressed in communities across the United States.

In light of these considerations, this Handbook should be viewed as a *planning resource*. It provides strategies, tools, and analytical methods to facilitate integrated and resilient decision making, despite potential future planning uncertainty. The Handbook should not be understood as dictating public policy or providing legal advice.

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Acronyms and Abbreviations

°F	degrees Fahrenheit
A/C	air conditioning
AADT	annual average daily traffic
ACCII	Advanced Clean Cars II
ACS	American Community Survey
ACT	Advanced Clean Truck
AF	acre-feet
AFUE	annual fuel utilization efficiency
APCD	Air Pollution Control District
AQI	air quality index
BEV	battery electric vehicle
BMR	below market rate
BRT	bus rapid transit
BTU	British Thermal Unit
CFR	Code of Federal Regulations
CAA	Clean Air Act
CAFE	Corporate Average Fuel Economy
CAPCOA	California Air Pollution Control Officers Association
CARB	California Air Resources Board
CBECS	Commercial Buildings Energy Consumption Survey
CBSA	core-based statistical area
CBTP	community-based travel planning
CCA	Climate Commitment Act
CCR	California Code of Regulations
CE	combustion efficiency
CEC	California Energy Commission; Commission for Environmental Cooperation
CES	Clean Energy (or Electricity) Standards
CEUS	California Commercial End-Use Survey
CFR	Code of Federal Regulations
CH_4	methane

CHP Tool	Combined Heat and Power Energy and Emission Calculator
CHP	combined heat and power
CLTC	California Lighting Technology Center
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COMET	COMET-Planner Tool
CTR	commute trip reduction
DEQ	Department of Environmental Quality
DOC	disposed organic carbon
DOT	Department of Transportation
Du	dwelling units
EA	environmental assessment
EBT	Electronic Benefit Transfer
EDFZ	Electricity Demand Forecast Zone
EMFAC	CARB's EMission FACtor model
EPCA	Energy Policy and Conservation Act
EPRI	Electric Power Research Institute
ET_o	evapotranspiration rate
eVMT	electric mode vehicle miles traveled
Explorer	Cool Surface Savings Explorer
FCEV	fuel cell electric vehicle
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
FVS	Forest Vegetation Simulator
g	grams
gal	gallon
GHG	greenhouse gas
GMP	gross metropolitan product
GREET	U.S. DOE's Greenhouse gases, Regulated Emissions, and Energy use in Transportation model
GWP	global warming potential
ha	hectare

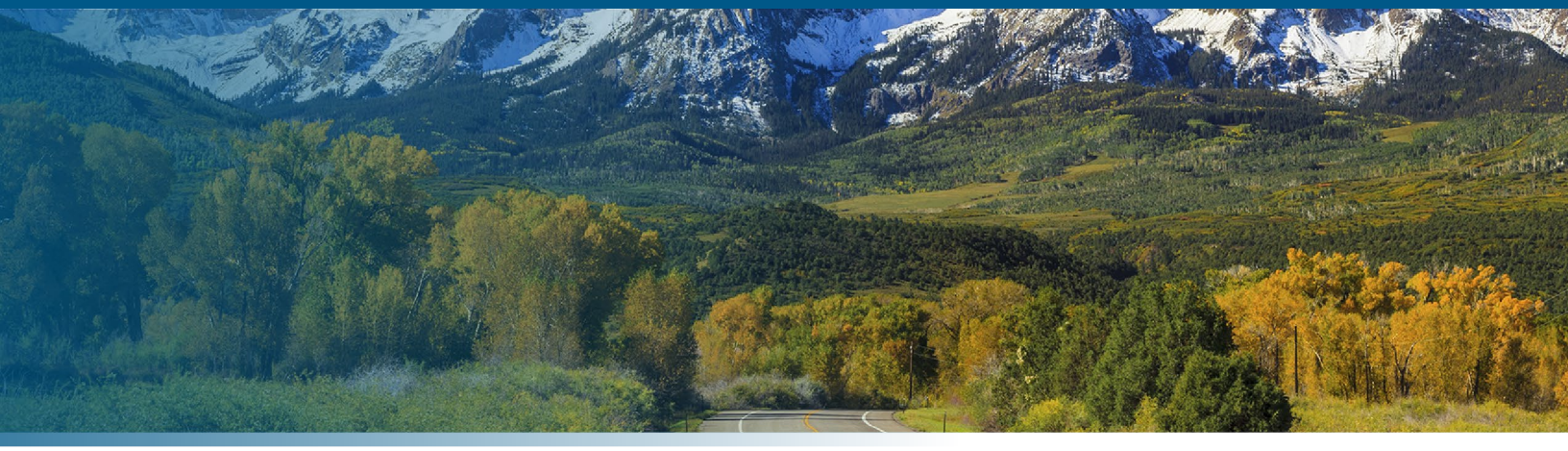
HCFC	hydrochlorofluorocarbons
HDPE	high-density polyethylene
HERS	Home Energy Rating System
HFCs	hydrofluorocarbons
HUD	U.S. Department of Housing and Urban Development
HVAC	heating ventilation and air conditioning
ICE	internal combustion engine
ICT	Innovative Clean Transit
IOUs	investor-owned utilities
IPCC	Intergovernmental Panel on Climate Change
ITE	Institute of Transportation Engineers
ITHIM	Integrated Transport and Health Impact Model
KSF	1,000 gross square feet
kWh	kilowatt-hours
lb	pound
LBNL	Lawrence Berkeley National Laboratory
LED	light-emitting diode
LFG	landfill gas
MCHX	microchannel heat exchanger
MHSA	Mental Health Services Act
MJ	megajoule
mmBTU	1 million British thermal units
MOVES	U.S. EPA's MOtor Vehicle Emission Simulator
mpg	miles per gallon
MPO	metropolitan planning organization
MSA	metropolitan statistical area
MSW	municipal solid waste
MT	metric ton
MTC	Metropolitan Transportation Commission
MWELO	Model Water Efficient Landscape Ordinance
MWh	megawatt-hour
N_2O	nitrous oxide
NAAQS	national ambient air quality standards

NEPA	National Environmental Policy Act
NH_3	ammonia
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic and Safety Administration
NO_2	nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
NOx	oxides of nitrogen
NREL	National Renewable Energy Laboratory
OCCRI	Oregon Climate Change Research Institute
OVC	Oregon Vehicle Code
PFCs	perfluorinated carbons
PHEV	plug-in hybrid electric vehicle
$PM_{2.5}$, PM_{10}	particulate matter less than 2.5 µm or 10 µm in size.
PMT	personal miles of travel
PUD	public utility district
PV	photovoltaic
RAD	Responsible Appliance Disposal
RASS	Residential Appliance Saturation Study
REC	renewable energy certificate
RECS	Residential Energy Consumption Survey
Reporting Rule	Greenhouse Gas Reporting Rule
ROG	reactive organic gases
RPS	Renewable Portfolio Standard
RTP	regional transportation plan
SAF	solar availability factor
SAFE	Safer Affordable Fuel-Efficient
SANDAG	San Diego Association of Governments
SB	Senate Bill
scf	standard cubic foot
sf	square feet
SF_6	sulfur hexafluoride
SHP	separate heat and power
SIP	State Implementation Plan

SO_2	sulfur dioxide
SOx	oxides of sulfur
SPP	Southwest Power Pool
SR2S	Safe Routes to Schools
TCR	The Climate Registry
TE	thermal efficiency
TNC	transportation network company
TOD	transit-oriented development
TRB	Transportation Research Board
TRU	Transport Refrigeration Unit
USDA	U.S. Department of Agriculture
U.S. DOE	U.S. Department of Energy
U.S. EIA	U.S. Energy Information Administration
U.S. EPA	U.S. Environmental Protection Agency
U.S.C.	United States Code
UHI	urban heat island
USFS	United States Forest Service
USGCRP	U.S. Global Change Research Program
USGS	United States Geological Survey
VMT	vehicle miles traveled
VOC	volatile organic compounds
WARM	Waste Reduction Model
WECC	Western Electricity Coordinating Council
WMO	World Meteorological Organization
WSU	Washington State University
WUCOLS	Water Use Classification of Landscape Species
ZNE	zero net energy

Introduction

CHAPTER 1



Background

Climate change has already profoundly affected people and planning in the United States. Local governments, institutions, project developers, and communities across the country must prepare for increasing impacts of climate change while working to reduce their greenhouse gas (GHG) emissions. These are real challenges, but they also represent new opportunities. States can design and build healthier neighborhoods, develop solutions for clean air, and create more equitable, resilient communities and economies. This Handbook offers data and methods to help effectively achieve these objectives.

Local governments and communities are increasingly experiencing the effects of climate change and, in response, are developing measures and plans to mitigate and adapt to those effects. Climate change is principally driven by human actions, particularly burning fossil fuels like coal, oil, and natural gas that emit greenhouse gases. Greenhouse gases trap heat in the atmosphere, which slowly increases global average temperatures, causing additional cascading effects such as extreme heat and heat waves, melting polar and glacial ice, disappearing snowpack, rising sea levels, changing precipitation patterns, ocean acidification, and more extreme or more frequent weather events.

To slow the pace of climate change and prevent its worst effects from materializing, local, state, and national governments must design measures that mitigate (i.e., lessen the severity

or even eliminate) the root cause of the issue: greenhouse gas emissions from human activities. To do so, they need tools and resources to accurately assess and quantify greenhouse gas emissions, and to design effective methods to reduce those emissions.

In response to this need, ICF, in conjunction with five western states: Arizona, Colorado, New Mexico, Oregon, and Washington, has updated the California Air Pollution Control Officers Association *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity* (CAPCOA Handbook) to be applicable to these same states through this *Handbook for Analyzing Greenhouse Gas Emission Reductions in Western States*, (hereafter referred to as the "Western States Handbook"). This Western States Handbook provides methods to quantify greenhouse gas emission reductions from a specified list of measures, primarily focused on project-level actions.

The CAPCOA Handbook includes a wide range of measures that are frequently used to reduce greenhouse gas emissions. Many of the data sources referenced and some of the measures in that Handbook are applicable only to California. This Western States Handbook adapts these data and methods for use outside of California, providing local data for use where available. In cases where measures themselves have been adapted, the changes are described. The measures included here have been screened according to the following factors:

- Feasibility of quantifying emissions reductions or benefits.
- Availability of robust and meaningful data, including peer reviewed studies.
- Ability of measures (alone or in combination with other measures) to appreciably reduce greenhouse gas emissions, reduce climate vulnerabilities, and improve health and equity.

This does not mean that other measures should not be considered or may not be effective or quantifiable; on the contrary, there are many ways to reduce emissions of GHGs. This Western States Handbook offers users a high-quality quantification tool and easily accessible data sources. Users of the Western States Handbook may also find this data useful to inform analysis beyond this Handbook. For example, states could use these methodologies to develop custom tools to support their planning analysis or to develop standard operating procedures to select measures for use in planning. Additionally, the Western States Handbook may be applicable outside of these states. In that case, the user would be responsible for identifying available data and applicability of the measures.

The organizations that helped to prepare this Handbook include:

- Arizona: Governor's Office of Resiliency; Northern Arizona University; and Arizona State University
- Colorado: Colorado Energy Office and Colorado Department of Transportation
- New Mexico: New Mexico Environment Department and Energy, Minerals and Natural Resources Department

- Oregon: Department of Land Conservation and Development; Oregon Department of Transportation; Department of Environmental Quality; Department of Land Conservation and Development; Department of Energy; and Portland Metro
- Washington: Washington State Department of Transportation; Department of Commerce; and Department of Ecology

Process and Approach for Handbook Development

This Handbook builds from the October 2024 version of the CAPCOA Handbook to include measures and data sources appropriate for use in the western states of Arizona, Colorado, New Mexico, Oregon, and Washington.

To revise the CAPCOA Handbook for applicability to these western states, ICF examined each method and data source referenced in the CAPCOA Handbook to determine its relevance outside of California. The availability of data from each state largely determined how methods would be adapted for inclusion here, as many strategies relied on data supporting California-specific regulations.



WHAT'S NEW IN THIS WESTERN STATES HANDBOOK?

This Handbook is all new. It is the first adaptation of the CAPCOA Handbook outside of California.

Data and methodologies have been updated to be applicable to the western states of Arizona, Colorado, New Mexico, Oregon, and Washington.

Measures were evaluated on suitability for use outside of California. Ultimately, all measures in the CAPCOA Handbook were adapted to the Western States Handbook. This is described in Chapter 3. All data from the CAPCOA guide were screened for their appropriateness outside of California and, where applicable, replacement data were collected from this Handbook's five participating states. As this replacement data did not always conform to the same type as the California data, the calculation methods were updated to accommodate the new, local data. Where locally sourced data were not available, ICF identified default values to be used. These values are listed in the Appendix.

Portions of the CAPCOA Handbook have not been adopted here. Specifically, chapters focused on assessing climate exposures and vulnerabilities, measures advancing health and equity, and resiliency and adaptation planning were determined to be excluded from this Western States Handbook. While chapters specifically addressing equity and resilience in planning are not included, we do provide a brief summary of each measure's cobenefits, relevance to supporting climate resilience, and health and equity considerations in the factsheet that introduces each measure.

Intent and Audience

The purpose of this Western States Handbook is to provide planners and governments in Arizona, Colorado, New Mexico, Oregon, and Washington with accurate, reliable, and standardized emission reduction quantification methods for land use, climate action, and long-term planning. The Western States Handbook is intended to support the efforts of local governments to address greenhouse gas emissions in their planning efforts and environmental review of new projects. By creating this standardized approach, the effectiveness of these policy measures can be considered and compared on a common basis. The Handbook will also be useful for project proponents and other parties interested in enhancing resiliency, sustainability, and equitable development.



The guidance provided in the Western States Handbook specifically addresses appropriate procedures to apply quantification methods to achieve accurate and reliable results. The Western States Handbook includes background information on programs and concepts associated with the quantification of reductions in GHG emissions. The Handbook does not provide policy guidance on any of these issues, nor does it dictate how a jurisdiction should address questions of policy. Policy considerations are left to individual agencies and their governing boards.

Using the Handbook

The Handbook is organized as follows.

- *Chapter 1: Introduction*—provides an overview of the Handbook and its contents.
- *Chapter 2: Integrated and Resilient Planning*—discusses the changing climate and state planning efforts to address the problem.
- *Chapter 3: Measures to Reduce Greenhouse Gas Emissions*—provides details on measures and methods to quantify and reduce greenhouse gas emissions, accompanied by measure factsheets.
- *Appendix: Emission Factors and Data Tables*—provides the emission factors and data used to estimate greenhouse gas emission reductions.

Throughout this Handbook, recommended approaches and data are provided. When other high-quality, project-specific data are available, those data should be used instead of the more generalized data presented in this Handbook.

Because the quantification and analysis methods in this Western States Handbook were developed to meet the highest standards for accuracy and reliability, the authors believe they will be generally accepted for most purposes, though the decision to accept any quantification method rests with the reviewing agency and Handbook user. The methods contained in this Western States Handbook include generalized information about the measures, such as considerations and best practices for successful implementation and assumptions that influence the expected measure outcome. These assumptions include emissions factors, energy usage rates, and other data from various sources (most commonly from published data from public agencies at the federal, state, or local level). The data were carefully reviewed to ensure they represent the best information available at the time of publication. The use of generalized information allows the quantification methods to be applied across a range of circumstances, including variations in location, climate, and population density, among others.

The regulatory environment is changing. Users are encouraged to ensure that the data included here align with applicable state and federal policies in place at the time of use. Generally, the methods detailed here will apply even when underlying data change. In cases where high-quality, project-specific data are available, those data should be used instead of the more generalized data presented in this Handbook. The quantification and analysis methods provided in this Handbook allow for such substitutions. Handbook users should confirm any substituted data meets quality standards and will result in an appropriate estimation of measure benefits. More information on the measures and analysis data are provided in Chapter 3, *Measures to Reduce Greenhouse Gas Emissions*.

Equally important to understanding how to effectively use the Handbook is knowing its limitations and potential *misuses*. This will help safeguard against inappropriate application of the Handbook in certain contexts. The Western States Handbook is a reference. It should not be understood to dictate public policy or provide legal advice. While the list of measures presented in the Western States Handbook is extensive, it should not be used to exclude or reject other strategies from consideration. As discussed above, there are many ways to reduce emissions, reduce climate vulnerabilities, and improve health and equity, some of



APPROPRIATE USES OF THIS HANDBOOK

- Explore emissions reduction measures and identify methods to quantify greenhouse gas reductions for a program or plan.
- Learn about co-benefits of reducing greenhouse gas emissions.
- Document current sources and methodologies for greenhouse gas reduction in planning.

which may not be captured in this Handbook or may be developed after its publication. Additionally, the Handbook measures and quantitative methods (including available defaults) should not be automatically applied to a project without thoughtful consideration of project-specific circumstances.

References

California Air Pollution Control Officers Association (CAPCOA). 2024. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Designed for Local Governments, Communities, and Project Developers.* October 2024. Prepared by CAPCOA in association with Sacramento Metropolitan Air Quality Management District, ICF, Fehr & Peers, and STI.

Context and Policy

CHAPTER 2



The Changing Climate

The Earth's climate is dynamic and has shifted over time. However, changes in the global climate have accelerated in recent decades due to human activities. Various federal and state regulations have been adopted to reduce greenhouse gas (GHG) emissions. Beyond regulation, developers and decisionmakers can build in emissions reduction through informed and holistic project planning.

The western United States is already seeing the impacts of climate change on its natural resources, populations, and infrastructure. Major environmental indicators continue to shift. The most recent National Climate Assessment (USGCRP 2023) notes some of the impacts already experienced across the western United States, including the following.

States in the Pacific Northwest, including Washington and Oregon, are increasingly susceptible to heat, flooding, and wildfires, which affect people and natural ecosystems. As climate change leads to hotter and drier conditions, wildfires and exposure to smoke and excessive heat has taken a toll on the population. Declining snowpack is leading to water supply vulnerabilities, particularly in Washington and across central and eastern Oregon, and impacts the efficacy of hydropower, a cornerstone of the Pacific Northwest economy. These developments occur while increased heat adds load demand on the grid. People in this area are also generally unaccustomed to high heat, exemplified by the deadly heatwave of 2021. As an example of the cascading, compounded impacts of climate change already experienced across the region, the 2023 National Climate Assessment notes:

A series of compound events between 2020 and 2021 stressed communities and ecosystems across the western US and caused economic damages exceeding $38.5 billion (in 2022 dollars). In 2020, co-occurring heat and drought caused concurrent destructive fires across California, Oregon, and Washington that resulted in infrastructure and property damage and human fatalities, threatened access to energy and water supplies, and strained firefighting resources. Millions of residents were exposed to harmful pollutants in wildfire smoke, affecting public health and worsening COVID-19 related mortality. Drought persisted into 2021 and amplified the record-breaking Northwest heatwave, killing over 229 people in the US. Co-occurring heat, drought, low streamflow, and low tides in 2021 triggered toxic algal blooms and mass die-offs of shellfish and low survival of salmon, species important to Indigenous communities and the West Coast economy. West Coast crab fishery revenue losses were exacerbated by management actions implemented during earlier marine heatwaves.

In the southwestern U.S., including Colorado, New Mexico, and Arizona, the primary concerns regarding climate change impacts are around heat and water resources. Increasing temperatures are leading to hotter extreme heat events, drier soils, and reduced flows in the most important rivers, including the Colorado and Rio Grande. The Southwest is currently experiencing a "megadrought," the driest 22-year period in 1,200 years (Williams et al., 2022). Extreme heat is increasing heat-related illness and hospitalizations, along with increased wildfire smoke exposure and vegetation shifts. Mountain snowpack is declining and melting earlier. This affects flooding concerns and hydropower availability.

These and other climate hazards have and will continue to negatively impact public health and infrastructure. Increased temperatures, increased specific humidity, and a higher frequency of extreme heat events will lead to worsening air quality and increased risk of dehydration, respiratory problems (e.g., asthma), and cardiovascular problems (e.g., heart attacks) among individuals. Cumulative deterioration of public health from heat-related ailments and other climate stressors are projected to increase emergency room visits and hospitalizations (Ziegler et al., 2017). Extreme events like heat waves, flooding, and wildfires can cause loss of life and directly damage buildings and infrastructure. Extreme weather events can shut down critical services and inhibit individuals from reaching healthcare and other critical supports. Power infrastructure and supply chains can also be disrupted (Health Care Without Harm n.d.). Climate hazards can also have significant indirect impacts, such as increased water prices during drought conditions and reduced recreational opportunities along coastal communities from sea level rise. Although all people will experience the impacts of climate change, underserved, low income, and other socio-economically disadvantaged communities will likely bear a disproportionate share of the burden.

Federal and State Planning Efforts

Policies and regulations are essential to helping economies and societies prosper. They provide structure and limits for government agencies, businesses, civil society organizations, and citizens. They also help realize public benefits like increased safety,

improved health, economic opportunities, and fairness. Regulations often set goals to guide future planning and development efforts and create strategies and mechanisms to achieve those goals.

This section describes important state regulations, policies, and legislation related to GHG emission reductions for the five western states addressed by this Handbook.

The regulatory landscape is constantly shifting as amendments, revocations, and new requirements are adopted. The text in this section was drafted in the first half of 2025 and reflects the regulatory landscape as of this date. Readers may need to conduct additional research to ensure they have the latest information.

Federal Regulations and Requirements

There is no comprehensive federal law specific to climate change or the reduction of GHG emissions, but several federal policies relate to transportation GHG emissions. The following are federal regulations and requirements that were in place when this Handbook was written.

The federal *Clean Air Act (CAA)* was enacted in 1963 and has been amended numerous times since, most recently in 1990. The CAA established federal national ambient air quality standards (NAAQS) for six criteria pollutants and specifies future dates for achieving compliance. These standards were set to improve air quality and public health outcomes. For local areas not meeting those standards, states must submit and implement a State Implementation Plan that demonstrates how the standards will be met (U.S. EPA 2021).

The *National Environmental Policy Act (NEPA)* was signed into law in 1970 and is the foundation of all federal planning efforts. NEPA requires federal agencies to incorporate environmental considerations into planning and decision-making processes by using a systematic, interdisciplinary approach. The purpose of NEPA is "to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans," (42 United States Code [U.S.C.] 4331(a)). Each federal agency adopts its own NEPA procedures, but all must assess the potential environmental effects, and related social and economic effects, of proposed and alternative actions in an environmental assessment (EA) that addresses the environmental impacts of the proposed action, adverse effects that cannot be avoided, alternatives to the proposed action, amongst other findings. For projects where the EA determines the environmental impacts of the proposed action will be significant, the agency must prepare an environmental impact statement, which involves much stricter requirements, greater public participation, and a more detailed analysis.



In 2009, the U.S. Environmental Protection Agency (U.S. EPA) released its final *Greenhouse Gas Reporting Rule (Reporting Rule)*. The Reporting Rule is a response to the 2008 Consolidated Appropriations Act, which required the U.S. EPA to develop mandatory reporting of GHGs above appropriate thresholds. The rule applies to most entities that emit 25,000 metric tons of carbon dioxide equivalent or more per year. Starting in 2010, facility owners were required to annually report their GHG emissions (U.S. EPA 2016).

The U.S. EPA signed the *Endangerment Finding* and *Cause or Contribute Finding for Greenhouse Gases* under Section 202(a) of the CAA in 2009. Under the Endangerment Finding, EPA found that the current and projected concentrations of the six key GHGs—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorinated carbons (PFCs), sulfur hexafluoride (SF_6), and hydrofluorocarbons (HFCs)—in the atmosphere threaten the public health and welfare of current and future generations (U.S. EPA 2020).

In response to the 1973 oil crisis, Congress enacted the *Energy Policy and Conservation Act (EPCA)*. It designed a comprehensive planning approach for federal energy policy with goals of simultaneously increasing energy production, reducing energy demand, and promoting energy efficiency including in buildings. The EPCA established the Strategic Petroleum Reserve, the Energy Conservation Program for Consumer Products, and Corporate Average Fuel Economy regulations.

In 1975, Congress enacted the *Corporate Average Fuel Economy (CAFE) Standards* to reduce vehicle energy consumption by increasing the fuel economy of cars and light trucks. CAFE standards are fleet-wide efficiency averages that must be achieved by each automaker each year. Under CAFE, the National Highway Traffic and Safety Administration (NHTSA) promulgates the CAFE standards in cooperation with the EPA, which regulates vehicle emissions and calculates average fuel economy levels for manufacturers. In 2007, Congress passed the *Energy Independence and Security Act*, raising fuel economy standards and requiring NHTSA to set standards that represent the maximum feasible levels through 2030. The Supreme Court's *Massachusetts v. EPA* decision led to global warming pollution standards for vehicles by EPA under the Clean Air Act. This led to a "harmonized" approach between NHTSA, EPA, and California—which can set its own vehicle emission standards under the Clean Air Act pending a waiver from the EPA. In April 2010, the CAFE standards for model year 2012–2016 passenger cars, light-duty trucks, and medium-duty passenger vehicles were finalized under the new harmonized National Program, with EPA finalizing greenhouse gas emissions standards under the Clean Air Act and NHTSA finalizing CAFE standards under the EPCA. In October 2012, the CAFE standards for model years 2017–2025 were increased. In March 2020, NHTSA passed the SAFE rule, repealing California's preemption waiver under Section 209 of the Clean Air Act (later reinstated in April 2021),

and slowing the increase in fuel economy and CO_2 standards to 1.5 percent annual increases for model years 2021–2026 passenger cars and light trucks. In April 2022, NHTSA updated the standard for passenger cars and light trucks for model years 2024–2026. In June 2024, NHTSA released Fuel Economy Standards for Model Years 2027–2031 passenger cars, light trucks, and heavy-duty pickup trucks and vans. On June 6, 2025, NHTSA published a final interpretive rule, foregoing the public review and comment period, *Resetting the Corporate Average Fuel Economy Program*, which disallows consideration of electric vehicles when setting the maximum feasible fuel economy standards mandated by EPCA and halting enforcement of the last two rounds of CAFE standards for post-2022 model year vehicles.

In 2011, the U.S. EPA and the NHTSA issued the first non-passenger standards, *Final Rule for Phase 1 GHG Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-duty Engines and Vehicles*. This rule includes three regulatory categories of heavy-duty vehicles—combination tractors, heavy-duty pickup trucks and vans, and vocational vehicles—and applies to model years 2014–2018. *Phase 2* of these standards was established in 2016 for model years 2019–2027 (U.S. EPA 2020b). In 2021, EPA finalized its *Rule to Revise Existing National GHG Emissions Standards for Passenger Cars and Light Trucks Through Model Year 2026* (U.S. EPA 2021). In 2022, the agency finalized its *Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards* rule (U.S. EPA 2022). Finally, in 2024 the agency published its *Final Rule: Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles* (U.S. EPA 2024a) and *Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles–Phase 3 rule* (U.S. EPA 2024b). All provide for increasingly stringent vehicle emissions and reduced GHG emissions. As of writing this Handbook, the U.S. EPA has announced plans to repeal certain standards, including EPA 2024a, EPA 2024b, and EPA 2022.

Congress enacted the *American Innovation and Manufacturing (AIM) Act of 2020* to authorize EPA to address the global warming implications of HFCs. It provides EPA new authorities in three main areas: to phase down the production and consumption of listed HFCs, manage these HFCs and their substitutes, and facilitate the transition to next-generation technologies through sector-based restrictions.

State GHG Emission Limits and Reduction Policies

Arizona

As of the publication of this Western States Handbook, the state of Arizona has not set statewide GHG reduction goals. However, the City of Phoenix implemented a goal of a carbon-neutral city by 2050 operating on 100 percent clean energy. The City of Flagstaff, the City of Tucson, the City of Tempe, and Pima County have also established robust action plans to pursue carbon neutrality and mitigate environmental and community impacts.



Arizona has committed to meeting GHG reduction goals set in cooperation with the U.S. Climate Alliance, a bipartisan coalition aiming for a national net zero future. This goal is 50-52 percent reduction below 2005 levels by 2030 and 61-63 percent reduction by 2035.

Colorado

HB19-1261, The Climate Action Plan to Reduce Pollution, signed in 2019, set a GHG reduction goal for Colorado to achieve economy-wide, net emission reductions of 50 percent below 2005 levels by 2030 and 90 percent below 2005 levels by 2050. The bill requires an air quality control commission to take specific considerations, such as cost of compliance or clean energy incentives, in implementing policies to reduce pollution. Governor Jared Polis signed SB23-016, Greenhouse Gas Emissions Reduction Measures, in 2023. The measures modified the economywide emissions reduction targets to add a 65 percent reduction by 2035, a 75 percent reduction by 2040, a 90 percent reduction by 2045, and an increase of the 2050 goal to net zero by 2050 when compared to 2005 GHG pollution levels.



In 2019, Governor Jared Polis's administration created the Roadmap to 100 percent Renewable Energy by 2040 and Bold Climate Action plan. The plan documented current and future funding opportunities and legal initiatives that achieve renewable energy goals.

The Greenhouse Gas Pollution Reduction Roadmap, released in 2021, carved a pathway to achieve

Colorado's statutory emissions reduction goals. The roadmap details actions for the electric utility, transportation, agricultural, and fuel industries to participate in meeting climate related goals in Colorado. A Greenhouse Gas Pollution Reduction Roadmap 2.0 was published in February 2024, which built upon the prior version and identified additional near-term actions to further reduce GHG emissions.

New Mexico



Executive Order 2019-003, signed in 2019, implemented a goal to reduce economy-wide GHG emissions to 45 percent below 2005 levels by 2030. The order created the Climate Change Task Force responsible for creating regulatory strategies to successfully achieve this goal.

Signed in 2025, SB83 established the Innovation in State Government Fund that provided critical funding to state agencies to assist in: (1) achieving net-zero emissions; (2) implementing sustainable economic policies; (3) providing technical support to entities applying for grants and other funding that seek to address climate change; and/or (4) implementing, enabling or reducing the barriers to implementing climate change policy.

Also signed in 2025, SB48 established the Community Benefits Fund to fund projects that decrease state greenhouse gas emissions, including updating public buildings, reducing leaks and releases attributable to the extractive industries, assisting decreasing use of internal combustion engines and assisting public entities with funding vehicles and infrastructure, increasing grid capacity and use of renewables, and establish or expand economic development needed to address the economic implications of climate change.

Submitted to the EPA in 2024, New Mexico's Priority Climate Action Plan identifies key strategies to reduce GHG emissions while delivering public health, economic, and air quality benefits across the state. Building on this foundation, New Mexico will release a Comprehensive Climate Action Plan in December 2025 to guide progress toward achieving its economy-wide GHG reduction targets.

Oregon

House Bill 3543, signed in 2007, originally set GHG reduction goals for the state of Oregon to reduce emission levels to 75 percent below 1990 levels by 2050; it also established the Oregon Climate Change Research Institute (OCCRI) to provide accessible information and technical assistance about climate change policy. The OCCRI has published biennial Oregon Climate Assessments to monitor effects of climate change and updated information on the state of climate change research. Executive Order 20-04,

signed in 2020, set new goals to reduce economy-wide, gross greenhouse gas levels to 45 percent below 1990 levels by 2035, and to 80 percent below 1990 levels by 2050.

In January 2025, Oregon became the nation's third state to create a carbon trading market. However, unlike California and Washington, it only affects emissions from fuels and certain industries. The Climate Protection Program establishes an enforceable cap and trade program on fuel suppliers to reduce state GHG emissions. Fuel suppliers either submit their allowances or submit a Community Climate Investment credit that covers 15 percent of their compliance by January 1, 2025. Community Climate Investment credits are earned by contributing money to fund projects reducing GHG emissions.

The Oregon Climate Action Roadmap to 2030 recommends accelerating the state's GHG reduction to 95 percent below 1990 levels by 2050. The roadmap uses an assessment from the Technical Integrated Greenhouse Gas Emissions Reduction Project Report to inform 26 sub-recommendations for climate actions. Recommendations include evaluations of current climate programs, future legislation, and promoting accountability.



The Statewide Transportation Strategy: A 2050 Vision for Greenhouse Gas Emissions Reduction is Oregon's roadmap to substantial emission reductions from the transportation sector. The strategy contains key actions that agencies, private industry, and Oregonians can take to reduce greenhouse gas emissions from transportation. Oregon state agencies have built on the Statewide Transportation Strategy for the last decade and are working within their authority under various programs and policies to reduce emissions from transportation. Each agency is working toward the common 80 percent reduction goal.

Washington

Washington has GHG emission limits established in state law RCW 70A.45. Under the law, the state is required to reduce emissions levels to 45 percent below 1990 levels by 2030, 70 percent below 1990 levels by 2040, and 95 percent below 1990 levels by 2050 with net zero emissions.



The Climate Commitment Act (CCA), signed in 2021, is a market instrument for carbon trading to limit emissions from major sources and uses revenue from allowance auctions to fund initiatives that reduce carbon emissions and address other environmental and social priorities. This includes investments in transportation, housing, public health and more. Washington is the nation's second state to adopt such a cap-and-invest program, requiring the state's biggest pollutors to participate in lowering an annual emissions limit over time to meet Washington's GHG reduction targets. Businesses receive allowances that are equal to their annual emissions and can sell allowances at quarterly auctions. Revenue from allowances are reinvested into a wide range of environmental, social, and equity priorities statewide. Emission reductions come from these investments and the declining emission cap.. The program began in 2023 and required businesses to submit their emission allowances and a four-year compliance schedule.

The Hydrofluorocarbons–Emissions Reduction bill, signed in 2021, requires the Washington Department of Ecology to set a maximum global warming potential of hydrofluorocarbons used in refrigeration and air conditioning equipment sold in the state. The state must establish a management program to reduce HFC leakage.

State Clean Energy and Conservation Policies

Arizona

Arizona developed and implemented its Efficiency Arizona rebate program for income-qualified households to install highly efficient appliances and electrical equipment. The program promotes energy efficiency, improves home comfort, and saves Arizonans money on their energy bills.

Colorado



SB 21-264 requires gas distribution utilities to reduce GHG emissions by 22 percent from 2015 levels. The bill also requires investor-owned gas utilities to file a "Clean Heat Plan" to meet reduction goals. A Clean Heat plan includes energy efficiency programs, methane capture, use of hydrogen, and electrification of heating systems.

The Energy Performance Buildings Act, adopted in 2021, requires Colorado's largest buildings to reduce emissions by 20 percent of 2021 levels by

2030. Under the act, the Colorado Air Quality Control Commission created a Building Performance Standards Rule, which requires building owners to report how much energy they use every year.

HB21-1303, signed in 2021, requires the Department of Personnel and Administration and the Colorado Department of Transportation to create a maximum global warming potential in construction materials and a method of tracking GHG emissions released by said materials.

HB21-1253 established renewable and clean energy grants for the state of Colorado by allocating $5 million to the Department of Local Affairs.

New Mexico

In 2019, New Mexico's Energy Transition Act (SB 48) set statewide renewable energy standards for IOUs and rural electric co-ops within the state. In 2025, New Mexico's Energy Natural Resources Department launched the state Comprehensive Energy Transition Strategy (CETS) to conduct additional planning for New Mexico to transition to a zero-carbon economy. It includes specific goals for renewable energy and zero-carbon resources, with targets for utilities and rural electric cooperatives. The CETS also aims to enhance New Mexico's decarbonization efforts and reflect the needs and equities of multiple state departments and their interested parties.

Executive Order 2019-003 directed the state's Environment and Energy, Minerals and Natural Resources Departments to jointly develop a regulatory framework to reduce oil and gas sector methane emissions and prevent waste. To fulfill this directive, a methane waste rule that requires oil and gas operators to capture 98 percent of their natural gas emissions by 2026 and prevents routine venting and flaring of natural gas was developed by the Energy, Minerals and Natural Resources Department. Similarly, the Environment Department developed a rule to limit ozone precursor emissions from the oil and gas industry, which has the co-benefit of reducing methane pollution.

Following the issuance of Executive Order 2021-052, New Mexico developed a 30 by 30 Advisory Committee that established conservation targets of conserving at least 30 percent of all lands in New Mexico by 2030. As part of the Committee's actions, the Forestry Division helped document that 35 percent of state lands are conserved, with over 39 MMT of carbon sequestered on private lands, including forests, woodlands, and grassland.

The 50-Year Water Action Plan puts forth 11 priority actions to ensure water conservation efforts result in healthy watersheds, reliable ground water supply, and access to clean water. Some objectives include reducing agricultural water usage by 20 percent and general community water consumption by 10 percent.

Additional recent clean energy legislation includes 2020 HB 93 (Efficient Use of Energy Act), 2020 HB 233 (Energy Grid Modernization Roadmap), 2021 HB 15 (Sustainable Building Tax Credit), 2021 HB 84 (Community Solar Act), 2022 HB 37 (Community Energy Efficiency Development Block Grant), and 2022 HB 95 (Renewable Energy Office in State Land Office).

The New Mexico Workforce Innovation and Oportunity Act outlines a strategy to prioritize clean energy jobs. Additonally, the New Mexico Department of Workforce Solutions received support from the Energy Transition Workforce Equity to connect employers, educational institutions, state agencies, and community-based orginizations to expand New Mexico's clean energy workforce.

Oregon

The Clean Energy Targets bill, signed in 2021, requires certain electricity suppliers to reduce GHG emissions from the electricity they provide. Oregon's Department of Environmental Quality and Public Utility is responsible for collecting emissions data from electricity suppliers and calculating reduction targets.

SB 1547, signed in 2016, increased Oregon's Renewable Portfolio Standard to 50 percent renewables by 2040. Through the portfolio, the Western Renewable Energy Generation Information System issues Renewable Energy Certificates (RECs) for energy facilities. One REC is received for one megawatt-hour of renewable energy delivered to the grid.

SB 582 or the Plastic Pollution and Recycling Modernization Act, signed in 2022, updates Oregon's recycling system by expanding recycling and reducing plastic pollution.

Washington



The Clean Energy Transformation Act, signed in 2019, commits Washington to an electricity supply that is carbon neutral by 2030 and free of GHG emissions by 2045. The law includes safeguards to keep affordable rates and reliable service.

The Clean Building Act, signed in 2019, required the Washington State Department of Commerce to develop and implement an energy performance standard and encourage energy efficiency. The act provides building owners with incentives to make energy efficiency improvements at a faster rate. It was expanded in 2022 through SB 5722, which mandates owners of large buildings to benchmark and disclose their building's energy use.

Under HB 1112, signed in 2019, newly manufactured equipment must be limited to using climate-safe alternatives to hydrofluorocarbons according to a series of deadlines for different equipment categories such as commercial refrigeration. In 2021, RCW 70A.60 expanded on these restrictions and directed the Department of Ecology to establish a refrigerant management program.

The Growth Management Act (RCW 36.70A) requires cities and counties to develop comprehensive plans and development regulations for their communities. Key goals of

the Growth Management Act include promoting urban growth while reducing sprawl and protecting undeveloped land. While originally enacted in 1990, the Growth Management Act has been amended multiple times since. HB 1181, signed in 2023, integrates climate planning with the comprehensive plans required under the Growth Management Act.

HB 1663, signed in 2022, set a goal of reducing organic material going into landfills by 75 percent by 2030 to target methane emissions. Municipal landfills must install equipment that captures and destroys methane. The bill requires quarterly monitoring of landfill surfaces and gas collection to check for methane leaks. Additionally, $15 million in grants from the CCA will assist landfill owners with compliance.

The Forest Products Sector Carbon Bill, signed in 2020, recognizes the vitality of the forestry sector in sequestering carbon. The bill supports reforestation and production of wood products that retain carbon.

The Climate Change Resilience Strategy maps out state-level climate resilience strategies to support communities and infrastructure in the state of Washington.

As of writing this handbook, Washington State is developing its Comprehensive Climate Action Plan, a long-term plan to meet state and federal climate and energy mandates.

State Clean Vehicle Policies and Incentives

California Vehicle Emission Standards

The Clean Air Act allows California to receive a waiver from the U.S. EPA on federal vehicle emissions standards and set its own standards for vehicles to address its historically unique air quality issues. Under Section 177 of the Clean Air Act, other states are allowed to adopt California's vehicle emissions standards. In 2022, the California Air Resources Board (CARB) adopted the Advanced Clean Cars II (ACC II) standard, which set regulations to target emissions of light-duty passenger cars, pickup trucks, and SUVs. The states of Washington and Oregon adopted ACC II to be enforced beginning in 2026, while New Mexico and Colorado will enforce the standard beginning in 2027. CARB also has adopted the Advanced Clean Trucks (ACT) regulation to require sales of medium- and heavy-duty zero emission vehicles. Washington, Oregon, New Mexico, and Colorado all plan to implement ACT regulations within the next three years. In May and June 2025, the U.S. Senate passed and the President signed three resolutions under the Congressional Review Act overturning the EPA waivers allowing these California regulations: H.J. Res. 88 voided the ACC II rule; H.J. Res. 87 voided ACT and related rules; and H.J. Res. 89 voided other pollution emissions limits.

California Low Carbon Fuel Standard

The California Air Resources Board (CARB) designed their Low Carbon Fuel Standard (LCFS) to decrease the carbon intensity of California's transportation fuel pool and provide a range of renewable and low-carbon alternatives. Each fuel type is given an associated life cycle assessment examining the greenhouse gas emissions associated with

the production, transportation, and use of the fuel in question, resulting in a carbon intensity (CI) score. These scores are then compared to a specific CI benchmark for each year and fuel type, which then generate either credits or deficits as compared to the benchmark. Transportation fuel providers are required to show that the mix of fuels they supply meets the LCFS carbon intensity standards. Oregon's and Washington's Clean Fuel Standard programs are modeled on California's standard.

Colorado

SB21-260, signed in 2021, created three transportation electrification enterprises to support electric vehicle charging, hydrogen fueling infrastructure, EV adoption, and conversion of zero emission vehicles.

Colorado offers $3,500 for the purchase or lease of an EV with a retail price of less than $80,000.

New Mexico

New Mexico offers tax credits for consumers purchasing clean cars. Clean car purchasers can receive up to $3,000 for a vehicle and up to $400 when installing an at-home vehicle charging station.

In December 2023, New Mexico implemented a suite of three rules that reduce transportation emissions, collectively referred to as New Motor Vehicle Emission Standards. The first rule, Advanced Clean Cars II, stipulates that starting in 2026, 43 percent of all new passenger cars and light-duty trucks shipped to New Mexico auto dealerships must be zero-emission vehicles. The percentage of zero emission light-duty vehicles shipped to New Mexico will increase over time. The second rule, Advanced Clean Trucks, stipulates that by 2035, 40–75 percent of new on-road, medium- to heavy-duty vehicles delivered for sale in the state must be zero-emission. Lastly, Heavy-Duty Omnibus requirements provide updated standards, testing, and compliance mechanisms for tailpipe emissions of nitrogen oxides and particulate matter from on-road heavy-duty vehicles.

In 2024, House Bill 41 established New Mexico's Clean Transportation Fuel Program, which will reduce the carbon intensity of transportation fuels used in the state by 20 percent by 2030 and 30 percent by 2040.

Oregon

The Oregon Clean Fuels Program, in 2022, set a goal of reducing carbon content of transportation fuels to 37 percent below 2015 levels by 2035. The Oregon Department of Environmental Quality determined carbon intensity for each fuel and gradually lowers carbon intensity allowed each year to meet their reduction goal.

The Oregon Clean Vehicle Rebate Program offers up to $7,500 for purchasing or leasing a qualified electric vehicle. For installing an EV charging station at a multifamily home or public parking area, Oregon offers rebates up to 75 percent off eligible project costs.

The Portland General Electric (PGE) Electric School Bus Fund helps public school districts support electric school buses in its service area. This program leverages funding from the Oregon Clean Fuels Program to pay for the incremental cost of an electric school bus and charging infrastructure.

Washington

Through Washington's Clean Vehicles Program, the state adopted California's vehicle emissions standards and mandates that a percentage of new vehicles sold in Washington must be zero-emission vehicles. Washington State has set a goal of 100 percent of new vehicle sales to be zero-emission vehicles by 2035.

The Clean Fuel Standard requires fuel suppliers to reduce transportation emissions to 20 percent below 2017 levels by 2034. Methods of reduction include fuel efficiency, producing low-carbon biofuels, and purchasing credits generated by low-carbon fuel providers. Under the Clean Fuel Standard, the Agricultural and Forestland Carbon Capture & Sequestration Advisory Panel advises on carbon sequestration on agricultural and forest lands.



SB 5974 established Washington State's target that passenger and light-duty vehicles of model year 2030 or later will be electric vehicles if they are to be sold, purchased, or registered in Washington.

Washington State has also set targets for vehicle-miles-traveled per capita reduction through RCW 47.01.440. These benchmarks aim for a 30 percent reduction by 2025 and a 50 percent reduction by 2050.

The Washington State Electric Vehicle Charging Program provides grants to incentivize the installation of EV chargers at eligible sites, including multi-family housing underserved urban and suburban locations, and rural and tribal locations.

The Washington Department of Commerce also offered eligible low-income residents the opportunity to apply for rebates in amounts between $2,500 and $9,000 to purchase or lease an EV at the time of purchase or lease. Automakers that provided point-of-sale rebates to eligible residents also received reimbursement.

Washington has many other programs to support projects consistent with Washington's climate goals. Appendix C of Washington State's Transportation Carbon Reduction Strategy provides a comprehensive list of state and federal funding opportunities.

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Measures to Reduce GHG Emissions

CHAPTER 3



This Western States Handbook includes a wide range of measures that are frequently used to reduce greenhouse gas (GHG) emissions and provide other benefits, like improved air quality, energy and fuel savings, and water conservation. This chapter provides methods and data to quantitively evaluate many of the measures. While there is no one-size-fits-all approach to GHG planning, the guidance presented in this chapter has been developed to broadly apply across project types, land use types, and regions throughout Arizona, Colorado, New Mexico, Oregon, and Washington (collectively referred to as the "Western States").

Categorizing Measures

When thinking about minimizing GHG emissions in a community or for a project, it is useful to organize GHG reduction measures into categories. A standard method of categorizing emissions is to group them by economic sector, such as transportation or energy. Consistent with this practice, the emission reduction measures presented in this chapter are categorized into the following nine sectors. Measures in each sector apply to a similar emissions source or process, as described below.

- Transportation: Measures that promote transit and alternative transportation, support use of alternatively fueled vehicles, or encourage land use planning practices that reduce vehicle trips and vehicle miles traveled (VMT). Measures within the transportation sector are separated into seven subsectors: Land Use, Neighborhood Design, Parking or Road Pricing/Management, Transit, Trip Reduction Programs, Clean Vehicles and Fuels, and School Programs.
- Energy: Measures that target energy efficiency improvements/reduced fossil fuel consumption, renewable energy generation, building electrification, or methane (CH_4) recovery at landfills and wastewater treatment plants.
- Water: Measures that reduce water demand and/or use a less energy-intensive water source.
- Lawn and Landscaping: Measures that promote zero-emission landscaping equipment over conventional fossil fuel-powered counterparts.
- Solid Waste: Measures that require alternative waste management pathways, such as recycling and composting, to increase landfill waste diversion and prevent edible food from going to the landfill so it can be consumed by those in need.
- Natural and Working Lands: Measures that enhance the sequestration/carbon storage capacity of natural lands (including wetlands) or reduce the intensity of emissions from working lands (including farms and working forests) and promote zero-emission agriculture equipment over fossil fuel-powered counterparts.
- Construction: Measures that promote efficient construction management practices or alternatively fueled construction equipment.
- Refrigerants: Measures to reduce or replace high global warming potential (GWP) refrigerants with lower impact compounds.
- Miscellaneous: General measures that will reduce GHG emissions through the implementation of novel or off-site projects defined by the user and promote zero-emission off-road equipment over fossil fuel-powered counterparts.

EMISSIONS SECTORS

Categorizing emissions by sector is standard practice for GHG inventories and reduction plans, but users should note that variation often occur in the scope and nomenclature of sectors. For example, the sectors in this Handbook do not align exactly with state or U.S. Environmental Protection Agency inventories because of differences in scale and intended use. Users should take care when comparing sectors in this Handbook to other inventories or plans.

The nine emission sectors are illustrated in Figure 3-1. The figure shows all quantified GHG reduction measures included in this chapter. Users may click on an individual measure to navigate directly to the quantification method for that measure. Figure 3-1 does not include non-quantified measures. These measures are presented later in this chapter in *Supporting or Non-Quantified GHG Reduction Measures*.

Figure 3-1. Navigation Trees for Quantitative GHG Reduction Measures



Energy

ENERGY EFFICIENCY IMPROVEMENTS

- E-1. Implement a Plan to Improve Building Energy Efficiency
- E-2. Require Energy Efficient Appliances
- E-3-A. Require Energy Efficient Residential Boilers
- E-3-B. Require Energy Efficient Commercial Packaged Boilers
- E-4. Install Cool Roofs and/or Cool Walls in Residential Development
- E-5. Install Green Roofs in Place of Dark Roofs
- E-6. Encourage Residential Participation in Existing Demand Response Program(s)
- E-7. Require Higher Efficacy Public Street and Area Lighting
- E-8. Replace Incandescent Traffic Lights with LED Traffic Lights
- E-9. Utilize a Combined Heat and Power System
- E-21. Install Cool Pavement

RENEWABLE ENERGY GENERATION

- E-10-A. Establish Onsite Renewable Energy Systems—Generic
- E-10-B. Establish Onsite Renewable Energy Systems—Solar Power
- E-10-C. Establish Onsite Renewable Energy Systems—Wind Power
- E-11. Procure Electricity from Lower Carbon Intensity Power Supply
- E-26. Biomass Energy

BUILDING DECARBONIZATION

- E-12. Install Electric Water Heater in Place of Gas Storage Tank Heater in Residences
- E-13. Install Electric Cooking Appliances in Place of Gas Appliances
- E-14. Limit Wood Burning Devices and Natural Gas/Propane Fireplaces in Residential Development
- E-15. Require All-Electric Development
- E-16. Require Zero Net Energy Buildings
- E-17. Require Renewable-Surplus Buildings

METHANE RECOVERY

- E-18. Establish Methane Recovery in Landfills
- E-19. Establish Methane Recovery in Wastewater Treatment Plants

Water

- W-1. Use Reclaimed Non-Potable Water
- W-2. Use Grey Water
- W-3. Use Locally Sourced Water Supply
- W-4. Require Low-Flow Water Fixtures
- W-5. Design Water-Efficient Landscapes
- W-6. Reduce Turf in Landscapes and Lawns
- W-7. Adopt a Water Conservation Strategy

Lawn and Landscaping

- LL-1. Replace Gas Powered Landscape Equipment with Zero-Emission Landscape Equipment

Solid Waste

- S-1. Institute or Extend Recycling Services
- S-2. Implement Organics Diversion Program
- S-3. Require Edible Food Recovery Program Partnerships with Food Generators

Natural and Working Lands

- N-1. Create New Vegetated Open Space
- N-2. Expand Urban Tree Planting
- N-3. Implement Management Practices to Improve the Health and Function of Natural and Working Lands
- N-4. Require Best Management Practices for Manure Management
- N-7. Wildfire Resilience and Management
- N-8. Agricultural Equipment Efficiency

Construction

- C-1-A. Use Electric or Hybrid Powered Equipment
- C-1-B. Use Cleaner-Fuel Equipment
- C-2. Limit Heavy-Duty Diesel Vehicle Idling
- C-3. Use Local Construction Contractors

Refrigerants

- R-1. Use Alternative Refrigerants Instead of High-GWP Refrigerants
- R-2. Install Secondary Loop and/or Cascade Supermarket Systems in Place of Direct Expansion Systems
- R-3. Install Transcritical CO_2 Supermarket Systems in Place of High-GWP Systems
- R-4. Install Microchannel Heat Exchangers in A/C Equipment in Place of Conventional Heat Exchanger
- R-5. Reduce Service Leak Emissions
- R-6. Reduce Operational Leak Emissions
- R-7. Reduce Disposal Emissions

Miscellaneous

- M-1. Establish a Carbon Sequestration Project
- M-2. Establish Offsite Mitigation
- M-3. Implement an Innovative Strategy for GHG Mitigation
- M-6. Off-Road Equipment Efficiency

Selecting Measures

The GHG reduction measures presented in this chapter are diverse. Users are encouraged to carefully review the measure factsheets to determine which measures are most applicable to their project and capable of achieving their GHG reduction goals. A user might implement measures to reduce GHG emissions for several reasons. Some measures may be implemented voluntarily, when users are seeking to reduce their GHG footprint. Other users may be obligated under law or statute to mitigate current or future impacts of specific actions or activities. This can include project-level impacts, such as those evaluated under state environmental regulations like Washington's State Environmental Policy Act, or plan-level impacts, such as those resulting from the implementation of a general plan or climate action plan.

When considering which measures are applicable from the Handbook, the underlying reasons and context for reducing GHG emissions should be incorporated into the decision-making process. For example, if a user is seeking to achieve substantial GHG reductions to comply with a regulatory requirement, measures that have the greatest potential to reduce emissions may be most applicable. Or, if a city is aiming to implement a climate action plan by engaging the community, measures that inspire community members and are easily accessible and affordable may be the most applicable.

Other factors for determining measure applicability include the project type, scale, and locational context. Some measures are broad and applicable to many types of projects (e.g., Measure E-2, *Require Energy Efficient Appliances*), while others have a narrower scope of application (e.g., Measure E-19, *Establish Methane Recovery in Wastewater Treatment Plants*). Additionally, certain measures are suitable for urban environments, while others are best implemented in rural contexts. The measure factsheets presented in *GHG Reduction Measure Factsheets and Quantification Methods* later in this chapter summarize these and other important considerations for measure selection to support informed decision making.

Consideration of Measure Co-Benefits

Co-benefits, or additional benefits that often are associated with emissions reduction measures, are valuable elements of climate action planning. Citing co-benefits has become increasingly prevalent when justifying the funding, planning, and implementing of emission reduction measures. Like the quantification of GHG reductions, only those benefits with literature and methodologies to support their accurate and reliable quantification are presented in this chapter. Where quantification is not achievable, co-benefits are noted qualitatively for each measure.

The co-benefit categories considered in this Handbook include the following and are visually depicted in the measure factsheets by the corresponding icons.



Improved air quality. Criteria pollutant reductions.



Energy and fuel savings. Electricity, natural gas, refrigerant, propane, gasoline, or diesel reductions.



VMT reductions. Reductions in vehicle miles traveled.



Water conservation. Water use reductions.



Enhanced pedestrian or traffic safety. Reduced collisions; pedestrian/bicyclist safety.



Improved public health. Toxic air contaminant reductions (including exposure); increased physical activity; improved public safety.



Improved ecosystem health. Increased biological diversity; improved soil and water quality.



Enhanced energy security. Systemwide load reduction; local energy generation, levelling out peaks.



Enhanced food security. Stability of food systems; improved household access to food.



Social equity. Address existing social inequities (e.g., housing/anti-displacement, community engagement, availability of disposable income).

This Handbook assigns co-benefits to measures that are likely to result from measure implementation; however, it should be noted that the achievement of co-benefits is not guaranteed because many co-benefits are dependent on how the measure is implemented. Determining what co-benefits apply to an individual measure in a specific circumstance is beyond the scope of this Handbook. Co-benefits vary widely, and no single methodology

can be uniformly applied for this purpose. When considering co-benefits that may be achieved, it is best to comprehensively think through the implications of implementing that measure. For example, Measure E-12, *Install Alternative Type of Water Heater in Place of Gas Storage Tank Heater in Residences,* reduces GHG emissions because it eliminates the onsite combustion of natural gas. Because combusting natural gas also results in emissions of other air pollutants that can cause adverse health effects, this measure would also improve air quality and achieve public health benefits. These co-benefits would be achieved by the measure in all project applications. Depending on where and how the measure is implemented, it may also reduce energy costs, address disparities in social equity, and protect a homeowner or renter from rapid changes in fossil fuel prices, especially if solar energy is produced locally or on site. Users are encouraged to use the co-benefit icons identified for each measure as a starting point for this type of thought exercise and expand or revise for their specific project or application.

Note that while all measures achieve at least one co-benefit, some measures may also yield a disbenefit. For example, measures that electrify a fossil-fuel source may lead to improved air quality and fuel savings but increased electricity consumption. Such measures may or may not reduce overall energy costs to consumers. Potential disbenefits are discussed, where appropriate, for individual measures.

Quantifying GHG Reductions

The emissions quantification methods in this chapter are designed to provide GHG estimates using readily available data and user-specified information. In general, emission reductions are quantified (1) as a percentage of emissions from a given source or activity, or (2) as absolute emissions reductions from a given source or activity implementation of the measure. Where appropriate, some measures refer readers to external tools to quantify GHG reductions.

Quantification methods that provide a percent reduction rely on the underlying assumption that GHG emissions are proportional to changes in the emissions source. For example, emissions reductions achieved by transportation measures are estimated using the expected percent reduction in vehicle trips or VMT, with an associated adjustment to account for the relationship between VMT reduction and vehicle emissions, as described further in the *Transportation* section. For these measures, users will need to multiply the reduction percentage by the amount of emissions that would be generated by that source without implementation of the measure to calculate the absolute reductions.[1] This Handbook does not include methods for inventorying emissions from specific sources or under various scenarios, such as baseline conditions.

Quantification methods that calculate absolute reductions estimate the amount of emissions that would be released as a result of the source or activity with implementation of the measure (e.g., the reduction in water sector GHG emissions achieved from using

[1] The reduction percentage is denoted as a positive value when specified in text or in tables as a "reduction," and is denoted as a negative value when calculated in equations.

reclaimed water). GHGs evaluated in this Handbook include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and commonly used refrigerants. All GHG reductions are expressed in metric tons (MT) of carbon dioxide equivalents (CO_2e), where individual GHGs that would be reduced by a measure are converted to CO_2e by multiplying emissions by their global warming potential (GWP). GWP represents a ratio of the heat trapping characteristic of a gas compared to CO_2, which has a GWP of 1.

This Handbook primarily uses GWPs from the Intergovernmental Panel on Climate Change's (IPCC) (2013) Fifth Assessment Report for the 100-year timescale (AR5). Net CO_2e values, determined by combining the different pollutants weighted by their GWP values, vary little between these reports, but we have standardized on AR5 as it is the version used in the EPA's MOVES (and NONROAD) model. This is a change from the CAPCOA report, which uses AR4 values throughout. GREET uses AR6 global warming potential values, which we incorporate by reference. Table 3-1 below compares the values from the different reports for the three most common exhaust pollutants. We also updated the GWPs for commonly used refrigerants to reflect AR5 values.[2]

Table 3-1. 100-year Global Warming Potential Values of Three Exhaust Pollutants under Different Versions of IPCC's Assessment Report

Pollutant	Chemical Formula	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)	Sixth Assessment Report (AR6)
Carbon dioxide	CO_2	1	1	1
Methane: non-fossil[a]	CH_4	25	28	27
Nitrous oxide	N_2O	298	265	273

[a] For methane, this report uses only the non-fossil values, as the "fossil" value is for methane emissions from fossil fuel fugitive emission sources (e.g., oil and gas systems, coal mining) and industrial processes where carbon in methane is of fossil origin.

Users are encouraged to consult the latest IPCC assessment report and statewide inventory guidance available at the time of their analysis to determine if alternative GWPs should be used.[3]

Measures presented in this chapter address those reductions over which a user can exercise direct control, as well as indirect emissions associated with upstream fuel production, electrical generation, and the use of natural gas.

[2] As an update to a prior document and one that combines information from multiple datasets and models, there remain some instances where the GWP values used are unknown or potentially differ from AR5 values:
- Electricity emission factors in Tables E-4.5 through E-4.10 of the Appendix were provided by the states and the GWPs used are not specified.
- Appendix Table E-26.2 for lifecycle emission factors for biomass electricity generation from EPRI use AR4 values.
- Appendix Table E-26.3 for lifecycle carbon intensity factors use values from GREET, which uses AR6.
- Waste measures S-1, S-2, and S-3 rely on WARM (S-1 and S-2) and a scientific article (S-3) for the waste emission factors. WARM uses AR4. It is unknown which values the article uses.

[3] GWPs are regularly reassessed by the IPCC, which published updated GWPs in their *Sixth Assessment Report* (IPCC 2023).

Selecting Measures

This Handbook is intended to support planning in five western states. Western states are large, distinct from each other, and geographically diverse within the states. As a multi-state handbook covering these states, it is important to note that not all measures will apply to all states nor to all regions within a state. This Handbook does not prescribe which measures will apply to each state or to an individual project or plan. Users should ensure the suitability of measures for their case.

Quantification Accuracy and Reliability

IPCC (2006) defines *good practices* for GHG emissions quantification as those that "contain neither over- nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable." Part of the challenge in developing methods that meet this standard of good practice is assuring the accuracy of the methods. This Handbook defines *accuracy* as the closeness of the agreement between the result of a measurement or calculation and the true value, or a generally accepted reference value. When a method is accurate, it will, for a particular case, produce a quantification of emissions that is as close to the actual emissions as can practicably be done with information that is reasonably available.

Quantification methods that meet the standard of good practice must also be *reliable*, which is different from being accurate. This Handbook defines a *reliable* method as one that will yield accurate results across a range of different cases, and not only in one case. In some cases, the accuracy of quantification may be sacrificed to achieve reliability. This is because a method that can be applied across a range of scenarios must be generalized to some extent. For example, methods for transportation sector measures do not, for the most part, differentiate between peak and off-peak vehicle trips, even though off-peak trips will have a lower emission impact because of the effects of congestion on travel time and engine performance. To fully address all the factors that affect the emissions associated with vehicle trips for a specific project, a far more detailed analysis would be needed, and it would not be readily applied to other situations. The methods contained in this Handbook have been developed to provide the best balance between accuracy and reliability.

The quantification methods included in this Handbook will only be accurate to the degree that a project adheres to the assumptions, limitations, and other criteria specified for a given measure. Most of the quantification methods provide default assumptions for user consideration. The default values are based on the most up-to-date regional-, state-, or national-level data and may not be appropriate for all projects. Accordingly, it is recommended that defaults only be used if they adequately reflect analysis conditions, and no local or project-specific information is available. When a range of effectiveness may be quantified for a specific measure depending on defaults, this Handbook often presents those defaults that would yield the lower end of reductions to avoid overstating potential measure benefits. Where defaults are not available for a specific assumption, data must be provided by the user for the calculations to be valid. The quality of the data provided by the

user will substantially affect the quality of the results achieved. Data supplied by the user could be a rough estimate, based on a small, one-time sample, or derived through a full project-specific study. Using a rough estimate for any of the data inputs will yield results that are less accurate than if higher quality data inputs are provided.

Users are encouraged to consider the intended use of the quantification, to make sure that the results achieved will be sufficiently rigorous to support the conclusions drawn from them. When quantification is performed for regulatory compliance, it is recommended that project-specific data be as robust as possible. Approximations and unsubstantiated numbers are discouraged. Moreover, it is strongly recommended that the source(s) and/or basis of all project-specific data supplied by the user be clearly identified in the analysis and the limitations of the data be discussed.

Measure Scales

GHG reduction measures can be applied at different scales or geographic levels. Some measures may only be applicable at the project-level, whereas others may be more appropriate within a broader planning context, such as for a general/comprehensive plan or climate action plan. Geographic levels considered in this Handbook include the Project/Site and Plan/Community. Project/Site refers to measures that reduce emissions at the scale of a parcel, employer, or development project. Plan/Community refers to measures that reduce emissions at the scale of a neighborhood (e.g., specific plan, general/comprehensive plan, climate action plan), corridor, or entire municipality (e.g., city- or county-level).

The transportation measures can be quantified at either the Project/Site scale or the Plan/Community scale, but never both. While some of the transportation measures could be implemented at both scales in practice, the quantification methods presented in this Handbook are limited to only the scale for which there is literature to defensibly support emissions quantification. For example, a bike-sharing program could be implemented at the Project/Site scale for employees to use at a business park, and it could be implemented at the Plan/Community scale by a municipality in their downtown district. However, there is limited defensible research on the GHG reductions associated with small scale, site-specific bike-share programs. Therefore, only the Plan/Community scale version of this measure is quantified in this Handbook. The *Transportation* section notes each instance in which a transportation measure could be implemented at a scale for which this document does not provide a quantification method.

Some non-transportation measures can be quantified at both the Project/Site scale and the Plan/Community scale. For example, a multi-family development at the Project/Site scale may construct homes without wood-burning devices, while a specific plan for new single-family housing at the Plan/Community scale could require that all future homes prohibit wood-burning devices. The quantification method for this measure would be the same, regardless of the scale of application.

Combining Measure Reductions

When quantifying measures, it is important to be mindful of potential interactions among different measures. Often, combining measures can lead to better emission reductions than implementing a single measure by itself. For example, for Measure LL-1, *Replace Gas Powered Landscape Equipment with Zero-Emission Landscape Equipment*, to succeed, electrical outlets on the exterior of buildings should be accessible so that the electric landscaping equipment can be charged. Measure LL-3, *Electric Yard Equipment Compatibility,* should, therefore, be considered as a supporting action to equipment electrification. Where appropriate, these synergistic relationships are noted within the individual measure quantification methods. However, the compounding effect of combining these select measures is not quantified in this Handbook.

Unfortunately, the effects of combining some measures are not always beneficial, linear, complementary, or accurate. There are two primary reasons for this. The first reason is that there may be diminishing returns when certain measures are implemented together to reduce a particular source of emissions. For example, there may be six measures to increase ridership on a public transit line, any one of which might increase transit ridership by 20 percent. But implementing all these measures will not necessarily increase ridership by 120 percent. In fact, for each successive measure applied, it is likely that a lesser effect will be observed. The second reason is that there may be competition between measures. For example, a campaign to increase ridership on a commuter rail line may be implemented while a new public transit bus line is established with overlapping service areas. Although the ridership campaign might be expected to cause 5 percent of drivers to switch to rail, some of those potential new riders might use the new bus service instead, making the ridership campaign less effective. At the same time, the new bus line might also be expected to reduce vehicle trips by 5 percent, but the actual reduction may be lower if some of the ridership comes from rail passengers. Together, the ridership campaign for the rail line and the new bus line may only reduce vehicle trips by 7 percent, and not the 10 percent predicted from summing the estimates of their independent effectiveness.

Where appropriate, guidance for combining measure reductions is provided within the introductions to each sector. Likewise, the quantification methods for each measure identify any applicable calculation maximums.

Combining Sector Reductions

The following procedures must be followed when combining measures among the nine sectors where the GHG reduction achieved by individual measures is calculated as a percentage of emissions from a given source or activity. Specifically, the relative magnitude of emissions between sectors must be considered. Users should first determine the percent contribution made by each individual sector to the overall project GHG emissions. This percent contribution by a sector should then be multiplied by the reduction percentages from measures in that sector to determine the scaled GHG emission reductions. This should be done for each sector to be combined. The scaled GHG

emissions for each sector can then be added together to give a total GHG reduction for the combined measures in all sectors.

For example, consider a project with total GHG emissions that come from the following sectors: transportation (50 percent), building energy use (40 percent), water (6 percent), and solid waste (4 percent). This project implements transportation measures that result in a 10 percent reduction in VMT. The project also implements measures that result in a combined 30 percent reduction in water usage. The overall reduction in GHG emissions is calculated in the example below.

$\%\ \text{Reduction}_{\text{Transport}} = 50\%\ \text{total emissions} \times 10\%\ \text{sector reduction} = 5\%\ \text{total reduction}$

$\%\ \text{Reduction}_{\text{Water}} = 6\%\ \text{total emissions} \times 30\%\ \text{sector reduction} = 1.8\%\ \text{total reduction}$

$\%\ \text{Reduction}_{\text{Total}} = 5\% + 1.8\% = 6.8\%\ \text{total reduction}$

As discussed above, GHG reductions for some measures in this Handbook are expressed in terms of the absolute MT CO_2e that would be reduced. Reductions from these measures should be combined following the same approach as shown above. However, rather than multiplying percentages, users can simply subtract the expected reductions from the sector emissions.

Users may need to combine sector reductions that are a product of measures where reductions are given as both percentages and absolute values. This can be achieved by modifying the above equations to include actual project emissions. The following equations extend the above project example to include a 10 MT CO_2e reduction achieved by waste sector measures. Uncontrolled project emissions are assumed to be 2,000 MT CO_2e.

$$\text{Absolute Reduction}_{\text{Transport}} = 2{,}000\ \text{MT CO}_2\text{e} \times 50\%\ \text{total emissions} \times 10\%\ \text{sector reduction}$$

$$= 100\ \text{MT CO}_2\text{e reduction}$$

$$\text{Absolute Reduction}_{\text{Water}} = 2{,}000\ \text{MT CO}_2\text{e} \times 6\%\ \text{total emissions} \times 30\%\ \text{sector reduction}$$

$$= 36\ \text{MT CO}_2\text{e reduction}$$

$$\text{Absolute Reduction}_{\text{Waste}} = 10\ \text{MT CO}_2\text{e}$$

$$\text{Absolute Reduction}_{\text{Total}} = 100\ \text{MT CO}_2\text{e} + 36\ \text{MT CO}_2\text{e} + 10\ \text{MT CO}_2\text{e} = 146\ \text{MT CO}_2\text{e}$$

Limitations and Uncertainty

There are uncertainties associated with any type of estimation method. It is important to understand the limitations to properly apply the quantification methods presented in this Handbook. The following briefly discusses key limitations for user awareness and consideration.

Combination of Data Sources

Developing quantification methods for some of the measures required the use of multiple data sources. Any time data are derived from different sources, there may be slight discrepancies in the underlying methodologies and data. When the information between two data sets is combined, the discrepancies may affect the ultimate quantification of emissions, either over- or underestimating them. It is impossible to determine the precise magnitude of error that combining data sets induces in the final quantification; however, every effort has been made to minimize potential errors through thorough review of available data and exclusion of incompatible data sets.

Level of Detail for Underlying Assumptions

Many of the calculations require users to input project-specific data or assumptions. Certain information about a project may not be known to the user and must be either estimated or assumed based on standard procedures. Likewise, users may rely on the available defaults provided in the Handbook to enable emissions quantification of applicable measures. While defaults provided in this Handbook are based on credible sources for use in emissions quantification, they are often based on historical regional, state, and national-level data and may produce an inaccurate representation of project-specific conditions or lead to an overestimate or underestimate of associated emissions. This limitation can be minimized to the extent the user can provide better quality data.

Use of Case Studies

Case studies generally have detailed information on reductions that may be achieved in practice by a measure. While these studies provide valuable insight that can support measure quantification, a few features or characteristics in the case study may not translate to a specific project and, therefore, may over- or underestimate the GHG emission reductions. Where case studies were used, they were carefully reviewed to ensure the study methods and data meet the quality requirements of this Handbook.

Prediction of Future Behavior

Some of these methods predict future behavior (e.g., water use and energy consumption) using historical data and trends. Although this is a commonly accepted practice, current behavior is not likely to remain constant over time due to technological improvements and increasing awareness of resource conservation. This limitation can be minimized to the extent the user can provide better quality data.

Combining Multiple Measures

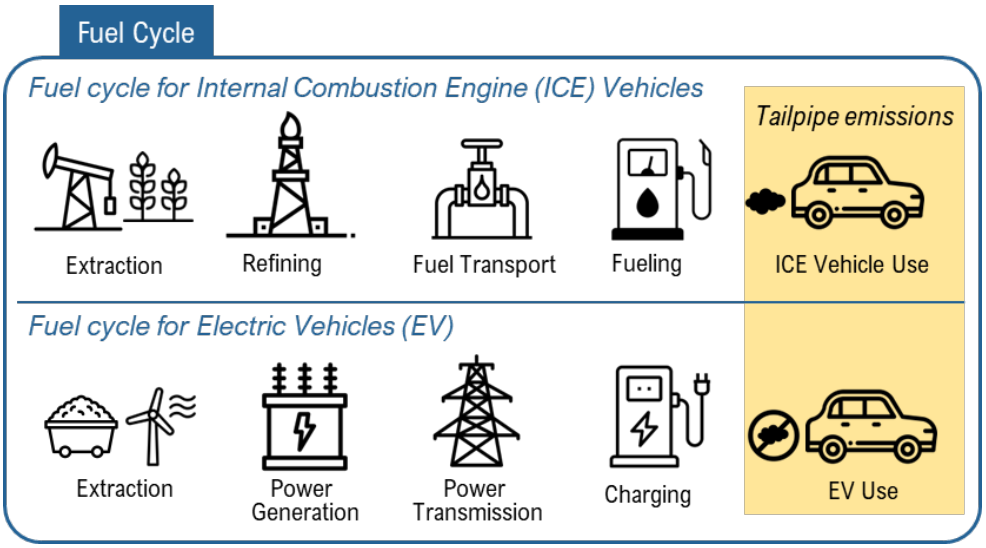
Projects may involve the application of more than one measure. As discussed above, combining measures can have an additive effect on GHG reductions, or result in diminishing returns. This limitation is minimized through the establishment of sector and measure reduction caps, as described within the individual measure methods, as

applicable. However, users should still exercise good judgement when selecting measures to ensure that the resulting quantification is appropriate and accurate.

Lifecycle Analysis and Exclusion of Biogenic CO_2 Emissions

Greenhouse gases are emitted by vehicles and equipment from their tailpipe by combusting fuels. However, other activities related to the use of these same vehicles also emit GHGs. Extraction, processing, and transport of materials such as crude oil and finished gasoline are part of the full fuel cycle of liquid fuels, along with their combustion emissions. Similarly, for electric vehicles, there are emissions associated with power generation (e.g., coal or natural gas combustion) and energy losses due to distribution that make up the fuel cycle. In a tailpipe (also known as downstream, tank-to-wheels, TTW) analysis, which only considers what comes out of the tailpipe, electric equipment has no emissions while diesel-fueled equipment does. On the other hand, a complete analysis would consider all the emissions associated with all the activities that supply the fuel to the vehicle along with the tailpipe emissions from the vehicle. This former category is referred to as upstream (well-to-pump, WTP) emissions. The complete analysis is called a full fuel-lifecycle analysis (well-to-wheels, WTW). In a WTW analysis, both electric and internal combustion equipment may have emissions, depending on the source of electricity. Figure 3-2 below illustrates this for electric (EV) and internal combustion engine (ICE) vehicles. Note that a similar description would also apply to other zero emission vehicles (ZEV), such as those fueled by hydrogen fuel cells. The highlighted component is the downstream emissions. Everything to the left comprises upstream fuel emissions. Tailpipe emissions occur on-site, while upstream emissions could occur anywhere. However, due to the long lifetime and well-mixed properties of GHGs in the atmosphere, location does not matter, and, for most considerations, timing of the emissions does not, either.

Figure 3-2. Components of the Fuel Lifecycle for Internal Combustion and Electric Vehicles



Other lifecycle components may be considered. GHGs are also emitted during the construction and maintenance of infrastructure. Emissions associated with materials extraction and production are often referred to as "embodied" emissions. Consideration of these may be referred to as infrastructure cycle emissions. Emissions associated with manufacture and disposal of vehicles are part of the vehicle cycle emissions.

This Handbook is not intended to be a guide to lifecycle analyses. As full lifecycle emissions analysis would include all of the processes related to extraction of raw resources, physical distribution, use of the product or material, and disposal at the end of a product's life, it is challenging to quantify these lifecycle emissions. Identifying all the inputs that are necessary, especially for a generalized guidance document such as this Handbook, is infeasible. Because of these difficulties, lifecycle considerations are only included in the quantitative methods for those measures that cannot be quantified correctly without a lifecycle analysis.

For example, transportation measures that consider replacing fuels provide information on full lifecycle impacts, because in those cases only by considering the full fuel lifecycle can the complete picture of reductions be obtained. Similarly, mixing analyses leads to mistaken results. A typical example is including upstream emissions for electricity production but only downstream emissions for liquid fuels. Thus, this Handbook provides options for the user to consider tailpipe or full lifecycle impacts in certain measures involving mobile sources. This includes measures T-30, C-1, N-8, M-6, and LL-1 in the transportation, construction, natural and working lands, miscellaneous, and landscaping sections, respectively. This is a change from the CAPCOA Handbook. Some other measures consider lifecycle implications but are not for mobile (on- or off-road) sources. In these cases, we follow the concept of "Scopes" as defined in the GHG Protocol. Considering Scope 2 "downstream"-only emissions, such as for gas combustion and EGU emissions in residential and industrial/commercial inventories is

defensible. In these cases we maintain consistency with the CAPCOA Handbook. The Transportation, Energy, Solid Waste, Construction, Landscaping, Natural and Working Lands, Miscellaneous, and Refrigerants sections of this Handbook all have at least one measure that provides an option to consider lifecycle analyses of the measure. These measures provide a fuel lifecycle approach for the reasons stated above. However, consistent with the CAPCOA Handbook, for all other measures, the quantification methods do not include analysis of full lifecycle emissions. Except for Measure E-14, *Limit Wood Burning Devices and Natural Gas/Propane Fireplaces in Residential Development*, the methods do not address biogenic CO_2 emissions. Biogenic CO_2 emissions result from materials that are derived from living cells, as opposed to CO_2 emissions derived from fossil fuels, limestone, and other materials that have been transformed by geological processes. Biogenic CO_2 contains carbon that is present in organic materials, including wood, paper, vegetable oils, animal fat, and waste from food, animals, and vegetation (such as yard or forest waste). Biogenic CO_2 emissions are excluded from these GHG emissions quantification methods because they are the result of materials in the biological/physical carbon cycle, rather than the geological or anthropogenic carbon cycle. That is, combusting these fuels does not contribute to additional carbon in the atmosphere on a net basis.

A related issue is the reduction in carbon sinks that may occur from land development. Develpment patterns that result in depletion of biogenic sinks that previously removed carbon also lead to increased CO_2 concentrations in the atmosphere. Furthermore, such development may replace what was previously a sink with new emissions sources. Although biogenic carbon removal may be critical to meeting net zero emission targets, this subject is considered out of scope for this Handbook.

Extent Reductions Are Achieved in Practice

The reduction methods presented in this Handbook are based on specific underlying data and assumptions for how each measure should be implemented. The quantification methods will yield the most accurate and reliable results when the user adheres to all implementation requirements described in this Handbook. In practice, there is likely to be a wide range of how individual measures are implemented given project-specific considerations, such as cost to implement the measure, physical constraints, availability of technology, and regulatory restrictions.

GHG Reduction Measure Factsheets and Quantification Methods

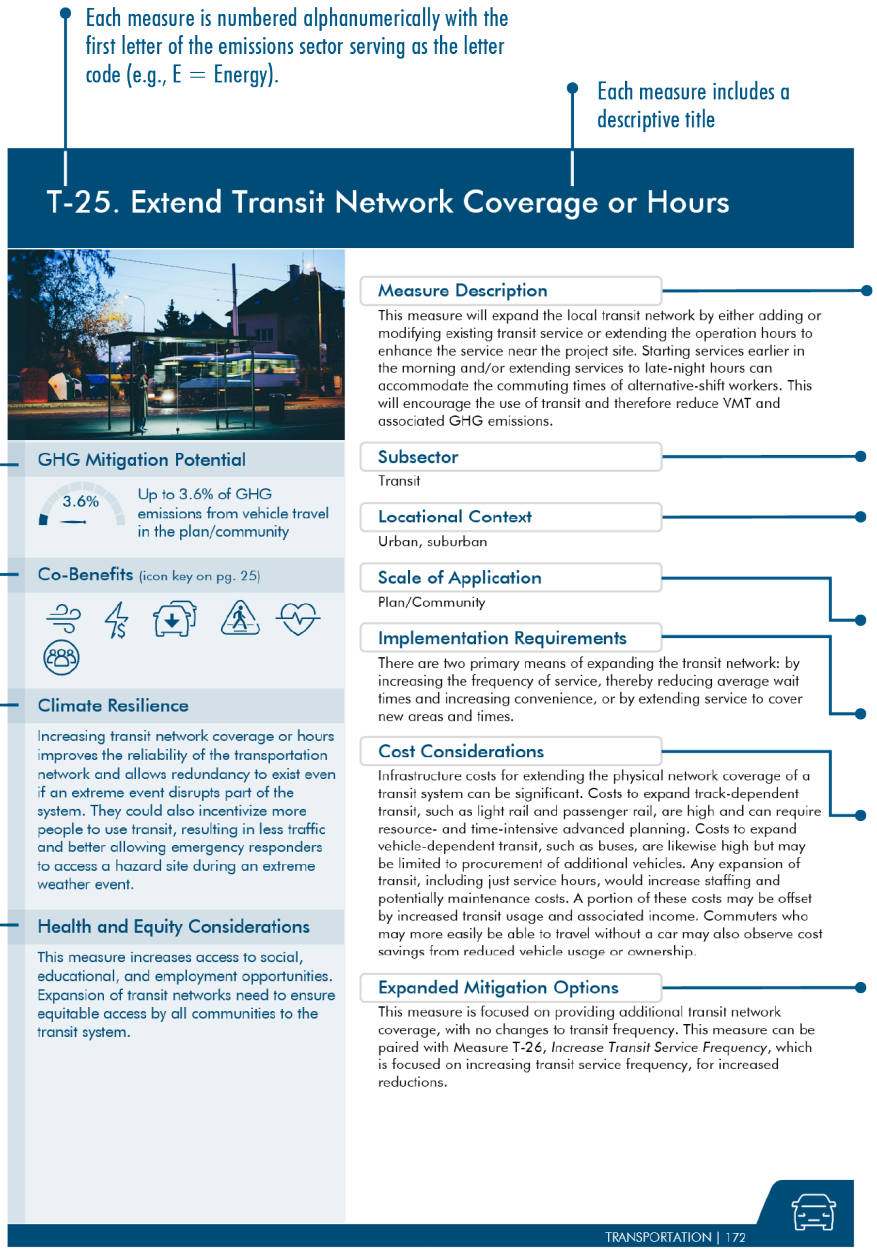
Anatomy of the Factsheets

All quantified GHG reduction measures in this Handbook include a one-page measure factsheet. The factsheet highlights important considerations for each measure. They describe the measure, locational context, scale of application, implementation

requirements, cost considerations, and options to expand measure effectiveness. The factsheets also show key measure indicators, such as the GHG reduction potential, co-benefits, and considerations for climate resilience and health and equity. Where available, the GHG reduction potential is provided as the estimated maximum percent reduction in emissions. When quantified, the reduction potential is appropriately normalized to the subject of the measure. This means the reductions can be large numbers but still affect a small amount of the overall inventory. For those measures where GHG reductions are calculated as absolute emissions, the GHG reduction potential is identified as small, moderate, large, or varies. This qualitative ranking characterizes the estimated quantity of reductions relative to the magnitude of emissions generated by the source. For example, Measure E-15, *Require All-Electric Development*, has the potential for a large reduction in GHG emissions from building energy use if all end uses are electrified and the local utility provides zero-carbon electricity. It's important to note that, while this measure could achieve a "large" reduction in building energy emissions, the overall reduction in project emissions could be small if building energy emissions are only a fraction of the project total.

Figure 3-3 illustrates the factsheet layout and annotates key content.

Figure 3-3. Annotated Outline of the Measure Factsheet



Following each measure's factsheet is the measure's quantification method. Accurate and reliable quantification of GHG reduction measures depends on properly identifying and understanding the important variables that affect the emissions from a source or activity. A consistent framework and presentation are used for all measure quantification methods to provide a clear summary of quantification variables and usable instructions on appropriate application of the method.

The quantification methodology for each measure is composed of the mathematical formula(s), summary of all variables used in the formula, explanation of any calculation caps or maximums, an example calculation, and information on quantified co-benefits. The variables in the GHG reduction formula(s) are shown as letters (e.g., A, B) and are defined in the table that immediately follows the equation. The table categorizes variables as outputs, user inputs, or constants, assumptions, and defaults. Bolded variables are required user inputs (i.e., variables for which no defaults are available). Variables that have been changed from the CAPCOA Handbook are noted in the *GHG Calculation Variables* subsection. More substantive changes to measures, such as revisions to the quantification methodology, are described in an introductory section at the beginning of the measure's quantification method. Note that the *Introduction* is only included for those measures that have substantively changed from the CAPCOA Handbook.

Only those measures with literature to defensibly support emissions quantification are discussed in this Handbook. Examples of credible sources consulted for this Handbook include government agency-sponsored studies, peer-reviewed scientific literature, case studies, government-approved modeling software, and widely adopted protocols. Additional measures for user consideration are presented in *Supporting or Non-Quantified GHG Reduction Measures*. Methods for quantifying these measures have not yet been developed, are not fully supported by available research, or require specific details that are difficult to address under a methodology with general applicability. Users are encouraged to consider including these non-quantified measures into their projects, as described further below.

The measure factsheets and quantification methods follow *Supporting or Non-Quantified GHG Reduction Measures*. As discussed above, measures are grouped into nine emission sectors. Information relevant to the general quantification of all measures within a sector is presented at the introduction of each sector. Users may manually scroll through the factsheets in this chapter or use Figure 3-1 (above) to automatically navigate to a specific measure's factsheet.

Supporting or Non-Quantified GHG Reduction Measures

As a supplement to the GHG reduction measures shown in the factsheets, supporting or non-quantified measures may be of interest to users. Although not quantitatively evaluated in the Handbook, supporting or non-quantified measures may achieve emissions reductions and co-benefits on their own or may enhance the ability of

quantified measures to attain expanded reductions and co-benefits. These measures may, therefore, strengthen implementation of a project mitigation strategy or community plan.

Beyond their potential to expand the efficacy of a reduction plan, supporting or non-quantified measures provide users with more options to develop a comprehensive set of mitigation strategies. For example, this section can be used as a resource for expanded mitigation to identify additional measures that may be feasible and applicable to a specific project. Local governments developing a climate action plan or updating their general plan may also find this section useful as inspiration for new or more comprehensive policies. Many of the measures will achieve co-benefits (e.g., water conservation), in addition to GHG reductions, and may therefore be impactful throughout several elements of a local general/comprehensive plan (e.g., air quality, conservation, environmental justice).

While benefits of supporting or non-quantified measures may not be quantitively captured (or fully captured), the measures can be implemented using many of the same mechanisms as for quantified measures. Cities and counties can update their municipal codes to require measures or certain measure components, which would ensure that the measures are implemented through new development or renovations in existing development. Measures can also be included as a set of best management practices that a local government or project sponsor encourages or incentivizes.

Table 3-2 presents the list of supporting or non-quantified GHG reduction measures. In general, these measures are numbered sequentially to follow the quantified measures within each sector (refer to the measure factsheets at the conclusion of this section). In some cases, formerly non-quantified measures have been moved into the quantified measures list but not renumbered, because those measures were found to be quantifiable in newer versions of the CAPCOA Handbook from which this Handbook is derived. Thus, the non-quantified measure numbering scheme is not perfectly sequential. The table defines the measure's sector, scale of application, locational context, and likely co-benefits. For simplicity, these measure "descriptors" have been abbreviated in Table 3-1 as follows.

- Shaded rows identify the sector and subsector (in parentheses, where applicable) for each group of measures. For example, "Transportation (Land Use)."
- The scale of application is abbreviated as one of the following:
  - P/S = Project/Site
  - P/C = Plan/Community
  - All = Project/Site and Plan/Community
- For transportation measures, abbreviations for locational context refer to the level of development at the census tract level. The three locational contexts identified in the Handbook are suburban (S), urban (U), and rural (R). Most transportation measures are applicable to development within at least one of these three locational context areas.

  The three locational contexts were developed from the eight neighborhood types described in *Quantifying the Effect of Local Government Actions on VMT* (Salon 2014), as summarized below.

  - S = suburb with multifamily housing; suburb with single-family homes
  - U = urban low transit; central city urban; urban high transit
  - R = rural; rural-in-urban
- Remaining columns identify co-benefits that may be achieved by the measure where:
  - ●= may be achieved by the measure
  - ⊙= may be achieved by the measure depending on local implementation specifics
  - ○= likely not achieved by the measure

Table 3-3 includes a more detailed description of each non-quantified measure, including equity considerations that lead agencies and project sponsors may consider.

Finally, note that the inclusion of a measure in this section does not preclude it from quantification or indicate that it is impossible to quantify the benefits of the measure. If a user has access to specific data or methods, or if quantification guidance becomes available in the future, then users can quantitatively evaluate measures in those circumstances, if desired.



LOCATIONAL CONTEXT

The following neighborhoods are provided as representative examples for the three locational context areas.

Suburban—Scottsdale, AZ; Aurora, CO; Corrales, NM

Urban—Central City Phoenix, AZ; Downtown Portland, OR; Downtown Seattle, WA

Rural—Grant County, NM; Montezuma County, CO; Lake County, OR

Table 3-2. Summary of Supporting or Non-Quantified GHG Reduction Measures and Descriptors

#	Measure Title	Scale of Application	Locational Context	Co-Benefits: Improved Air Quality	Energy and Fuel Savings	VMT Reductions	Water Conservation	Enhanced Pedestrian or Traffic Safety	Improved Public Health	Improved Ecosystem Health	Enhanced Energy Security	Enhanced Food Security	Social Equity
Transportation (Land Use)													
T-31-A	Locate Project in Area with High Destination Accessibility	P/S	U, S	●	●	●	○	●	●	○	○	○	⊙
T-31-B	Improve Destination Accessibility in Underserved Areas	P/C	U, S	●	●	●	○	●	●	○	○	○	●
T-32	Orient Project Toward Transit, Bicycle, or Pedestrian Facility	P/S	U, S, R [a], R [b], R [c]	●	●	●	○	●	●	○	○	○	⊙
T-33	Locate Project Near Bike Path/Bike Lane	P/S	U, S	●	●	●	○	●	●	○	○	○	⊙
Transportation (Neighborhood Design)													
T-34	Provide Bike Parking	All	All	●	●	●	○	●	●	○	○	○	⊙
T-35	Provide Traffic Calming Measures	P/C	All	●	●	●	○	●	●	○	○	○	⊙
T-36	Create Urban Non-Motorized Zones	P/C	U	●	●	●	○	●	●	○	○	○	⊙
T-37	Dedicate Land for Bike Trails	P/C	All	●	●	●	○	●	●	○	○	○	⊙
Transportation (Trip Reduction Programs)													
T-38	Provide First and Last Mile TNC Incentives	P/C	U, S, R [b]	●	●	●	○	●	●	○	○	○	⊙
T-39	Implement Preferential Parking Permit Program	P/S	U, S	●	●	●	○	●	●	○	○	○	○

#	Measure Title	Scale of Application	Locational Context	Co-Benefits: Improved Air Quality	Energy and Fuel Savings	VMT Reductions	Water Conservation	Enhanced Pedestrian or Traffic Safety	Improved Public Health	Improved Ecosystem Health	Enhanced Energy Security	Enhanced Food Security	Social Equity
T-41	Implement a School Pool Program	P/S	All	●	●	●	○	●	●	○	○	○	⊙
T-42	Implement Telecommute and/or Alternative Work Schedule Program	P/S	All	⊙	⊙	⊙	○	⊙	⊙	○	○	○	⊙
Transportation (Transit)													
T-43	Provide Real-Time Transit Information	P/C	All	●	●	●	○	●	●	○	○	○	⊙
T-44	Provide Shuttles (Gas or Electric)	P/S	U, S	●	●	●	○	●	●	○	○	○	⊙
T-45	Provide On-Demand Microtransit	All	U, S	●	●	●	○	●	●	○	○	○	⊙
T-47	Provide Bike Parking Near Transit	P/C	U, S	●	●	●	○	●	●	○	○	○	⊙
Transportation (Parking or Road Pricing/Management)													
T-48	Implement Area or Cordon Pricing	P/C	U	●	●	●	○	●	●	○	○	○	○
T-49	Replace Traffic Controls with Roundabout	P/C	All	●	●	●	○	●	●	○	○	○	○
T-50	Required Project Contributions to Transportation Infrastructure Improvement	P/C	All	●	●	●	○	●	●	○	○	○	○
T-51	Install Park-and-Ride Lots	P/C	S, R	●	●	●	○	●	●	○	○	○	⊙
T-52	Designate Zero Emissions Delivery Zones	P/C	U	●	●	●	○	●	●	○	○	○	⊙

#	Measure Title	Scale of Application	Locational Context	Co-Benefits: Improved Air Quality	Energy and Fuel Savings	VMT Reductions	Water Conservation	Enhanced Pedestrian or Traffic Safety	Improved Public Health	Improved Ecosystem Health	Enhanced Energy Security	Enhanced Food Security	Social Equity
Transportation (Clean Vehicles and Fuels)													
T-53	Electrify Loading Docks	P/S	All	●	●	○	○	○	○	○	●	○	⊙
T-54	Install Hydrogen Fueling Infrastructure	All	—	●	●	○	○	○	●	○	●	○	○
Energy (Energy Efficiency Improvements)													
E-20	Install Whole-House Fans	P/S	—	○	●	○	○	○	○	○	●	○	⊙
E-22	Obtain Third-party HVAC Commissioning and Verification of Energy Savings	P/S	—	○	●	○	○	○	○	○	●	○	⊙
Energy (Renewable Energy Generation)													
E-23	Use Microgrids and Energy Storage	All	—	⊙	●	○	○	○	●	○	●	○	⊙
E-24	Provide Battery Storage	All	—	⊙	●	○	○	○	●	○	●	○	⊙
Energy (Building Decarbonization)													
E-25	Install Electric Heat Pumps	All	—	●	●	○	○	○	●	○	⊙	○	⊙
Lawn and Landscaping													
LL-2	Implement Yard Equipment Exchange Program	P/S	—	●	●	○	○	○	●	●	●	○	⊙
LL-3	Electric Yard Equipment Compatibility	P/S	—	○	○	○	○	○	●	○	○	○	○

#	Measure Title	Scale of Application	Locational Context	Co-Benefits: Improved Air Quality	Energy and Fuel Savings	VMT Reductions	Water Conservation	Enhanced Pedestrian or Traffic Safety	Improved Public Health	Improved Ecosystem Health	Enhanced Energy Security	Enhanced Food Security	Social Equity
Solid Waste													
S-4	Recycle Demolished Construction Material	P/S	—	○	●	○	○	○	○	⊙	○	○	○
S-5	Source Wood Materials from Urban Wood Re-Use Program	All	—	○	●	●	●	○	○	●	○	○	○
Natural and Working Lands													
N-5	Establish a Local Farmers Market	P/C	—	●	●	●	○	●	●	○	○	●	⊙
N-6	Establish Community Gardens	P/C	—	●	○	⊙	○	○	●	●	○	●	⊙
Construction													
C-4	Use Local and Sustainable Building Materials	All	—	○	●	●	○	○	○	⊙	○	○	○
Miscellaneous													
M-4	Require Environmentally Responsible Purchasing	P/S	—	⊙	⊙	○	⊙	○	○	⊙	○	○	○
M-5	Fund Incentives for Green Technologies	P/C	—	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙

Sector abbreviations: T = transportation; E = energy; W = water; LL = lawn and landscaping; S = solid waste; N = natural and working lands; C = construction; M = miscellaneous.

Scale of application column abbreviations: P/S = Project/Site; P/C = Plan/Community; All.

Locational context column abbreviations: — = not applicable; R = rural; S = suburban; U = urban. Where applicable, the Handbook provides three land use distinctions within the R locational context category, where R [a] = rural only if the project is in master-planned community; R [b] = rural only if the project is adjacent to a commuter rail station with convenient rail service to a major employment center; R [c] = rural only if there is available transit and the project is close to jobs/services.

Co-benefits columns symbols: ● = may be achieved by the measure; ⊙ = may be achieved by the measure depending on local implementation specifics; ○ = likely not achieved by the measure.

Table 3-3. Description of Supporting or Non-Quantified GHG Reduction Measures

Transportation (Land Use)
T-31-A. Locate Project in Area with High Destination Accessibility The measure requires development in an area with high accessibility to destinations. Destination accessibility is measured in terms of the number of jobs or other attractions (e.g., schools, supermarkets, and health care services) that are reachable within a given travel time or travel distance and tends to be highest at central locations and lowest at peripheral ones. When destinations are nearby, the travel time between them is less, thus increasing the potential for people to walk and bike to those destinations and, therefore, reducing the vehicle miles traveled (VMT) and associated greenhouse gas (GHG) emissions. As an implementation consideration, projects should consider accessibility by people of all functional abilities and incorporate design principles such as Universal Design.[4] See Measure T-31-B for a variation of this measure.
T-31-B. Improve Destination Accessibility in Underserved Areas This measure accounts for the VMT reduction that would be achieved by constructing job centers or other attractions (e.g., schools, supermarkets, and health care services) for residents in underserved areas (e.g., food deserts). When destinations are nearby, the travel time between them is less, thus increasing the potential for people to walk and bike to those destinations, reducing VMT and associated GHG emissions. As an implementation consideration, projects should consider accessibility by people of all functional abilities and incorporate design principles such as Universal Design. See Measure T-31-A for a variation of this measure.
T-32. Orient Project Toward Transit, Bicycle, or Pedestrian Facility This measure requires projects to minimize setback distance between the project and planned or existing transit, bicycle, or pedestrian corridors. A project that is designed around an existing or planned transit, bicycle, or pedestrian corridor encourages sustainable mode use. As an implementation consideration, projects should consider accessibility by people of all functional abilities and incorporate design principles such as Universal Design.
T-33. Locate Project Near Bike Path/Bike Lane This measure requires projects to be located within 0.5-mile bicycling distance to an existing Class I or IV path or Class II bike lane. A project that is designed around an existing or planned bicycle facility encourages sustainable mode use. The project design should include a comparable network that connects the project uses to the existing off-site facilities that connect to work/retail destinations. As an implementation consideration, projects should provide sufficient and convenient bicycle parking and long-term storage, ideally near the bike lane itself, for residents, employees, and visitors, and a bicycle repair station with tools and equipment. This measure can be implemented with Measure T-9.
Transportation (Neighborhood Design)
T-34. Provide Bike Parking This measure requires projects to provide short-term and long-term bicycle parking facilities to meet peak season maximum demand. Parking can be provided in designated areas or added within rights-of-way, including by replacing parking spaces with bike parking corrals. Ensure that bike parking can be accessed by all, not just project employees or residents.

[4] Universal Design is a concept that comprises seven principles that seek to make buildings and infrastructure accessible to all people. Accessibility is achieved by considering and implementing each principle during the design process. A project designed by Universal Design standards would ensure that adjacent transit facilities are accessible to people with diverse abilities, preferences, and language skills.

T-35. Provide Traffic Calming Measures

This measure requires projects to include pedestrian/bicycle safety and traffic calming measures above jurisdictional requirements. Roadways should also be designed to reduce motor vehicle speeds and encourage pedestrian and bicycle trips with traffic calming features. Traffic calming features may include marked crosswalks, count-down signal timers, curb extensions, speed tables, raised crosswalks, raised intersections, median islands, tight corner radii, roundabouts or mini-circles, on-street parking, planter strips with street trees, chicanes/chokers, and others. Providing traffic calming measures encourages people to walk or bike instead of using a vehicle. This mode shift will result in a decrease in vehicle miles traveled. Traffic calming also promotes active transportation, which improves physical health.

T-36. Create Urban Non-Motorized Zones

The measure requires projects to convert a percentage of its roadway miles to transit malls, linear parks, or other non-motorized zones. These features encourage non-motorized travel and thus a reduction in vehicle miles traveled. This measure is only applicable to projects located in urban environments. Consider access issues for paratransit users and those with mobility impairments.

T-37. Dedicate Land for Bike Trails

This measure requires projects to provide for, contribute to, or dedicate land for the provision of off-site bicycle trails linking the project to designated bicycle commuting routes in accordance with an adopted citywide or countywide bikeway plan. Existing desire paths can make good locations, as it represents a community-identified transportation need.

Transportation (Trip Reduction Programs)

T-38. Provide First and Last Mile TNC Incentives

This measure requires a first-last mile partnership between a municipality/transit agency and a transportation network company (TNC) for subsidized, shared TNC rides to or from the local transit station within a specific geographic area. This measure encourages a shift to transit mode for longer trips. Consider providing inclusive mechanisms so people without bank accounts, credit cards, or smart phones can access the incentives.

T-39. Implement Preferential Parking Permit Program

This measure requires that projects provide preferential parking in terms of free or reduced parking fees, priority parking, or reserved parking in convenient locations (such as near public transportation or building entrances) for commuters who carpool, vanpool, ride-share, or use sustainably fueled vehicles. Projects should also provide wide parking spaces to accommodate vanpool vehicles. Commercial preferential parking can accommodate employees who work non-standard hours by providing opportunities to participate. Residential preferential parking can consider an equitable distribution of permits, giving priority to owners of sustainably fueled vehicles.

T-41. Implement a School Pool Program

This measure requires that projects create a ridesharing program for school children. Most school districts provide busing services to public schools only. School pool helps match parents to transport students to private schools, or to schools where students cannot walk or bike but do not meet the requirements for busing. A school pool program can help reduce onsite air pollutant emissions at the school by reducing private vehicle trips, especially if the pool vehicle is zero emissions.

T-42. Implement Telecommute and/or Alternative Work Schedule Program

This measure requires projects to permit employee telecommuting and/or alternative work schedules and monitor employee involvement to ensure forecasted participation matches observed participation. While this measure certainly reduces commute-related VMT, recent research has shown that total VMT from telecommuters can exceed VMT from non-telecommuters (Goulias et al. 2020). In addition, telecommuting affects commercial and residential electricity use, complicating the calculation of the net effect and attribution of emissions. More specifically, an office with fewer employees could result in a decrease in the project's energy used to operate equipment and provide space heating and air conditioning. Conversely, an increase in telecommuters using their private homes as workspaces could result in a residential increase in energy for those same end uses and appliances. Although this measure is currently not quantified and, according to some studies, could result in total VMT increases and other disbenefits, it is recommended that users review the most recent literature at the time of their project initiation to see if new findings more conclusively support a quantifiable emissions reduction.

Transportation (Transit)

T-43. Provide Real-Time Transit Information

This measure requires projects to provide real-time bus/train/ferry arrival time, travel time, alternative routings, or other transit information via electronic message signs, dedicated monitor or interactive electronic displays, websites, or mobile apps. This makes transit service more convenient and may result in a mode shift from auto to transit, which reduces VMT.

T-44. Provide Shuttles (Gas or Electric)

This measure will provide local shuttle service through coordination with the local transit operator or private contractor. The shuttles will provide service to and from commercial centers to nearby transit centers to help with first and last mile connectivity, thereby incentivizing a shift from private vehicles to transit, reducing associated GHG emissions. Electric shuttle vehicles provide a marginally more effective reduction to GHG emissions compared to gas- or diesel-fueled shuttles due to their use of less emissions-intensive electric power. Shuttles that serve only the project residents and/or employees may be seen as increasing gentrification and exclusionary. Consider allowing all people to use the shuttle, regardless of status. Note that this measure can also be implemented at the Project/Site scale by a large employer as part of a Trip Reduction Program.

T-45. Provide On-Demand Microtransit

This measure will provide small-scale, on-demand public transit services that can offer fixed routes and schedules or flexible routes and on-demand scheduling (e.g., Metro Micro) through coordination with the local transit operator or private contractor. Microtransit aims to offer shorter wait times and improved reliability compared to the bus and rail system to further incentivize alternative transportation modes that are less emissions-intensive than private vehicle trips. On-demand rides can be booked using smartphone applications or call centers. Note that this measure may also be applicable at the Project/Site scale for a large employer (e.g., Google's Via2G pilot) as part of a Trip Reduction Program.

T-47. Provide Bike Parking Near Transit

This measure requires the project to provide short-term and long-term bicycle parking near rail stations, transit stops, and freeway access points where there are commuter or rapid bus lines. Include locations for shared micromobility devices as well as higher-security parking for personal bicycles.

Transportation (Parking or Road Pricing/Management)

T-48. Implement Area or Cordon Pricing[5]

This measure requires projects to implement a cordon pricing scheme. The pricing scheme will set a cordon (boundary) around a specified area to charge a toll to enter the area by vehicle. The cordon location is usually the boundary of a central business district or urban center but could also apply to substantial development projects with limited points of access. The toll price can be based on a fixed schedule or be dynamic, responding to real-time congestion levels. It is critical to have an existing, high quality transit infrastructure for the implementation of this strategy to reach a significant level of effectiveness. The pricing signals will only cause mode shifts if alternative modes of travel are available and reliable. This measure should provide an exception for low-income residents or workers within the pricing zone.

T-49. Replace Traffic Controls with Roundabout

This measure requires projects to install a roundabout as a traffic control device to smooth traffic flow, reduce idling, eliminate bottlenecks, and manage speed. In some cases, roundabouts can improve traffic flow and reduce emissions. The emission reduction depends heavily on what the roundabout is compared to (e.g., uncontrolled intersection, stop sign, traffic signal). Design roundabout so cyclists have the option to join traffic or bypass the roundabout with an adjacent path.

T-50. Required Project Contributions to Transportation Infrastructure Improvement

This measure requires that projects contribute to traffic-flow improvements or other multi-modal infrastructure projects that reduce emissions and are not considered as substantially growth inducing. The local transportation agency should be consulted for specific needs. Larger projects may be required to contribute a proportionate share to the development and/or continuation of a regional transit system. Contributions may consist of dedicated right-of-way, capital improvements, or easements. Ensure the jurisdictional fee system does not disadvantage infill projects over greenfield projects.

T-51. Install Park-and-Ride Lots

This measure requires projects to install park-and-ride lots near transit stops and high occupancy vehicle lanes. Park-and-ride lots also facilitate car- and vanpooling. Parking lots can also incorporate cool pavements, tree canopy, or solar photovoltaic shade canopies to reduce the urban heat island effect as well as evaporative emissions from parked vehicles and dedicated electric vehicle parking spots and/or charging infrastructure.

T-52. Designate Zero Emissions Delivery Zones

This measure requires the municipality to designate certain curbside locations as commercial loading zones exclusively available for zero-emission commercial delivery vehicles. Doing so replaces tailpipe diesel emissions from last-mile delivery vehicles as well as heavy duty drayage trucks moving goods with less emissions-intensive electric vehicles and potentially micromobility for food and parcel delivery. Locations should be prioritized based on land use density and existing exposure from air pollution.

Transportation (Clean Vehicles and Fuels)

T-53. Electrify Loading Docks

This measure will require that Transport Refrigeration Units and auxiliary power units (APUs) be plugged into the electric grid at the loading dock instead of running on diesel. The indirect GHG emission from electricity generation can partially offset the emissions reduction from fuel reductions. Electrifying loading docks can reduce exposure to air pollutants for workers and drivers.

[5] As noted, not all measures apply to all states. For example, RCW 70A.45.120(5) prohibits the Washington State Department of Commerce from proposing or adopting any fees or surcharges related to vehicle miles traveled.

T-54. Install Hydrogen Fueling Infrastructure

The measure requires projects to implement accessible hydrogen fuel cell fueling infrastructure. Drivers of fuel cell electric vehicles (FCEV), from individual passenger vehicles to haul truck fleets, will be able to refuel using this infrastructure. The expansion of hydrogen fueling locations indirectly supports the uptake of FCEV in place of the typical internal combustion engine vehicle fueled by carbon-emitting gasoline and diesel.

Energy (Energy Efficiency)

E-20. Install Whole-House Fans

This measure requires installation of whole-house fans. Whole-house fans draw cooler outdoor air through open windows, exhaust the warmer air into the attic, and then expel the air outside through attic vents. Whole-house cooling using a whole house fan can substitute for an air conditioner most of the year in most climates, resulting in a reduction in emissions associated with building energy use. Whole-house fans may be inappropriate in locations near sources that generate air pollutants during the evening hours, such as major roads and freeways.

E-22. Obtain Third-party HVAC Commissioning and Verification of Energy Savings

This measure requires third-party review of heating ventilation and air conditioning (HVAC) systems to ensure proper installation and construction of energy reduction features. A user can obtain HVAC commissioning and third-party verification of energy savings in thermal efficiency components including HVAC systems, insulation, windows, and water heating. Note that the 2019 Title 24 Standards requires Home Energy Rating System (HERS) verification for all new low-rise residential building (three stories or less). Taller residential buildings and non-residential buildings may or may not require a HERS verification depending on other building elements.

Energy (Renewable Energy Generation)

E-23. Use Microgrids and Energy Storage

This measure requires management of a microgrid. Microgrids offer the opportunity to deploy more zero-emission electricity sources, thereby reducing GHG emissions. The microgrid manager (e.g., local energy management system) can balance generation from non-controllable renewable power sources, such as solar, with distributed, controllable generation, such as natural gas-fueled combustion turbines. They can also use energy storage and the batteries in electric vehicles to balance energy distribution and usage within the microgrid. Reliable electricity is vital for public health, especially for vulnerable populations and people dependent on medical equipment.

E-24. Provide Battery Storage

This measure requires strategically deployed battery storage. Energy storage has no direct emissions effect. When deployed strategically, energy storage can make the grid more flexible, unlocking renewable energy and reducing GHG emissions. When deployed non-strategically, owners of energy storage assets are more likely to charge their facilities during off-peak periods when power prices are lower, in order to supply power during more expensive peak hours. Off-peak generation times such as nighttime hours are more likely to be dominated by conventional power sources, which, with the exception of nuclear and hydropower, are likely to be more emissions-intensive (Bistline and Young 2020). Although this measure is currently not quantified and, according to some studies, could result in regional GHG and criteria pollutant emissions increases, it is recommended that users (1) review the most recent literature at the time of their project initiation and (2) evaluate any changes in policy or market for renewable energy to see if new findings more conclusively support a quantifiable emissions reduction.

Energy (Building Decarbonization)

E-25. Install Electric Heat Pumps

This measure requires installation of electric heat pumps as alternatives to conventional furnaces or air conditioners. Electric heat pumps use electricity to transfer heat between cool and warm spaces to either provide cooling or heating. When cooling is needed during the summer months, the pumps remove heat from inside air to outside. The pumps operate in reverse during the winter, moving heat from outdoor air into the building. Because heat pumps move heat instead of generating it, they are more efficient than conventional heating systems. When electric heat pumps replace fossil-fuel heating or cooling sources, they achieve a dual efficiency and decarbonization benefit. The most common types of heat pumps collect heat from the air (are air-to-air), water (water-to-air), or ground (geothermal-to-air). The performance and emissions reductions achieved by electric heat pumps depend heavily on the system type, cooling and heating loads, climate zone, season, and other project-specific variables.

Lawn and Landscaping

LL-2. Implement Yard Equipment Exchange Program

This measure requires the project to participate in an established yard equipment exchange program, supplement an established program, or implement a new program. When conventional gasoline-powered yard equipment (e.g., lawn mowers, leaf blowers and vacuums, shredders, trimmers, and chain saw) are exchanged for electric and rechargeable battery-powered yard equipment, direct GHG emissions from fossil-fuel combustion are displaced by indirect GHG emissions associated with the generation of electricity used to power the equipment. Commercial users of yard equipment should be targeted for this measure given their comparatively low adoption rate of electric yard equipment relative to residential users. If the specific equipment being replaced through the program is known, reductions may be quantified using the method described under Measure LL-1.

LL-3. Electric Yard Equipment Compatibility

This measure requires projects to provide electrical outlets on the exterior of buildings as necessary for sufficient powering of electric lawnmowers and other landscaping equipment. For Measures LL-1 and LL-2 to be successfully implemented, electrical outlets on the exterior of buildings must be accessible so that the electric landscaping equipment can be charged.

Solid Waste

S-4. Recycle Demolished Construction Material

This measure requires recycling of construction waste. Recycling demolished construction material reduces GHGs by displacing new construction materials, thereby reducing the need for new raw material acquisition and manufacturing. If the process of recycling construction materials is less carbon-intensive than the processes required to harvest and produce new construction materials, recycling results in a net reduction in GHG emissions. Using local recycled construction material would also reduce emissions associated with the transportation of new construction materials, which are typically manufactured farther away from a project site. Finally, recycling avoids sending materials to landfills. Wood-based materials decompose in landfills and contribute to methane (CH_4) emissions. Ensure onsite processing does not create nuisance issues for nearby residents.

S-5. Source Wood Materials from Urban Wood Re-Use Program

This measure requires projects to source wood materials from urban wood re-use programs. In areas where removed trees are sent to landfills, they decompose and contribute to CH_4 emissions. Wood re-use programs extend a tree's lifetime by converting it into a range of products and prolonging the sequestration benefit. Re-uses range from logs, lumber, woodchips, mulch, compost, biochar, animal fuel, paper products, engineered wood, furniture, and cellulosic ethanol.

Natural and Working Lands

N-5. Establish a Local Farmers Market

This measure would establish a local farmers market to provide project residents with a more local source of food, potentially reducing the number of trips and VMT by both consumers and food distribution to grocery stores and supermarkets. If the food sold at the local farmers market is produced organically, it can also contribute to GHG reductions by displacing carbon-intensive food production practices. Work with local nonprofits or foundations to provide Electronic Benefit Transfer (EBT) acceptance at the market, which facilitates access for lower-income populations. The U.S. Department of Agriculture (2025) offers resources and guidance for farmers markets that accept EBT, while some foundations offer multiplier programs, in which $1 of EBT funds becomes a greater value if spent at a farmers market.

N-6. Establish Community Gardens

This measure would establish a community garden to provide project residents with locally sourced food, potentially reducing the number of trips and VMT by both consumers and food distribution to grocery stores and supermarkets. Community gardens can also contribute to GHG reductions by displacing carbon-intensive food production practices. Work with community residents and community-based organizations to make sure the gardens are designed inclusively and are open to all residents.

Construction

C-4. Use Local and Sustainable Building Materials

This measure requires using building materials that are locally sourced and processed (i.e., close to the project site, as opposed to in another state or country). This reduces VMT and therefore GHG emissions from fuel combustion. Using sustainable building materials, such as recycled concrete or sustainably harvested wood, also reduces GHG emissions due to the less carbon-intensive production process. Unlike measures that reduce GHG emissions during the operational lifetime of a project, using local and sustainable building materials mitigates emissions prior to the actual operational lifetime of a project.

Miscellaneous

M-4. Require Environmentally Responsible Purchasing

This measure requires projects to implement an environmentally responsible purchasing plan. Examples of environmentally responsible purchases include but are not limited to: purchasing products made from recycled materials or with sustainable packaging; purchasing post-consumer recycled paper, paper towels, and stationery; purchasing and stocking communal kitchens with reusable dishes and utensils; choosing sustainable cleaning supplies; purchasing products from restaurants, farms, or ranches that source materials or goods from locations that use soil conservation practices; and leasing equipment from manufacturers who will recycle the components at their end of life. Choosing locally made and distributed products reduces the distance required to transport the products from the distribution or manufacturing center to the project, thus reducing GHG emissions associated with transportation.

M-5. Fund Incentives for Green Technologies

This measure would fund incentives for green technologies. Examples of green technologies include energy-efficient and zero-emission vehicle fleets and off-road equipment, building electrification upgrades, low-flow fixtures in buildings, or energy-efficient stationary sources. The user may choose to contribute to an existing municipal energy fund or establish a new energy fund for the project. Recipients of energy fund grants could include neighborhood developers, home and commercial space builders, homeowners, and utilities. Energy funds allow recipients flexibility in choosing efficiency strategies while still achieving the desired effects of reduced energy use and associated GHG emissions. If coupled with local apprenticeship and job training, this measure can help provide workforce development in green jobs for the local community.

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Transportation



Fossil-fuel powered vehicles are the primary source of GHG emissions within the transportation sector. On-road vehicles traditionally use gasoline and diesel fuel and release emissions based on the amount of fuel combusted and the properties of the fuel and engine. Cleaner fuels and engines can reduce these emissions. Transportation emissions can be reduced by improving the emissions profile of the vehicle fleet, by shifting trips to less carbon-intensive modes (e.g., via land use planning strategies and multimodal infrastructure improvements) and by improving transportation efficiency and reducing VMT.

Moving to zero emissions technologies, such as electric and fuel cell vehicles, may eliminate the "tailpipe" emissions entirely. To fully understand the impacts, the combined emissions from fuel consumption and fuel production must be considered. In this section, measures typically refer to percentage changes in GHG emissions. However, some measures require methods that consider absolute benefits, which are converted into percents by normalizing against transportation emissions from that site or community. For these measures, we must distinguish between "tailpipe" (a.k.a. downstream, or tank-to-wheels) and full lifecycle (a.k.a., well-to-wheels) emission reductions. Downstream emissions are those that come from the vehicle (e.g., coming from the tailpipe). Lifecycle emissions also consider emissions from upstream sources. In the case of fossil fuels, upstream emissions consider the emissions from processes such as extraction, refining, and transportation of the fuel and feedstock. For measures where GHG emission factors are cited in the Appendix, this Western States Handbook discusses whether they are lifecycle emissions (preferred as they provide a comprehensive comparison between fuels) or tailpipe only. For many of the transportation measures quantified in this Western States Handbook, emission reductions are achieved by reducing VMT and encouraging mode shifts from single-occupancy vehicles to active modes of transportation (e.g., bicycle), or public transportation (e.g., transit), or micromobility modes of transportation. This can be accomplished by coordinating trip reduction or incentive programs; optimizing the land use of the project study area; enhancing road, bike, and pedestrian networks; implementing parking policies; or improving transit systems. In these cases, we show percent reductions based on downstream emissions only.

WHAT'S ELASTICITY?

Elasticity refers to how much a dependent variable changes based on changes in another variable. For example, the elasticity of a bike lane project could represent the change in VMT in an area in response to an increase in bicycle lanes.

Most of the emission reductions are determined by evaluating the *elasticity* of a measure relative to the amount of VMT that may be reduced by the measure. A few transportation measures are aimed at improving the emissions profile of the vehicle fleet. These measures promote alternative fuels and vehicle types. The emission reductions from these measures are based on the improved emission factors and on changes to the assumed vehicle fleet mix.

This section provides guidance for computing emissions savings from a measure and combining emission reductions from transportation measures. The measure factsheets and quantification methods for individual measures follow. Use the graphic below to click on an individual measure to navigate directly to the measure's factsheet.

Transportation

LAND USE

- T-1. Increase Residential Density
- T-2. Increase Job Density
- T-3. Provide Transit-Oriented Development
- T-4. Integrate Affordable and Below Market Rate Housing
- T-17. Improve Street Connectivity
- T-55. Infill Development

TRIP REDUCTION PROGRAMS

- T-5. Implement Commute Trip Reduction Program (Voluntary)
- T-6. Implement Commute Trip Reduction Program (Mandatory Implementation and Monitoring)
- T-7. Implement Commute Trip Reduction Marketing
- T-8. Provide Ridesharing Program
- T-9. Implement Subsidized or Discounted Transit Program
- T-10. Provide End-of-Trip Bicycle Facilities
- T-11. Provide Employer-Sponsored Vanpool
- T-12. Price Workplace Parking
- T-13. Implement Employee Parking Cash-Out
- T-23. Provide Community-Based Travel Planning

PARKING OR ROAD PRICING/MANAGEMENT

- T-14. Provide Electric Vehicle Charging Infrastructure
- T-15. Limit Residential Parking Supply
- T-16. Unbundle Residential Parking Costs from Property Cost
- T-24. Implement Market Price Public Parking (On-Street)

NEIGHBORHOOD DESIGN

- T-18. Provide Pedestrian Network Improvement
- T-19-A. Construct or Improve Bike Facility
- T-19-B. Construct or Improve Bike Boulevard
- T-20. Expand Bikeway Network
- T-21-A. Implement Conventional Carshare Program
- T-21-B. Implement Electric Carshare Program
- T-22-A. Implement Pedal (Non-Electric) Bikeshare Program
- T-22-B. Implement Electric Bikeshare Program
- T-22-C. Implement Scootershare Program
- T-22-D. Transition Conventional to Electric Bikeshare

TRANSIT

- T-25. Extend Transit Network Coverage or Hours
- T-26. Increase Transit Service Frequency
- T-27. Implement Transit-Supportive Roadway Treatments
- T-28. Provide Bus Rapid Transit
- T-29. Reduce Transit Fares
- T-46. Provide Transit Shelters

CLEAN VEHICLES AND FUELS

- T-30. Use Cleaner-Fuel Vehicles

SCHOOL PROGRAMS

- T-40 Establish a School Bus Program
- T-56. Active Modes of Transportation for Youth

Selecting and Combining Transportation Measures

Depending on how VMT has been quantified for a project or program, users should exercise caution when selecting transportation measures to avoid double counting VMT benefits that may already be accounted for in the model used to produce the unmitigated or baseline VMT estimate. For example, regional travel demand models are generally sensitive to built environment and transit service variables (e.g., density, proximity to transit). VMT estimates developed for projects or programs that use such models may, therefore, already account for VMT reductions associated with certain measures in this Western States Handbook (e.g., T-1, *Increase Residential Density*).

Interactions between transportation measures are complex and sometimes counterintuitive, whereby combining measures can have a substantive impact on reported emission reductions. To safeguard the accuracy and reliability of the methods, while maintaining their ease of use, the following rules should be followed when combining reductions achieved by transportation measures.

Combining Measures Across Scales

The first level of organization for the transportation measures is the scale of application. There are 19 quantified measures at the Project/Site scale that can be combined with each other and 19 quantified measures at the Plan/Community scale that can be combined with each other.[6] *The GHG reductions of transportation measures from different scales of application should never be combined.* Although a user's project might involve measures that affect vehicle trips or VMT at both scales, combining the percent reduction from measures of different scales likely would not be valid. This rule does not apply to non-transportation measures that calculate the emissions reduction in terms of absolute emissions.

Combining Measures within a Subsector

The second level of organization for the transportations measures is the subsector. Transportation measures are separated into seven subsectors: Land Use, Neighborhood Design, Trip Reduction Programs, Parking Management, Transit, Parking or Road Pricing/Management, Clean Vehicles and Fuels, and School Programs.

Effectiveness levels for multiple measures within a subsector may be multiplied to determine a combined effectiveness level. Because the combination of measures and independence of measures are complicated, this Western States Handbook recommends that measure reductions within a subsector be multiplied unless the user can provide substantial evidence indicating that emission reductions are independent of one another and that they should therefore be added. This will take the following form:

$$\text{Reduction}_{\text{subsector}} = 1 - [(1 - A) \times (1 - B) \times (1 - C)]$$

Where A, B, and C are the individual measure reduction percentages for the measures to be combined in each subsector.

[6] There is one additional quantified transportation measure: Measure T-30, *Use Cleaner-Fuel Vehicles*. All below discussion related to combining measures and determining maximums does not apply to this measure, which is part of the Clean Vehicles and Fuels subsector.

Each measure has a maximum allowable reduction, discussed in the quantification methods for each measure. The user should calculate the reduction from each measure, compare it to the individual measure maximum, and use the lower value of the two in the equation above.

In addition, each subsector has a maximum allowable reduction. These were derived by combining the maximum allowable reduction of each individual non–mutually-exclusive measure within the subsector using the above formula (see table below for more details). The subsector maximum is intended to ensure that emissions are not double counted when measures within the subsector are combined. The subsector maximums are provided in the below table by scale of application.

Scale	Subsector	Quantified Measures [a]	Subsector Maximum [b, c, d, e, f]
P/S	Land Use	5	65%
	Neighborhood Design	—	—
	Trip Reduction Programs	9	45% commute VMT
	Parking or Road Pricing/ Management	3	35%
	Transit	—	—
	School Programs	2	72% school VMT
P/C	Land Use	1	30%
	Neighborhood Design	10	10%
	Trip Reduction Programs	1	2.3% commute VMT
	Parking or Road Pricing/ Management	1	30%
	Transit	6	15%
	School Programs	—	—

P/S = project/site; P/C = plan/community; VMT = vehicle miles traveled.

[a] Excludes Measure T-30, *Use Cleaner-Fuel Vehicles*, within the Clean Vehicles and Fuels subsector and all supporting or non-quantified measures from other subsectors.

[b] — = no measure within the subsector at the specified scale.

[c] Where a subsector consists of only one measure, the subsector maximum listed is the individual measure maximum.

[d] Most maximums were conservatively rounded down to the nearest multiple of five or whole number.

[e] Measure T-1 and Measure T-2 were assumed to be mutually exclusive for the purpose of deriving a project's single land use type maximum emissions reduction. More specifically, residential density (T-1) only applies to residential development, and job density only applies to commercial development (T-2). Similarly, Measure T-26, Measure T-27, and Measure T-46 were assumed to be mutually exclusive with Measure T-28 for the purpose of deriving a plan/community's total transit-related emissions reduction. Measure T-28 accounts for the VMT reduction associated with increased transit frequency (T-26), station improvements like shelters (T-46), and decreased transit travel time from transit supportive roadway treatments (T-27). It was assumed that bus rapid transit (BRT) (T-28) would cover all of the community's transit routes, and therefore no additional frequency, station, or time improvements would be attainable (T-26, T-27, and T-46).

[f] Measures within the Trip Reduction Programs and School Programs primarily reduce VMT from *employee commute* trips and *student commute* trips, respectively, whereas all other measures reduce VMT from *all* trips associated with the relevant land use type.

The user should calculate the reduction from each subsector, compare it to the corresponding sector maximum, and use the lower value of the two.

Combining Measures Across Subsectors

There is limited research directly analyzing the combined VMT impact on a project/site or plan/community from implementation of all, or a majority, of the non–mutually-exclusive transportation sector measures provided in this Western States Handbook. However, a University of California, Davis study compared household VMT across different place types in California and found that the difference in average VMT in single-family suburban neighborhoods and central city neighborhoods was approximately 70 percent.[7] Central city neighborhoods are more likely to have implemented transportation strategies like those measures included in the Handbook, when compared to suburban neighborhoods. The Handbook therefore adopts 70 percent as a maximum for the combined VMT impact from the following four subsectors: Land Use, Neighborhood Design, Parking or Road Pricing/Management, and Transit.

$$\text{Reduction}_{\text{multi-subsector}} = 1 - [(1 - \text{Land}) \times (1 - \text{Design}) \times (1 - \text{Parking}) \times (1 - \text{Transit})] \leq 70\%$$

Note that this multi-subsector maximum purposefully excludes the Trip Reduction Program subsector. This is because measures in the Trip Reduction Program subsector are often implemented at the Project/Site scale based on the individual employer and are not as directly correlated with place type as the other subsectors. For example, all central city neighborhoods have a high residential and commercial density (i.e., Measure T-1 and Measure T-2 from the Land Use subsector), and most single-family suburban neighborhoods have low density. Conversely, not all employers in a central city neighborhood provide their employees with discounted transit passes (Measure T-9 from the Trip Reduction Program subsector), and the same is equally likely for the much smaller group of employers in a single-family suburban neighborhood.

Limitations of Maximums and Caps

The words *maximum* and *cap* are used interchangeably to describe either the highest percent reduction in GHG emissions or the highest expected value for a variable in the GHG reduction formula. Each subsector has a maximum allowable reduction and individual measures have a maximum allowable reduction, which is often based on one or more of the capped GHG reduction variables. In most instances, these values are a rule of thumb, or practical approximation, to limit the unrealistic influence of multiplicative measure variables. Where the maximum is derived based on a more precise methodology (e.g., research results), the source is cited. Users should always confirm the appropriateness of these maximums for their project.

Adjusting VMT Reductions to Emission Reductions

Most of the transportation measures in this Western States Handbook reduce GHG emissions and criteria pollutants (co-benefit) by decreasing the source metric of VMT.[8] The below equation highlights the main variables used to calculate VMT in a study area. Note that VMT decreases if any of the following occurs: (1) vehicle ownership declines; (2) vehicle trips are reduced, including through mode shift; (3) vehicle trip lengths are reduced; or (4) any combination of these three variables.

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[7] Salon, D. 2014. *Quantifying the Effect of Local Government Actions on VMT*. Institute of Transportation Studies, University of California, Davis. Prepared for the California Air Resources Board and the California Environmental Protection Agency. February 2014. Accessed October 2021. https://ww2.arb.ca.gov/sites/default/files/classic/research/apr/past/09-343.pdf.

[8] Exceptions include Measures T-14, *Provide Electric Charging Infrastructure*, and T-30, *Use Cleaner-Fuel Vehicles*.

$$\text{VMT} = \frac{\text{vehicles}}{\text{study area}} \times \frac{\text{trips}}{\text{vehicle·day}} \times \frac{\text{distance (miles)}}{\text{trip}} = \frac{\text{miles}}{\text{study area·day}}$$

Vehicles emit pollutants during all hours of the day. The magnitude of these emissions varies with the activity phase, such as running on the road, idling while stationary, sitting outside in the sun (evaporative), or starting up. The quantification methods presented in this Handbook account for emissions that occur during the four major emission processes of running, evaporation, idling and starting.

Emissions generated by these processes are determined, in part,[9] by the above VMT variables: (1) emissions from evaporation are a factor of vehicle ownership, (2) emissions from starting are a factor of vehicle ownership and number of vehicle starts (i.e., trips), and (3) emissions from running are a factor of vehicle ownership and number of vehicle trips and distance per trip (i.e., VMT).

$$\text{Emissions}_{\text{total}} = \text{Emissions}_{\text{evap}} + \text{Emissions}_{\text{start}} + \text{Emissions}_{\text{run}} + \text{Emissions}_{\text{idle}}$$

$$\text{Emissions}_{\text{evap}} = \frac{\text{vehicles}}{\text{study area}} \times \frac{\text{pollutant mass (grams)}}{\text{vehicle·day}} = \frac{\text{grams}}{\text{study area·day}}$$

$$\text{Emissions}_{\text{start}} = \frac{\text{vehicles}}{\text{study area}} \times \frac{\text{trips}}{\text{vehicle·day}} \times \frac{\text{pollutant mass (grams)}}{\text{trip·day}} = \frac{\text{grams}}{\text{study area·day}}$$

$$\text{Emissions}_{\text{run}} = \frac{\text{vehicles}}{\text{study area}} \times \frac{\text{trips}}{\text{vehicle·day}} \times \frac{\text{miles}}{\text{trip}} \times \frac{\text{pollutant mass (grams)}}{\text{distance (miles)}} = \frac{\text{grams}}{\text{study area·day}}$$

$$\text{Emissions}_{\text{idle}} = \frac{\text{vehicles}}{\text{study area}} \times \frac{\text{hours idling}}{\text{vehicle·day}} \times \frac{\text{pollutant mass (grams)}}{\text{hours idling}} = \frac{\text{grams}}{\text{study area·day}}$$

GHG and criteria pollutant reductions achieved by transportation measures are primarily presented in terms of a percent reduction, where the total emissions reduction was determined based on a ratio comparison to the VMT reduction. In other words, if a measure reduces VMT by some percent, the total emissions are reduced by the same percent (or a fraction of that percent, as described below). As discussed above, VMT can be reduced by decreasing any of the three variables of vehicle ownership, number of vehicle trips, and trip distance. The ratio comparison between reductions in VMT and emissions depends on the pollutant and which VMT variable(s) decrease with implementation of a transportation measure.

1. *Less vehicle ownership*. If a transportation measure reduces VMT by decreasing vehicle ownership, the measure would decrease running, starting, idling, and evaporative emissions by the same rate.[10] The measures where this applies are Measures T-15, *Limit Residential Parking Supply*, and T-16, *Unbundle Residential Parking Costs from Property Cost*, where the VMT reduction is a function of avoided vehicle ownership in residents disincentivized to park offsite or pay the separate cost of parking for a vehicle. For these measures, there is a 1:1 relationship between reductions in VMT and emissions because these measures reduce all emission processes at the same rate, not just running emissions.

2. *Fewer vehicle trips*. If a transportation measure reduces VMT by decreasing the number of vehicle trips, the measure would decrease running, starting, and idling emissions by approximately the same rate. This applies to all transportation measures except Measures T-14,

[9] Vehicle emissions are also a function of the chosen analysis year, project location, and fleet mix. When using MOVES, future year emissions decline over time, reflecting assumed changes in fleet mix for the location and cleaner engine and fuel technologies.

[10] Assuming emission factor variables are held constant.

Provide Electric Vehicle Charging Infrastructure; T-15, *Limit Residential Parking Supply;* T-16, *Unbundle Residential Parking Costs from Property Cost;* and T-30, *Use Cleaner-Fuel Vehicles*. This is because each measure would result in, at minimum,[11] fewer vehicle trips by promoting alternative modes of transportation in place of single-occupancy vehicles.

These measures would not decrease evaporative emissions, which are a function of vehicle ownership and environmental factors like temperature. However, this does not affect the ratio comparison between reductions in VMT and GHG emissions because there are no direct evaporative GHG emissions (i.e., 100 percent of CO_2, CH_4, and nitrous oxide (N_2O) from most vehicles. These result instead from combustion during running and starting processes. This is also true for nitrogen oxides (NOx), particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), and sulfur dioxide (SOx). Therefore, trip reduction measures reduce GHG and most criteria pollutant emissions in a 1:1 relationship with reductions in VMT; volatile organic carbon (VOC) and, in some cases, CH_4 are the exceptions.

VOC from vehicles include not only running and starting emissions, but also evaporative emissions.[12] Running and starting VOC emissions represent approximately 87 percent of total VOC emissions in passenger vehicles.[13] This adjustment factor should be applied when converting the percent GHG reduction to the percent reduction in total VOC emission.

$$\% \text{ reduction in VOC emissions} = \% \text{ reduction in GHG} \times 87\%$$

This is noted in the co-benefits section of *Improved Air Quality* for each applicable transportation measure.

3. *Shorter vehicle trips*. If a transportation measure reduces VMT by only decreasing the distance of vehicle trips, the measure would not reduce starting or evaporative emissions. There are no transportation measures in this Western States Handbook where this scenario occurs and, therefore, an adjustment factor is not developed.

The criteria pollutants CO, NO_2, SO_2, and PM are local pollutants that can potentially affect populations near the emissions source. Accordingly, measures that reduce localized criteria pollutant emissions can improve ambient air quality. Measures that reduce emissions of ozone precursors (NOx and VOC), which are regional pollutants, can improve regional air quality.

Note that the Handbook's use of a ratio comparison of VMT reduction to GHG and criteria pollutant reductions makes two key assumptions that may not be valid for every user's project. It is important users consider the validity of these assumptions on a project-by-project basis and either (1) perform any post-processing to the emissions reductions achieved by the transportation measures to better reflect their project conditions, or (2) provide a qualitative disclaimer about the accuracy of the estimated reductions considering the below assumptions.

[11] Many of these measures also result in shorter vehicle trips. In these instances, the VMT reduction is either largely a function of the reduction in vehicle trips or is an equal function of the reduction in vehicle trips and the reduction in trip distances. There are no measures where the VMT reduction is largely a function of the reduction in trip distances with a lesser contribution from the reduction in vehicle trips.

[12] See the *Overview of EPA's MOtor Vehicle Emission Simulator (MOVES5)* for more detail on these emission processes: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P101DQ9V.pdf.

[13] Combined emissions from the MOVES regulatory classes of LDV and LDT.

1. *Vehicle class is assumed to remain unchanged with implementation of a measure*. Say a user is interested in calculating the plan/community-level GHG reduction from Measure T-22-B, *Implement Electric Bikeshare Program*. The user has community-level VMT without the measure and elects to calculate community-wide mobile emissions using MOVES. The user calculates in MOVES that the existing percentage of the community VMT by vehicle class is 75 percent light-duty vehicles and 25 percent non-light-duty vehicles. In this example, the average emission factor for light-duty vehicles is 250 grams CO_2 per mile and for non–light-duty vehicles is 400 grams CO_2 per mile. The average community emission factor, as weighted by VMT, would be 288 grams per mile [(75% X 250 grams CO_2 per mile) + (25% X 400 grams CO_2 per mile)]. Users then estimate vehicle emissions prior to implementation of Measure T-22-B by applying this average vehicle emission factor to their community-level VMT.

   The user then implements Measure T-22-A, *Implement Pedal (Non-Electric) Bikeshare Program*, and reduces GHG emissions from vehicle travel by 4 percent by replacing vehicle trips with bikeshare trips. The majority of those replaced vehicle trips are private trips as light-duty vehicles. As a result, the percentage of the community VMT by vehicle class is now 70 percent light-duty vehicles and 30 percent non–light-duty vehicles, effectively increasing the community average vehicle emission factor, as weighted by VMT, from 288 grams per mile to 295 grams per mile [70% X 250 grams CO_2 per mile) + (30% X 400 grams CO_2 per mile)]. This increase in the community's average vehicle emission factor would overpower the decrease in VMT from replacing vehicle trips.

   Conversely, the circumstances could be such that a measure increases the GHG reduction that would be achieved from reduced vehicle trips. For example, Measure T-22-A may replace existing vehicle trips that are primarily from more emissions-intensive non–light-duty vehicles (e.g., transit buses). In this case, the percentage of the community VMT by the less–emissions-intensive light-duty vehicle would be higher, reducing the community average vehicle emission factor. This decrease in the community average vehicle emission factor would increase the GHG reduction that would be achieved from reduced vehicle trips.

   The Handbook method cannot predict or know how each measure could affect the user's specific fleet mix. Therefore, the fleet mix is assumed to remain constant before and after implementation of all transportation measures.

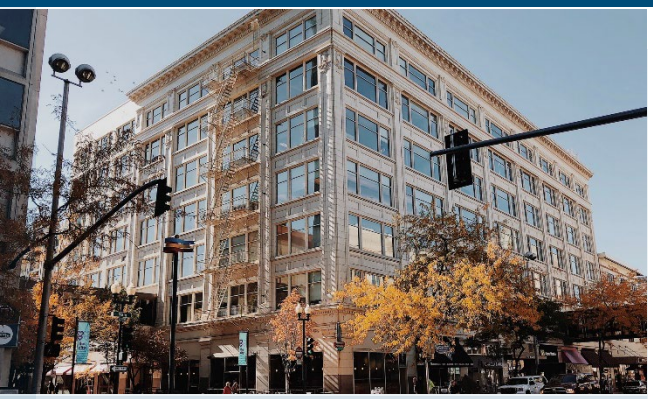
2. *Vehicle speeds are assumed to remain unchanged with implementation of a measure*. The logic of this assumption is similar to the first assumption. If a user is interested in calculating the plan/community-level GHG reduction from Measure T-20, *Expand Bikeway Network*. The user elects to calculate community-wide mobile emissions prior to implementation of the measures using MOVES and aggregated vehicle speeds. In this example, MOVES aggregates the vehicle speeds in the user's community at approximately 30 miles per hour (mph).[14] The user implements Measure T-20 and expansion of the bikeway network reduces the average vehicle speed to approximately 25 mph. Because internal combustion engine (ICE) vehicles are slightly more GHG emissions-intensive at 25 mph compared to 30 mph, the GHG reduction achieved by the measure would be less if the impact of vehicle speeds were included in the quantification method.

[14] Vehicle running emission factors are, in part, dependent on vehicle speed. Vehicles are generally more emissions-intensive at speeds that are very low (e.g., 5 mph) and very high (e.g., greater than 70 mph), though this varies by pollutant and vehicle class.

Conversely, the circumstances could be such that a measure increases the GHG reduction that would be achieved from reduced vehicle trips. For example, Measure T-11, *Provide Employer-Sponsored Vanpool*, replaces private vehicle trips with shared vanpool trips, reducing the number of cars on the road. If roadways are currently congested and causing vehicles to move at low speeds, implementation of this measure could alleviate roadway congestion and increase vehicle speeds to a speed in which they are less GHG emissions intensive. The decrease in the community average vehicle emission factor would increase the GHG reduction that would be achieved from reduced vehicle trips.

The Handbook method cannot predict or know how each measure could affect vehicle speeds under the various use cases. Therefore, the vehicle speeds are assumed to remain constant before and after implementation of all transportation measures.

T-1. Increase Residential Density



GHG Mitigation Potential



Up to 30.0% of GHG emissions from project VMT in the study area

Co-Benefits (icon key on pg. 31)



Climate Resilience

Increased density can put people closer to resources they may need to access during an extreme weather event. Increased density can also shorten commutes, decreasing the amount of time people are on the road and exposed to hazards such as extreme heat or flooding.

Health and Equity Considerations

Neighborhoods should include different types of housing to support a variety of household sizes, age ranges, and incomes.

Measure Description

This measure accounts for the VMT reduction achieved by a project that is designed with a higher density of dwelling units (du) compared to the average residential density in the U.S. Increased densities affect the distance people travel and provide greater options for the mode of travel they choose. Increasing residential density results in shorter and fewer trips by single-occupancy vehicles and thus a reduction in GHG emissions. This measure is best quantified when applied to larger developments and developments where the density is similar to the surrounding area due to the underlying research being founded in data from the neighborhood level. This requirement is based on the understanding that varying housing density can lead to shifting transportation behavioral patterns, thus varying transportation-related emissions.

Subsector

Land Use

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

This measure is most accurately quantified when applied to larger developments and/or developments where the density is somewhat similar to the surrounding neighborhood.

Cost Considerations

Depending on the location, increasing residential density may increase housing and development costs. However, the costs of providing public services, such as health care, education, policing, and transit, are generally lower in more dense areas where things are closer together. Infrastructure that provides drinking water and electricity also operates more efficiently when the service and transmission area is reduced. Local governments may provide approval streamlining benefits or financial incentives for infill and high-density residential projects.

Expanded Mitigation Options

When paired with Measure T-2, *Increase Job Density*, the cumulative densification from these measures can result in a highly walkable and bikeable area, yielding increased co-benefits in VMT reductions, improved public health, and social equity. This measure can be further matched with improved transit, biking, and walking, expanding the increasing co-benefits aforementioned.

GHG Reduction Formula

$$A = \frac{B - C}{C} \times D$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project VMT in study area	0–30.0	%	calculated
User Inputs				
B	Residential density of project development	[ ]	du/acre	user input
Constants, Assumptions, and Available Defaults				
C	Residential density of typical development	9.1	du/acre	Ewing et al. 2007
D	Elasticity of VMT with respect to residential density	-0.22	unitless	Stevens 2016

Further explanation of key variables:

- (C) – The residential density of typical development is based on the blended average density of residential development in the U.S. forecasted for 2025. This estimate includes apartments, condominiums, and townhouses, as well as detached single-family housing on both small and large lots. An acre in this context is defined as an acre of developed land, not including streets, school sites, parks, and other undevelopable land. If reductions are being calculated from a specific baseline derived from a travel demand forecasting model, the residential density of the relevant transportation analysis zone should be used instead of the value for a typical development.
- (D) – Based on 37 studies, a meta-regression model finds that when residential density increases by 1 percent, driving (or VMT) decreases by 0.22 percent on average (Stevens 2016). While the findings provide users an average estimate of the elasticity of VMT with respect to residential density in general, the actual elasticity, if available, could vary depending on project context.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions (A) is capped at 30 percent. The purpose for the 30 percent cap is to limit the influence of any single built environmental factor (such as density). Projects that implement multiple land use strategies (e.g., density, design, diversity) will show more of a reduction than relying on improvements from a single built environment factor.

Subsector Maximum

($\sum A_{max_{T\text{-}1 \text{ through } T\text{-}4,\ T\text{-}55}} \leq 65\%$) This measure is in the Land Use subsector. This subcategory includes Measures T-1 through T-4 and T-55. The VMT reduction from the combined implementation of all measures within this subsector is capped at 65 percent.

Example GHG Reduction Quantification

The user reduces VMT by increasing the residential density of the project study area. In this example, the project's residential density would be 15 du per acre (B), which would reduce GHG emissions from project VMT by 14.2 percent.

$$A = \frac{15\ \frac{du}{ac} - 9.1\ \frac{du}{ac}}{9.1\ \frac{du}{ac}} \times -0.22 = -14.2\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

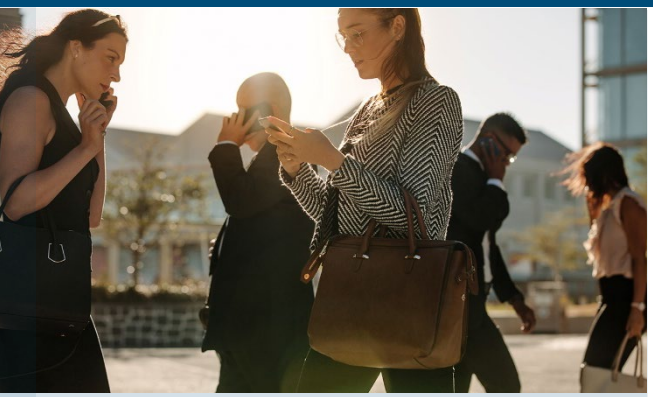
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- Ewing, R., K. Bartholomew, S. Winkelman, J. Walters, and D. Chen. 2007. *Growing Cooler: The Evidence on Urban Development and Climate Change*. October 2007. Accessed January 2021. https://www.nrdc.org/sites/default/files/cit_07092401a.pdf.
- Stevens, M. 2016. "Does Compact Development Make People Drive Less?" *Journal of the American Planning Association* 83, no. 1 (November): 7–18. Accessed January 2021. DOI: 10.1080/01944363.2016.1240044. https://www.researchgate.net/publication/309890412_Does_Compact_Development_Make_People_Drive_Less.

T-2. Increase Job Density



GHG Mitigation Potential

30%

Up to 30.0% of GHG emissions from project VMT in the study area

Co-Benefits (icon key on pg. 31)

Climate Resilience

Increased density can put people closer to resources they may need to access during an extreme weather event. Increased density can also shorten commutes, decreasing the amount of time people are on the road and exposed to hazards such as extreme heat or flooding.

Health and Equity Considerations

Increased job density may increase nearby housing prices. Jurisdictions should consider the jobs-housing balance and consider measures to reduce displacement and increase affordable housing.

Measure Description

This measure accounts for the VMT reduction achieved by a project that is designed with a higher density of jobs compared to the average job density in the U.S. Increased densities affect the distance people travel and provide greater options for the mode of travel they choose. Increasing job density results in shorter and fewer trips by single-occupancy vehicles and thus a reduction in GHG emissions.

Subsector

Land Use

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

This measure is most accurately quantified when applied to larger developments and/or developments where the density is somewhat similar to the surrounding neighborhood.

Cost Considerations

Areas with increased job density generally have higher economic gross metropolitan product (GMP) and job growth. Prosperity, measured as GMP per job, also grows faster in areas with increased job density. Decreased commute times and car use may also generate funds for public transit and reduce the need for infrastructure spending on road maintenance.

Expanded Mitigation Options

When paired with Measure T-1, *Increase Residential Density*, the cumulative densification from these measures can result in a highly walkable and bikeable area, yielding increased co-benefits in VMT reductions, improved public health, and social equity.

GHG Reduction Formula

$$A = \frac{B - C}{C} \times D$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project VMT in study area	0–30.0	%	calculated
User Inputs				
B	Job density of project development	[ ]	jobs per acre	user input
Constants, Assumptions, and Available Defaults				
C	Job density of typical development	145	jobs per acre	ITE 2020
D	Elasticity of VMT with respect to job density	-0.07	unitless	Stevens 2016

Further explanation of key variables:

- (C) – The jobs density is based on the calculated density of a development with a floor-area ratio of 1.0 and 300 square feet (sf) of building space per employee:

  $$\frac{43{,}560 \frac{\text{sf}}{\text{acre}}}{300 \frac{\text{sf}}{\text{employee}}} \times 1.0 \frac{\text{sf}}{\text{acre}} = 145 \frac{\text{employees}}{\text{acre}}$$

  If reductions are being calculated from a specific baseline derived from a travel demand forecasting model, the job density of the relevant transportation analysis zone should be used for this variable instead of the default value presented above.
- (D) – A meta-regression analysis of two studies that controlled for self-selection found that a 0.07 percent decrease in VMT occurs for every 1 percent increase in job density (Stevens 2016).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions (A) is capped at 30 percent. The purpose for the 30 percent cap is to limit the influence of any single built environmental factor (such as density). Projects that implement multiple land use strategies (e.g., density, design, diversity) will show more of a reduction than relying on improvements from a single built environment factor.

Subsector Maximum

($\sum A_{max_{T\text{-}1 \text{ through } T\text{-}4,\ T\text{-}55}} \leq 65\%$) This measure is in the Land Use subsector. This subcategory includes Measures T-1 through T-4 and T-55. The VMT reduction from the combined implementation of all measures within this subsector is capped at 65 percent.

Example GHG Reduction Quantification

The user reduces VMT by increasing the job density of the project study area. In this example, the project's job density would be 400 jobs per acre (B), which would reduce GHG emissions from project VMT by 12.3 percent.

$$A = \frac{400 \frac{job}{acre} - 145 \frac{job}{acre}}{145 \frac{job}{acre}} \times -0.07 = -12.3\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

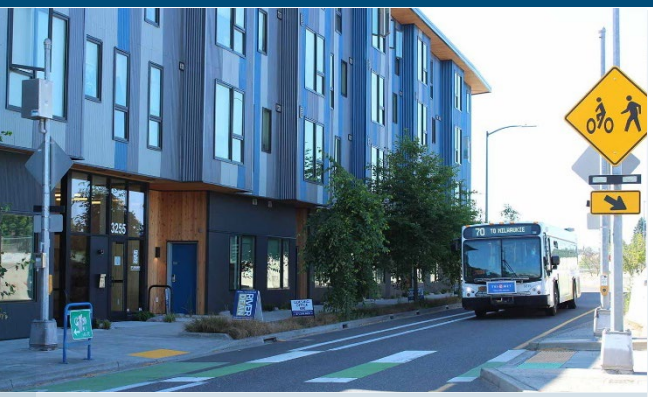
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- ITE (Institute of Transportation Engineers). *Trip Generation Manual.* 10th Edition. Accessed January 2021. https://www.ite.org/technical-resources/topics/trip-and-parking-generation/resources/.
- Stevens, M. 2016. "Does Compact Development Make People Drive Less?" *Journal of the American Planning Association* 83, no. 1 (November): 7–18. DOI: 10.1080/01944363.2016.1240044. November 2016. Accessed January 2021. https://www.researchgate.net/publication/309890412_Does_Compact_Development_Make_People_Drive_Less.

T-3. Provide Transit-Oriented Development



GHG Mitigation Potential



Up to 34.9% of GHG emissions from project VMT in study area

Co-Benefits (icon key on pg. 31)

Climate Resilience

Providing TOD puts many people close to reliable public transportation, diversifying their transportation options during an extreme weather event.

Health and Equity Considerations

TOD may increase housing prices, leading to gentrification and displacement. TOD coupled with affordable housing options can help to support equity by helping to lower transportation costs for residents and increase active mobility.

Measure Description

This measure would reduce project VMT in the study area relative to the same project sited in a non-transit-oriented development (TOD) location. TOD refers to projects built in compact, walkable areas that have easy access to public transit, ideally in a location with a mix of uses, including housing, retail offices, and community facilities. Project site residents, employees, and visitors would have easy access to high-quality public transit, thereby encouraging transit ridership and reducing the number of single-occupancy vehicle trips and associated GHG emissions.

Subsector

Land Use

Locational Context

Urban and suburban. Rural only if adjacent to commuter rail station with convenient rail service to a major employment center.

Scale of Application

Project/Site

Implementation Requirements

To qualify as a TOD, the development must be a residential or office project that is within a 10-minute walk (0.5 mile) of a high frequency transit station (either rail, or bus rapid transit with headways less than 15 minutes). Ideally, the distance should be no more than 0.25 to 0.3 of a mile but could be up to 0.5 mile if the walking route to station can be accessed by pedestrian-friendly routes. While quantifying the GHG mitigation potential of this measure, users are suggested to ensure that the "unmitigated" or "baseline" VMT does not account for reductions from transit proximity.

Cost Considerations

TOD reduces car use and car ownership rates, providing cost savings to residents. It can also increase property values and public transit use rates, providing additional revenue to municipalities, as well as open new markets for business development. Increased transit use will likely necessitate increased spending on maintaining and improving public transit systems, the costs of which may be high.

Expanded Mitigation Options

When building TOD, a best practice is to incorporate bike and pedestrian access—such as Measure 18, Measure 19A and 19B, Measure 20, Measure 22A and 22B—into the larger network to increase the likelihood of transit use.

GHG Reduction Formula

$$A = \frac{(B \times C)}{-D}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project VMT in study area	6.9–34.9	%	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
B	Transit mode share in surrounding city	Table T-3.1	%	See Appendix
C	Ratio of transit mode share for TOD area with measure compared to existing transit mode share in surrounding city	4.9	unitless	Lund et al. 2004
D	Auto mode share in surrounding city	Table T-3.1	%	See Appendix

Further explanation of key variables:

- (B and D) – Ideally, the user will calculate transit and auto mode share for a Project/Site at a scale no larger than a census tract. Ideally, variables B and D will reflect travel behavior in locations that are *not* already within 0.5 mile of a high-quality transit stop and may instead substitute data from nearby tracts further from transit if such locations exist. Potential data sources include the U.S. Census, state household travel surveys, or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the mode share for one of the geographic areas in Arizona, Colorado, Oregon, New Mexico, or Washington as presented in Table T-3.1 in the Appendix, *Emission Factors and Data Tables*. While selecting the appropriate values from Table T-3.1 for the project area, users are suggested to take into account criteria such as similarity of the built environment context. Transit mode share is likely to be smaller for areas outside of the listed CBSAs, which represent the most transit-accessible areas of each state. Conversely, auto mode share is likely to be larger.
- (C) – A study of people living in TODs in California found that, on average, transit shares for TOD residents exceed the surrounding city by a factor of 4.9 (Lund et al. 2004). A similar study in the Portland area found that 26 percent of commuters use transit, a higher rate than city-wide residents, with factors like proximity of rail stations and parking pricing influencing their transit use (Dill 2008).

GHG Calculation Caps or Maximums

Measure Maximum

$((B \times C)_{max})$ The transit mode share in the project study area with the measure is capped at 27 percent. This is based on the weighted average transit commute mode share of five surveyed sites where residents lived within 3 miles of rail stations (Lund et al. 2004). As transit mode share is typically higher for commute trips compared to all trips, 27 percent represents a reasonable upper bound for expected transit mode share in a TOD area.

(A_{max}) For projects that use default CBSA data from Table T-3.1 in the Appendix, the maximum percent reduction in GHG emissions (A) is 34.9 percent. This is based on a project in the CBSA of Portland, OR with a transit mode share that reaches the cap $((B \times C)_{max})$. This maximum scenario is presented in the below example quantification.

Subsector Maximum

$(\sum A_{max_{T\text{-}1 \text{ through } T\text{-}4,\ T\text{-}55}} \leq 65\%)$ This measure is in the Land Use subsector. This subcategory includes Measures T-1 through T-4 and T-55. The VMT reduction from the combined implementation of all measures within this subsector is capped at 65 percent.

Example GHG Reduction Quantification

The user reduces VMT by locating their project in a TOD location. Project site residents, employees, and visitors would have easy access to high-quality public transit, thereby encouraging transit use and reducing single occupancy vehicle travel. In this example, the project is within the Portland Metro area with an existing transit mode share (B) of 8.6 percent. Applying a 4.9 ratio of transit mode share for TOD area with the measure compared to existing transit mode share in the surrounding city yields 42.1 percent, which exceeds the 27 percent cap $((B \times C)_{max})$. Therefore, 27 percent is used to define $(B \times C)$. The existing vehicle mode share is 77.2 percent (D). The user would reduce GHG emissions from project study area VMT (as compared to the same project in a non-TOD location) by 34.9 percent.

$$A = \frac{27\%}{-77.2\%} = -34.9\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

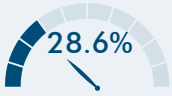
Sources

- Colorado Department of Transportation. 2025. *StateFocus Travel Demand Model*. Received from Colorado State in February 2025.
- Dill, Jennifer. 2008. "Transit Use at Transit-Oriented Developments in Portland, Oregon, Area." In *Transportation Research Record* 2063, No. 1 (January). Accessed March 2025. https://media.oregonlive.com/news_impact/other/Dill_TODs-TRR_2063.pdf.
- Federal Highway Administration (FHWA). 2017a. *National Household Travel Survey–2017 Table Designer*. Annual PMT by TRPTRANS by HH_CBSA/HH_STATE. Accessed January 2025. https://nhts.ornl.gov/.
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- New Mexico Environment Department. 2025. *Correspondence*. Received from New Mexico State in February 2025.
- Oregon Department of Transportation. 2011. *2010 Oregon Travel Study*. Received from Oregon State in February 2025.
- Portland Metro. 2023. *Regional Transportation Plan*. Received from Portland Metro in February 2025.

T-4. Integrate Affordable and Below Market Rate Housing



GHG Mitigation Potential



Up to 28.6% of GHG emissions from project/site multifamily residential VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

Increasing affordable housing creates the opportunity for a greater diversity of people to be closer to their desired destinations and the resources they may need to access during an extreme weather event. Close proximity to destinations allows for more opportunities to use active transportation and transit and to be less reliant on private vehicles. Alleviating the housing-cost burden also enables more people to remain housed, and increases people's capacity to respond to disruptions, including climate impacts.

Health and Equity Considerations

Neighborhoods should include different types of housing to support a variety of household sizes, age ranges, abilities, and incomes.

Measure Description

This measure requires below market rate (BMR) housing. BMR housing provides greater opportunity for lower income families to live closer to job centers and achieve a jobs/housing match near transit. It is also an important strategy to address the limited availability of affordable housing that might force residents to live far away from jobs or school, requiring longer commutes. The quantification method for this measure accounts for VMT reductions achieved for multifamily residential projects that are deed restricted or otherwise permanently dedicated as affordable housing.

Subsector

Land Use

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

Multifamily residential units must be permanently dedicated as affordable for lower income families. The Department of Housing and Urban Development (HUD 2019) defines lower-income as 80 percent of area median income or below, and affordable housing as costing 30 percent of gross household income or less.

Cost Considerations

Depending on the source of the affordable subsidy, BMR housing may have implications for development costs but would also have the benefit of reducing costs for public services, similar to Measure T-1, *Increase Residential Density*.

Expanded Mitigation Options

Pair with Measure T-1, *Increase Residential Density*, and Measure T-2, *Increase Job Density*, to achieve greater population and employment diversity.

GHG Reduction Formula

$A = B \times C$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from Project/Site VMT for multifamily residential developments	0–28.6	%	calculated
User Inputs				
B	Percentage of multifamily units permanently dedicated as affordable	0–100	%	user input
Constants, Assumptions, and Available Defaults				
C	Percent reduction in VMT for qualified units compared to market rate units	-28.6	%	ITE 2021

Further explanation of key variables:

- (B) – This refers to percentage of multifamily units in the project that are deed restricted or otherwise permanently dedicated as affordable.
- (C) – The 11th Edition of the *ITE Trip Generation Manual* (ITE 2021) contains daily vehicle trip rates for market rate multifamily housing that is low-rise and not close to transit (ITE code 221) as well as affordable multifamily housing (ITE code 223). While these rates do not account for trip length, they serve as a proxy for the expected difference in vehicle trip generation and VMT generation presuming similar trip lengths for both types of land use. If the user has information about trip length differences between market rate and affordable housing, then adjusting the percent reduction accordingly is recommended.

  Users should note that the ITE trip rate estimates are based on a small sample of studies for the affordable housing rate and that no stratification of affordable housing by number of stories was available. This is an important distinction since the multifamily low-rise vehicle trip rate applies to four or fewer stories. Therefore, this measure may not apply to affordable housing projects with more than four stories.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum GHG reduction from this measure is 28.6 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}1 \text{ through } T\text{-}4,\ T\text{-}55}} \leq 65\%$) This measure is in the Land Use subsector. This subsector includes Measures T-1 through T-4 and T-55. The VMT reduction from the combined implementation of all measures within this subsector is capped at 65 percent.

Example GHG Reduction Quantification

The user reduces project VMT by requiring a portion of the multifamily residential units to be permanently dedicated as affordable. In this example, the percentage of units (B) is 100 percent, which would reduce GHG emissions from VMT by 28.6 percent.

$$A = 100\% \times -28.6\% = -28.6\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

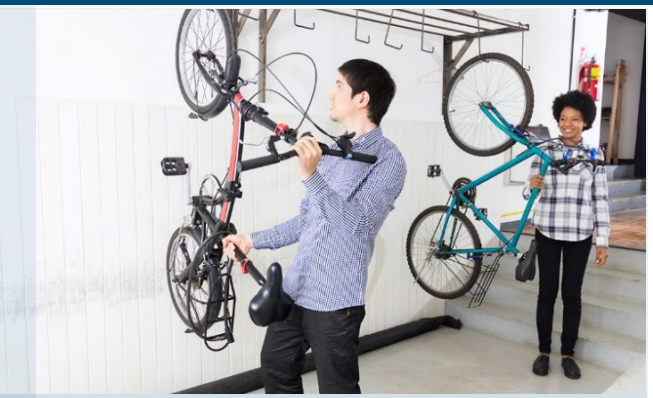
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

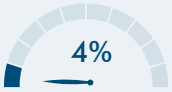
Sources

- HUD (U.S. Department of Housing and Urban Development). 2019. *Methodology for Determining Section 8 Income Limits*. Accessed January 2025. https://www.huduser.gov/portal/datasets/il/il19/IncomeLimitsMethodology-FY19.pdf.
- ITE (Institute of Transportation Engineers). 2021. *Trip Generation Manual*. 11th Edition. Accessed November 2021. https://www.ite.org/technical-resources/topics/trip-and-parking-generation/.

T-5. Implement Commute Trip Reduction Program (Voluntary)



GHG Mitigation Potential



Up to 4.0% of GHG emissions from project/site employee commute VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

CTR programs could result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. When this reduction occurs during extreme weather events, it better allows emergency responders to access a hazard site. Lower transportation costs would also increase community resilience by freeing up resources for other purposes.

Health and Equity Considerations

Design of CTR programs need to ensure equitable access and benefits to all employees are provided considering disparate existing mobility options in diverse communities.

Measure Description

This measure will implement a voluntary commute trip reduction (CTR) program with employers. CTR programs discourage single-occupancy vehicle trips and encourage alternative modes of transportation such as carpooling, taking transit, walking, and biking, thereby reducing VMT and GHG emissions. Voluntary implementation elements are described in this measure.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

Voluntary CTR programs must include the following elements to apply the VMT reductions reported in literature.

- Employer-provided services, infrastructure, and incentives for alternative modes such as ridesharing (Measure T-8), discounted transit (Measure T-9), bicycling (Measure T-10), vanpool (Measure T-11), and guaranteed ride home.
- Information, coordination, and marketing for said services, infrastructure, and incentives (Measure T-7).

Cost Considerations

Employer costs may include recurring costs for transit subsidies, capital and maintenance costs for the alternative transportation infrastructure, and labor costs for staff to manage the program. Where the local municipality has a VMT reduction ordinance, costs may include the labor costs for government staff to track the efficacy of the program.

Expanded Mitigation Options

Other strategies may also be included as part of a voluntary CTR program, though they are not included in the VMT reductions reported by literature and thus are not incorporated in the VMT reductions for this measure.

This program typically serves as a complement to the more effective workplace CTR measures such as pricing workplace parking (Measure T-12) or implementing employee parking "cash-out" (Measure T-13).

GHG Reduction Formula

$A = B \times C$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project/site employee commute VMT	0–4.0	%	calculated
User Inputs				
B	Percentage of employees eligible for program	0–100	%	user input
Constants, Assumptions, and Available Defaults				
C	Percent reduction in commute VMT from eligible employees	-4	%	Boarnet et al. 2014

Further explanation of key variables:

- (B) – This refers to the percentage of employees who would be able to participate in the program. Employees who might not be able to participate could include those who work nighttime hours when transit and rideshare services are not available or employees who are required to drive to work as part of their job duties. This input refers to the percentage of eligible employees from the program.
- (C) – A policy brief summarizing the results of employer-based trip reduction studies concluded that these programs reduce total commute VMT for employees at participating work sites by 4 to 6 percent (Boarnet et al. 2014). To be conservative, the low end of the range is cited.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum GHG reduction from this measure is 4 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{\text{T-5 through T-13}}} \leq 45\%$) This measure is in the Trip Reduction Programs subsector. This subcategory includes Measures T-5 through T-13. The employee commute VMT reduction from the combined implementation of all measures within this subsector is capped at 45 percent.

Mutually Exclusive Measures

If this measure is selected, the user may not also take credit for Measure T-6, which represents the same implementation activities as Measure T-5, except that the CTR program would be mandatory. Users should select either Measure T-5 or T-6.

If this measure is selected, the user may not also take credit for Measures T-7 through T-11. Measure T-5 accounts for the combined GHG reductions achieved by each of these individual measures. To combine the GHG reductions from T-5 with any of these measures would be considered double counting. However, the user may take credit for Measures T-12 through T-13 within the larger CTR subcategory, so long as the combined VMT reduction does not exceed 45 percent, as noted above.

Example GHG Reduction Quantification

The user reduces employee commute VMT by requiring that employers of a project offer a voluntary commute trip reduction program to their employees. In this example, the percentage of employees eligible (B) is 100 percent, which would reduce GHG emissions from employee commute VMT by 4 percent.

$$A = 100\% \times -4\% = -4\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

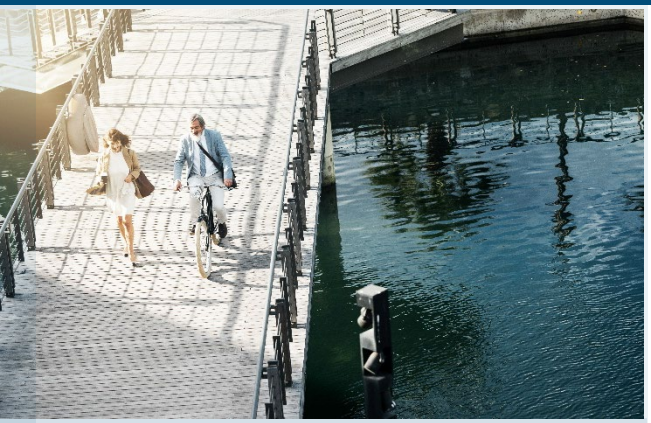
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Source

- Boarnet, M., H. Hsu, and S. Handy. 2014. *Impacts of Employer-Based Trip Reduction Programs and Vanpools on Passenger Vehicle Use and Greenhouse Gas Emissions*. September 2014. Accessed January 2021. https://ww2.arb.ca.gov/sites/default/files/2020-06/Impacts_of_Employer-Based_Trip_Reduction_Programs_and_Vanpools_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Policy_Brief.pdf.

T-6. Implement Commute Trip Reduction Program (Mandatory Implementation and Monitoring)



GHG Mitigation Potential



Up to 29% of GHG emissions from project/site employee commute VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

Commute trip reduction programs could result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. When this reduction occurs during extreme weather events, it better allows emergency responders to access a hazard site. Lower transportation costs would also increase community resilience by freeing up resources for other purposes.

Health and Equity Considerations

Design of CTR programs needs to consider existing mobility options in diverse communities and ensure equitable access and benefit to all employees.

Measure Description

This measure will implement a mandatory CTR program with employers. CTR programs discourage single-occupancy vehicle trips and encourage alternative modes of transportation such as carpooling, taking transit, walking, and biking, thereby reducing VMT and GHG emissions.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site; Plan/Community

Implementation Requirements

The mandatory CTR program must include all other elements (i.e., Measures T-7 through T-11) described for the voluntary program (Measure T-5) plus include mandatory trip reduction requirements (including penalties for non-compliance) and regular monitoring and reporting to ensure the calculated VMT reduction matches the observed VMT reduction.

Cost Considerations

Employer costs may include recurring, direct costs for transit subsidies, capital and maintenance costs for alternative transportation infrastructure, and labor costs for staff to manage the program. If the local municipality has a mandatory VMT reduction ordinance, additional employer costs could include non-compliance penalties if the municipality fines CTR programs that do not meet a VMT goal. Municipal costs may include the labor costs for government staff to track the efficacy of the program, which may be outweighed by revenue generated from fines collected from non-compliant businesses.

Expanded Mitigation Options

This program typically serves as a complement to the more effective workplace CTR measures, such as pricing workplace parking (Measure T-12) or implementing employee parking "cash-out" (Measure T-13).

GHG Reduction Formula

$A = B \times C \times D$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project/site employee commute VMT	0–26.0	%	calculated
User Inputs				
B	Percentage of employees eligible for program	0–100	%	user input
Constants, Assumptions, and Available Defaults				
C	Percent reduction in vehicle mode share of employee commute trips	-26	%	Nelson\Nygaard Consulting Associates 2015
D	Adjustment from vehicle mode share to commute VMT	1	unitless	assumed

Further explanation of key variables:

- (B) – This refers to the percentage of employees who would be able to participate in the program. This will usually be 100 percent. Employees who might not be able to participate could include those who work nighttime hours when transit and rideshare services are not available or employees who are required to drive to work as part of their job duties. This input does not refer to the percentage of employees who participate in the program.
- (C) – A multiyear study of mode share on Genentech's campuses tracked the long-run change in employee commute mode share with implementation of mandatory CTR. Between 2006 and 2014, employee vehicle mode share (includes single-occupied vehicles and carpools) decreased from approximately 90 percent to 64 percent, which is an absolute decrease of 26 percentage points (Nelson\Nygaard Consulting Associates 2015).
- (D) – The adjustment factor from vehicle mode share to commute VMT is 1. This assumes that all vehicle trips will average out to typical trip length. Thus, it can be assumed that a percentage reduction in vehicle trips will equal the same percentage reduction in VMT.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum GHG reduction from this measure is 26 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}5 \text{ through } T\text{-}13}} \leq 45\%$) This measure is in the Trip Reduction Programs subsector. This subcategory includes Measures T-5 through T-13. The employee commute VMT reduction from

the combined implementation of all measures within this subsector is capped at 45 percent.

Mutually Exclusive Measures

If this measure is selected, the user may not also take credit for Measure T-5, which represents the same implementation activities as Measure T-5, except that the CTR program would be mandatory. Users should select either Measure T-5 or T-6.

If this measure is selected, the user may not also take credit for Measures T-7 through T-11. Measure T-6 accounts for the combined GHG reductions achieved by each of these individual measures. To combine the GHG reductions from T-6 with any of these measures would be considered double counting. However, the user may take credit for Measure T-12 and T-13 within the larger CTR subcategory, so long as the combined VMT reduction does not exceed 45 percent, as noted above.

Example GHG Reduction Quantification

The user reduces employee commute VMT by requiring that the employer of the proposed project offer a mandatory CTR program to their employees. In this example, the percentage of employees eligible (B) is 100 percent, which would reduce GHG emissions from employee commute VMT by 29 percent.

$$A = 100\% \times -26\% \times 1 = -26\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

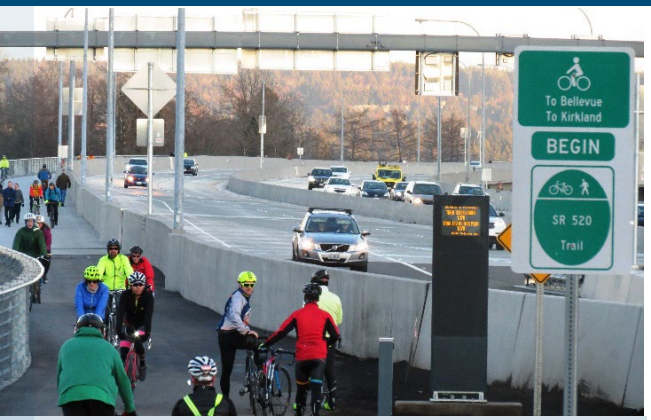
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Source

- Nelson/Nygaard Consulting Associates. 2015. *Genentech–South San Francisco Campus TDM and Parking Report*. June 2015. Accessed January 2021. http://ci-ssf-ca.granicus.com/MetaViewer.php?view_id=2&clip_id=859&meta_id=62028.

T-7. Implement Commute Trip Reduction Marketing



GHG Mitigation Potential



Up to 4.0% of GHG emissions from project/site employee commute VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

Commute trip reduction programs could result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. When this reduction occurs during extreme weather events, it better allows emergency responders to access a hazard site. Lower transportation costs would also increase community resilience by freeing up resources for other purposes.

Health and Equity Considerations

Design of CTR programs needs to consider existing mobility options in diverse communities and ensure equitable access and benefit to all employees. CTR programs may need to include multi-language materials.

Measure Description

This measure will implement a marketing strategy to promote the project site employer's CTR program. Information sharing and marketing promote and educate employees about their travel choices to the employment location beyond driving such as carpooling, taking transit, walking, and biking, thereby reducing VMT and GHG emissions.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

The following features (or similar alternatives) of the marketing strategy are essential for effectiveness.

- Onsite or online commuter information services.
- Employee transportation coordinators.
- Onsite or online transit pass sales.
- Guaranteed ride home service.

Cost Considerations

Employer costs include labor and materials for development and distribution of survey and marketing materials to promote the program and educate potential participants.

Expanded Mitigation Options

This measure could be packaged with other commute trip reduction measures (Measures T-8 through T-13) as a comprehensive CTR program (Measure T-5 or T-6).

GHG Reduction Formula

$A = B \times C \times D$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project/site employee commute VMT	0–4.0	%	calculated
User Inputs				
B	Percentage of employees eligible for program	0–100	%	user input
Constants, Assumptions, and Available Defaults				
C	Percent reduction in employee commute vehicle trips	-4	%	TRB 2010
D	Adjustment from vehicle trips to VMT	1	unitless	assumed

Further explanation of key variables:

- (B) – This refers to the percentage of employees who would be able to participate in the program. This will usually be 100 percent. Employees who might not be able to participate could include those who work nighttime hours when transit and rideshare services are not available or employees who are required to drive to work as part of their job duties. This input does not refer to the percentage of employees who actually participate in the program.
- (C) – A review of studies measuring the effect of transportation demand management measures on traveler behavior notes that the average empirically-based estimate of reductions in vehicle trips for full-scale, site-specific employer support programs is 4 to 5 percent. To be conservative, the low end of the range is cited (TRB 2010).
- (D) – The adjustment factor from vehicle trips to VMT is 1. This assumes that all vehicle trips will average out to typical trip length ("assumes all trip lengths are equal"). Thus, it can be assumed that a percentage reduction in vehicle trips will equal the same percentage reduction in VMT.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum GHG reduction from this measure is 4 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}5 \text{ through } T\text{-}13}} \leq 45\%$) This measure is in the Trip Reduction Programs subsector. This subcategory includes Measures T-5 through T-13. The employee commute VMT reduction

from the combined implementation of all measures within this subsector is capped at 45 percent.

Mutually Exclusive Measures

If this measure is selected, the user may not also take credit for either Measure T-5 or T-6. However, this measure may be implemented alongside other individual CTR measures (Measures T-8 through T-13). The efficacy of individual programs may vary highly based on individual employers and local contexts and per the nature of the program.

Example GHG Reduction Quantification

The user reduces employee commute VMT by requiring that employers of a project market to employees travel options for modes alternative to single-occupied vehicles. In this example, the percentage of employees eligible (B) is 100 percent, which would reduce GHG emissions from employee commute VMT by 4 percent.

$$A = 100\% \times -4\% \times 1 = -4\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Source

- TRB (Transportation Research Board). 2010. "Chapter 19: Employer and Institutional TDM Strategies." In *Traveler Response to Transportation System Changes Handbook, Third Edition*. June 2010. Accessed January 2021. http://www.trb.org/Publications/Blurbs/163781.aspx.

T-8. Provide Ridesharing Program



GHG Mitigation Potential



Up to 8.0% of GHG emissions from project/site employee commute VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

Ridesharing programs could result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. When this reduction occurs during extreme weather events, it better allows emergency responders to access a hazard site. Lower transportation costs would also increase community resilience by freeing up resources for other purposes.

Health and Equity Considerations

Program should include all onsite workers, such as contractors, interns, and service workers. Because ridesharing is vehicle-based, and some employees may not be in areas with feasible rideshare networks, design of programs need to ensure equitable benefits to those with and without access to rideshare opportunities.

Measure Description

This measure will implement a ridesharing program and establish a permanent transportation management association with funding requirements for employers. Ridesharing encourages carpooled vehicle trips in place of single-occupied vehicle trips, thereby reducing the number of trips, VMT, and GHG emissions. This differs from transportation network companies or taxis, which do not take advantage of trips that would happen anyways and add deadhead miles.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

Ridesharing must be promoted through a multifaceted approach. Examples include the following.

- Designating a certain percentage of desirable parking spaces for ridesharing vehicles.
- Designating adequate passenger loading and unloading and waiting areas for ridesharing vehicles.
- Providing an app or website for coordinating rides.

Cost Considerations

Costs of developing, implementing, and maintaining a rideshare program in a way that encourages participation are generally borne by municipalities or employers. The beneficiaries include the program participants saving on commuting costs, the employer reducing onsite parking expenses, and the municipality reducing cars on the road, which leads to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

When providing a ridesharing program, a best practice is to establish funding by a non-revocable funding mechanism for employer-provided subsidies. In addition, encourage use of low-emission ridesharing vehicles (e.g., shared Uber Green).

This measure could be paired with any combination of the other commute trip reduction strategies (Measures T-7 through T-13) for increased reductions.

GHG Reduction Formula

$A = B \times C$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project/site employee commute VMT	0–8.0	%	calculated
User Inputs				
B	Percentage of employees eligible for program	0–100	%	user input
Constants, Assumptions, and Available Defaults				
C	Percent reduction in employee commute VMT	Table T-8.1	%	SANDAG 2019

Further explanation of key variables:

- (B) – This refers to the percentage of employees who would be able to participate in the program. This will usually be 100 percent. Employees who might not be able to participate could include those who work nighttime hours when transit and rideshare services are not available or employees who are required to drive to work as part of their job duties. This input does not refer to the percentage of employees who actually participate in the program.
- (C) – The percent reduction in employee commute VMT by place type is provided in Table T-8.1 in the Appendix. The reduction differs by place type because the willingness and ability to participate in carpooling is higher in urban areas than in suburban areas. Note that this measure is not applicable for implementation in rural areas (SANDAG 2019).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum GHG reduction from this measure is 8 percent.

Subsector Maximum

($\sum A_{max_{T\text{-}5 \text{ through } T\text{-}13}} \leq 45\%$) This measure is in the Trip Reduction Programs subsector. This subcategory includes Measures T-5 through T-13. The employee commute VMT reduction from the combined implementation of all measures within this subsector is capped at 45 percent.

Mutually Exclusive Measures

If this measure is selected, the user may not also take credit for either Measure T-5 or T-6. However, this measure may be implemented alongside other individual CTR measures (Measures T-7 and T-9 through T-13). The efficacy of individual programs may vary highly based on individual employers and local contexts.

Example GHG Reduction Quantification

The user reduces employee commute VMT by requiring that employers of a project provide a ridesharing program to their employees. In this example, the percentage of employees eligible (B) at a packaging and distribution center is 50 percent and the place type of the project is urban (C). GHG emissions from employee commute VMT would be reduced by 4 percent.

$A = 50\% \times -8\% = -4\%$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Source

- SANDAG (San Diego Association of Governments). 2019. *Mobility Management VMT Reduction Calculator Tool–Design Document*. June 2019. Accessed January 2021.

T-9. Implement Subsidized or Discounted Transit Program



GHG Mitigation Potential



Up to 4.3% of emissions from employee/resident vehicles accessing the site

Co-Benefits (icon key on pg. 31)

Climate Resilience

Subsidized and discounted transit programs increase the capacity of low-income populations to use transit to evacuate or access resources during an extreme weather event. They could also incentivize more people to use transit, resulting in less traffic and better allowing emergency responders to access a hazard site during an extreme weather event. Lower overall out-of-pocket costs would also help increase community resilience by freeing up resources for other purposes.

Health and Equity Considerations

Program should include all onsite workers, such as contractors, interns, and service workers.

Measure Description

This measure will provide subsidized, discounted, or free transit passes for employees and/or residents. Reducing the out-of-pocket cost for choosing transit improves the competitiveness of transit against driving, increasing the total number of transit trips and decreasing vehicle trips. This decrease in vehicle trips results in reduced VMT and thus a reduction in GHG emissions.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

The project should be accessible either within 1 mile of high-quality transit service (rail or bus with headways of less than 15 minutes), 0.5 mile of local or less frequent transit service, or along a designated shuttle route providing last-mile connections to rail service. If a well-established bikeshare service (Measure T-22-A) is available, the site may be located up to 2 miles from a high-quality transit service.

If more than one transit agency serves the site, subsidies should be provided that can be applied to each of the services available. If subsidies are applied for only one service, all variable inputs below should also pertain only to the service that is subsidized.

Cost Considerations

The employer cost is the recurring, direct cost for transit subsidies. If a discount is provided by the transit service, the subsidies will lower the per capita income of the transit service, decreasing the revenue of the local transit agency. This cost may be offset by increased revenue from increased ridership. The beneficiaries include the program participants saving on commuting cost, the employer reducing onsite parking expenses, and the municipality reducing cars on the road, which leads to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

This measure could be paired with any combination of the other commute trip reduction strategies (Measures T-7 through T-13) for increased reductions.

GHG Reduction Formula

$$A = \frac{C}{B} \times G \times D \times E \times F \times H \times I$$

GHG Calculation Variables

If subsidies or discounts target employees, the GHG reduction from this measure may be limited to work-related employee trips only (i.e., home-to- work) and work-to-other, where at least one trip end is work). If residents are targeted, the GHG reductions extend to all trips.

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from employee/resident vehicles accessing the site	0–4.3	%	calculated
User Inputs				
B	Average transit fare without subsidy	[ ]	$	user input
C	Subsidy amount	[ ]	$	user input
D	Percentage of employees/residents eligible for subsidy	0–100	%	user input
E	Percentage of project-generated VMT from employees/residents	0–100	%	user input
Constants, Assumptions, and Available Defaults				
F	Transit mode share of all trips or work trips	Table T-3.1 or Table T-9.1	%	See Appendix
G	Elasticity of transit boardings with respect to transit fare price	-0.43	unitless	Taylor et al. 2008
H	Percentage of transit trips that would otherwise be made in a vehicle	50	%	Handy and Boarnet 2013
I	Conversion factor of vehicle trips to VMT	1.0	unitless	assumption

Further explanation of key variables:

- (B and C) – The average transit fare and subsidy amount can be presented as either a fare per ride, or the cost of a monthly pass for typical transit service near the site. Pricing should be based on the expected means of subsidy implementation; for instance, if a monthly pass is provided to all residents, prices should be input on a monthly basis.
- (D) – The percentage of employees/residents associated with the site who have access to the subsidy. If subsidy is provided as an employee benefit, care should be taken to account for any contract or temporary workers who do not receive such benefits.
- (E) – The percentage of project-generated VMT from employees/residents is used to adjust the percent reduction in GHG emissions from the scale of employee and/or resident-generated VMT to project-generated VMT. If subsidies or discounts target employees at an office development, this value would simply be 100 percent. If the

project site is a multifamily development with no onsite workers, this value would also be 100 percent. If the project site is a retail development, this value would be less than 100 percent, as it does not account for retail shopper trips to the site. The share of total VMT generated by employees for visitor-intensive uses, such as retail or medical offices, can be roughly estimated by multiplying the total number of employees by two (to account for both arrival and departure), divided by the total number of daily trips.

- (F) – Ideally, the user will calculate transit mode share for work trips or all trips of a Project/Site at a scale no larger than a census tract. Potential data sources include the U.S. Census, state household travel surveys, or local survey efforts. Care should be taken *not* to present the reported commute mode share as retrieved from the American Community Survey (ACS), unless the land use is office or employment based and the tables are based on work location (rather than home location). If the subsidies or discounts target employees and their commute trips, then the mode share should use the home-to-work trip purpose. If the user is not able to provide a project-specific value using one of the data sources described above, they have the option to input the transit mode share for one of the geographic areas in Arizona, Oregon, New Mexico, or Washington. The transit mode share for work trips by geographic area is presented in Table T-9.1 (see the Appendix). The transit mode share for all trips is provided in Table T-3.1 (see the Appendix).
- (G) – A cross-sectional analysis of transit use in 265 urbanized areas in the U.S. found that a 0.43 percent decrease in transit boardings occurs for every 1 percent increase in transit fare price (Taylor et al. 2008). A policy brief summarizing the results of transit service strategies found this analysis to fall in the mid-point of observed, short-term values (Handy and Boarnet 2013). Price elasticities of transit demand vary based on both long-term and short-term demand, service type, and service location (Litman 2020; Handy and Boarnet 2013).
- (H) – Not all new transit trips replace a vehicle trip. The share of transit trips that would otherwise be made by private vehicle ranges from less than 5 percent to 50 percent across studies. This assumption is based on observed values for high quality BRT service under the assumption that this measure is implemented alongside marketing measures and is targeted primarily at reducing vehicle commute trips. (Handy and Boarnet 2013). Note that this study looked at service improvements rather than fare changes and is used as a proxy variable. If project-specific or location-specific information is available, it should be substituted for this assumptive variable.
- (I) – The adjustment factor from vehicle trips to VMT is 1. This assumes that all vehicle trips will average out to typical trip length ("assumes all trip lengths are equal"). Thus, it can be assumed that a percentage reduction in vehicle trips will equal the same percentage reduction in VMT. Subsidies or discounts targeting commute trips may have a higher factor as they are generally longer than the trip lengths for other purposes.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The GHG reduction is capped at 4.3 percent, which is based on the following assumptions:

- (C=B) – The subsidy coverage is capped at 100 percent of the typical transit fare.

- (D) – All employees are eligible for the subsidy.
- (E) – All project-generated VMT is from employee-generated VMT.
- (F) – Employees at an office development in King County, Washington, have a default transit mode share for work trips of 20.21 percent.

Subsector Maximum

$(\sum A_{max_{T\text{-}5 \text{ through } T\text{-}13}} \leq 45\%)$ This measure is in the Trip Reduction Programs subsector. This subcategory includes Measures T-5 through T-13. The employee commute VMT reduction from the combined implementation of all measures within this subsector is capped at 45 percent.

Mutually Exclusive Measures

If this measure is selected, the user may not also take credit for either Measure T-5 or T-6. However, this measure may be implemented alongside other individual CTR measures (Measures T-7, T-8, T-10 through T-13). The efficacy of individual programs may vary highly based on individual employers and local contexts.

Example GHG Reduction Quantification

In this example, the user reduces VMT by providing all employees (D) of a proposed office development in King County a 100 percent transit subsidy in the form of a $100 monthly transit pass (C=B). The user would reduce GHG emissions from VMT by 4.3 percent.

$$A = \left(\frac{\$100}{\$100} \times 0.43\right) \times 100\% \times 100\% \times 20.21\% \times 50\% \times 1 = -4.3\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

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T-10. Provide End-of-Trip Bicycle Facilities



GHG Mitigation Potential



Up to 2.0% of GHG emissions from project/site employee commute VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

End-of-trip bicycle facilities could take more cars off the road, resulting in less traffic and better allowing emergency responders to access a hazard site during an extreme weather event. They could also make it easier for bicycle users to access resources in an extreme weather event.

Health and Equity Considerations

Facilities should be inclusive of all gender identities and expressions. Consider including gender-neutral, single-occupancy options to allow for additional privacy for those who want it.

Measure Description

This measure will install and maintain end-of-trip facilities for employee use. End-of-trip facilities include bike parking, bike lockers, showers, and personal lockers. The provision and maintenance of secure bike parking and related facilities encourages commuting by bicycle, thereby reducing VMT and GHG emissions.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

End-of-trip facilities should be installed at a size proportional to the number of commuting bicyclists and regularly maintained.

Cost Considerations

Employer costs include capital and maintenance costs for construction and maintenance of facilities and potentially labor and materials costs for staff to monitor facilities and provide marketing to encourage use of new facilities. The beneficiaries include the program participants saving on commuting cost, the employer reducing onsite parking expenses, and the municipality reducing cars on the road, which leads to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

Best practice is to include an onsite bicycle repair station and post signage on or near secure parking and personal lockers with information about how to reserve or obtain access to these amenities.

This measure could be paired with any combination of the other commute trip reduction strategies (Measures T-7 through T-13) for increased reductions.

GHG Reduction Formula

$$A = \frac{C \times (E - (B \times E))}{D \times F}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from employee project/site commute VMT	0.0–1.97	%	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
B	Bike mode adjustment factor	1.78 or 4.86	unitless	Buehler 2012
C	Average one-way bicycle trip length of all trips in geographic areas	Table T-10.1	miles	See Appendix
D	Average one-way vehicle trip length of all trips in geographic areas	Table T-10.1	miles	See Appendix
E	Average bicycle mode share of work trips in geographic areas	Table T-10.2	%	See Appendix
F	Average vehicle mode share of work trips in geographic areas	Table T-10.2	%	See Appendix

Further explanation of key variables:

- (B) – The bike mode adjustment factor should be provided by the user based on type of bike facility. A study found that commuters with showers, lockers, and bike parking at work are associated with 4.86 times greater likelihood to commute by bicycle when compared to individuals without any bicycle facilities at work. Individuals with bike parking, but no showers and lockers at the workplace, are associated with 1.78 times greater likelihood to cycle to work than those without trip-end facilities (Buehler 2012).
- (C and D) – Ideally, the user will calculate bicycle and auto trip length for a Project/Site at a scale no larger than a census tract. Potential data sources include the U.S. Census or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the average one-way trip lengths for bicycles and vehicles for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington as presented in Table T-10.1 (see the Appendix). Trip lengths are likely to be longer for areas not covered by the listed CBSAs, which represent the denser areas of the state.
- (E and F) – Ideally, the user will calculate bicycle and auto mode share for work trips for a Project/Site at a scale no larger than a census tract. Potential data sources include the U.S. Census, National Household Travel Survey or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the regional average mode shares for bicycle and vehicle work trips for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and

Washington, as presented in Table T-10.2 (see the Appendix). For areas not covered by the listed CBSAs, which represent the denser areas of the state, bicycle mode share is likely to be lower and vehicle share higher than presented in Table T-10.2.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum GHG reduction from this measure is 1.97 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}5 \text{ through } T\text{-}13}} \leq 45\%$) This measure is in the Trip Reduction Programs subsector. This subcategory includes Measures T-5 through T-13. The employee commute VMT reduction from the combined implementation of all measures within this subsector is capped at 45 percent.

Mutually Exclusive Measures

If this measure is selected, the user may not also take credit for either Measure T-5 or T-6. However, this measure may be implemented alongside other individual CTR measures (Measures T-7, T-8, T-9, and T-11 through T-13). The efficacy of individual programs may vary highly based on individual employers and local contexts.

Example GHG Reduction Quantification

The user reduces VMT by providing end-of-trip facilities for the project's employees, which encourages bicycle trips in place of vehicle trips. In this example, the type of bike facility provided by the project is parking with showers, bike lockers, and personal lockers (B). The project is within Portland-Vancouver-Hillsboro, OR-WA CBSA, and the user does not have project-specific values for trip lengths and mode shares and for bicycles and vehicles. Per Tables T-10.1 and T-10.2 in the Appendix, inputs for these variables are 3.5 miles, 10.8 miles, 1.5 percent, and 93.5 percent, respectively (C, D, E, and F). GHG emissions from employee commute VMT would be reduced by 1.97 percent.

$$A = \frac{3.5 \text{ miles} \times \left(1.5\% - (4.86 \times 1.5\%)\right)}{10.8 \text{ miles} \times 93.5\%} = -1.97\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

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- Portland Metro. 2023. *Regional Transportation Plan*. Received from Portland Metro in February 2025.

T-11. Provide Employer-Sponsored Vanpool



GHG Mitigation Potential



Up to 42% of GHG emissions from project/site employee commute VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

Employer-sponsored vanpools could result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. When this reduction occurs during extreme weather events, it better allows emergency responders to access a hazard site.

Health and Equity Considerations

Consider using zero-emission or plug-in electric vehicles (PHEVs) for additional emission reduction benefits.

Measure Description

This measure will implement an employer-sponsored vanpool service. Vanpooling is a flexible form of public transportation that provides groups of 5 to 15 people with a cost-effective and convenient rideshare option for commuting. The mode shift from long-distance, single-occupied vehicles to shared vehicles reduces overall commute VMT, thereby reducing GHG emissions.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban, rural

Scale of Application

Project/Site

Implementation Requirements

Vanpool programs are more appropriate for the building occupant or tenant (i.e., employer) to implement and monitor than the building owner or developer.

Cost Considerations

Employer costs primarily include the capital costs of vehicle acquisition and the labor costs of drivers, either through incentives to current employees or the hiring of dedicated drivers. The beneficiaries include the program participants saving on commuting cost, the employer reducing onsite parking expenses, and the municipality reducing cars on the road, which leads to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

When implementing a vanpool service, best practice is to subsidize the cost for employees who have a similar origin and destination and provide priority parking for employees who vanpool.

This measure could be paired with any combination of the other commute trip reduction strategies (Measures T-7 through T-13) for increased reductions.

GHG Reduction Formula

$$A = \frac{((1 - B) \times C \times F) + \left(B \times \frac{D}{E} \times G\right)}{((1 - B) \times C \times F) + (B \times D \times F)} - 1$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project/site employee commute VMT	0–42	%	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
B	Proportion of employees who participate in vanpool program	0.027	Unitless	SANDAG 2019
C	Average one-way vehicle commute trip length in core-based statistical area	Table T-11.1	miles per trip	See Appendix
D	Average length of one-way vanpool commute trip	Table T-11.5	miles per trip	See Appendix
E	Average vanpool occupancy (including driver)	Table T-11.6	occupants	See Appendix
F	Average emission factor of employee vehicle	Table T-11.2	g CO_2e per mile	U.S. EPA 2025
G	Average emission factor of vanpool vehicle	Table T-11.3	g CO_2e per mile	U.S. EPA 2025

Further explanation of key variables:

- (B) – The proportion of employees who would participate in a vanpool program is based on a survey of commuters in San Diego County (SANDAG 2019). If the user is able to provide a project-specific value, they should replace the default value with the project-specific value in the GHG reduction formula.
- (C) – Ideally, the user will calculate auto commute trip lengths for a Project/Site at a scale no larger than a census tract. Potential data sources include the U.S. Census or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the average one-way vehicle commute trip length by geographic area as presented in Table T-11.1 (see the Appendix). Trip lengths are likely to be longer for areas not covered by the listed cities and CBSAs, which represent the denser areas of the state.
- (D and E) – The average one-way vanpool commute trip length and occupancy are based on data from the Federal Transit Administration (FTA 2024) and values provided by Colorado, New Mexico, and Washington (see the Appendix). If the project is not within the listed geographic areas or the user is able to provide a project-specific value, the user should replace these defaults in the GHG reduction formula.

- (F and G) – The average GHG emission factors for employee commute and vanpool vehicles were calculated in terms of CO2e per mile using MOVES5. The model was run for a 2025 statewide average for Arizona, Colorado, New Mexico, Oregon, and Washington. The average of the passenger car and passenger truck categories represents employee non-vanpool vehicles and the LHD2b3 regulatory Class conservatively represents a vanpool vehicle. The running emission factors includes emissions from CO2, CH4, and N2O. If the user can provide a project-specific value (i.e., for a future year and project location), the user should run MOVES to replace the defaults in the GHG reduction formula.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects in states that use default data from Table T-11.1 and (B_{max}), the maximum percent reduction in GHG emissions (A) is 42.2 percent. This maximum scenario is presented in the below example quantification.

(B_{max}) The proportion of employees who participate in the vanpool program is capped at 0.015, which is based on the high end of vanpool participation survey data for several successful programs in the U.S. (SANDAG 2019).

Subsector Maximum

($\sum A_{max_{T\text{-}5 \text{ through } T\text{-}13}} \leq 45\%$) This measure is in the Trip Reduction Programs subsector. This subcategory includes Measures T-5 through T-13. The employee commute VMT reduction from the combined implementation of all measures within this subsector is capped at 45 percent.

Mutually Exclusive Measures

If this measure is selected, the user may also not take credit for either Measure T-5 or T-6. However, this measure may be implemented alongside other individual CTR measures (Measures T-7 through T-10, T-12, and T-13). The efficacy of individual programs may vary highly based on individual employers and local contexts.

Example GHG Reduction Quantification

The user reduces employee commute VMT by requiring that the employer of the project to sponsor a vanpool program. In this example, the project is in the Denver, Colorado, region and would have an average vehicle commute trip length of 11.7 miles (C). The percentage of employees who participate in the vanpool program is 15 percent (B_{max}). GHG emissions from employee commute would be reduced by 42.2 percent.

$$A = \frac{\left((1-0.15)\times 11.7\ \frac{\text{miles}}{\text{trip}}\times 347.9\ \frac{\text{g CO}_2\text{e}}{\text{miles}}\right)+\left(0.15\times\frac{51.5\ \frac{\text{miles}}{\text{trip}}}{5.07\ \text{occupants}}\times 409.8\ \frac{\text{g CO}_2\text{e}}{\text{miles}}\right)}{\left((1-0.15)\times 13.97\ \frac{\text{miles}}{\text{trip}}\times 347.9\ \frac{\text{g CO}_2\text{e}}{\text{miles}}\right)+\left(0.15\times 51.5\ \frac{\text{miles}}{\text{trip}}\times 380.0\ \frac{\text{g CO}_2\text{e}}{\text{miles}}\right)} - 1 = -42.2\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption (H) can be calculated using the GHG reduction formula except that (F) and (G) should be replaced by (I) and (J), as follows.

Fuel Use Reduction Formula

$$H = \frac{\left((1-B)\times C\times I\right)+\left(B\times\frac{D}{E}\times J\right)}{\left((1-B)\times C\times I\right)+(B\times D\times I)} - 1$$

Fuel Use Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
H	Percent reduction in fuel use from project/site employee commute VMT	4.7–21.4	%	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
I	Fuel efficiency of average employee vehicle	Table T-11.4	gallon (gal) per mile	U.S. EPA 2025
J	Fuel efficiency of vanpool vehicle	Table T-11.4	gal per mile	U.S. EPA 2025

Further explanation of key variables:

- (I and J) – The average fuel efficiencies for employee commute and vanpool vehicles were calculated using MOVES. The model was run for a 2025 statewide

average in the following states: Arizona, Colorado, New Mexico, Oregon, and Washington. The average of the passenger car and passenger truck vehicle categories represents employee non-vanpool vehicles, and the LHD2b3 vehicle regulatory Class category conservatively represents a large cargo vanpool vehicle. If the user can provide a project-specific value (i.e., for a future year and project location), the user should run MOVES to replace the defaults in the fuel use reduction formula.

- Please refer to the GHG Calculation Variables table above for definitions of variables that have been previously defined.

VMT Reductions

The percent reduction in VMT can be calculated using a modified version of the GHG reduction formula, as shown below.

$$\%\ \text{VMT Reduction} = \frac{((1 - B) \times C) + \left(B \times \frac{D}{E}\right)}{C} - 1$$

Sources

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T-12. Price Workplace Parking



GHG Mitigation Potential



Up to 20.0% of GHG emissions from project/site employee commute VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

Priced workplace parking could incentivize increased use of public transit and thus result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. When this reduction occurs during extreme weather events, it better allows emergency responders to access a hazard site.

Health and Equity Considerations

Parking pricing should include hourly and daily options so part-time staff do not need a monthly pass. If the project includes low-waged employees who have fewer transportation choices or time and resource constraints, it is instead recommended to consider implementing Measure T-13, *Implement Employee Parking Cash-Out*, or other transportation subsidy.

Measure Description

This measure will price onsite parking at workplaces. Because free employee parking is a common benefit, charging employees to park onsite increases the cost of choosing to drive to work. This is expected to reduce single-occupancy vehicle commute trips, resulting in decreased VMT, thereby reducing associated GHG emissions.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

Implementation may include the following.

- Explicitly charging for employee parking.
- Implementing above-market rate pricing.
- Validating parking only for invited guests (or not providing parking validation at all).
- Not providing employee parking and transportation allowances.

In addition, this measure should include marketing and education regarding available alternatives to driving.

Cost Considerations

Parking fees would be a direct, recurring cost for employees. Employer costs include labor costs for program management and monitoring, but this may be offset by revenue generated by the program.

Expanded Mitigation Options

The best practice is to ensure that other transportation options are available, convenient, and have competitive travel times (i.e., transit service near the project site, shuttle service, or a complete active transportation network serving the site and surrounding community), and that there is not alternative free parking available nearby (such as on-street). This measure is substantially less effective in environments that do not have other modes available or where unrestricted street parking or other offsite parking is available nearby and has adequate capacity to accommodate project-related vehicle parking demand.

GHG Reduction Formula

For calculating effectiveness of pricing residential parking, see Measure T-16, *Unbundle Residential Parking Costs from Property Cost*. For calculating effectiveness of pricing parking at visitor-intensive land uses, see Measure T-24, *Implement Market Price Public Parking (On-Street)*.

$$A = \frac{B - C}{C} \times E \times D \times F$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from employee commute VMT	0–20.0	%	calculated
User Inputs				
B	Proposed parking price	[ ]	$	user input
C	Baseline parking price	[ ]	$	user input
D	Share of employees paying for parking	[ ]	%	user input
Constants, Assumptions, and Available Defaults				
E	Elasticity of parking demand with respecting to parking price	-0.4	unitless	Concas and Nayak 2012; Pierce and Shoup 2013
F	Ratio of vehicle trip reduction to VMT	1	unitless	assumption

Further explanation of key variables:

- (B) – Parking price can be provided on an hourly, daily, or monthly basis. Monthly pricing is less effective than requiring daily or hourly payment since the price signal is diluted to only once a month.
- (C) – If baseline parking price is $0 (that is, if parking is typically free), set C = 2/3 B, allowing for the maximum 50 percent increase in price. Alternatively, for locations that are located within 0.5 mile of transit service, set C = average transit fare to/from the location.
- (D) – Many organizations allow some employees free parking benefits. VMT reductions should be adjusted based on the share of employees who would be paying for parking.
- (E) – A meta-analysis of parking price studies found that a 0.4 percent decrease in parking demand occurs for every 1 percent increase in parking price (Concas and Nayak 2012). An evaluation of the SFPark program in San Francisco also found that a 0.4 percent decrease in parking demand occurs for every 1 percent increase in parking price (Pierce and Shoup 2013). Price elasticity of parking demand varies by location, day of the week, and time of day.
- (F) – The adjustment factor from vehicle trips to VMT is 1. This assumes that all vehicle trips will average out to typical trip length ("assumes all trip lengths are equal"). Thus, it

can be assumed that a percentage reduction in vehicle trips will equal the same percentage reduction in VMT. Subsidies or discounts targeting commute trips may have a higher factor as they are generally longer than the trip lengths for other purposes.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The GHG reduction from priced workplace parking is capped at 20 percent. This maximum scenario is presented in the below example quantification.

($\frac{B-C}{C}_{max}$) The percent increase in parking price is capped at 50 percent.

Subsector Maximum

($\sum A_{max_{T\text{-}5 \text{ through } T\text{-}13}} \leq 45\%$) This measure is in the Trip Reduction Programs subsector. This subcategory includes Measures T-5 through T-13. The employee commute VMT reduction from the combined implementation of all measures within this subsector is capped at 45 percent.

Mutually Exclusive Measures

If this measure is selected, the user may not also take credit for Measure T-13, *Implement Employee Parking Cash-Out*. While both measures focus on providing a price signal for employees to consider other modes for their work commute, this measure actively charges all employees to park, while Measure T-13 reimburses employees who do not park. Users should select either Measure T-12 or T-13.

Example GHG Reduction Quantification

The user reduces VMT by increasing the price of a monthly parking permit. In this example, the permit fee is increased from $50 (C) to $75 (B). If 100 percent of employees are subject to parking pricing (D), the user would reduce GHG emissions from VMT by 20 percent.

$$A = \frac{\$75 - \$50}{\$50} \times -0.4 \times 100\% \times 1 = -20\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

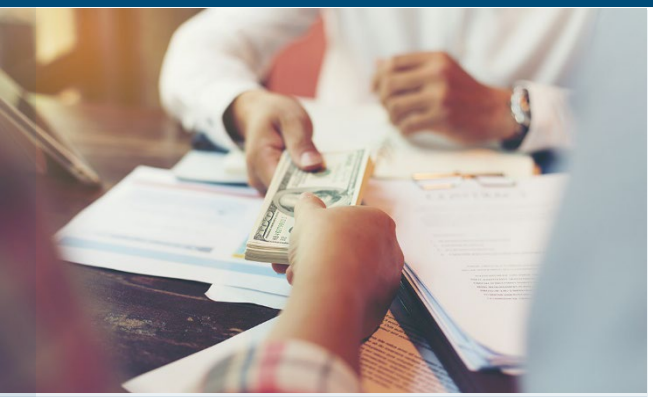
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- Concas, S., and N. Nayak. 2012. *A Meta-analysis of Parking Pricing Elasticity*. Transportation Research Board, 91st Annual Meeting. https://trid.trb.org/View/1130741.
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T-13. Implement Employee Parking Cash-Out



GHG Mitigation Potential



Up to 12.0% of GHG emissions from project/site employee commute VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

Employee parking cash-out could incentivize increased use of public transit and thus result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. When this reduction occurs during extreme weather events, it better allows emergency responders to access a hazard site.

Health and Equity Considerations

Not-Applicable

Measure Description

This measure will require project employers to offer employee parking cash-out. Cash-out is when employers provide employees with a choice of forgoing their current subsidized/free parking for a cash payment equivalent to or greater than the cost of the parking space. This encourages employees to use other modes of travel instead of single occupancy vehicles. This mode shift results in people driving less and thereby reduces VMT and GHG emissions.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

To prevent spill-over parking and continued use of single occupancy vehicles, residential parking in the surrounding area must be permitted, and public on-street parking must be market rate.

Cost Considerations

Employer costs include recurring, direct cost for payment to program participants and labor costs for program management. Employees who participate in the program would achieve cost savings through the cash-out benefit and potentially through reduced vehicle ownership and usage.

Expanded Mitigation Options

This measure could be paired with many other commute trip reduction strategies (Measures T-7 through T-11) for increased reductions.

GHG Reduction Formula

$A = B \times C$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project/site commute VMT	0–12.0	%	calculated
User Inputs				
B	Percentage of employees eligible	[ ]	%	user input
Constants, Assumptions, and Available Defaults				
C	Percent reduction in commute VMT from implementation of measure	-12	%	Shoup 2005

Further explanation of key variables:

- (B) – The percentage of employees eligible refers to the employees who would be able to participate in the program. This will usually be 100 percent. Employees who might not be able to participate could include those who work nighttime hours when transit and rideshare services are not available or employees who are required to drive to work as part of their job duties. This does not refer to the percentage of employees who end up participating in the program.
- (C) – If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the default value listed in the table above. The default value is based on a study of eight California firms that complied with California's 1992 parking cash-out law found employee commute VMT decreased by an average of 12 percent (Shoup 2005). The percentage of reduction in commute VMT from implementation of the measure is more representative for cities that are denser or car centric.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum percent reduction in GHG emissions (A) is 12.0 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}5 \text{ through } T\text{-}13}} \leq 45\%$) This measure is in the Trip Reduction Programs subsector. This subcategory includes Measures T-5 through T-13. The employee commute VMT reduction from the combined implementation of all measures within this subsector is capped at 45 percent.

Mutually Exclusive Measures

If this measure is selected, the user may also not take credit for Measure T-12, *Price Workplace Parking*. While both measures focus on providing a price signal for employees to consider other modes for their work commute, this measure reimburses employees who do not park, while Measure T-12 actively charges all employees to park. Users should select either Measure T-12 or T-13.

Example GHG Reduction Quantification

The user reduces project/site VMT by offering commuters the option to choose a cash payment equal to or greater than the current parking subsidy offered by their employer. In this example, all employees (i.e., 100 percent) are eligible to participate (B), which would reduce GHG emissions from employee commute VMT by 12 percent.

$$A = 100\% \times -12\% = -12\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

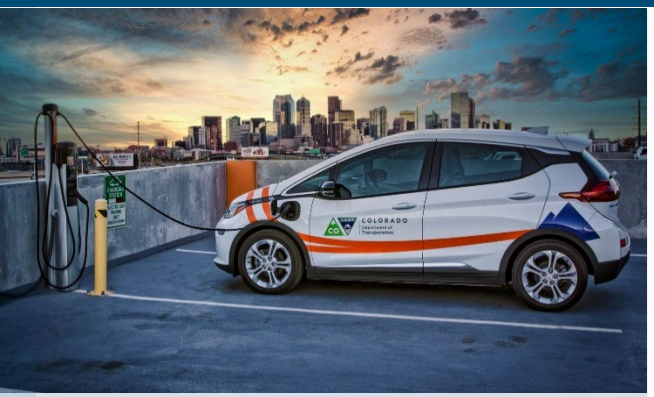
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Source

- Shoup, D. 2005. *Parking Cash Out.* Planners Advisory Service, American Planning Association. Accessed January 2021. http://shoup.bol.ucla.edu/ParkingCashOut.pdf.

T-14. Provide Electric Vehicle Charging Infrastructure



GHG Mitigation Potential



Up to 14.4% of GHG emissions from vehicles accessing the commercial or multifamily housing building

Co-Benefits (icon key on pg. 31)

Climate Resilience

Providing electric vehicle charging infrastructure increases fuel redundancy for electric vehicles even if an extreme weather event disrupts other fuel sources. Electric vehicles could also provide benefits to buildings and the grid, such as emergency backup, energy reserves, and demand response.

Health and Equity Considerations

Differential costs of EVs compared to conventional vehicles are decreasing over time, but at present are more expensive, which means this measure could disproportionately benefit those of greater economic means. On the other hand, increased EV adoption promotes a secondary market for EVs, which reduced prices. Any discrepancies will resolve over time. Employer, electricity provider, and state incentives for EV purchase could help address near-term disparities.

Measure Description

Install onsite electric vehicle chargers in an amount beyond what is required at buildings with designated parking areas (e.g., commercial, educational, retail, multifamily). This will enable owners of electric passenger vehicles to displace distance driven by internal combustion engine vehicles (ICE VMT) with electric (eVMT), thereby displacing GHG emissions from gasoline consumption with a lesser amount of indirect emissions from electricity (and is thus dependent on having ICE VMT to reduce). Many EV owners charge their vehicles at home overnight. Access at other sites supports additional EV ownership and long-distance travel by EV by mitigating "range anxiety" concerns. The methodology used in this measure differs from the one used in the CAPCOA handbook by considering reductions from battery electric vehicles instead of PHEVs.

Subsector

Parking or Road Pricing/Management

Locational Context

Urban, suburban, rural

Scale of Application

Project/Site

Implementation Requirements

Parking at the chargers must be limited to electric vehicles.

Cost Considerations

The primary costs associated with electric vehicle charging infrastructure include the capital costs of purchasing and installing charging stations, electricity costs from use of stations, and maintenance costs of keeping the charging stations in working order. Costs initially fall to the station owners, either municipalities or private owners, but can be passed along to station users with usage fees. Depending on station placement and charging times required for EVs, businesses near charging stations can derive benefits from patronage of station users.

Expanded Mitigation Options

In addition to allowing EVs to displace trips from ICE vehicles, the increased availability of chargers from implementation of this measure could mitigate consumer "range anxiety" concerns and increase the adoption of battery electric vehicles (BEVs), but this potential effect is not included in the calculations as a conservative assumption. Expanded mitigation could include quantification of the effect of this measure on BEV adoption.

GHG Reduction Formula

In the numerator, the GHG savings per mile traveled for a typical light-duty electric vehicle are quantified. This represents the benefit of driving an EV compared to a typical ICE vehicle. The denominator represents the site baseline without chargers and assumes vehicles using the site have a carbon intensity per mile equal to the non-electric average intensity in the region. Here, charging events are assumed to be equivalent to parking events for the purposes of normalizing the percent reduction in site level emissions. One key assumption here is that the average BEV and the average ICE vehicle visiting the site are traveling the same distance. This makes it more straightforward and avoids making assumptions about the differences in travel behavior between EV drivers using public charging and the average site user. If the user has accurate data to differentiate these users for a given site, the eVMT term would multiply the numerator and the VMT term would multiply by the denominator.

$$A1 = \frac{B \times I}{C} \text{ (tank-to-wheels emission reduction)}$$

$$A2 = \frac{B \times I \times (D-(E \times F \times G \times H))}{C \times D} \text{ (well-to-wheels emission reduction)}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Percent reduction in tank-to-wheels GHG emissions from vehicles accessing the office building or housing	0–37	%	calculated
A2	Percent reduction in well-to-wheels GHG emissions from vehicles accessing the office building or housing	0–14.4	%	calculated
User Inputs				
B	Number of charging ports installed at site	[ ]	integer	user input
C	Total vehicles accessing the site per day (parking events)	[ ]	integer	user input
Constants, Assumptions, and Available Defaults				
D	Average well-to-wheels emission factor of non-electric light-duty vehicles	Table T-14.1	g CO_2e per mile	U.S. EPA 2025
E	Energy efficiency of BEV	Table T-14.2	kilowatt hours (kWh) per mile	U.S. EPA 2025
F	Carbon intensity of local electricity provider	Tables E-4.5-4.10	lb CO_2e per megawatt hour (MWh)	See Appendix
G	Conversion from lb to g	454	g per lb	conversion
H	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
I	Average charging events per day per port	0.59 for L2, 2.6 for DCFC	visits per port per day	Energetics 2024

Further explanation of key variables:

- (D) – Emission factors for non-electric light-duty vehicles were solicited from each of the states in this study, and backup values were calculated using default data from MOVES5 and GREET for the year 2025 (U.S. EPA 2024, Argonne 2025). These can be found in the Appendix Table T-14.1. The light-duty average was composed of both light-duty cars and trucks, weighted by annual VMT of each class. More details on the sources can be found in the Appendix.
- (E) – Energy efficiency values for light-duty vehicles were derived from MOVES5 runs for the year 2025 and consider the light-duty cars and trucks weighted by VMT (U.S. EPA 2024). These values are in Table T-14.2 in the Appendix.
- (F) – Each state provided carbon intensity values for a select range of utilities within their state and these are found in Tables E-4.5 through E-4.9. Lifecycle carbon intensity values are included for larger regions in E-4.10. If the project study area is not serviced by a listed electricity provider, or the user is able to provide a project-specific value (i.e., for the future year not referenced in the Appendix), the user should replace the default in the GHG calculation formula. If the electricity provider is not known, the user may elect to use the statewide grid average carbon intensity.
- (I) – Charging events per day should be estimated from real world data in the region of the project or from the installing company if possible. In the case that this data is not available, the user can substitute defaults from the EV WATTS dashboard.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions (A) is capped at 14.4 percent, which is based on the following assumptions used to generate a maximum scenario:

- (B) – number of chargers installed = 80. Recently, the City of Mount Vernon, Washington, opened the largest municipal EV charging facility in the nation with 76 charging stations at the library commons. We postulate this is a safe maximum threshold, however, it is clear that larger installations could be possible in the future (Showalter 2024). Of these, 20 percent are DC fast chargers.
- (C) – total vehicles accessing the site = 552. The Mount Vernon complex hosts 276 parking stalls. If we conservatively assume that each space is used 2 times per day, then a total of 552 vehicles would be visiting per day. For sites where a majority of traffic is coming to use the chargers, it is possible that a higher fraction of vehicles visiting would be just for charging than this example.
- (D) – We assume that the charging project takes place in Arizona, where there is the highest average GHG per light-duty vehicle, which is 380.1 g CO2/mi.
- (F) – carbon intensity of local electricity provider = 0 lb CO_2e per MWh. This assumes that the local electricity provider is powered 100 percent by renewables and thus has a carbon intensity of zero.

Subsector Maximum

($\sum A_{max_{T\text{-}14 \text{ through } T\text{-}16}} \leq 35\%$) This measure is in the Parking or Road Pricing/Management subsector. This subcategory includes Measures T-14 through T-16. The VMT reduction from the combined implementation of all measures within this subsector is capped at 35 percent.

Example GHG Reduction Quantification

The user will install electric vehicle chargers at their proposed office or multifamily housing development, which will enable employees or residents with EVs to displace ICE vehicle trips, thereby displacing GHG emissions from gasoline consumption with a lesser amount of indirect emissions from indirect electricity. In this example, 10 DC fast chargers (B) will be installed at a workplace with 200 daily employee vehicles accessing the site (C). The electricity provider for the project area is the Public Service Company of New Mexico and the analysis year is 2025. The carbon intensity of electricity is therefore 316 lb CO_2e per MWh (I). The GHG impact is calculated as an 11 percent reduction from the total emissions from vehicles accessing the site.

$$A = \frac{\textbf{10 chargers} \times 2.6 \text{ events/charger·day} \times \left(361.1 \frac{\text{g } CO_2e}{\text{miles}} - \left(316 \frac{\text{lb } CO_2e}{\text{MWh}} \times 454 \frac{\text{g}}{\text{lb}} \times 0.001 \frac{\text{MWh}}{\text{kWh}} \times 0.39 \text{ kWh/mi}\right)\right)}{\textbf{200 events} \times 361.1 \frac{\text{g } CO_2e}{\text{miles}}} = 11.0\%$$

Quantified Co-Benefits

While the measure will achieve fuel savings, it will also increase electricity consumption. This section defines the methods for quantifying Improved Local Air Quality and fuel savings, as well as increased electricity consumption.

Improved Local Air Quality

Local criteria pollutants will be reduced by the reduction in fossil fuel combustion. The percent reduction in criteria pollutants can be calculated using the GHG reduction formula. Electricity supplied by statewide fossil-fueled or bioenergy power plants will generate criteria pollutants. However, because these power plants are located throughout the state, electricity consumption from vehicles charging will not generate localized criteria pollutant emissions. Consequently, for the quantification of criteria pollutant emission reductions, either the electricity portion of the equation can be removed, or the electricity intensity (I) can be set to zero.

Fuel Savings (Increased Electricity)

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in criteria pollutant emissions. The percent increase in electricity use (M) from this measure can be calculated as follows.

Electricity Use Increase Formula

$$J = \frac{B \times K \times M}{L}$$

Electricity Use Increase Calculation Variables

ID	Variable	Value	Unit	Source
Output				
J	Increase in electricity from EVs	[ ]	%	calculated
User Inputs				
K	Average amount of energy dispensed per charging event	27.6 for DCFC, 15.6 for L2	kWh per event	Energetics 2024
L	Existing electricity consumption of project/site	[ ]	kWh per year	user input
M	Days per year with vehicles accessing the site	260–365	days per year	user input
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (D) – The average energy dispensed per charging port is derived from public data shared with the U.S. DOE and aggregated by Energetics in their EV WATTS dashboard (Energetics 2024). If site level data is known, use that instead as well-placed sites can see higher utilization and poorly placed sites can see much lower utilization.
- (L) – The user should take care to properly quantify building electricity using accepted methodologies.
- (M) – If the proposed development is a workplace in which employees access the site an average of 5 days per week, the user should input 260 workdays. If the development is multifamily dwelling, the user should input 365 days.
- Please refer to the GHG Calculation Variables table above for definitions of variables that have been previously defined.

Sources

- Argonne National Laboratory. 2025. *Research and Development (R&D) GREET Life Cycle Assessment Model.* Accessed March 2025. https://www.energy.gov/eere/rd-greet-life-cycle-assessment-model.
- Colorado Department of Transportation. 2025. *Correspondence*. Received from Colorado State in February 2025.
- Energetics. 2024. *EV WATTS Charging Station Dashboard.* Accessed February 2025. https://www.clearesult.com/insights/evwatts.
- IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Cambridge and New York: Cambridge University Press. Accessed January 2021. https://www.ipcc.ch/report/ar4/wg1/.
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- U.S. EPA (U.S. Environmental Protection Agency). 2024. *Motor Vehicle Emission Simulator: MOVES5*. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024.

T-15. Limit Residential Parking Supply



GHG Mitigation Potential



Up to 15.9% of GHG emissions from resident vehicles accessing the site

Co-Benefits (icon key on pg. 31)



Climate Resilience

Limiting residential parking supply could incentivize increased use of public transit and thus result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. When this reduction occurs during extreme weather events, it better allows emergency responders to access a hazard site. Evacuation plans and plans for transport to cooling/heating/clean air centers during power outages or unhealthy air quality events, however, would need to consider needs of households without access to private vehicles.

Health and Equity Considerations

Limiting parking supply can reduce the cost of housing development and, potentially, increase housing supply and decrease housing expenses. However, this may negatively affect residents who do not have a viable alternative to personal vehicle travel.

Measure Description

This measure will reduce the total parking supply available at a residential project or site. Limiting the amount of parking available creates scarcity and adds additional time and inconvenience to trips made by private vehicles, thus disincentivizing driving as a mode of travel. Reducing the convenience of driving results in a shift to other modes and decreased VMT and thus a reduction in GHG emissions. Evidence of the effects of the reduced parking supply is strongest for residential developments.

Subsector

Parking or Road Pricing/Management

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

This measure is ineffective in locations where unrestricted street parking or other offsite parking is available nearby and has adequate capacity to accommodate project-related vehicle parking demand.

Cost Considerations

Reducing residential parking supply, especially in high density residential areas, can have significant cost savings if it reduces the need for additional investment in parking infrastructure. Some of these savings may be offset by investments in alternative transport solutions, which will need to be robust to ensure that residents can effectively travel to work and all other destinations without a car.

Expanded Mitigation Options

When limiting the parking supply, the best practice is to do so at sites that are located near high quality alternative modes of travel (such as a rail station, frequent bus line, or in a higher density area with multiple walkable locations nearby). Limiting the parking supply may also allow for more active uses on any given lot, which may support Measures T-1 and T-2 by allowing for higher density construction.

GHG Reduction Formula

$$A = -\frac{B - C}{B} \times D \times E \times F$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from resident vehicles accessing the site	0–15.9	%	calculated
User Inputs				
B	Residential parking demand	[ ]	parking spaces	user input
C	Project residential parking supply	[ ]	parking spaces	user input
D	Percentage of project VMT generated by residents	[ ]	%	user input
Constants, Assumptions, and Available Defaults				
E	Percentage of household VMT that is commute based	Table T-15	%	Replica 2025
F	Percent reduction in commute mode share by driving among households in areas with scarce parking	37	%	Chatman 2013

Further explanation of key variables:

- (B) – The user can calculate the parking demand in the *ITE Parking Generation Manual* based on the project building square footage or number of du. For residential projects, this demand varies based on the size of each unit, and ranges from 1.0 spaces/unit for one-bedroom apartments to 2.6 spaces/unit for single-family homes with 3+ bedrooms.
- (D) – Available research on changes in parking supply focuses on residential land uses. Therefore, reductions are applied only to the share of VMT generated by residents of a project. For most residential projects, this will be 100 percent; however, for mixed-use projects, the user will need to provide project-specific data.
- (E) – The percentage of household VMT that is commute-based varies from location to location; averages by geographic area are included using data from Replica for a weekday in spring 2024. If the user can provide a project-specific value based on their project type and area, they should replace the default in the GHG reduction formula.
- (F) – A study found that among households with limited off-street parking (<1 space per adult), there was a 37 percent decrease in vehicle mode share for commute trips. The method above pro-rates this reduction based on how much of the project's parking supply is reduced from demand rates calculated in the *ITE Parking Generation Manual* (ITE 2019). In addition, this reduction is only applied to commute trips due to the limitations of the research.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions is capped at 15.9 percent. The project is assumed to be in Greeley, Colorado. The project is assumed to have no onsite parking (C), 100 percent of VMT arising from residential land use (D), and 43 percent of all VMT arising from commute trips (E). This maximum scenario is presented in the below example quantification.

(C>B) Parking supply is considered to be limited when demand (C) exceeds supply (B). If demand is equal to or less than supply, then implementation of this measure would not result in a GHG reduction.

Subsector Maximum

($\sum A_{max_{T\text{-}14 \text{ through } T\text{-}16}} \leq 35\%$) This measure is in the Parking or Road Pricing/Management subsector. This subcategory includes Measures T-14 through T-16. The VMT reduction from the combined implementation of all measures within this subsector is capped at 35 percent.

Example GHG Reduction Quantification

The user reduces VMT by reducing a project's parking supply. In this example, the parking demand per ITE is 100 parking spaces (B) and the project would not supply any parking spaces (C). The user would reduce GHG emissions from VMT by 15.9 percent.

$$A = -\frac{100 \text{ spaces} - 0 \text{ spaces}}{100 \text{ spaces}} \times 100\% \times 43\% \times 37\% = -15.9\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- Chatman, D. 2013. "Does TOD need the T? On the importance of factors other than rail access." *Journal of the American Planning Association* 79 (1). Accessed January 2021. https://trid.trb.org/view/1243004.
- ITE (Institute of Transportation Engineers). 2019. *Parking Generation Manual*. 5th Edition. February 2019. Accessed May 2021. https://www.ite.org/technical-resources/topics/trip-and-parking-generation/resources/.
- Replica. 2025. *Residential VMT by CBSA and Trip Purpose*. Accessed February 2025.

T-16. Unbundle Residential Parking Costs from Property Cost



GHG Mitigation Potential

15.7%

Up to 15.7% of GHG emissions from project VMT in the study area

Co-Benefits (icon key on pg. 31)

Climate Resilience

Unbundling residential parking costs from property costs could incentivize increased use of public transit and thus result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. When this reduction occurs during extreme weather events, it better allows emergency responders to access a hazard site.

Health and Equity Considerations

The unbundling of parking costs would help decrease housing costs for individuals who do not own personal vehicles.

Measure Description

This measure will unbundle, or separate, a residential project's parking costs from property costs, requiring those who wish to purchase parking spaces to do so at an additional cost. On the assumption that parking costs are passed through to the vehicle owners/drivers utilizing the parking spaces, this measure results in decreased vehicle ownership and, therefore, a reduction in VMT and GHG emissions. Unbundling may not be available to all residential developments, depending on funding sources.

Subsector

Parking or Road Pricing/Management

Locational Context

Urban

Scale of Application

Project/Site

Implementation Requirements

Parking costs must be passed through to the vehicle owners/drivers utilizing the parking spaces for this measure to result in decreased vehicle ownership.

Cost Considerations

Unbundling residential parking costs from property costs may decrease revenue for property owners. This loss may be partially offset by reduced costs needed to maintain parking facilities with less car occupancy and the potential for non-resident parking as a supplementary income stream. For residents, reduced fees and the ability to go without owning a car are major cost benefits. Municipalities also benefit from a reduction of cars on the road, which can lead to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

Pair with Measure T-19-A or T-19-B to ensure that residents who eliminate their vehicle and shift to a bicycle can safely access the area's bikeway network.

GHG Reduction Formula

$$A = \frac{B}{C} \times D \times E$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project VMT in study area	0–15.7	%	calculated
User Inputs				
B	Annual parking cost per space	[ ]	$ per year	user input
Constants, Assumptions, and Available Defaults				
C	Average annual vehicle cost	$9,282	$ per year	AAA 2019
D	Elasticity of vehicle ownership with respect to total vehicle cost	-0.4	unitless	Litman 2020
E	Adjustment factor from vehicle ownership to VMT	1.01	unitless	FHWA 2017

Further explanation of key variables:

- (B) – For most projects, this represents a monthly parking fee multiplied by 12. For deeded parking spaces, an estimate of the additional cost to a mortgage may be used, or the total cost may be prorated over 30 years. Costs to park will vary widely based on location; however, this value should consider if other nearby offsite parking options are available at lower cost. See Table T-16.1 in the Appendix for examples of monthly parking prices for different facility types.
- (C) – The average vehicle cost per year in 2019 was $9,282, based on a car driven 15,000 miles per year. Costs include gasoline, maintenance, insurance, license and registration, loan finance charges, and depreciation but do not include parking (AAA 2019).
- (D) – A synthesis of literature reported that, on the low end, a 0.4 percent decrease in vehicle ownership occurs for every 1 percent increase in total vehicle costs (Litman 2020).
- (E) – The adjustment factor from vehicle ownership to VMT is based on the following (FHWA 2017):
  - The average Pacific region household with 1 vehicle drives 11,117 miles per vehicle while households with 2 vehicles drive 11,223 miles per vehicle.
  - The reduction of 1 vehicle from a 2-vehicle household is associated with a 0.94 percent decrease in VMT per vehicle.
  - So, $E = 1 - \left(\frac{11{,}117 \frac{\text{miles}}{\text{vehicle}} - 11{,}223 \frac{\text{miles}}{\text{vehicle}}}{11{,}223 \frac{\text{miles}}{\text{vehicle}}} \right) = 1.01$

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The GHG reduction from unbundled parking is capped at 15.7 percent, which is based on the use of (B_{max}) in the GHG reduction formula.

(B_{max}) The annual cost of parking space is capped at $3,600, or $300 per month. At monthly costs above $300, the cost of parking represents more than a 30 percent increase in total vehicle cost. In addition, this reflects the upper maximum of observed parking prices outside of extremely dense downtown areas (such as Seattle's Central Business District).

Subsector Maximum

($\sum A_{max_{T\text{-}14 \text{ through } T\text{-}16}} \leq 35\%$) This measure is in the Parking or Road Pricing/Management subsector. This subcategory includes Measures T-14 through T-16. The VMT reduction from the combined implementation of all measures within this subsector is capped at 35 percent.

Example GHG Reduction Quantification

The user reduces VMT by unbundling the parking costs from property costs of a project, discouraging vehicle ownership, and therefore reducing VMT. In this example, the annual parking cost per space is $1,800 (B), which would reduce GHG emissions from project study area VMT (as compared to the same project with bundled parking costs) by 7.8 percent.

$$A = \left(\frac{\$1{,}800}{\$9{,}282}\right) \times -0.4 \times 1.01 = -7.8\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

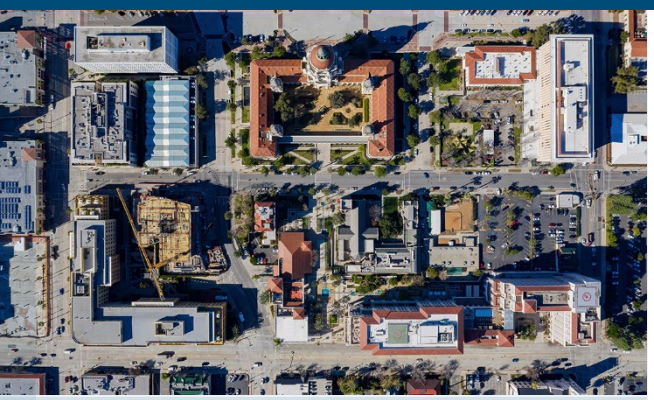
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- AAA. 2019. *Your Driving Costs.* September 2019. Accessed January 2021. https://exchange.aaa.com/wp-content/uploads/2019/09/AAA-Your-Driving-Costs-2019.pdf.
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T-17. Improve Street Connectivity



GHG Mitigation Potential



Up to 30.0% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)



Climate Resilience

Improving street connectivity could increase route redundancy, allowing faster and more efficient travel during extreme weather events, evacuations, or for emergency vehicles requiring access to hazard sites.

Health and Equity Considerations

Multiple active modes routing options allows vulnerable road users to choose based on perceived safety, comfort, speed, and other factors.

Measure Description

This measure accounts for the VMT reduction achieved by a project that is designed with a higher density of vehicle intersections compared to the average intersection density in the U.S. Increased vehicle intersection density is a proxy for street connectivity improvements, which help to facilitate a greater number of shorter trips and thus a reduction in GHG emissions.

Subsector

Land Use

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

Projects that increase intersection density would be building a new street network in a subdivision or retrofitting an existing street network to improve connectivity (e.g., converting cul-de-sacs or dead-end streets to grid streets).

Cost Considerations

Capital and infrastructure costs for improved street connectivity may be high. Depending on the location, losses may also be incurred through the reduction of sellable land due to the increased street footprint. Benefits come mainly from the reduction of traffic on arterial corridors, which reduces congestion and allows for safer use of nonmotorized transportation, such as bikes. These outcomes, in turn, can reduce car usage, which provides costs savings to commuters and municipalities.

Expanded Mitigation Options

Pair with Measure T-18, *Provide Pedestrian Network Improvement*, to best support use of the local pedestrian network.

GHG Reduction Formula

$$A = \frac{B - C}{C} \times D$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–30.0	%	calculated
User Inputs				
B	Intersection density in project site with measure	[ ]	intersections per sq mile	user input
Constants, Assumptions, and Available Defaults				
C	Average intersection density	36	intersections per sq mile	Fehr and Peers 2009
D	Elasticity of VMT with respect to intersection density	-0.14	unitless	Stevens 2016

Further explanation of key variables:

- (C) – The average intersection density is based on the standard suburban intersection density in the U.S. (Fehr and Peers 2009). This density is approximately equivalent to block faces of 750 to 800 feet, or cul-de-sac–style built environments, which are appropriate for suburban areas.
- (D) – A meta-regression analysis of 15 studies found that a 0.14 percent decrease in VMT occurs for every 1 percent increase in intersection density (Stevens 2016).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions (A) is capped at 30 percent. The purpose of the 30 percent cap is to limit the influence of any single built environmental factor (such as intersection density).

Subsector Maximum

Same as (A_{max}). Measure T-17 is the only measure at the Plan/Community scale within the Land Use subsector.

Example GHG Reduction Quantification

The user reduces VMT by constructing their project with a higher intersection density than the surrounding city. In this example, the project intersection density (B) would be 72

intersections per square mile (sq mile), which would reduce GHG emissions from project VMT by 14 percent.

$$A = \frac{72 \frac{\text{int}}{\text{sq mile}} - 36 \frac{\text{int}}{\text{sq mile}}}{36 \frac{\text{int}}{\text{sq mile}}} \times -0.14 = -14\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

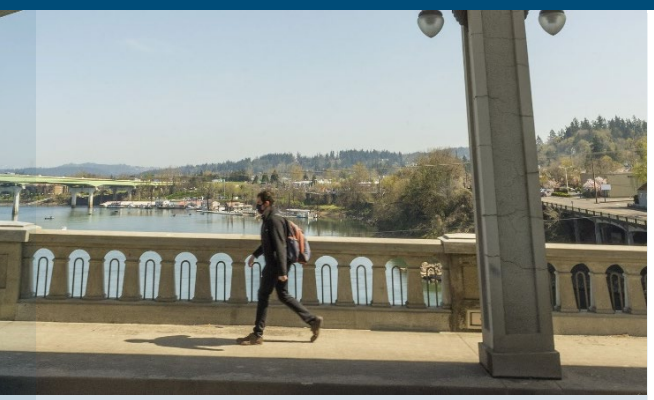
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- Fehr and Peers. 2009. *Proposed Trip Generation, Distribution, and Transit Mode Split Forecasts for the Bayview Waterfront Project Transportation Study*.
- Stevens, M. 2016. "Does Compact Development Make People Drive Less?" *Journal of the American Planning Association* 83, No. 1 (November): 7–18. DOI: 10.1080/01944363.2016.1240044. Accessed January 2021. https://www.researchgate.net/publication/309890412_Does_Compact_Development_Make_People_Drive_Less.

T-18. Provide Pedestrian Network Improvement



GHG Mitigation Potential



Up to 6.4% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Improving pedestrian networks increases accessibility of outdoor spaces, which can provide health benefits and thus improve community resilience. This can also improve connectivity between residents and resources that may be needed in an extreme weather event. Moreover, pedestrian facilities can be used as evacuation facilities in some cases and can be improved to be more evacuation friendly in responding to disasters.

Health and Equity Considerations

Ensure that the improvements also include accessibility features to allow for people of all abilities to use the network safely and conveniently. Ensure that sidewalks connect to nearby community assets, such as schools, retail, and health care.

Measure Description

This measure will increase the sidewalk coverage to improve pedestrian access. Providing sidewalks and an enhanced pedestrian network encourages people to walk instead of drive. This mode shift results in a reduction in VMT and GHG emissions.

Subsector

Neighborhood Design

Locational Context

Urban, suburban, rural

Scale of Application

Plan/Community

Implementation Requirements

The GHG reduction of this measure is based on the VMT reduction associated with expansion of sidewalk coverage expansion, which includes not only building of new sidewalks but also improving degraded or substandard sidewalk (e.g., damaged from street tree roots). However, pedestrian network enhancements with non-quantifiable GHG reductions are encouraged to be implemented, as discussed under *Expanded Mitigation Options*.

Cost Considerations

Depending on the improvement, capital and infrastructure costs may be high. However, improvements to the pedestrian network will increase pedestrian activity, which can increase businesses' patronage and provide a local economic benefit. The local municipality may achieve cost savings through a reduction of cars on the road leading to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

When improving sidewalks, a best practice is to ensure they are contiguous and link externally with existing and planned pedestrian facilities. Barriers to pedestrian access and interconnectivity, such as walls, landscaping buffers, slopes, and unprotected crossings should be minimized. Other best practice features could include high-visibility crosswalks; pedestrian hybrid beacons and other pedestrian signals; mid-block crossing walks; pedestrian refuge islands; speed tables; bulb-outs (curb extensions); curb ramps; signage; pavement markings; pedestrian-only connections and districts; landscaping; and other improvements to pedestrian safety.

GHG Reduction Formula

$$A = \left(\frac{C}{B} - 1\right) \times D$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from household vehicle travel in plan/community	0–6.4	%	calculated
User Inputs				
B	Existing sidewalk length in study area	[ ]	miles	user input
C	Sidewalk length in study area with measure	[ ]	miles	user input
Constants, Assumptions, and Available Defaults				
D	Elasticity of household VMT with respect to the ratio of sidewalks-to-streets	-0.05	unitless	Frank et al. 2011

Further explanation of key variables:

- (B and C) – Sidewalk length should be measured on both sides of the street. For example, if one 0.5-mile-long street has full sidewalk coverage, the sidewalk length would be 1.0 mile. If there is only sidewalk on one side of the street, the sidewalk length would be 0.5 mile. The recommended study area is 0.6 mile around the pedestrian network improvement. This represents a 6- to 10-minute walking time.
- (D) – A study found that a 0.05 percent decrease in household vehicle travel occurs for every 1 percent increase in the sidewalk-to-street ratio (Frank et al. 2011; Handy et al. 2014).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions (A) is capped at 6.4 percent, which is based on the following assumptions:

- 35.2 percent of vehicle trips are short trips (2 mile or less, average of 1.29 miles) and thus could easily shift to walking (FHWA 2019).
- 64.8 percent of vehicle trips are longer trips that are unlikely to shift to walking (2 miles or more, average of 10.93 miles) (FHWA 2019).
- So $A_{max} = \frac{35.2\% \times 1.29 \text{ miles}}{64.8\% \times 10.93 \text{ miles}} = 6.4\%$

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user reduces household VMT by improving the pedestrian network in the study area. In this example, the existing sidewalk length (B) is 9 miles, and the sidewalk length with the measure (C) would be 10 miles. With these conditions, the user would reduce GHG emissions from household VMT within the study area by 0.6 percent.

$$A = \left(\frac{10 \text{ miles}}{9 \text{ miles}} - 1\right) \times -0.05 = -0.6\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in household VMT would be the same as the percent reduction in GHG emissions (A).

Improved Public Health

Users are directed to the Integrated Transport and Health Impact Model (ITHIM) (CARB et al. 2020). The ITHIM can quantify the annual change in health outcomes associated with active transportation, including deaths, years of life lost, years of living with disability, and incidence of community and individual disease.

Sources

- CARB (California Air Resources Board), California Department of Public Health, and Nicholas Linesch Legacy Fund. 2020. *Integrated Transport and Health Impact Model*. Accessed March 2025. http://cal-ithim.org/ithim/#RunITHIM.
- FHWA (Federal Highway Administration). 2019. *2017 National Household Travel Survey Popular Vehicle Trip Statistics*. Accessed January 2021. https://nhts.ornl.gov/vehicle-trips.

- Frank, L., M. Greenwald, S. Kavage, and A. Devlin. 2011. *An Assessment of Urban Form and Pedestrian and Transit Improvements as an Integrated GHG Reduction Strategy*. WSDOT Research Report WA-RD 765.1, Washington State Department of Transportation. April 2011. Accessed January 2021. www.wsdot.wa.gov/research/reports/fullreports/765.1.pdf.
- Handy, S., S. Glan-Claudia, and M. Boarnet. 2014. *Impacts of Pedestrian Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions: Policy Brief*. September 2014. Accessed January 2021. https://ww2.arb.ca.gov/sites/default/files/2020-06/Impacts_of_Pedestrian_Strategies_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Policy_Brief.pdf.

T-19-A. Construct or Improve Bike Facility



GHG Mitigation Potential



Up to 0.9% of GHG emissions from vehicles parallel roadways

Co-Benefits (icon key on pg. 31)



Climate Resilience

Constructing and improving bike facilities can incentivize more bicycle use and decrease vehicle use, which have health benefits and can thus improve community resilience. This can also improve connectivity between residents and resources that may be needed in an extreme weather event. Similar to pedestrian facilities, a bike facility can be used as an emergency evacuation asset in some cases too, especially for leaving a hazardous area quickly.

Health and Equity Considerations

Prioritize low-income and underserved areas and communities with lower rates of vehicle ownership or fewer transit options. Make sure that the bicycle facility connects to a larger existing bikeway network that accesses destinations visited by low-income or underserved communities.

Measure Description

This measure will construct or improve a single bicycle lane facility (not including bike boulevards) that connects to a larger existing bikeway network. Providing bicycle infrastructure helps to improve biking conditions within an area. This encourages a mode shift on the roadway parallel to the bicycle facility from vehicles to bicycles, displacing VMT and thus reducing GHG emissions. When constructing or improving a bicycle facility, a best practice is to consider local or state bike lane width standards. A variation of this measure is provided as T-19-B, *Construct or Improve Bike Boulevard*.

Subsector

Neighborhood Design

Locational Context

Urban, suburban

Scale of Application

Plan/Community. This measure reduces VMT on the roadway segment parallel to the bicycle facility (i.e., the corridor). An adjustment factor is included in the formula to scale the VMT reduction from the corridor level to the plan/community level.

Implementation Requirements

The bicycle lane facility must be either Class I, II, or IV. Class I bike paths are physically separated from motor vehicle traffic. Class IV bikeways are protected on-street bikeways, also called cycle tracks. Class II bike lanes are striped bicycle lanes that provide exclusive use to bicycles on a roadway.

Cost Considerations

Capital and infrastructure costs for new bike facilities may be high. The local municipality may achieve cost savings through a reduction of cars on the road leading to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

Implement alongside Measures T-22-A, T-22-B, T-22-C, and/or T-22-D to ensure that micromobility users can ride safely along bicycle lane facilities and not have to ride along pedestrian infrastructure, which is a risk to pedestrian safety.

GHG Reduction Formula

$$A = -B \times \frac{\frac{F}{I} \times (C + D) \times E \times G}{H}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from displaced vehicles on roadway parallel to bicycle facility	0–0.8	%	calculated
User Inputs				
B	Percentage of plan/community VMT on parallel roadway	0–100	%	user input
C	Active transportation adjustment factor	Table T-19.1	unitless	CARB 2020
D	Credits for key destinations near project	Table T-19.2	unitless	CARB 2020
E	Growth factor adjustment for facility type	Table T-19.3	unitless	CARB 2020
Constants, Assumptions, and Available Defaults				
F	Annual days of use of new facility	Table T-19.4	days per year	NOAA 2021-2023
G	Existing regional average one-way bicycle trip length	Table T-10.1	miles per trip	See Appendix
H	Existing regional average one-way vehicle trip length	Table T-10.1	miles per trip	See Appendix
I	Days per year	365	days per year	standard

Further explanation of key variables:

- (B) – The percentage of total plan/community VMT within the roadway parallel to the bike facility should represent the expected total VMT generated by all land use in that area, including office, residences, retail, schools, and other uses. The most appropriate source for this data is from a local travel demand forecasting model. An alternate method uses VMT per worker or VMT per resident multiplied by the population in the area.
- (C, D, and E) – The active transportation adjustment factor, key destination credit, and growth factor adjustment should be looked up by the user in Tables T-19.1 through T-19.3 in the Appendix. The active transport adjustment factor is based on the existing annual average daily traffic (AADT) of the facility, length of the proposed bike facility, and the city population. The key destination credit is based on the number of key destinations within 0.5-mile of the facility. The growth factor is based on the type of bicycle facility proposed.
- (F) – The annual days of use for the new facility should be looked up by users in Table T-19.4 based on the weather forecast office that best represents the area in which the project is located. The days of use are based on the number of weather events per year that would discourage or limit bicycle use (NOAA 2021-2023).

- (G and H) – Ideally, the user will calculate bicycle and vehicle trip lengths for the corridor at a scale no larger than the surrounding census tract. Potential data sources include the U.S. Census, statewide household travel surveys, or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input regional average one-way bicycle and vehicle trip lengths for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington as provided in Table T-10.1 (see the Appendix).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use geographic data from Table T-10.1 in the Appendix, the maximum percent reduction in GHG emissions (A) is 0.9 percent. This is based on a neighborhood project the size of a large corridor (B = 100%) within the geographic scope of Eugene, Oregon, that uses the highest values for (C, D, and E) in Tables T-19.1 through T-19.3 and annual use days for Eugene (F) in Table T-19.4. This maximum scenario is presented in the below example quantification.

(C_{max}) The active transportation adjustment factor (C) was determined for roadways with AADT ranging from 1 to 30,000 (CARB 2020). Roadways with AADT greater than 30,000 are generally not appropriate for bicycle facilities. Care should be taken by the user in interpreting the results from this equation for a project roadway with AADT greater than 30,000.

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user reduces VMT by constructing a bicycle facility that displaces vehicle trips with bicycle trips. In this example, the following assumptions are made to obtain inputs from Tables T-19.1 through T-19.3 in the Appendix:

- Percentage of plan/community VMT on parallel roadway (B) = 100%. The project would establish a bike corridor the whole length of a central commercial thoroughfare. It is assumed this main street makes up the entire neighborhood.
- Active transportation adjustment factor (C) = 0.0207. Existing AADT on the roadway parallel to the proposed bicycle facility is 10,000, the facility length is 2.5 miles, and the project site is in a university town with a population of 200,000.
- Key destination credit (D) = 0.003. There are 10 key destinations within 0.25 mile of the project site.
- Growth factor adjustment (E) = 1.54. The bike facility would be a new Class IV bikeway.

The project is within the Eugene, Oregon, region and the user does not have project-specific values for average bicycle and vehicle trip lengths. Accordingly, the inputs of 3.71 miles and 10.99 miles, respectively (G and H), from Table T-10.1 in the Appendix are assumed. The user would displace GHG emissions from project study area VMT by 1 percent.

$$A = \textbf{-100\%} \times \left(\frac{\frac{337 \text{ days}}{365 \text{ days}} \times (\textbf{0.0207} + \textbf{0.003}) \times \textbf{1.54} \times 1.55 \text{ miles}}{5.8 \text{ miles}} \right) = -0.9\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Improved Public Health

Users are directed to the ITHIM (CARB et al. 2020). The ITHIM can quantify the annual change in health outcomes associated with active transportation, including deaths, years of life lost, years of living with disability, and incidence of community and individual disease.

Sources

- CARB (California Air Resources Board). 2020. *Quantification Methodology for the Strategic Growth Council's Affordable Housing and Sustainable Communities Program*. September 2020. Accessed January 2021. https://ww2.arb.ca.gov/sites/default/files/classic/cc/capandtrade/auctionproceeds/draft_sgc_ahsc_qm_091620.pdf.
- CARB, California Department of Public Health, and Nicholas Linesch Legacy Fund. 2020. *Integrated Transport and Health Impact Model*. Accessed March 2025. http://cal-ithim.org/ithim/#RunITHIM.
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- Oregon Department of Transportation. 2011. *2010 Oregon Travel Study*. Received from Oregon State in February 2025.
- Washington Department of Transportation. *Commute Trip Reduction Program Survey Cycle 2021-2022*. Received from Washington State in February 2025.

T-19-B. Construct or Improve Bike Boulevard



GHG Mitigation Potential



Up to 0.6% of GHG emissions from vehicles on roadway

Co-Benefits (icon key on pg. 31)

Climate Resilience

Constructing and improving bike boulevards can incentivize more bicycle use and decrease vehicle use, which have health benefits and can thus improve community resilience. This can also improve connectivity between residents and resources that may be needed in an extreme weather event.

Health and Equity Considerations

Prioritize low-income and underserved areas and communities with lower rates of vehicle ownership or fewer transit options. Make sure that the bicycle boulevard connects to a larger existing bikeway network that accesses destinations visited by low-income or underserved communities.

Measure Description

Construct or improve a single bicycle boulevard that connects to a larger existing bikeway network. Bicycle boulevards are a designation for streets that create safe, low-stress connections for people biking and walking on streets. This encourages a mode shift from vehicles to bicycles, displacing VMT and thus reducing GHG emissions. A variation of this measure is provided as T-19-A, *Construct or Improve Bike Facility*, which is for more impactful bicycle infrastructure such as bike lanes and separated bike paths.

Subsector

Neighborhood Design

Locational Context

Urban, suburban

Scale of Application

Plan/Community. This measure reduces VMT on the roadway segment parallel to the bicycle facility (i.e., the corridor). An adjustment factor is included in the formula to scale the VMT reduction from the corridor level to the plan/community level.

Implementation Requirements

The following roadway conditions must be met.

- Functional classification: local and collector if there is no more than a single general-purpose travel lane in each direction.
- Design speed: <= 25 miles per hour.
- Design volume <= 5,000 average daily traffic.
- Treatments at major intersections: both directions have traffic signals (or an effective control device that prioritizes pedestrian and bicycle access such as rapid flashing beacons, pedestrian hybrid beacons, high-intensity activated crosswalks, TOUCANs), bike route signs, "sharrowed" roadway markings, and pedestrian crosswalks.

Cost Considerations

Capital and infrastructure costs for new bike boulevards may be high, though lower than implementing the same length of protected bicycle lanes (Class IV). After the bike boulevard is complete, the local municipality may achieve cost savings from reduced infrastructure and roadway maintenance costs.

Expanded Mitigation Options

Construct boulevards with forced turns for vehicles every few blocks to minimize through traffic while ensuring that speed and volume metrics are met. Implement alongside Measures T-22-A, T-22-B, T-22-C, and/or T-22-D to ensure that micromobility users can ride safely along bicycle lane facilities and not pedestrian infrastructure, which is a risk to pedestrian safety.

GHG Reduction Formula

$$A = B \times \frac{D \times (F - (C \times F))}{E \times G}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from displaced vehicles on roadway with bicycle boulevard	0–0.2	%	calculated
User Inputs				
B	Percentage of plan/community VMT on roadway to have bicycle boulevard	0–100	%	user input
Constants, Assumptions, and Available Defaults				
C	Bike mode adjustment factor	1.14	unitless	Schwartz 2021
D	Existing bicycle trip length for all trips in geographic area	Table T-10.1	miles	See Appendix
E	Existing vehicle trip length for all trips in geographic area	Table T-10.1	miles	See Appendix
F	Existing bicycle mode share for work trips in geographic area	Table T-10.2	%	See Appendix
G	Existing vehicle mode share for work trips in geographic area	Table T-10.2	%	See Appendix

Further explanation of key variables:

- (C) – The bike mode adjustment factor is based on a database of before/after bicycle counts for 10 projects in four U.S. cities that invested in bicycle boulevards. Bicycle ridership increased on average by 114 percent (Schwartz 2021).
- (D and E) – Ideally, the user will calculate bicycle and vehicle trip lengths for the corridor at a scale no larger than the surrounding census tract. Potential data sources include the U.S. Census, state household travel surveys, or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input regional average one-way bicycle and vehicle trip lengths for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington as provided in Table T-10.1 (see the Appendix).
- (F and G) – Ideally, the user will calculate bicycle and auto mode share for work trips for a Project/Site at a scale no larger than a census tract. Potential data sources include the U.S. Census, state household travel surveys, or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the regional average mode shares for bicycle and vehicle work trips for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington, as presented in Table T-10.2 (see the Appendix). If the project study area

is not within the listed geographic areas or the user is able to provide a project-specific value, the user should replace these regional defaults in the GHG reduction formula. For areas not covered by the listed CBSAs, which represent the denser areas of the state, bicycle mode share is likely to be lower and vehicle share higher than presented in Table T-10.2.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use CBSA data from Tables T-10.1 and T-10.2 in the Appendix, the maximum percent reduction in GHG emissions (A) is 0.56 percent. This is based on a neighborhood project the size of a large corridor (B = 100%) within the CBSA of Corvalis MPO, OR, where there is by far the highest bike mode share of any of the cities in the Western States. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user reduces VMT by providing a bicycle boulevard on the targeted roadway, which encourages bicycle trips in place of vehicle trips. In this example, it is assumed this main street makes up the entire plan area, i.e., (B) is 100 percent. The project is within Corvalis MPO, OR, geographic scope and the user does not have project-specific values for trip lengths and mode shares for bicycles and vehicles. Per Tables T-10.1 and T-10.2, inputs for these variables are 1.25 miles, 5.55 miles, 13.9 percent, and 78.1 percent, respectively (D, E, F, and G). GHG emissions from plan/community VMT would be reduced by 0.56 percent.

$$A = 100\% \times \frac{1.25 \text{ miles} \times \left(13.9\%\text{-}(1.14 \times 13.9\%)\right)}{5.55 \text{ miles} \times 78.1\%} = \text{-}0.56\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

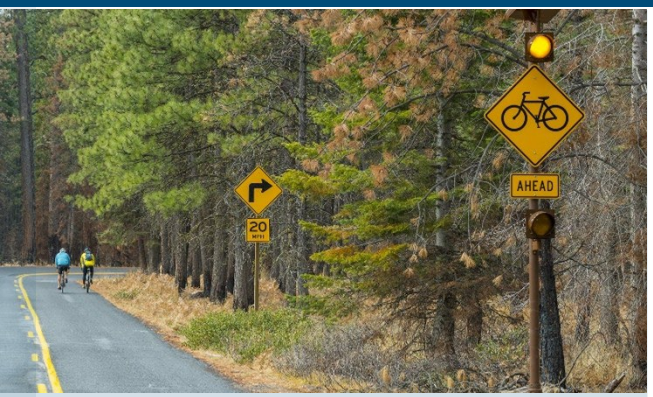
Improved Public Health

Users are directed to the ITHIM (CARB et al. 2020). The ITHIM can quantify the annual change in health outcomes associated with active transportation, including deaths, years of life lost, years of living with disability, and incidence of community and individual disease.

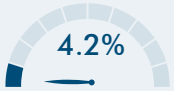
Sources

- CARB (California Air Resources Board), California Department of Public Health, and Nicholas Linesch Legacy Fund. 2020. *Integrated Transport and Health Impact Model*. Accessed March 2025. http://cal-ithim.org/ithim/#RunITHIM.
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T-20. Expand Bikeway Network



GHG Mitigation Potential



Up to 4.2% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Expanding bikeway networks can incentivize more bicycle use and decrease vehicle use, which have health benefits and can thus improve community resilience. This can also improve connectivity between residents and resources that may be needed in an extreme weather event.

Health and Equity Considerations

Prioritize low-income and underserved areas and communities with lower rates of vehicle ownership or fewer transit options. Make sure that destinations visited by low-income or underserved communities are served by the network.

Measure Description

This measure will increase the length of a city or community bikeway network. A bicycle network is an interconnected system of bike lanes, bike paths, bike routes, and cycle tracks. Providing bicycle infrastructure with markings and signage on appropriately sized roads with vehicle traffic traveling at safe speeds helps to improve biking conditions (e.g., safety and convenience). In addition, expanded bikeway networks can increase access to and from transit hubs, thereby expanding the "catchment area" of the transit stop or station and increasing ridership. This encourages a mode shift from vehicles to bicycles, displacing VMT and thus reducing GHG emissions. When expanding a bicycle network, a best practice is to consider bike lane width standards from local agencies, state agencies, or the National Association of City Transportation Officials' *Urban Bikeway Design Guide*.

Subsector

Neighborhood Design

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

The bikeway network must consist of either Class I, II, III, or IV infrastructure.

Cost Considerations

Capital and infrastructure costs for expanding the bikeway network may be high. Construction of these facilities may also increase vehicle traffic, leading to more congestion and temporarily longer trip times for motorists. However, the local municipality may achieve cost savings through a reduction of cars on the road leading to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

As networks expand, ensure safe, secure, and weather-protected bicycle parking facilities at origins and destinations. Also, implement alongside T-22-A, T-22-B, T-22-C, and/or T-22-D to ensure that micromobility options can ride safely along bicycle lane facilities and not have to ride along pedestrian infrastructure, which is a risk to pedestrian safety.

GHG Reduction Formula

$$A = -1 \times \frac{\left(\frac{C - B}{B}\right) \times D \times F \times H}{E \times G}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from employee commute vehicle travel in plan/community	0–0.5	%	calculated
User Inputs				
B	Existing bikeway miles in plan/community	[ ]	miles	user input
C	Bikeway miles in plan/community with measure	[ ]	miles	user input
Constants, Assumptions, and Available Defaults				
D	Bicycle mode share in plan/community	Table T-20.1	%	See Appendix
E	Vehicle mode share in plan/community	Table T-3.1	%	See Appendix
F	Average one-way bicycle trip length in plan/community	Table T-10.1	miles per trip	See Appendix
G	Average one-way vehicle trip length in plan/community	Table T-10.1	miles per trip	See Appendix
H	Elasticity of bike commuters with respect to bikeway miles per 10,000 population	0.25	unitless	Pucher and Buehler 2011

Further explanation of key variables:

- (B) – The existing bikeway miles in a plan/community should be calculated by measuring the distance of all Class I, II, III, and IV bikeways within the plan/community. This information can sometimes be found in a city's bicycle master plan, if a plan has been prepared and is up to date.
- (D, E, F, and G) – Ideally, the user will calculate bicycle and auto mode share and trip length for a plan/community at the city scale. Potential data sources include the state household travel surveys or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the mode shares and trip lengths for bicycles and vehicles for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington, as presented in Table T-3.1, T-10.2, and T-20.1 in the Appendix. Trip lengths are likely to be longer for areas not covered by the listed CBSAs, which represent the denser areas of the state. Similarly, it is likely for areas outside of the area covered by the listed CBSAs to have higher vehicle mode shares and lower bicycle mode shares than the values provided in the tables.

- (H) – A multivariate analysis of the impacts of bike lanes on cycling levels in the 100 largest U.S. cities found that a 0.25 percent increase in commute cycling occurs for every 1 percent increase in bike lane distance (Pucher and Buehler 2011).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use default data from Tables T-3.1, T-10.2, and T-20.1 in the Appendix, the maximum percent reduction in GHG emissions (A) is 18.5 percent. This is based on a project within the geographic scope of Corvalis MPO, OR, in a development that has no existing bike lane infrastructure. This maximum scenario is presented in the below example quantification.

($\left(\frac{C-B}{B}\right)_{max}$) The maximum percent increase in bike lane miles in the plan/community is conservatively capped at 1,000 percent; in another words, ($\left(\frac{C-B}{B}\right)_{max}$) is capped at 10 times of C. Therefore, if there is no existing bike lane infrastructure in the plan/community, (B) should be set to (1/11×C), resulting in a percentage change of 1,000 percent.

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user reduces employee commute VMT by increasing the length of a bicycle network within a plan/community, which displaces commute vehicle trips with bicycle trips. In this example, the existing bikeway length in the plan/community (B) is 0 miles and the length with the measure (C) is 11 miles. The project is within Corvalis MPO, OR, yielding the following inputs from Tables T-3.1, T-10.2, and T-20.1 in the Appendix.

- Bicycle mode share (D) = 7.4 percent.
- Vehicle mode share (E) = 79.9 percent.
- Average one-way bicycle trip length (F) = 1.25 miles.
- Average one-way vehicle trip length (G) = 5.55 miles.

The user would displace GHG emissions from project study area employee commute VMT by 4.2 percent.

$$A = -1 \times \left(\frac{(1000\%) \times 7.40\% \times 1.25 \text{ miles} \times 0.25}{79.9\% \times 5.55 \text{ miles}} \right) = -4.2\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in employee commute VMT would be the same as the percent reduction in GHG emissions (A).

Improved Public Health

Users are directed to the ITHIM (CARB et al. 2020). The ITHIM can quantify the annual change in health outcomes associated with active transportation, including deaths, years of life lost, years of living with disability, and incidence of community and individual disease.

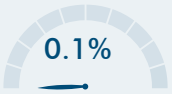
Sources

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T-21-A. Implement Conventional Carshare Program



GHG Mitigation Potential



Up to 0.1% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Carshare programs can increase accessibility and provide redundancy to vehicles that can be used to evacuate or obtain resources during an extreme weather event. Carshare programs can allow residents to give up or avoid car ownership, leading to cost savings that can help build economic resilience.

Health and Equity Considerations

Provide inclusive mechanisms so people without bank accounts, credit cards, or smart phones can access the system.

Measure Description

This measure will increase carshare access in the user's community by deploying conventional carshare vehicles. Carsharing offers people convenient access to a vehicle for personal or commuting purposes. This helps encourage transportation alternatives and reduces vehicle ownership, thereby avoiding VMT and associated GHG emissions. A variation of this measure, electric carsharing, is described in Measure T-21-B, *Implement Electric Carshare Program*.

Subsector

Neighborhood Design

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

The GHG mitigation potential is based, in part, on literature analyzing one-way carsharing service with a free-floating operational model. This measure should be applied with caution if using a different form of carsharing (e.g., roundtrip, peer-to-peer, fractional).

Cost Considerations

The costs incurred by the carshare program service manager (typically a municipality or carshare company) may include the capital costs of purchasing vehicles; costs of storing, maintaining, and replacing the fleet; and costs for marketing and administration. Some of these costs may be offset by income generated through program use.

Expanded Mitigation Options

When implementing a carshare program, best practice is to discount carshare membership and provide priority parking for carshare vehicles to encourage use of the service.

GHG Reduction Formula

$$A = \frac{B \times (E - D)}{C}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–0.09	%	calculated
User Inputs				
B	Number of vehicles deployed in plan/community	[ ]	integer	user input
C	VMT in plan/community without measure	[ ]	VMT per day	user input
Constants, Assumptions, and Available Defaults				
D	Conventional VMT avoided with measure	68.2	VMT per day per vehicle	Martin and Shaheen 2016
E	Conventional VMT added with measure	24.4	VMT per day per vehicle	Martin and Shaheen 2016

Further explanation of key variables:

- (B) – The number of cars in the carshare program is selected by the carshare provider, but its magnitude is relative to the size of the service area. A study of several carsharing programs (Martin and Shaheen 2016) documented a range of carshare fleet sizes for different North American cities: Calgary (590), San Diego (406), Seattle (640), Vancouver (920), and Washington, D.C. (626).
- (C) – The total plan/community VMT should represent the expected total VMT generated by all land use in that area. The most appropriate source for this data is from a local travel demand model.
- (D) – Conventional VMT avoided per deployed carshare vehicle was derived based on a study of conventional-engine based car share programs in Calgary, Seattle, Vancouver, and Washington, D.C. It accounts for VMT avoided from carshare users who sold their personal vehicles and carshare users who decided not to purchase a personal vehicle, both directly because of the availability of carshare (Martin and Shaheen 2016).
- (E) – Conventional VMT added per deployed carshare vehicle was derived based on a study of conventional-engine based car share programs in Calgary, Seattle, Vancouver, and Washington, D.C. It accounts for the VMT of the carshare vehicles (Martin and Shaheen 2016).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum GHG reduction from this measure is 0.14 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user reduces plan/community VMT by deploying carshare vehicles. In this example, the project would be in Seattle-Tacoma-Bellevue, WA, which in 2023 had a VMT per day of 40,613,000 miles (C) (WSDOT 2023). Assuming twice the number of vehicles used in the Gig carshare program from Seattle (B), the GHG emissions from plan/community VMT would be reduced by 0.14 percent.

$$A = \frac{800 \text{ vehicles} \times \left(24.4 \frac{\text{VMT}}{\text{day·vehicle}} - 68.2 \frac{\text{VMT}}{\text{day·vehicle}}\right)}{40{,}613{,}000 \frac{\text{VMT}}{\text{day}}} = -0.09\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- Martin, E., and S. Shaheen. 2016. *The Impacts of Car2go on Vehicle Ownership, Modal Shift, Vehicle Miles Traveled, and Greenhouse Gas Emissions: An Analysis of Five North American Cities.* July 2016.

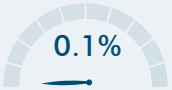
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T-21-B. Implement Electric Carshare Program



GHG Mitigation Potential



Up to 0.1% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Electric carshare programs can increase accessibility and provide redundancy to vehicles that can be used to evacuate or obtain resources during an extreme weather event. Electric vehicles also provide fuel redundancy by allowing an alternative fuel source if an extreme event disrupts other fuel sources. For instance, two-way equipped EVs can boost the grid during outages and provide power to shelters and deliver supplies where needed. In some other cases, however, they may decrease resilience if they are the only option available during a power outage.

Health and Equity Considerations

Provide inclusive mechanisms so people without bank accounts, credit cards, or smart phones can access the system.

Measure Description

This measure will increase carshare access in the user's community by deploying electric carshare vehicles. Carsharing offers people convenient access to a vehicle for personal or commuting purposes. This helps encourage transportation alternatives and reduces vehicle ownership, thereby avoiding VMT and associated GHG emissions. This also encourages a mode shift from internal combustion engine vehicles to electric vehicles, displacing the emissions-intensive fossil fuel energy with less emissions-intensive electricity. Electric carshare vehicles require more staffing support compared to conventional carshare programs for shuttling electric vehicles to and from charging points. A variation of this measure, conventional carsharing, is described in Measure T-21-A, *Implement Conventional Carshare Program*.

Subsector

Neighborhood Design

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

The GHG mitigation potential is based, in part, on literature analyzing one-way carsharing service with a free-floating operational model. This measure should be applied with caution if using a different form of carsharing (e.g., roundtrip, peer-to-peer, fractional).

Cost Considerations

Costs incurred by the service manager (e.g., municipality, carshare company) may include the capital costs of purchasing vehicles; costs of storing, maintaining, and replacing the fleet; and costs for marketing and administration. Some of these costs may be offset by income generated through program use. Participants' recurring costs of renting a carshare vehicle may be offset by the cost savings from access to cheaper transportation.

Expanded Mitigation Options

When implementing a carshare program, best practice is to discount carshare membership and provide priority parking for carshare vehicles to encourage use of the service.

GHG Reduction Formula

$$A = -1 \times \frac{B \times ((E \times G \times H \times I \times J) - (D \times F))}{C \times F}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–0.11	%	calculated
User Inputs				
B	Number of electric vehicles deployed in plan/community	[ ]	integer	user input
C	VMT in plan/community without measure	[ ]	VMT per day	user input
Constants, Assumptions, and Available Defaults				
D	Conventional VMT avoided with measure	54.8	VMT per day per EV	Martin and Shaheen 2016
E	Electric VMT added with measure	13.7	VMT per day per EV	Martin and Shaheen 2016
F	Emission factor of non-electric light duty fleet mix	Table T-14.1	g CO_2e per mile	U.S. EPA 2024
G	Energy efficiency of carshare electric vehicle	Table T-30.1	kWh per mile	U.S. EPA 2024
H	Carbon intensity of local electricity provider	Tables E-4.3 E-4.4, and E-4.9	lb CO_2e per MWh	See Appendix
I	Conversion from lb to g	454	g per lb	conversion
J	Conversion from kWh to MWh	0.001	MWh per kWh	conversion

Further explanation of key variables:

- (B) – The number of cars in the carshare program is selected by the carshare provider, but its magnitude is relative to the size of the service area. A study of several carsharing programs (Martin and Shaheen 2016) documented a range of carshare fleet sizes for different North American cities: Calgary (590), San Diego (406), Seattle (640), Vancouver (920), Washington, D.C. (626).
- (C) – The total plan/community VMT should represent the expected total VMT generated by all land use in that area. The most appropriate source for this data is from a local travel demand forecasting model.
- (D) – Conventional VMT avoided per deployed carshare vehicle was derived based on a study of an electric vehicle carshare program in San Diego. It accounts for VMT avoided from carshare users who sold their personal vehicles and carshare users who decided

not to purchase a personal vehicle, both directly because of the availability of carshare (Martin and Shaheen 2016).

- (E) – Electric VMT added per deployed carshare vehicle was derived based on a study of an electric vehicle carshare program in San Diego. It accounts for the VMT of the carshare vehicles and includes staff-driven VMT needed to bring the vehicles to charging points (Martin and Shaheen 2016).
- (F) – The average GHG emission factor for non-electric vehicles was calculated in terms of CO_2e per mile using MOVES5 (U.S. EPA 2024). The model was run for a 2025 statewide average of light-duty cars and trucks using diesel and gasoline fuel. Colorado Department of Transportation provided a statewide value calculated using local inputs processed through MOVES5 (CDOT Correspondence 2025). If the user can provide a project-specific value (i.e., for a future year and project location), the user should run MOVES to replace the default in the GHG reduction formula.
- (G) – The average light-duty EV efficiency was calculated in units of kWh/mi using MOVES5 (U.S. EPA 2024). The model was run for a 2025 statewide average of light-duty cars and trucks weighted by VMT.
- (H) – GHG intensity factors for major electricity providers within Arizona, Colorado, New Mexico, Oregon, and Washington are provided in Tables E-4.3 and E-4.4 in the Appendix. If the project study area is not serviced by a listed electricity provider, or the user is able to provide a project-specific value (i.e., for the future year not referenced in the Appendix), the user should replace the default in the GHG calculation formula. If the electricity provider is not known, the user may elect to use the statewide grid average carbon intensity.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum GHG reduction from this measure is 0.11 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user reduces plan/community VMT by deploying carshare vehicles. In this example, the project would be in the CBSA of Seattle-Tacoma-Bellevue, WA, which in 2023 had a VMT per day of 41,257,000 miles (C) (FHWA 2023). Assuming twice the number of vehicles used in the Seattle Gig program (B), and a commitment by the carshare service provider to purchase zero-carbon electricity for all carshare charging stations (H), the GHG emissions from plan/community VMT would be reduced by 0.11 percent.

$$A = -1 \times \frac{800 \times (0\ g\ CO_2e - (54.8 \frac{cVMT}{day \cdot vehicle} \times 366.9 \frac{g\ CO_2e}{mile}))}{41{,}257{,}000\ \frac{VMT}{day} \times 366.9 \frac{g\ CO_2e}{mile}} = -0.11\%$$

Quantified Co-Benefits

Improved Local Air Quality

Local criteria pollutants will be reduced by the reduction in vehicle fuel consumption. Electricity supplied by statewide fossil-fueled or bioenergy power plants will generate criteria pollutants. However, because these power plants are located throughout the state, electricity consumption from electric vehicles will not generate localized criteria pollutant emissions. Accordingly, the percentage reduction in NO_X, CO, NO_2, SO_2, and PM (K) is calculated using a simplified version of the GHG reduction formula, as follows:

$$K = -1 \times \frac{B \times -D}{C}$$

Reductions in VOC emissions can be calculated by multiplying the percentage reduction in other criteria pollutant emissions (K) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Fuel Savings (Increased Electricity)

The percentage reduction in vehicle fuel consumption would be the same as the percentage reduction in criteria pollutant emissions (K). The percentage increase in electricity use (L) from this measure can be calculated using a variation of the GHG reduction formula, as follows.

Electricity Use Increase Formula

$$L = \frac{B \times E \times G \times N}{M}$$

Electricity Use Increase Calculation Variables

ID	Variable	Value	Unit	Source
Output				
L	Increase in electricity from electric vehicles	[ ]	%	calculated
User Inputs				
M	Existing electricity consumption of plan/community	[ ]	kWh per year	user input

Constants, Assumptions, and Available Defaults				
N	Days per year carshare program operational	365	days per year	assumed

Further explanation of key variables:

- (M) – The user should take care to properly quantify building electricity using accepted methodologies.
- Please refer to the GHG Calculation Variables table above for definitions of variables that have been previously defined.

VMT Reductions

The percent reduction in VMT (O) is calculated using a simplified version of the GHG reduction formula that excludes the variables related to emission factors, as follows.

$$O = -1 \times \frac{B \times (E - D)}{C}$$

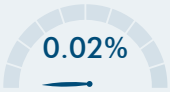
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T-22-A. Implement Pedal (Non-Electric) Bikeshare Program



GHG Mitigation Potential



Up to 0.02% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Bikeshare programs can incentivize more bicycle use and decrease vehicle use, which have health benefits and can thus improve community resilience. This can also improve connectivity between residents and resources that may be needed in an extreme weather event. As mentioned in Measure 19-A, facilities associated with bikeshare programs can also be used as evacuation assets in some cases.

Health and Equity Considerations

Provide inclusive mechanisms so people without bank accounts, credit cards, or smart phones can access the system.

Measure Description

This measure will establish a bikeshare program. Bikeshare programs provide users with on-demand access to bikes for short-term rentals. This encourages a mode shift from vehicles to bicycles, displacing VMT and thus reducing GHG emissions. Variations of this measure are described in Measure T-22-B, *Implement Electric Bikeshare Program*, Measure T-22-C, *Implement Scootershare Program,* and Measure T-22-D, *Transition Conventional to Electric Bikeshare*.

Subsector

Neighborhood Design

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

The GHG mitigation potential is based, in part, on literature analyzing docked (i.e., station-based) bikeshare programs. This measure should be applied with caution if using dockless (free-floating) bikeshare.

Cost Considerations

The costs incurred by the service manager (e.g., municipality or bikeshare company) may include the capital costs for purchasing a bicycle fleet; installing accessible and secure docking stations; storing, maintaining, and replacing the fleet; and marketing and administration. Some of these costs may be offset by income generated through program use. Program participants will benefit from the cost savings from access to cheaper transportation alternatives (compared to private vehicles, private bicycles, or use of ride-hailing services). The local municipality may achieve cost savings through a reduction of cars on the road leading to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

Best practice is to discount bikeshare membership and dedicate bikeshare parking to encourage use of the service. Also consider including space on the vehicle to store personal items while traveling, such as a basket.

GHG Reduction Formula

This measure methodology does not account for the direct GHG emissions from vehicle travel of program employees picking up and dropping off bikes.

$$A = -1 \times \frac{(C - B) \times D \times E \times F}{G \times H}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–0.02	%	calculated
User Inputs				
B	Percentage of residences in plan/community with access to bikeshare system without measure	0–100	%	user input
C	Percentage of residences in plan/community with access to bikeshare system with measure	0–100	%	user input
Constants, Assumptions, and Available Defaults				
D	Daily bikeshare trips per person	Table T-22.1	trips per day per person	See Appendix
E	Vehicle to bikeshare substitution rate	19.6	%	McQueen et al. 2020
F	Bikeshare average one-way trip length	Table T-22.2	miles per trip	See Appendix
G	Daily vehicle trips per person	2.7	trips per day per person	FHWA 2018
H	Regional average one-way vehicle trip length	Table T-10.1	miles per trip	See Appendix

Further explanation of key variables:

- (B and C) – Access to bikesharing is measured as the percentage of residences in the plan/community within 0.25 mile of a bikeshare station. For dockless bikes, assume that all residences within 0.25 mile of the designated dockless service area would have access.
- (D and F) – Public Ride Report provides historical data on bikeshare and scootershare use for certain cities throughout the U.S., and the City of Seattle maintains a public dashboard for their scootershare and bikeshare data. The Colorado Department of Transportation also provided values for Denver, Colorado. Table 22.1 provides the daily bikeshare trips per person for cities in Arizona, Colorado, Oregon, and Washington. Bikeshare use data is not available for New Mexico, although values from similar areas could be substituted.

- (E) – A literature review of several academic and government reports found that the average car trip substitution rate by bikeshare trips was 19.6 percent. This included bikeshare programs in Washington D.C., Minneapolis, and Montreal (McQueen et al. 2020).
- (G) – A summary report of the 2017 National Household Travel Survey data found that the average person in the U.S. takes 2.7 vehicle trips per day (FHWA 2018).
- (H) – Ideally, the user will calculate auto trip length for a plan/community at a scale no larger than a census tract. Potential data sources include the U.S. Census, state household travel surveys, or local survey efforts. If the user is not able to provide a plan-specific value using one of these data sources, they have the option to input the existing regional average one-way auto trip length for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, or Washington, as presented in Table T-10.1 (see the Appendix). Trip lengths are likely to be longer for areas not covered by the listed CBSAs, which represent the denser areas of the state.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use default CBSA data from Table T-10.1, the maximum percent reduction in GHG emissions (A) is 0.004 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user reduces plan/community VMT by deploying bikesharing throughout the area. In this example, the project is in Seattle-Tacoma-Bellevue, WA, and the one-way vehicle trip length would be 8.3 miles (H). Assuming 100 percent of residents in the plan/community would have bikeshare access (C) where there was no existing access (B), the user would reduce GHG emissions from plan/community VMT by 0.004 percent.

$$A = -1 \times \frac{(100\%\text{-}0\%) \times 0.0033 \frac{\text{trips}}{\text{day·person}} \times 19.6\% \times 1.5 \frac{\text{miles}}{\text{trip}}}{2.7 \frac{\text{trips}}{\text{day·person}} \times 8.3 \frac{\text{miles}}{\text{trip}}} = -0.004\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be

calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- City of Seattle. (2025). Scooter and Bikeshare Data Dashboard. Accessed February 2025. https://www.seattle.gov/transportation/projects-and-programs/programs/new-mobility-program/scooter-bike-share-data.
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T-22-B. Implement Electric Bikeshare Program



GHG Mitigation Potential



Up to 0.03% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Bikeshare programs can incentivize more bicycle use and decrease vehicle use, which have health benefits and can thus improve community resilience. This can also improve connectivity between residents and resources that may be needed in an extreme weather event. However, they may decrease resilience if they are the only option available during a power outage.

Health and Equity Considerations

Provide inclusive mechanisms so people without bank accounts, credit cards, or smart phones can access the system.

Measure Description

This measure will establish an electric bikeshare program. Electric bikeshare programs provide users with on-demand access to electric pedal assist bikes for short-term rentals. This encourages a mode shift from vehicles to electric bicycles, displacing VMT and reducing GHG emissions. Variations of this measure are described in Measure T-22-A, *Implement Pedal (Non-Electric) Bikeshare Program*, Measure T-22-C, *Implement Scootershare Program,* and Measure T-22-D, *Transition Conventional to Electric Bikeshare*.

Subsector

Neighborhood Design

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

The GHG mitigation potential is based, in part, on literature analyzing docked (i.e., station-based) bikeshare programs. This measure should be applied with caution if using dockless (free-floating) bikeshare.

Cost Considerations

The costs incurred by the service manager (e.g., municipality or bikeshare company) may include the capital costs for purchasing a bicycle fleet; installing accessible and secure charging stations; storing, maintaining, and replacing the fleet; and marketing and administration. Some of these costs may be offset by income generated through program use. Program participants will benefit from the cost savings from access to cheaper transportation alternatives (compared to private vehicles, private bicycles, or use of ride-hailing services). The local municipality may achieve cost savings through a reduction of cars on the road leading to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

Best practice is to discount electric bikeshare membership and dedicate electric bikeshare parking to encourage use of the service. Consider also including space on the vehicle to store personal items while traveling, such as a basket.

GHG Reduction Formula

The quantification methodology does not account for indirect GHG emissions from electricity used to charge bicycles or direct GHG emissions from vehicle travel of program employees picking up and dropping off bikes.

$$A = -1 \times \frac{(C - B) \times D \times E \times F}{G \times H}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–0.03	%	calculated
User Inputs				
B	Percentage of residences in plan/community with access to electric bikeshare system without measure	0–100	%	user input
C	Percentage of residences in plan/community with access to electric bikeshare system with measure	0–100	%	user input
Constants, Assumptions, and Available Defaults				
D	Daily electric bikeshare trips per person	Table 22.1	trips per day per person	See Appendix
E	Vehicle to electric bikeshare substitution rate	35	percent	Fitch et al. 2021
F	Electric bikeshare average one-way trip length	2.1	miles per trip	Fitch et al. 2021
G	Daily vehicle trips per person	2.7	trips per day per person	FHWA 2018
H	Regional average one-way vehicle trip length	Table T-10.1	miles per trip	See Appendix

Further explanation of key variables:

- (B and C) – Access to electric bikesharing is measured as the percentage of residences in the plan/community within 0.25-mile of an electric bikeshare station. For dockless bikes, assume that all residences within 0.25 mile of the designated dockless service area would have access.
- (D) – Public Ride Report provides historical data on bikeshare and scootershare use for certain cities throughout the U.S, and the City of Seattle maintains a public dashboard for their scootershare and bikeshare data. The Colorado Department of Transportation also provided values for Denver, Colorado. Table 22.1 provides the daily bikeshare trips per person for cities in Arizona, Colorado, Oregon, and Washington. Bikeshare use data is not available for New Mexico, although values from similar areas could be substituted.

- (E) – A study of dockless electric bike share in Sacramento found that the substitution rate of vehicles trips by electric bikeshare trips was 35 percent (Fitch et al. 2021).
- (F) – A study of dockless electric bike share in Sacramento found that the average one-way bikeshare trip was 2.1 miles (Fitch et al. 2021).
- (G) – A summary report of the 2017 National Household Travel Survey data found that the average person in the U.S. takes 2.7 vehicle trips per day (FHWA 2018).
- (H) – Ideally, the user will calculate auto trip length for a plan/community at a scale no larger than a census tract. Potential data sources include the U.S. Census, state household travel surveys, or local survey efforts. If the user is not able to provide a plan-specific value using one of these data sources, they have the option to input the existing regional average one-way auto trip length for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington, as presented in Table T-10.1 in the Appendix (see the Appendix). Trip lengths are likely to be longer for areas not covered by the listed CBSAs, which represent the denser areas of the state.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use default CBSA data from Table T-10.1, the maximum percent reduction in GHG emissions (A) is 0.03 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user reduces plan/community VMT by deploying electric bikesharing throughout the area. In this example, the project is in the Boulder, Colorado, and the one-way vehicle trip length would be 5.55 miles (H). Assuming 100 percent of residents in the plan/community would have bikeshare access (C) where there was no existing access (B), the user would reduce GHG emissions from plan/community VMT by 0.03 percent.

$$A = -1 \times \frac{(\mathbf{100\%\text{-}0\%}) \times 0.012 \ \frac{\text{trips}}{\text{day·person}} \times 35\% \times 2.1 \ \frac{\text{miles}}{\text{trip}}}{2.7 \ \frac{\text{trips}}{\text{day·person}} \times 10.99 \ \frac{\text{miles}}{\text{trip}}} = -0.03\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A). This quantification methodology does not account for the increase in electricity used to charge the vehicles or the fuel consumption from vehicle travel of program employees picking up and dropping off bikes.

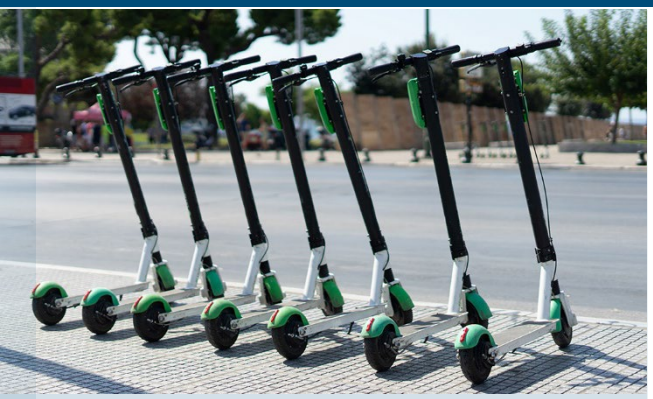
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A). This quantification methodology does not account for the miles traveled from vehicle travel of program employees picking up and dropping off bikes.

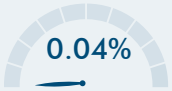
Sources

- City of Seattle. 2025. Scooter and Bikeshare Data Dashboard. Accessed February 2025. https://www.seattle.gov/transportation/projects-and-programs/programs/new-mobility-program/scooter-bike-share-data.
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- Oregon Department of Transportation. 2011. *2010 Oregon Travel Study*. Received from Oregon State in February 2025.
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- Ride Report. 2021-2023. Data as available by city, average trip distance (miles), and average trips per day. Accessed February 2025. https://public.ridereport.com.

T-22-C. Implement Scootershare Program



GHG Mitigation Potential



Up to 0.04% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Scootershare programs can incentivize more scooter use and decrease vehicle use, which have health benefits and can thus improve community resilience. This can also improve connectivity between residents and resources that may be needed in an extreme weather event. Furthermore, facilities associated with scootershare programs can also be used as evacuation assets, boosting initial evacuation speed.

Health and Equity Considerations

Provide inclusive mechanisms so people without bank accounts, credit cards, or smart phones can access the system.

Measure Description

This measure will establish a scootershare program. Scootershare programs provide users with on-demand access to electric scooters for short-term rentals. This encourages a mode shift from vehicles to scooters, displacing VMT and thus reducing GHG emissions. Variations of this measure are described in Measure T-22-A, *Implement Pedal (Non-Electric) Bikeshare Program*, and Measure T-22-B, *Implement Electric Bikeshare Program,* and Measure T-22-D, *Transition Conventional to Electric Bikeshare*.

Subsector

Neighborhood Design

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

The GHG mitigation potential is based, in part, on literature analyzing docked (i.e., station-based) bikeshare programs. This measure should be applied with caution given the likely higher popularity of scootershare compared to bikeshare.

Cost Considerations

The costs incurred by the service manager (e.g., municipality or scootershare company) may include the capital costs for purchasing a scooter fleet; installing accessible and secure docking stations; storing, maintaining, and replacing the fleet; and marketing and administration. Some of these costs may be offset by income generated through program use. Program participants will benefit from cost savings from access to cheaper transportation alternatives (compared to private vehicles, private scooters, or use of ride-hailing services). The local municipality may achieve cost savings through a reduction of cars on the road leading to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

Best practice is to discount scootershare membership and dedicate scootershare parking to encourage use of the service. Consider also including space on the vehicle to store personal items while traveling, such as a basket.

GHG Reduction Formula

This measure methodology does not account for the indirect GHG emissions from electricity used to charge the scooters or direct GHG emissions from vehicle travel of program employees picking up and dropping off scooters.

$$A = -1 \times \frac{(C - B) \times D \times E \times F}{G \times H}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–0.037	%	calculated
User Inputs				
B	Percentage of residences in plan/community with access to scootershare system without measure	0–100	%	user input
C	Percentage of residences in plan/community with access to scootershare system with measure	0–100	%	user input
Constants, Assumptions, and Available Defaults				
D	Daily scootershare trips per person	Table T-22.1	trips per day per person	See Appendix
E	Vehicle to scootershare substitution rate	38.5	%	McQueen et al. 2020
F	Scootershare average one-way trip length	Table T-22.2	miles per trip	See Appendix
G	Daily vehicle trips per person	1.9	trips per day per person	FHWA 2023
H	Regional average one-way vehicle trip length	Table T-10.1	miles per trip	See Appendix

Further explanation of key variables:

- (B and C) – Access to scootersharing is measured as the percentage of residences in the plan/community within 0.25-mile of a scootershare station. For dockless scooters, assume that all residences within 0.25-mile of the designated dockless service area would have access.
- (D and F) – Public Ride Report provides historical data on bikeshare and scootershare use for certain cities throughout the U.S, and the City of Seattle maintains a public dashboard for their scooter and bikeshare data. The Colorado Department of Transportation also provided values for Denver, Colorado. Table 22.1 provides the daily bikeshare trips per person for cities in Arizona, Colorado, Oregon, and

Washington. Bikeshare use data is not available for New Mexico, although values from similar areas could be substituted.

- (E) – A literature review of several academic and government reports found that the average car trip substitution rate by scootershare trips was 38.5 percent. This included scootershare programs in Santa Monica, Minneapolis, San Francisco, and Portland (McQueen et al. 2020).
- (G) – A summary report of the 2022 National Household Travel Survey data found that the average person in the U.S. takes 1.9 vehicle trips per day (FHWA 2024).
- (H) – Ideally, the user will calculate auto trip length for a plan/community at a scale no larger than a census tract. Potential data sources include the U.S. Census, state household travel surveys, or local survey efforts. If the user is not able to provide a plan-specific value using one of these data sources, they have the option to input the existing regional average one-way auto trip length for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington, as presented in Table T-10.1 in the Appendix (see the Appendix). Trip lengths are likely to be longer for areas not covered by the listed CBSAs, which represent the denser areas of the state.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use default CBSA data from Table T-10.1, the maximum percent reduction in GHG emissions (A) is 0.037 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user reduces plan/community VMT by deploying scootershare throughout the area. In this example, the project is in Denver, Colorado, and the one-way vehicle trip length would be 10.99 miles (H). Assuming 100 percent of residents in the plan/community would have scootershare access (C) where there was no existing access (B), the user would reduce GHG emissions from plan/community VMT by 0.037 percent.

$$A = -1 \times \frac{(100\%\text{-}0\%) \times 0.017 \frac{\text{trips}}{\text{day·person}} \times 38.5\% \times 1.17 \frac{\text{miles}}{\text{trip}}}{1.9 \frac{\text{trips}}{\text{day·person}} \times 10.99 \frac{\text{miles}}{\text{trip}}} = -0.037\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A). This quantification methodology does not account for the increase in electricity used to charge the scooters or the fuel consumption from vehicle travel of program employees picking up and dropping off scooters.

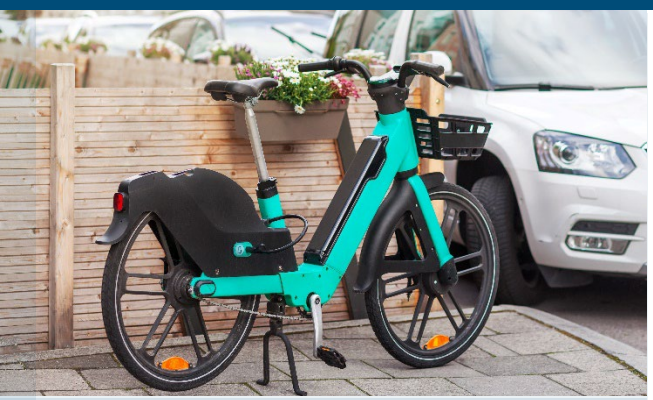
VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A). This quantification methodology does not account for the miles traveled from vehicle travel of program employees picking up and dropping off scooters.

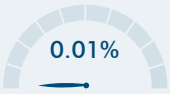
Sources

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- McQueen, M., G. Abou-Zeid, J. MacArthur, and K. Clifton. 2020. "Transportation Transformation: Is Micromobility Making a Macro Impact on Sustainability?" *Journal of Planning Literature* 36 (1). Accessed March 2021. https://doi.org/10.1177/0885412220972696.
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- Portland Metro. 2023. *Regional Transportation Plan*. Received from Portland Metro in February 2025.
- Ride Report. 2021-2023. Data as available by city, average trip distance (miles), and average trips per day. Accessed February 2025. https://public.ridereport.com.

T-22-D. Transition Conventional to Electric Bikeshare



GHG Mitigation Potential



Up to 0.01% of GHG emissions from transitioning an existing traditional bikeshare system to electric bikes.

Co-Benefits (icon key on pg. 31)

Climate Resilience

Bikeshare programs can incentivize more bicycle use and decrease vehicle use, which have health benefits and can thus improve community resilience. This can also improve connectivity between residents and resources that may be needed in an extreme weather event. However, they may decrease resilience if they are the only option available during a power outage. Nevertheless, facilities associated with electric bikeshare programs can also be used as evacuation assets, boosting initial evacuation speed.

Health and Equity Considerations

Commuters who switch from passenger vehicle use to electric bicycle use initiate regular physical activity, reducing their health risk. Electric bicycles are more affordable than owning a car and can improve access to health care and other health-promoting goods and services. Program implementers should provide inclusive mechanisms so people without bank accounts, credit cards, or smart phones can access the system.

Measure Description

This measure accounts for the VMT reduction achieved by transitioning an existing traditional bikeshare program to an electric bikeshare program. Research in the United States has found that electric bikeshare programs lead to increased ridership and accessibility over traditional bikes. This makes sense because, with an electric bike, it is easier to climb hills and is faster for riders to get where they are going, leading to increased utility. Variations of this measure are described in Measure T-22-A, *Implement Pedal (Non-Electric) Bikeshare Program*, Measure T-22-B, *Implement Electric Bikeshare Program*, and Measure T-22-C, *Implement Scootershare Program*.

Subsector

Neighborhood Design

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

The GHG mitigation potential is based, in part, on literature analyzing docked (i.e., station-based) bikeshare programs. This measure should be applied with caution if using dockless (free-floating) bikeshare.

Cost Considerations

The costs incurred by the service manager (e.g., municipality or bikeshare company) may include the capital costs for purchasing an electric bicycle fleet; installing accessible and secure charging stations; storing, maintaining, and replacing the fleet; and marketing and administration. Some of these costs may be offset by income generated through program use. Program participants will benefit from the cost savings from access to cheaper transportation alternatives (compared to private vehicles, private bicycles, or use of ride-hailing services). The local municipality may achieve cost savings through a reduction of cars on the road leading to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

Best practice is to discount electric bikeshare membership and dedicate electric bikeshare parking to encourage use of the service. Consider also including space on the vehicle to store personal items while traveling, such as a basket.

GHG Reduction Formula

The quantification methodology does not account for indirect GHG emissions from electricity used to charge the bicycles or direct GHG emissions from vehicle travel of program employees picking up and dropping off bikes.

$$A = \frac{-B \times C \times D \times ((E \times F) - (G \times H))}{I \times J}$$

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0-0.059	%	calculated
User Inputs				
B	Percentage of residences in plan/community with access to traditional bikeshare system	0–100	%	user input
C	Percentage of bikeshare bikes transitioned to electric bikeshare	0–100	%	user input
Constants, Assumptions, and Available Defaults				
D	Daily bikeshare trips per person	Table T-22.1	trips per day per person	See Appendix
E	Vehicle to electric bikeshare substitution rate	35	%	Fitch et al. 2021
F	Electric bikeshare average one-way trip length	2.1	miles per trip	Fitch et al. 2021
G	Vehicle to conventional bikeshare substitution rate	19.6	%	McQueen et al. 2020
H	Conventional bikeshare average one-way trip length	Table T-22.2	miles per trip	See Appendix
I	Daily vehicle trips per person	1.9	trips per day per person	FHWA 2023
J	Regional average one-way vehicle trip length	Table T-10.1	miles per trip	See Appendix

Further explanation of key variables:

- (B) – Access to bike sharing is measured as the percentage of residences in the plan/community within 0.25 mile of a bikeshare station. For dockless bikes, users can assume that all residences within 0.25 mile of the designated dockless service area would have access.
- (C) – This is the percentage of bikes within the existing system that are switched from conventional bikeshare bikes to electric bicycles. For example, if a system with 100 conventional bikes retires 50 bikes and replaces them with 50 e-bikes, then this would

represent a 50 percent transition. This calculation assumes that a bikeshare transition is not combined with a bikeshare expansion. If it is, the new areas can be estimated using Measure T-22-A, *Implement Pedal (Non-Electric) Bikeshare Program*, Measure T-22-B, *Implement Electric Bikeshare*.

- (D and H) – Public Ride Report provides historical data on bikeshare and scootershare use for certain cities throughout the U.S, and the City of Seattle maintains a public dashboard for their scootershare and bikeshare data. The Colorado Department of Transportation also provided trips per person values for Denver, Colorado. Table 22.1 provides the daily bikeshare trips per person for cities in Arizona, Colorado, Oregon, and Washington. Table 22.1 provides the average trip lengths for bikeshare and scootershare for cities in Arizona, Colorado, Oregon, and Washington. Bikeshare use data is not available for New Mexico, although values from similar areas could be substituted (see the Appendix).
- (E) – A study of dockless electric bikeshare in Sacramento found that the substitution rate of vehicles trips by electric bikeshare trips was 35 percent (Fitch et al. 2021).
- (F) – A study of dockless electric bikeshare in Sacramento found that the average one-way bikeshare trip was 2.1 miles (Fitch et al. 2021).
- (G) – A literature review of several academic and government reports found that the average car trip substitution rate by bikeshare trips was 19.6 percent. This included bikeshare programs in Washington D.C., Minneapolis, and Montreal (McQueen et al. 2020).
- (I) – A summary report of the 2022 National Household Travel Survey (data found that the average person in the United States takes 1.9 vehicle trips per day (FHWA 2023).
- (J) – Ideally, the user will calculate auto trip length for a plan/community at a scale that is appropriate to the geographical area of the electrification efforts. Potential data sources include the metropolitan planning organization travel model, state household travel surveys, or local survey efforts. If the user is not able to provide a plan-specific value using one of these data sources, they have the option to input the existing regional average one-way auto trip length for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington, as presented in Table T-10.1 (see the Appendix). Trip lengths are likely to be longer for areas not covered by the listed CBSAs, which represent the denser areas of the state.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use default data from Table T-10.1, the maximum percent reduction in GHG emissions (A) is 0.014 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}18 \text{ through } T\text{-}22\text{-}D}} \leq 10\%$) This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-D. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

Example GHG Reduction Quantification

The user is transitioning from a large conventional bikeshare system to an electric bikeshare system. For this example, the project is in Denver-Aurora-Centennial, CO geographic, and the one-way vehicle trip length would be 10.99 miles (J). If we assume that 100 percent of the residents in the plan/community have bikeshare access (B) and that the fleet is fully transitioning (C), the user would reduce GHG emissions from the plan/community VMT by 0.012 percent.

$$A = \frac{\text{-}100\% \times 100\% \times 0.012 \frac{\text{trips}}{\text{day person}} \times \left(35\% \times 2.1 \frac{\text{miles}}{\text{trip}} \text{-} 19.6\% \times 2.65 \frac{\text{miles}}{\text{trip}}\right)}{1.9 \frac{\text{trips}}{\text{day person}} \times 10.99 \frac{\text{miles}}{\text{trip}}} = \text{-}0.0124\%$$

Quantified Co-Benefits

Improved Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NOx, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A). This quantification methodology does not account for the increase in electricity used to charge the vehicles or the fuel consumption from vehicle travel of program employees picking up and dropping off bikes.

VMT Reductions

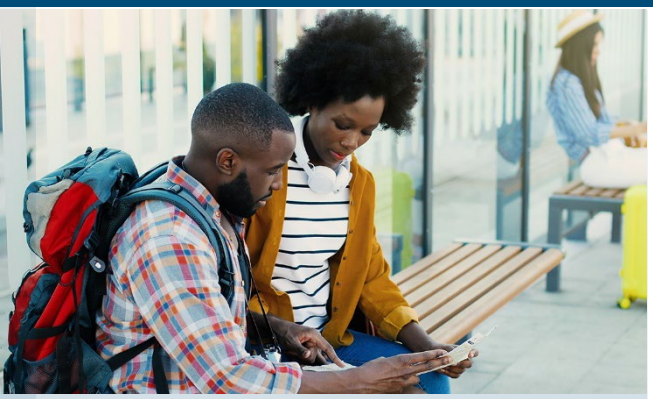
The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A). This quantification methodology does not account for the miles traveled from vehicle travel of program employees picking up and dropping off bikes.

Sources

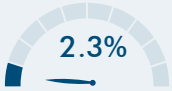
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T-23. Provide Community-Based Travel Planning



GHG Mitigation Potential



Up to 2.3% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

CBTP can decrease vehicle use and thus improve air quality, resulting in health impacts that may increase the resilience of communities near freeways and roads. This can also increase the adaptive capacity of communities by informing them of travel alternatives if certain modes become disrupted due to extreme events. Knowing alternative routes are available, especially in an urgent situation, also contributes to the improvement of adaptive capacity, making the planning and upkeep of alternative routes part of the process of adaptive planning from multiple levels of jurisdictions.

Health and Equity Considerations

Outreach materials may need to be in multiple languages to address diverse linguistic communities.

Measure Description

This measure will target residences in the plan/community with community-based travel planning (CBTP). CBTP is a residential-based approach to outreach that provides households with customized information, incentives, and support to encourage the use of transportation alternatives in place of single occupancy vehicles, thereby reducing household VMT and associated GHG emissions.

Subsector

Trip Reduction Programs

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

CBTP involves teams of trained travel advisors visiting all households within a targeted geographic area, having tailored conversations about residents' travel needs, and educating residents about the various transportation options available to them. Due to the personalized outreach method, communities are typically targeted in phases.

Cost Considerations

The main cost consideration for CBTP is labor costs for program managers and resident outreach staff plus material costs for development of educational material. The beneficiaries are the commuters who may be able to reduce vehicle usage or ownership. The local municipality may achieve cost savings through a reduction of cars on the road leading to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

Pair with any of the Measures from T-17 through T-22-D to ensure that residents who are targeted by CBTP and who want to use alternative transportation have the infrastructure and technology to do so.

GHG Reduction Formula

$$A = \frac{C}{B} \times D \times -E \times F$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from household vehicle travel in plan/community	0–2.3	%	calculated
User Inputs				
B	Residences in plan/community	[ ]	residences	user input
C	Residences in plan/community targeted with CBTP	[ ]	residences	user input
Constants, Assumptions, and Available Defaults				
D	Percentage of targeted residences that participate	19	%	MTC 2021
E	Percent vehicle trip reduction by participating residences	12	%	MTC 2021
F	Adjustment factor from vehicle trips to VMT	1	unitless	assumed

Further explanation of key variables:

- (D) – Results from program evaluations of CBTP in several counties in Washington and Oregon across multiple years indicate that an average of 19 percent of residences targeted will participate (MTC 2021).
- (E) – Results from program evaluations of CBTP in several counties in Washington and Oregon across multiple years indicate that a 12 percent vehicle trip reduction will occur among participating residences (MTC 2021).
- (F) – The adjustment factor from vehicle trips to VMT is 1. This assumes that all vehicle trips will average out to typical trip length ("assumes all trip lengths are equal"). Thus, it can be assumed that a percentage reduction in vehicle trips will equal the same percentage reduction in VMT.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum percent reduction in GHG emissions (A) is 2.3 percent. This maximum scenario is presented in the below example quantification.

Subsector Maximum

Same as (A_{max}). Measure T-23 is the only measure at the Plan/Community scale within the Trip Reduction Programs subsector.

Example GHG Reduction Quantification

The user reduces household VMT by having residences in the plan/community participate in CBTP. In this example, all of the residences in a city of 5,000 are targeted (B and C), which would reduce GHG emissions from citywide household VMT by 2.3 percent.

$$A = \left(\frac{\text{5,000 residences}}{\text{5,000 residences}}\right) \times 19\% \times \text{-}12\% \times 1 = \text{-}2.3\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

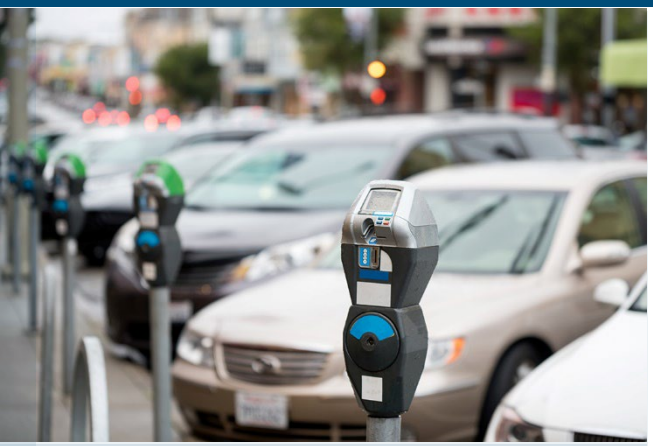
VMT Reductions

The percent reduction in household VMT would be the same as the percent reduction in GHG emissions (A).

Source

- MTC (Metropolitan Transportation Commission). 2021. *Plan Bay Area 2050: Forecasting and Modeling Report*. October 2021. Accessed November 2021. https://www.planbayarea.org/sites/default/files/documents/Plan_Bay_Area_2050_Forecasting_Modeling_Report_October_2021.pdf.

T-24. Implement Market Price Public Parking (On-Street)



GHG Mitigation Potential



Up to 30% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)



Climate Resilience

Implementing the market price public parking could incentivize increased use of public transit and thus result in less traffic, potentially reducing congestion or delays on major roads during peak AM and PM traffic periods. In addition, this reduces illegal loading/standing in bus stops and travel lanes. When these reductions occur during extreme weather events, they better allow emergency responders to access a hazard site.

Health and Equity Considerations

Pricing on-street parking at market rates reduces illegal loading/standing in bus stops and travel lanes, improving transit times.

Measure Description

This measure will price all on-street parking in a given community, with a focus on parking near central business districts, employment centers, and retail centers. Increasing the cost of parking increases the total cost of driving to a location, incentivizing shifts to other modes and thus decreasing total VMT to and from the priced areas. This VMT reduction results in a corresponding reduction in GHG emissions.

Subsector

Parking or Road Pricing/Management

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

When pricing on-street parking, the best practice is to allow for dynamic adjustment of prices to ensure approximately 85 percent occupancy, which helps prevent induced VMT due to circling behaviors as individuals search for a vacant parking space. In addition, this method should primarily be implemented in areas with available alternatives to driving, such as transit availability within 0.5. mile or areas of high residential density nearby (allowing for increased walking/biking). If the measure is implemented in a small area, residential parking permit programs should be considered to prevent parking intrusion on nearby streets in residential areas without priced parking.

Cost Considerations

Municipalities may incur costs from installing the meter network, which may require meters at individual spaces or at more central terminals. There would also be staffing costs to monitor the metered spaces and collect payments. Residents also incur a cost by having to pay for on-street parking. A portion of costs to the municipality may be offset through revenue collected by the parking system.

Expanded Mitigation Options

Pricing on-street parking also helps support individual projects with priced onsite parking by removing potential alternative parking locations.

GHG Reduction Formula

$$A = \frac{B}{C} \times \frac{D - E}{E} \times F \times G \times H$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0.0–30.0	%	calculated
User Inputs				
B	VMT in priced area without measure	[ ]	VMT per day	user input
C	VMT in plan/community without measure	[ ]	VMT per day	user input
D	Proposed parking price	1.00–5.00	$ per hour	user input
E	Initial parking price	0.00–5.00	$ per hour	user input
F	Default percentage of trips parking on street	5–75	%	user input
Constants, Assumptions, and Available Defaults				
G	Elasticity of parking demand with respect to price	-0.4	unitless	Pierce and Shoup 2013, Concas and Nayak 2012
H	Ratio of VMT to vehicle trips	1	unitless	assumption

Further explanation of key variables:

- (B and C) – Total daily VMT in both the priced area and the plan/community area should represent the expected total VMT generated by all land use in that area, including office, residences, retail, schools, and other uses. The most appropriate source for this data is from a local travel demand forecasting model. An alternate method uses VMT per worker or VMT per resident multiplied by the population in the area.
  - These variables for VMT by area are used to ensure that the percent GHG reduction from the priced area is at the same geographic scale as the vehicle travel in the plan/community. If the area priced is a business district and the analysis is limited to the business district, then the VMT would be equal (B=C).
- (D) – The proposed parking price can be presented in cost per minute, hour, or day, provided that the same units are used for variable (E)
- (E) – Because this is used to calculate the percent change in parking price, if parking is free under existing conditions, (E) should be set to (1/2×D), resulting in a percentage change of 100 percent. In areas where metered parking is common, E may instead be set to equal the average metered parking price in nearby areas or districts.

- (F) – On-street parking represents only a portion of the total available parking supply. An estimate will typically range from 5 percent (in locations with offsite parking garages available) to 75 percent (in locations where most parcels have little to no onsite parking for visitors). The user should provide a project-specific value within this range, by surveying the total on-street vs. off-street parking spaces within ¼ mile of the study area.
- (G) – If the user is not able to provide a project-specific value, they have the option to input the default value listed in the table above. The default value is based on an evaluation of the SFPark program in San Francisco, which found that a 0.4 percent decrease in parking demand occurs for every 1 percent increase in parking price (Pierce and Shoup 2013). A meta-analysis of parking price studies also found that a 0.4 percent decrease in parking demand occurs for every 1 percent increase in parking price (Concas and Nayak 2012). Price elasticity of parking demand varies by location, day of the week, and time of day.
- (H) – The adjustment factor from vehicle trips to VMT is 1. This assumes that all vehicle trips will average out to typical trip length ("assumes all trip lengths are equal"). Thus, it can be assumed that a percentage reduction in vehicle trips will equal the same percentage reduction in VMT.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The total reduction in VMT due to on-street parking pricing is capped at 30 percent, which is based on the following assumptions:

- $\left(\frac{D-E}{E}=100\%\right)$ – Parking prices double (i.e., increase by 100 percent) or parking pricing is introduced in previously free areas.
- (F) – 75 percent of all vehicle trips utilize on-street parking. Note that only within a small-scale commercial district is 75 percent of parking likely to occur on street.

This maximum scenario is presented in the below example quantification.

Subsector Maximum

Same as (A_{max}). Measure T-24 is the only measure at the Plan/Community scale within the Parking or Road Pricing/Management subsector.

Example GHG Reduction Quantification

The user reduces VMT by increasing hourly on-street parking costs. In this example, the hourly parking cost increases from $1.00 (E) to $2.00 (D) in a business district. The business district daily VMT is 1,000,000 (B), and the scale of implementation is the business district (B=C). If around 75 percent of the district's parking supply is on street (F), the user would reduce GHG emissions from VMT by 30 percent.

$$A = \frac{1{,}000{,}000\,\frac{VMT}{day}}{1{,}000{,}000\,\frac{VMT}{day}} \times \frac{\$2.00 - \$1.00}{\$1.00} \times 75\% \times -0.4 \times 1 = -30\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- Concas, S., and N. Nayak. 2012. *A Meta-analysis of Parking Pricing Elasticity*. Transportation Research Board, 91st Annual Meeting. https://trid.trb.org/View/1130741.
- Pierce, G., and D. Shoup. 2013. "Getting the Prices Right: An Evaluation of Pricing Parking by Demand in San Francisco." *Journal of the American Planning Association* 79 (1): 67–81. Accessed January 2021. https://www.tandfonline.com/doi/pdf/10.1080/01944363.2013.787307?needAccess=true.

T-25. Extend Transit Network Coverage or Hours



GHG Mitigation Potential



Up to 3.6% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)



Climate Resilience

Increasing transit network coverage or hours improves the reliability of the transportation network and allows redundancy to exist even if an extreme event disrupts part of the system. They could also incentivize more people to use transit, resulting in less traffic and better allowing emergency responders to access a hazard site during an extreme weather event.

Health and Equity Considerations

This measure increases access to social, educational, and employment opportunities. Expansion of transit networks need to ensure equitable access by all communities to the transit system.

Measure Description

This measure will expand the local transit network by either adding or modifying existing transit service or extending the operation hours to enhance the service near the project site. Starting services earlier in the morning and/or extending services to late-night hours can accommodate the commuting times of alternative-shift workers. This will encourage the use of transit and therefore reduce VMT and associated GHG emissions.

Subsector

Transit

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

There are two primary means of expanding the transit network: by increasing the frequency of service, thereby reducing average wait times and increasing convenience, or by extending service to cover new areas and times.

Cost Considerations

Infrastructure costs for extending the physical network coverage of a transit system can be significant. Costs to expand track-dependent transit, such as light rail and passenger rail, are high and can require resource- and time-intensive advanced planning. Costs to expand vehicle-dependent transit, such as buses, are likewise high but may be limited to procurement of additional vehicles. Any expansion of transit, including just service hours, would increase staffing and potentially maintenance costs. A portion of these costs may be offset by increased transit usage and associated income. Commuters who may more easily be able to travel without a car may also observe cost savings from reduced vehicle usage or ownership.

Expanded Mitigation Options

This measure is focused on providing additional transit network coverage, with no changes to transit frequency. This measure can be paired with Measure T-26, *Increase Transit Service Frequency*, which is focused on increasing transit service frequency, for increased reductions.

GHG Reduction Formula

$$A = -1 \times \frac{C - B}{B} \times D \times E \times F \times G$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from plan/community VMT	0–3.6	%	calculated
User Inputs				
B	Total transit service miles or service hours in plan/community before expansion	[ ]	miles	user input
C	Total transit service miles or service hours in plan/community after expansion	[ ]	miles	user input
D	Transit mode share in plan/community	Table T-3.1	%	user input
Constants, Assumptions, and Available Defaults				
E	Elasticity of transit demand with respect to service miles or service hours	0.7	unitless	Handy et al. 2013
F	Statewide mode shift factor	Table T-25.1	%	See Appendix
G	Ratio of vehicle trip reduction to VMT	1	unitless	assumption

Further explanation of key variables:

- (A) – This formula does not reflect any increase in transit vehicle travel and emissions, which can at least partially offset the reduction in GHG emissions from passenger vehicle travel. Inclusion of this component in the percent GHG reduction formula would require inputs that would not be available to most users.
- (B and C) – Transit service miles are defined as the total service mileage. Service hours represent the hours of operation. Either metric can be used in the GHG reduction formula so long as both B and C use the same metric.
- (D) – The transit mode share for the four CBSAs in Arizona, Colorado, Oregon, and Washington and a statewide value for New Mexico are provided in Table T-3.1 in the Appendix (FHWA 2017). If the project study area is not within the listed CBSAs or the user is able to provide a project-specific value, the user should replace these regional defaults in the GHG reduction formula. It is likely for areas outside of the area covered by the listed CBSAs to have transit mode shares lower than the values provided in the table. Ideally, the user will calculate existing transit mode share for work trips or all trips at a scale no larger than a census tract. Potential data sources include the U.S. Census, state household travel surveys (preferred), or local survey efforts. Care should be taken to not present the reported commute mode share as retrieved from the ACS, unless the land use is office or employment based and the ACS tables are based on work location (rather than home location).

- (E) – A policy brief summarizing the results of transit service strategies concluded that a 0.7 percent increase in transit ridership occurs for every 1 percent increase in service miles or hours (Handy et al. 2013).
- (F) – The mode shift factors for Arizona, Colorado, New Mexico, Oregon, and Washington are provided in Table T-25.1 (see the Appendix). Mode shift factor is an adjustment to reflect the reduction in vehicle trips associated with a reduction in person trips, since some vehicles carry more than one person. It is calculated as (1/average vehicle occupancy).
- (G) – The adjustment factor from vehicle trips to VMT is 1. This assumes that all vehicle trips will average out to typical trip length ("assumes all trip lengths are equal"). Thus, it can be assumed that a percentage reduction in vehicle trips will equal the same percentage reduction in VMT.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The GHG reduction from expanding the transit network is capped at 3.6 percent, which is based on the following assumptions:

- $\left(\frac{C-B}{B} \leq 100\%\right)$ – The transit network increase is capped at a doubling in size, or 100 percent (twice as many revenue miles are provided, for a 100 percent increase).
- (D) – The CBSA is Seattle-Tacoma-Bellevue, which has a default transit mode share for all trips of 8.44 percent.
- (F) – The mode shift factor for Washington State is 61.7 percent.

This maximum scenario is presented in the below example quantification.

Subsector Maximum

($\sum A_{max_{T\text{-}25 \text{ through } T\text{-}29,\ T\text{-}46}} \leq 15\%$) This measure is in the Transit subsector. This subcategory includes Measures T-25 through T-29 and T-46. The VMT reduction from the combined implementation of all measures within this subsector is capped at 15 percent.

Example GHG Reduction Quantification

The user reduces VMT by extending the existing transit route or lengthening the service hours. In this example, the project in a neighborhood of the Seattle-Tacoma-Bellevue CBSA and would increase transit coverage in the area from 20 miles (B) to 40 miles (C). If the existing transit mode share in the study area is 8.44 percent (D) and the mode shift factor for Washington State is 61.7 percent, the user would reduce GHG emissions from VMT by 3.6 percent.

$$A = -1 \times \frac{(40 \text{ miles} - 20 \text{ miles})}{20 \text{ miles}} \times 8.44\% \times 0.7 \times 61.7\% \times 1 = -3.6\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions (A).

Sources

- Colorado Department of Transportation. 2025. *Correspondence*. Received from Colorado State in February 2025.
- Colorado Department of Transportation. 2025. *StateFocus Travel Demand Model*. Received from Colorado State in February 2025.
- FHWA (Federal Highway Administration). 2017. *National Household Travel Survey–2017 Table Designer*. Average Vehicle Occupancy by HHSTFIPS. Accessed January 2025. https://nhts.ornl.gov/.
- Handy, S., K. Lovejoy, M. Boarnet, and S. Spears. 2013. *Impacts of Transit Service Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions*. October 2013. Accessed January 2021. https://ww2.arb.ca.gov/sites/default/files/2020-06/Impacts_of_Transit_Service_Strategies_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Policy_Brief.pdf.
- New Mexico Environment Department. 2025. *Correspondence*. Received from New Mexico State in February 2025.
- Oregon Department of Transportation. 2011. *2010 Oregon Travel Study*. Received from Oregon State in February 2025.
- Portland Metro. 2023. *Regional Transportation Plan*. Received from Portland Metro in February 2025.

T-26. Increase Transit Service Frequency



GHG Mitigation Potential



Up to 8.8% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Increasing transit service frequency improves the reliability of the transportation network and allows redundancy to exist even if an extreme event disrupts part of the system. It could also incentivize more people to use transit, resulting in less traffic and better allow emergency responders to access a hazard site during an extreme weather event.

Health and Equity Considerations

This measure increases access to social, educational, and employment opportunities. Expansion of transit service needs to ensure equitable access by all communities to the transit system.

Measure Description

This measure will increase transit frequency on one or more transit lines serving the plan/community. Increased transit frequency reduces waiting and overall travel times, which improves the user experience and increases the attractiveness of transit service. This results in a mode shift from single occupancy vehicles to transit, which reduces VMT and associated GHG emissions.

Subsector

Transit

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

See measure description.

Cost Considerations

Increasing transit service frequency may require capital investment to purchase additional vehicles. Staff and maintenance costs may also increase. A portion of these costs may be offset by increased transit usage and associated income. Commuters who may more easily be able to travel without a car may also observe cost savings from reduced vehicle usage or ownership.

Expanded Mitigation Options

This measure is focused on providing increased transit frequency, with no changes to transit network coverage. This measure can be paired with Measure T-25, *Extend Transit Network Coverage or Hours*, which is focused on increasing transit network coverage, for increased reductions.

GHG Reduction Formula

$$A = -C \times \frac{B \times E \times D \times G}{F}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–8.8	%	calculated
User Inputs				
B	Percent increase in transit frequency	0–300	%	user input
C	Level of implementation	0–100	%	user input
Constants, Assumptions, and Available Defaults				
D	Elasticity of transit ridership with respect to frequency of service	0.5	unitless	Handy et al. 2013
E	Transit mode share in plan/community	Table T-3.1	%	See Appendix
F	Vehicle mode share in plan/community	Table T-3.1	%	See Appendix
G	Statewide mode shift factor	Table T-25.1	%	See Appendix

Further explanation of key variables:

- (A) – This formula does not reflect any increase in transit vehicle travel and emissions, which can at least partially offset the reduction in GHG emissions from passenger vehicle travel. Inclusion of this component in the percent GHG reduction formula would require inputs that would not be available to most users. Users can calculate the absolute changes in passenger vehicle and bus VMT and emissions using the process described under *Co-Benefits*.
- (B) – Frequency is measured as the number of arrivals over a given time (e.g., buses per hour). Frequency is the inverse of transit headway, defined as the time between transit vehicle arrivals on a given route. This variable can be calculated as [transit frequency with measure minus existing transit frequency] divided by existing transit frequency.
- (C) – The level of implementation refers to the number of transit routes receiving the frequency improvement as a fraction of the total transit routes in the plan/community.
- (D) – A policy brief summarizing the results of transit service strategies concluded that a 0.5 percent increase in transit ridership occurs for every 1 percent increase in frequency (Handy et al. 2013).
- (E and F) – Ideally, the user will calculate transit and auto mode shares for a plan/community at the city scale (or larger). Potential data sources include state household travel surveys or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the mode shares for transit and vehicles for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington, as presented in Table T-3.1 in the

Appendix. It is likely for areas outside of the area covered by the listed CBSAs to have vehicle mode shares higher and transit mode shares lower than the values provided in the table.

- (G) – The mode shift factors for Arizona, Colorado, Oregon, New Mexico, Washington, and Portland Metro MPO are provided in Table T-25.1 (see the Appendix). Mode shift factor is an adjustment to reflect the reduction in vehicle trips associated with a reduction in person trips, since some vehicles carry more than one person. It is calculated as (1/average vehicle occupancy).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use default CBSA data from Table T-3.1 and (B_{max}), the maximum percent reduction in GHG emissions (A) is 8.8 percent. This maximum scenario is presented in the below example quantification.

(B_{max}) The percent change in transit frequency is capped at 300 percent (SANDAG 2019).

Subsector Maximum

($\sum A_{max_{T\text{-}25 \text{ through } T\text{-}29,\ T\text{-}46}} \leq 15\%$) This measure is in the Transit subsector. This subcategory includes Measures T-25 through T-29 and T-46. The VMT reduction from the combined implementation of all measures within this subsector is capped at 15 percent.

Mutually Exclusive Measures

If the user selects Measure T-28, *Provide Bus Rapid Transit*, and converts all transit routes in the plan/community to BRT, then the user cannot also take credit for this measure, Measure T-27, *Implement Transit-Supportive Roadway Treatments*, or Measure T-46, *Provide Transit Shelters*. This is because Measure T-28 accounts for the VMT reduction associated with increased transit frequency and decreased transit travel time as well as the additional BRT-specific bonus. To combine the GHG reductions from Measure T-28 with Measure T-27, Measure T-26, and/or Measure T-46 would be considered double counting. However, where BRT is proposed on less than all of the existing bus routes in the plan/community area, this measure, Measure T-27, and/or Measure T-46 could be applied to the remaining bus routes, and the measure reductions could be combined with Measure T-28 to determine the emissions reduction at the larger plan/community scale.

Example GHG Reduction Quantification

The user reduces plan/community GHGs by increasing transit frequency, thereby encouraging a mode shift from vehicles to transit and reducing VMT. In this example, the project is in the Seattle-Tacoma-Bellevue CBSA where the transit and vehicle mode shares would be 8.44 percent and 88.74 percent, respectively (E and F) and the mode shift factor for Washington State would be 61.7 percent. Assuming the maximum increase in transit frequency of 300 percent (B) and implementation for all transit routes (100 percent) in the

plan/community (C), the user would reduce plan/community GHG emissions from VMT by 8.8 percent.

$$A = -100\% \times \frac{300\% \times 8.44\% \times 0.5 \times 61.7\%}{88.74\%} = -8.8\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

VMT Reductions

The decrease in passenger vehicle miles (H) and increase in bus miles (L) by the measure can be calculated as follows.

Passenger Vehicle VMT Reduction Formula

The percent reduction in passenger VMT would be the same as the percent reduction in GHG emissions (A). The absolute reduction in passenger VMT can be calculated using the following formula.

$$H = I \times E \times J \times B \times D \times G \times K$$

Passenger Vehicle VMT Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
H	Reduction in passenger vehicle miles in plan/community	[ ]	miles per year	calculated
User Inputs				
I	Total daily person trips in corridor(s)	[ ]	trips per day	user input
J	Vehicle trip length	[ ]	miles per trip	user input
Constants, Assumptions, and Available Defaults				
K	Days per year transit available	365	days per year	assumed

Further explanation of key variables:

- (I) – The total daily person trips in the corridor(s) represents the total daily trips by all modes between the bus route origin area and the bus route destination area. This may be obtained through travel demand modeling. If the strategy involves frequency improvements for more than one transit route, then the total person trips should reflect the sum of all the routes being improved.

- (J) – If the strategy involves frequency improvements for more than one transit route, then the trip length should reflect the average of all the routes being improved.
- Please refer to the GHG Calculation Variables table above for definitions of variables that have been previously defined.

Bus VMT Increase Formula

The absolute increase in bus VMT can be calculated using the formula below. As noted above, the formula for the percent GHG reduction (A) does not reflect any increase in bus VMT and bus emissions. Users that wish to capture these impacts should calculate absolute changes.

$$L = P \times (M_2 - M_1) \times N \times O \times K$$

Bus VMT Increase Calculation Variables

ID	Variable	Value	Unit	Source
Output				
L	Increase in annual bus miles in plan/community	[ ]	miles per year	calculated
User Inputs				
M_1	Bus frequency without measure	[ ]	transit vehicle roundtrips per hour	user input
M_2	Bus frequency with measure	[ ]	transit vehicle roundtrips per hour	user input
N	Bus hours of operation	0–24	hours per day	user input
O	Bus route one-way length	[ ]	miles per route	user input
Constants, Assumptions, and Available Defaults				
P	One-way trips in a roundtrip	2	one-way trips per roundtrip	conversion

Further explanation of key variables:

- (L) – If the strategy involves frequency improvements for more than one transit route, then the increase in bus miles should be calculated separately for each route.
- Please refer to the GHG Calculation Variables table above for definitions of variables that have been previously defined.

Energy and Fuel Savings

The decrease in passenger vehicle fuel consumption and increase in bus fuel consumption by the measure can be calculated as follows.

Passenger Vehicle Fuel Use Reduction Formula

Multiply the reduction in passenger vehicle miles (H) above by the fuel efficiency of the vehicle type (see Table T-30.2 in the Appendix) to output the change in fuel consumption.

Bus Fuel Use Increase Formula

The absolute increase in bus fuel consumption (Q) can be calculated using the formula below.

$$Q = L \times R$$

Bus Fuel Use Increase Calculation Variables

ID	Variable	Value	Unit	Source
Output				
Q	Increase in annual bus fuel consumption in plan/community	[ ]	gal per year	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
R	Fuel economy of a transit bus, by fuel type	Table T-26.1	gal or kilowatt hour per mile	U.S. EPA 2024

Further explanation of key variables:

- (R) – The average fuel economy for gasoline, diesel, electric and natural gas transit buses was calculated using MOVES5 (U.S. EPA 2024). The model was run for a 2025 statewide average of transit bus vehicles, disaggregated by fuel type. The user should reference Table T-26.1 for the fuel economy of the appropriate fuel type for their location's transit system. If the user can provide a project-specific value (i.e., for a future year and project location), the user should run MOVES to replace the default in the fuel use increase formula (see the Appendix).
- Please refer to the Bus VMT Increase Calculation Variables table above for definitions of variables that have been previously defined.

Sources

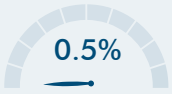
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T-27. Implement Transit-Supportive Roadway Treatments



GHG Mitigation Potential



Up to 0.5% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)



Climate Resilience

Implementing transit-supportive roadway treatments improves the reliability of the transportation network and allows redundancy to exist even if an extreme event disrupts part of the system. It could also incentivize more people to use transit, resulting in less traffic and better allowing emergency responders to access a hazard site during an extreme weather event. Furthermore, emergency responders can use queue jumps and dedicated bus lanes when needed.

Health and Equity Considerations

Transit facilities can have conflicts with cyclists. Consider appropriate treatments to minimize conflicts. Improved transit investments should be equitably distributed prioritizing areas with transit deficiencies in underserved communities.

Measure Description

This measure will implement transit-supportive treatments on the transit routes serving the plan/community. Transit-supportive treatments incorporate a mix of roadway infrastructure improvements and/or traffic signal modifications to improve transit travel times and reliability. This results in a mode shift from single occupancy vehicles to transit, which reduces VMT and the associated GHG emissions.

Subsector

Transit

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

Treatments can include transit signal priority, bus-only signal phases, queue jumps, curb extensions to speed passenger loading, and dedicated bus lanes.

Cost Considerations

Costs and savings of transit-supportive roadway treatments vary depending on the strategy pursued, ranging from low-cost route optimization changes to high-cost infrastructure projects (e.g., bus-only lanes). Reducing route cycle time without significantly increasing the number of transit vehicles can result in net cost savings for the transit system. Dedicated transit infrastructure will improve transit reliability and increase ridership. This supplements existing transit income streams for municipalities. Increased ridership similarly reduces vehicle use, which has cost benefits for both commuters and municipalities.

Expanded Mitigation Options

This measure could be paired with other Transit subsector strategies (Measures T-25, T-29, and T-46) for increased reductions.

GHG Reduction Formula

$$A = -1 \times \frac{B \times C \times D \times E \times G}{F}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–0.5	%	calculated
User Inputs				
B	Percentage of plan/community transit routes that receive treatments	0–100	%	user input
Constants, Assumptions, and Available Defaults				
C	Percent change in transit travel time due to treatments	-10	%	TRB 2007
D	Elasticity of transit ridership with respect to transit travel time	-0.4	unitless	TRB 2007
E	Transit mode share in plan/community	Table T-3.1	%	See Appendix
F	Vehicle mode share in plan/community	Table T-3.1	%	See Appendix
G	Statewide mode shift factor	Table T-25.1	%	See Appendix

Further explanation of key variables:

- (C) – A literature review of studies from the U.S. and United Kingdom indicates that the travel time savings associated with one type of transit-supportive roadway treatment—transit signal prioritization—typically ranged from 8 to 12 percent (TRB 2007). To account for the likelihood that a user would implement multiple transit-supportive treatments, the midpoint of this range is used for the measure formula. Use of the midpoint is still conservative given the additional travel time savings associated with other transit-supportive treatments. If the user can provide a project-specific value based on the suite of their treatments, then the user should replace this default in the GHG reduction formula.
- (E and F) – Ideally, the user will calculate transit and auto mode shares for a plan/community at the city scale (or larger). Potential data sources include state household travel surveys (preferred) or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the mode shares for transit and vehicles for one of the geographic areas in Arizona, Colorado, New Mexico, Oregon, and Washington, as presented in Table T-3.1 (see the Appendix). It is likely for areas outside of the area covered by the listed CBSAs to have vehicle mode shares higher and transit mode shares lower than the values provided in the table.

- (G) – The mode shift factors for Arizona, Colorado, New Mexico, Oregon, Washington, and Portland Metro MPO are provided in Table T-25.1 (see the Appendix). Mode shift factor is an adjustment to reflect the reduction in vehicle trips associated with a reduction in person trips as some vehicles carry more than one person. It is calculated as (1/average vehicle occupancy).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use default CBSA data from Table T-3.1 and (C_{max}), the maximum percent reduction in GHG emissions (A) is 0.5 percent. This maximum scenario is presented in the below example quantification.

(C_{max}) The percent reduction in transit travel time is capped at 20 percent, which is based on the values reported in a literature review of studies from the U.S. and United Kingdom (TRB 2007).

Subsector Maximum

($\sum A_{max_{T\text{-}25 \text{ through } T\text{-}29,\ T\text{-}46}} \leq 15\%$) This measure is in the Transit subsector. This subcategory includes Measures T-25 through T-29 and T-46. The VMT reduction from the combined implementation of all measures within this subsector is capped at 15 percent.

Mutually Exclusive Measures

If the user selects Measure T-28, *Provide Bus Rapid Transit*, and converts all transit routes in the plan/community to BRT, then the user cannot also take credit for this measure, Measure T-26, *Increase Transit Service Frequency*, or Measure T-46, *Provide Transit Shelters*. This is because Measure T-28 accounts for the VMT reduction associated with increased transit frequency and decreased transit travel time as well as the additional BRT-specific bonus. To combine the GHG reductions from Measure T-28 with Measure T-27, Measure T-26, and/or Measure T-46 would be considered double counting. However, where BRT is proposed on less than all of the existing bus routes in the plan/community area, this measure, Measure T-26, and/or Measure T-46 could be applied to the remaining bus routes, and the measure reductions could be combined with Measure T-28 to determine the emissions reduction at the larger plan/community scale.

Example GHG Reduction Quantification

The user reduces plan/community GHGs by implementing transit-supportive roadway treatments that decrease transit travel time, thereby encouraging a mode shift from vehicles to transit and reducing VMT. In this example, the project is in the Seattle-Tacoma-Bellevue CBSA where the transit and vehicle mode shares would be 8.44 percent and 88.74 percent, respectively (E and G). The mode shift factor for Washington State would be 61.7 percent. Assuming the maximum decrease in transit travel time of 20 percent (C_{max}) and

implementation for all transit routes (100 percent) in the plan/community (B), the user would reduce plan/community GHG emissions from VMT by 0.5 percent.

$$A = -1 \times \frac{100\% \times -20\% \times -0.4 \times 8.44\% \times 61.7\%}{88.74\%} = -0.5\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in passenger vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in passenger VMT would be the same as the percent reduction in GHG emissions (A).

Sources

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- Colorado Department of Transportation. 2025. *StateFocus Travel Demand Model*. Received from Colorado State in February 2025.
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T-28. Provide Bus Rapid Transit



GHG Mitigation Potential



Up to 10.7% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Providing BRT can incentivize more people to use transit, resulting in less traffic and better allowing emergency responders to access a hazard site during an extreme weather event. Furthermore, emergency responders can use queue jumps and dedicated BRT lanes when needed.

Health and Equity Considerations

Transit facilities can have conflicts with cyclists. Consider appropriate BRT components to minimize conflicts. Improved transit investments should be equitably distributed, prioritizing areas with transit deficiencies in underserved communities.

Measure Description

This measure will convert an existing bus route to a bus rapid transit (BRT) system. BRT includes the following additional components, compared to traditional bus service: exclusive right-of-way (e.g., busways, queue jumping lanes) at congested intersections, increased limited-stop service (e.g., express service), intelligent transportation technology (e.g., transit signal priority, automatic vehicle location systems), advanced technology vehicles (e.g., articulated buses, low-floor buses), enhanced station design, efficient fare-payment smart cards or smartphone apps, branding of the system, and use of vehicle guidance systems. BRT can increase the transit mode share in a community due to improved travel times, service frequencies, and the unique components of the BRT system. This mode shift reduces VMT and the associated GHG emissions.

Subsector

Transit

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

The measure quantification methodology accounts for the increase in ridership from (1) improved travel times from transit signal prioritization, (2) increased service frequency, and (3) the unique ridership increase associated with a full-featured BRT service operating on a fully segregated running way with specialized (or stylized) vehicles, attractive stations, and efficient fare collection practices. To take credit for the estimated emissions reduction, the user should implement, at minimum, these components.

Cost Considerations

Providing BRT will require capital investment to purchase specialized vehicles, develop passenger information systems, and construct stations and busways. Total costs vary depending on the suite of BRT components pursued. Grade-separated busways are more expensive than at-grade busways and mixed flow lanes. Dedicated transit infrastructure will improve transit reliability and increase ridership. This supplements existing transit income streams for municipalities. Increased ridership similarly reduces vehicle use, which has cost benefits for both commuters and municipalities.

Expanded Mitigation Options

This measure could be paired with Measure T-25, *Extend Transit Network Coverage or Hours,* and Measure T-29, *Reduce Transit Fares,* for increased reductions.

GHG Reduction Formula

$$A = -C \times \frac{D \times F \times ((B \times I) + (H \times J) + G)}{E}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–10.7	%	calculated
User Inputs				
B	Percent increase in transit frequency due to BRT	0–300	%	user input
C	Level of implementation	0–100	%	user input
Constants, Assumptions, and Available Defaults				
D	Transit mode share in plan/community	Table T-3.1	%	See Appendix
E	Vehicle mode share in plan/community	Table T-3.1	%	See Appendix
F	Statewide mode shift factor	Table T-25.1	%	See Appendix
G	Percent change in transit ridership due to BRT	25	%	TRB 2007
H	Percent change in transit travel time due to BRT	-10 to -20	%	TRB 2007
I	Elasticity of transit ridership with respect to frequency of service	0.5	unitless	Handy et al. 2013
J	Elasticity of transit ridership with respect to transit travel time	-0.4	unitless	TRB 2007

Further explanation of key variables:

- (A) – This formula does not reflect any increase in transit vehicle travel and emissions, which can at least partially offset the reduction in GHG emissions from passenger vehicle travel.[15] Inclusion of this component in the percent GHG reduction formula would require inputs that would not be available to most users. Users can calculate the absolute changes in passenger vehicle and bus VMT and emissions using the process described under *Co-Benefits*.
- (B) – Frequency is measured as the number of arrivals over a given time (e.g., buses per hour). Frequency is the inverse of transit headway, defined as the time between transit vehicle arrivals on a given route. This variable can be calculated as [transit frequency with measure minus existing transit frequency] divided by existing transit frequency.

[15] As discussed in Chapter 2, *Integrated and Resilient Planning*, the ICT regulation requires all public transit agencies to gradually transition to 100 percent zero-emission bus fleets by 2040. Accordingly, combustion emissions from transit operation will decline as vehicle fleets move to achieve the state's zero-emission bus goals.

- (C) – The level of implementation refers to the number of transit routes receiving the frequency improvement as a fraction of the total transit routes in the plan/community.
- (D and E) – Ideally, the user will calculate transit and auto mode shares for a plan/community at the city scale (or larger). Potential data sources include state household travel surveys (preferred) or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, the user has the option to input the mode shares for transit and vehicles for one of the geographic areas within Arizona, Colorado, New Mexico, Oregon, and Washington, as presented in Table T-3.1 (see the Appendix). It is likely for areas outside of the area covered by the listed CBSAs to have vehicle mode shares higher and transit mode shares lower than the values provided in the table.
- (F) – The mode shift factors for Arizona, Colorado, New Mexico, Oregon, Washington, and Portland Metro MPO are provided in Table T-25.1 (see the Appendix). Mode shift factor is an adjustment to reflect the reduction in vehicle trips associated with a reduction in person trips, since some vehicles carry more than one person. It is calculated as (1/average vehicle occupancy).
- (G) – A BRT practitioner's guide summarizing the results of numerous BRT case studies concluded that, on top of the ridership gains from improved travel times and increased service frequency, an additional 25 percent increase in ridership would occur from a full-featured BRT service operating on a fully segregated running way with specialized (or stylized) vehicles, attractive stations, and efficient fare collection practices.
- (H) – A literature review of studies from the United States and United Kingdom indicates that the travel time savings associated with one type of BRT component—transit signal prioritization—typically average 10 percent (TRB 2007). If the user can provide a project-specific value based on the suite of BRT components, then the user should replace this default in the GHG reduction formula. Note that, as described below, (H) should not exceed 20 percent.
- (I) – A policy brief summarizing the results of transit service strategies concluded that a 0.5 percent increase in transit ridership occurs for every 1 percent increase in frequency (Handy et al. 2013).
- (J) – A BRT practitioner's guide summarizing the results of numerous BRT case studies concluded that a -0.4 percent decrease in transit ridership occurs for every 1 percent increase in transit travel time (TRB 2007).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use default CBSA data from Table T-3.1 and (B_{max}), the maximum percent reduction in GHG emissions (A) is 10.7 percent. This maximum scenario is presented in the below example quantification.

(B_{max}) The percent change in transit frequency is capped at 300 percent (SANDAG 2019).

(H_{max}) The percent reduction in transit travel time is capped at 20 percent, which is based on the values reported in a literature review of studies from the United States and United Kingdom (TRB 2007).

Subsector Maximum

($\sum A_{max_{T\text{-}25 \text{ through } T\text{-}29,\ T\text{-}46}} \leq 15\%$) This measure is in the Transit subsector. This subcategory includes Measures T-25 through T-29 and T-46. The VMT reduction from the combined implementation of all the non–mutually-exclusive measures within this subsector is capped at 15 percent.

Mutually Exclusive Measures

If the user selects this measure and converts all transit routes in the plan/community to BRT (B), then the user cannot also take credit for Measure T-26, *Increase Transit Service Frequency*, Measure T-27, *Implement Transit-Supportive Roadway Treatments,* or Measure T-46, *Provide Transit Shelters*. This is because Measure T-28 accounts for the VMT reduction associated with increased transit frequency and decreased transit travel time as well as the additional BRT-specific bonus. To combine the GHG reductions from Measure T-28 with Measure T-27, Measure T-26, and/or Measure T-46 would be considered double counting. However, where BRT is proposed on less than all of the existing bus routes in the plan/community area, Measure T-26, Measure T-27, and/or Measure T-46 could be applied to the remaining bus routes, and the measure reductions could be combined to determine the emissions reduction at the larger plan/community scale.

Example GHG Reduction Quantification

The user reduces plan/community GHGs by implementing a full-featured BRT system, thereby encouraging a mode shift from vehicles to transit and reducing VMT. In this example, the project is in the Seattle-Tacoma-Bellevue CBSA where transit and vehicle mode shares would be 8.44 percent and 88.74 percent, respectively (D and E), and the mode shift factor for Washington State would be 61.7 (F). Assuming the maximum increase in transit frequency of 300 percent (B_{max}), the maximum decrease in transit travel time of 20 percent (H_{max}), and implementation for all transit routes (100 percent) in the plan/community (B), the user would reduce plan/community GHG emissions from VMT by 10.7 percent.

$$A = \text{-}100\% \times \frac{8.44\% \times 61.7\% \times ((300\% \times 0.5) + (\text{-}20\% \times \text{-}0.4) + 25\%)}{88.74\%} = \text{-}10.7\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

VMT Reductions

The decrease in passenger vehicle miles (K) and increase in BRT miles (O) by the measure can be calculated as follows.

Passenger Vehicle VMT Reduction Formula

The percent reduction in passenger VMT would be the same as the percent reduction in GHG emissions (A). The absolute reduction in passenger VMT can be calculated using the following formula.

$$K = -\left(D \times \mathbf{L} \times \mathbf{M} \times N \times \left((\mathbf{B} \times I) + (H \times J) + G\right)\right)$$

Passenger Vehicle VMT Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
K	Reduction in passenger vehicle miles in plan/community	[ ]	miles per year	calculated
User Inputs				
L	Total daily person trips in corridor(s)	[ ]	trips per day	user input
M	Vehicle trip length	[ ]	miles per trip	user input
Constants, Assumptions, and Available Defaults				
N	Days per year BRT available	365	days per year	assumed

Further explanation of key variables:

- (L) – The total daily person trips in the corridor(s) represents the total daily trips by all modes between the BRT origin area and the BRT destination area. This may be obtained through travel demand modeling. If the strategy involves BRT for more than one route, then the total person trips should reflect the sum of all the routes being improved.
- (M) – If the strategy involves BRT for more than one transit route, then the trip length should reflect the average of all the routes being converted.
- Please refer to the GHG Calculation Variables table above for definitions of variables that have been previously defined.

BRT VMT Increase Formula

The absolute increase in BRT VMT can be calculated using the formula below. As noted above, the formula for the percent GHG reduction (A) does not reflect any increase in BRT VMT or BRT emissions. Users that wish to capture these impacts should calculate absolute changes.

$$O = S \times (\mathbf{P_2} - \mathbf{P_1}) \times \mathbf{Q} \times \mathbf{R} \times N$$

BRT VMT Increase Calculation Variables

ID	Variable	Value	Unit	Source
Output				
O	Increase in annual BRT miles in plan/community	[ ]	miles per year	calculated
User Inputs				
P_1	Bus frequency without measure	[ ]	transit vehicle roundtrips per hour	user input
P_2	BRT frequency with measure	[ ]	transit vehicle roundtrips per hour	user input
Q	BRT hours of operation	0–24	hours per day	user input
R	BRT route one-way length	[ ]	miles per route	user input
Constants, Assumptions, and Available Defaults				
S	One-way trips in a roundtrip	2	One-way trips per roundtrip	conversion

Further explanation of key variables:

- (O) – If the strategy involves frequency improvements for more than one transit route, then the increase in BRT miles should be calculated separately for each route.
- Please refer to the Passenger Vehicle VMT Reduction Calculation Variables table above for definitions of variables that have been previously defined.

Energy and Fuel Savings

The decrease in passenger vehicle fuel consumption and increase in BRT fuel consumption by the measure can be calculated as follows.

Passenger Vehicle Fuel Use Reduction Formula

Multiply the reduction in passenger vehicle miles (K) above by the fuel efficiency of the vehicle type (see Table T-30.2 in the Appendix) to output the change in fuel consumption.

BRT Fuel Use Increase Formula

The absolute increase in BRT fuel consumption (T) can be calculated using the formula below.

$$T = O \times U$$

BRT Fuel Use Increase Calculation Variables

ID	Variable	Value	Unit	Source
Output				
T	Increase in annual BRT fuel consumption in plan/community	[ ]	gal per year	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
U	Fuel economy of BRT, by fuel type	Table T-26.1	gal or kilowatt hour per mile	U.S. EPA 2024

Further explanation of key variables:

- (U) – The average fuel economy for gasoline, diesel, electric and natural gas transit buses was calculated using MOVES5 (U.S. EPA 2024). The model was run for a 2025 statewide average of transit bus vehicles, disaggregated by fuel type. The user should reference Table T-26.1 for the fuel economy of the appropriate fuel type for their location's transit system. If the user can provide a project-specific value (i.e., for a future year and project location), the user should run MOVES to replace the default in the fuel use increase formula. Also, if the BRT vehicles are fueled by hydrogen, the user will need to calculate the increase in hydrogen fuel consumption using project-specific values, as hydrogen is currently not included as a fuel type in MOVES.
- Please refer to the BRT VMT Increase Calculation Variables table above for definitions of variables that have been previously defined.

Sources

- Colorado Department of Transportation. 2025a. *Correspondence*. Received from Colorado State in February 2025.
- Colorado Department of Transportation. 2025b. *StateFocus Travel Demand Model*. Received from Colorado State in February 2025.
- Federal Highway Administration (FHWA). 2017a. *National Household Travel Survey–2017 Table Designer*. Annual PMT by TRPTRANS by HH_CBSA. Accessed January 2025. https://nhts.ornl.gov/.
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- U.S. EPA (U.S. Environmental Protection Agency). 2024. *Motor Vehicle Emission Simulator: MOVES5*. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024.

T-29. Reduce Transit Fares



GHG Mitigation Potential



Up to 0.9% of GHG emissions from vehicle travel in the plan/community

Co-Benefits (icon key on pg. 31)

Climate Resilience

Reducing transit fares increases the capacity of low-income populations to use transit to evacuate or access resources during extreme weather events. Reduced fares could also incentivize more people to use transit, resulting in less traffic and better allowing emergency responders to access sites. This also reduces transit system disruptions due to extreme weather events. Lower transportation costs would also increase community resilience by freeing up resources needed for other costly adaptations that benefit families, such as increased cooling costs.

Health and Equity Considerations

Transit fare reduction programs should first prioritize routes with higher-volume potential in underserved communities and those most reliant on transit for travel (e.g., students, persons with disabilities, seniors).

Measure Description

This measure will reduce transit fares on the transit lines serving the plan/community. A reduction in transit fares creates incentives to shift travel to transit from single-occupancy vehicles and other traveling modes, which reduces VMT and associated GHG emissions.

This measure differs from Measure T-8, *Implement Subsidized or Discounted Transit Program*, which can be offered through employer-based benefits programs in which the employer fully or partially pays the employee's cost of transit.

Subsector

Transit

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

Transit fare reductions can be implemented systemwide or in specific fare-free or reduced-fare zones.

Cost Considerations

Reducing transit fares will lower the per capita income of the transit service. This may be outweighed by increased ridership, and savings on infrastructure costs due to reduced car usage. Reduced fares can be targeted to specific populations or groups, depending on need. Individuals receiving the reduced fare will obtain a cost savings.

Expanded Mitigation Options

This measure could be paired with other Transit subsector strategies (Measure T-25, *Extend Transit Network Coverage or Hours,* and Measure T-26, *Increase Transit Service Frequency*) for increased reductions.

GHG Reduction Formula

$$A = \frac{B \times C \times D \times E \times G}{F}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel in plan/community	0–0.9	%	calculated
User Inputs				
B	Percent reduction in transit fare with measure	0–50	%	user input
C	Percentage of plan/community transit routes that receive reduced fares	0–100	%	user input
Constants, Assumptions, and Available Defaults				
D	Elasticity of transit ridership with respect to transit fare	-0.3	unitless	Handy et al. 2013
E	Transit mode share in plan/community	Table T-3.1	%	See Appendix
F	Vehicle mode share in plan/community	Table T-3.1	%	See Appendix
G	Statewide mode shift factor	Table T-25.1	%	See Appendix

Further explanation of key variables:

- (B) – The user can calculate the percent reduction in transit fare based on the percent difference between the existing fare price and the proposed fare price.
- (C) – The level of implementation refers to the fraction of transit routes that on which fare reductions are implemented. Typically, fare reductions are made system-wide, so this variable would be 100.
- (D) – A policy brief summarizing the results of transit service studies reported that a 0.3 to 1.0 percent increase in transit ridership occurs for every 1.0 percent decrease in transit fares (Handy et al. 2013). To be conservative, the low end of this range is cited.
- (E and F) – Ideally, the user will calculate transit and auto mode shares for a plan/community at the city scale (or larger). Potential data sources include state household travel surveys (preferred) or local survey efforts. If the user is not able to provide a project-specific value using one of these data sources, they have the option to input the mode shares for transit and vehicles for one of the geographic areas in Arizona, Colorado, New Mexico, Oregon, and Washington, as presented in Table T-3.1 (see the Appendix). It is likely for areas outside of the area covered by the listed CBSAs to have vehicle mode shares higher and transit mode shares lower than the values provided in the table.
- (G) – The mode shift factors for Arizona, Colorado, New Mexico, Oregon, Washington, and Portland Metro are provided in Table T-25.1 (see the Appendix). Mode shift factor is an adjustment to reflect the reduction in vehicle trips associated with a reduction in

person trips as some vehicles carry more than one person. It is calculated as (1/average vehicle occupancy).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) For projects that use default CBSA data from Table T-3.1 and (B_{max}), the maximum percent reduction in GHG emissions (A) is 0.9 percent.

(B_{max}) The percent reduction in transit fare is capped at 50 percent (SANDAG 2019).

Subsector Maximum

($\sum A_{max_{T\text{-}25 \text{ through } T\text{-}29,\ T\text{-}46}} \leq 15\%$) This measure is in the Transit subsector. This subcategory includes Measures T-25 through T-29 and T-46. The VMT reduction from the combined implementation of all measures within this subsector is capped at 15 percent.

Example GHG Reduction Quantification

The user reduces plan/community GHGs by reducing the costs associated with using transit, thereby encouraging a mode shift from single occupancy vehicles to transit and reducing VMT. In this example, the project is in the Seattle-Tacoma-Bellevue CBSA, where the transit and vehicle mode shares would be 8.44 percent and 88.74 percent, respectively (E and F), and the mode shift factor for Washington State would be 61.7 percent. Assuming the maximum decrease in transit fares of 50 percent (B) and implementation for all transit routes (100 percent) in the plan/community (C), the user would reduce plan/community GHG emissions from VMT by 0.9 percent.

$$A = \frac{50\% \times 100\% \times -0.3 \times 8.44\% \times 61.7\%}{88.74\%} = -0.9\%$$

Quantified Co-Benefits

Improved Local Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* above for further discussion.

Energy and Fuel Savings

The percent reduction in passenger VMT would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in passenger vehicle fuel consumption would be the same as the percent reduction in GHG emissions (A).

Sources

- Colorado Department of Transportation. 2025a. *Correspondence*. Received from Colorado State in February 2025.
- Colorado Department of Transportation. 2025b. *StateFocus Travel Demand Model*. Received from Colorado State in February 2025.
- Federal Highway Administration (FHWA). 2017a. *National Household Travel Survey–2017 Table Designer*. Annual PMT by TRPTRANS by HH_CBSA. Accessed January 2025. https://nhts.ornl.gov/.
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T-30. Use Cleaner-Fuel Vehicles



GHG Mitigation Potential



Up to 100% of on-road GHG emissions from vehicles

Co-Benefits (icon key on pg. 31)

Climate Resilience

Using cleaner-fuel vehicles increases transportation resilience by providing a wider range of vehicles if other fuels (like gasoline) become unavailable. In the rural and coastal context, cleaner-fuel vehicles are generally more acceptable on weight-limited routes, better supporting local businesses and basic life movements.

Health and Equity Considerations

While most cleaner fuels reduce both GHG and criteria air pollutants, a few may increase criteria pollutant emissions. The most prominent example of this is biodiesel, which generally results in higher NO_x emissions, but lower PM emissions compared to diesel.

Measure Description

This measure requires the use of cleaner-fuel vehicles in lieu of similar vehicles powered by gasoline or diesel fuel. Cleaner-fuel vehicles addressed in this measure include electric vehicles, natural gas and propane vehicles, and vehicles powered by biofuels such as composite diesel (blend of renewable diesel, biodiesel, and conventional fossil diesel), ethanol, and renewable natural gas.

The full GHG emissions impact of cleaner fuels depends on the emissions from the vehicle's tailpipe as well as the emissions associated with production of the fuel (sometimes termed "upstream" emissions). For example, tailpipe GHG emissions from renewable natural gas are identical to tailpipe GHG emissions from conventional natural gas; the GHG benefits of renewable natural gas come from the fact that it is produced from biomass, which absorbs carbon from the air during growth, and thus has no net increase in carbon emitted to the atmosphere. Similarly, BEVs have zero tailpipe emissions, but properly accounting for their GHG impacts requires quantifying the emissions associated with the electricity generation needed to charge the vehicle's batteries and comparing that to the full lifecycle (fuel and feedstock) of emissions for a conventional fuel like diesel. This measure differs from the CAPCOA handbook in that it properly differentiates calculations based on tank-to-wheels emissions from those using well-to-wheel emissions.

Subsector

Clean Vehicles and Fuels

Locational Context

Not applicable

Scale of Application

Project/Site or Plan/Community

Implementation Requirements

See measure description.

Cost Considerations

Capital costs to purchase cleaner fuel vehicles are high. Fueling infrastructure may be required, which will add to the upfront cost of transitioning to cleaner fuel vehicles. Fuel costs and savings compared to gasoline and diesel will vary depending on the type of fuel and market conditions. It is feasible to expect reduced fuel costs from cleaner fuels with an increased market and overall fuel cost savings over the life of the vehicle fleet.

Expanded Mitigation Options

If using electric vehicles, pair with Measure T-14 to ensure electric vehicles have sufficient access to charging infrastructure.

GHG Reduction Formula

Here two types of GHG emission analysis are offered. One is an emissions calculation that considers both vehicle tailpipe and upstream fuel production emissions is sometimes referred to as a "well-to-wheels" analysis (A3 below). Alternatively, an emissions calculation that considers only vehicle tailpipe emissions is referred to as a "tank-to-wheels" analysis (A1 and A2 below). These equations differ from those used in the CAPCOA Handbook by adhering strictly to the definitions of tank-to-wheel and lifecycle emissions.

$A1 = -B$ (tank-to-wheels for ZEVs)

$A2 = B \times (\frac{1-D}{E} - 1)$ (tank-to-wheels for PHEVs)

$A3 = B \times \frac{F-G}{G}$ (well-to-wheels for any clean-fuel vehicle)

$A4 = B \times \frac{H-C}{C}$ (tank-to-wheels for any clean-fuel vehicle)

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Percent reduction in tank-to-wheels GHG emissions from on-road vehicle emissions for BEVs	0–100	%	calculated
A2	Percent reduction in tank-to-wheels GHG emissions from on-road vehicle emissions for PHEVs	0–64	%	calculated
A3	Percent reduction in well-to-wheels GHG emissions from cleaner fuels or vehicle technologies	0–100	%	calculated
A4	Percent reduction in tank-to-wheels GHG emissions from cleaner fuels or vehicle technologies	0–100	%	calculated
User Inputs				
B	Percentage of vehicle fleet being converted to cleaner fuels	1–100	%	user input
C	Emission factor for existing (conventional fuel) vehicle	Table T-30.2	g CO_2e per mile	U.S. EPA 2025
Constants, Assumptions, and Available Defaults				
D	Percentage of PHEV miles in electric mode	46	%	CARB 2020a
E	Ratio of average hybrid vehicle mpg to comparable gasoline vehicle mpg	1.5	unitless	U.S. DOE 2021
F	Well-to-wheels emission factor for cleaner vehicle/fuel	Table T-30.2	g CO_2e per mile	U.S. EPA 2025, GREET

ID	Variable	Value	Unit	Source
G	Well-to-wheels emission factor for existing (conventional fuel) vehicle	Table T-30.2	g CO_2e per mile	U.S. EPA 2025, GREET
H	Emission factor for new (clean fuel) vehicle	Table T-30.2	g CO_2e per mile	U.S. EPA 2025

Further explanation of key variables:

- (A1 or A2) – Use of these equations is appropriate for a typical analysis which considers tailpipe GHG emissions.
- (A3) – Use of this equation is appropriate for a user interested in a well-to-wheels analysis for all fuel types. The user should determine the appropriate emission factors for the conventional fuel and cleaner fuel.
- (C) – Users have the option to input the default values of emission factors as presented in the Appendix Table T-30.2. The default values are based on MOVES run for 2025 and for each vehicle type and fuel type in Washington, Oregon, New Mexico, Colorado, and Arizona. Emission factors include GHG emission factors (CO_2, CH_4, and N_2O) for the existing (conventional fuel) vehicles. Users can also perform their own MOVES run to get a more project-specific result.
- (D) – Based on the MOVES model, 46 percent of miles traveled by PHEVs in California are in electric mode (eVMT), with 54 percent in gasoline mode. If users can provide a project-specific value, users should replace the value in the formular with the project-specific value.
- (E) – Assumes that a PHEV operating in gasoline mode is similar to a gasoline hybrid (non-plug-in) vehicle. A typical gasoline hybrid vehicle has 50 percent higher fuel economy (mpg) than a comparable gasoline vehicle, based on a comparison of the gasoline and hybrid Toyota Camry and Corolla models (U.S. DOE 2021).
- (F and G) – The average default values for fuel efficiency, energy density, well-to-wheels carbon intensity, and emission factor by vehicle types and fuel types are presented in Table T-30.2 (U.S. EPA 2025, Argonne 2025). If the user can provide a project-specific value, then the user should replace it with the GHG calculation formula. When quantifying lifecycle emission for electric vehicles, the user will need to the equivalent vehicle emission factor from the carbon intensity of power generation (measured at the plug), using the following formula:

$$\text{Emission Factor (g/mi)} = \text{C.I. (lb/MWh)} \times 453.6 \text{ g/lb} \times (1\text{MWh}/1000 \text{ kWh}) \times \text{Fuel Efficiency (kWh/mi)}$$

GHG Calculation Caps or Maximums

Measure Maximum

($A1_{max}$) The GHG reduction from the use of BEVs is capped at 100 percent, which assumes that 100 percent of the fleet would be converted (B) and that the local electricity provider is powered 100 percent by renewables and thus has a carbon intensity of zero (E).

($A2_{max}$) The GHG reduction from the use of PHEVs is capped at 64 percent, which assumes that 100 percent of the fleet would be converted (B) and that the local electricity provider is powered 100 percent by renewables and thus has a carbon intensity of zero (E).

($A3_{max}$) For a well-to-wheels analysis, the GHG reduction from the use of electric vehicles is capped at 100 percent, which assumes that the local electricity provider is powered 100 percent by renewables and thus has a carbon intensity of zero (L). Note that the maximum percent reduction for all other cleaner vehicles and fuels presented in Table T-30.2 will not reach this maximum.

Subsector Maximum

Same as (A_{max}). Measure T-30 is the only measure at the Plan/Community scale within the Clean Vehicles and Fuels subsector.

Example GHG Reduction Quantification

The user reduces vehicle emissions by avoiding the use of conventional fuels in place of cleaner fuels or vehicle technologies. In this example, the project is assumed to take place in Oregon and the local utility provider is Eugene Water and Electric Board (EWEB). In this project, the local municipality sources their electricity from an electricity provider powered 100 percent by renewables (E) is converting half of their fleet of gasoline passenger cars to BEVs (B). The user has run MOVES for their county, vehicle category, and project year, and determined the fleet emission factor to be 320.4 g CO_2e (C). The user would reduce GHG emissions from the existing fleet by 50 percent.

$$A1 = 50\% \times \frac{(0.3\frac{kWh}{mi} \times 0\ \frac{lb\ CO_2e}{MWh} \times 454\ \frac{g}{lb} \times 0.001\frac{MWh}{kWh}) - 320.4\frac{g\ CO_2e}{mi}}{320.4\frac{g\ CO_2e}{mi}} = -50\%$$

Quantified Co-Benefits

Improved Local Air Quality

(O1) – The use of BEVS in lieu of conventional vehicles would decrease local criteria pollutants. The percent reduction is equal to (B). Electricity supplied by statewide fossil-fueled or bioenergy power plants will generate criteria pollutants. However, because these power plants are located throughout the state or outside the state, electricity consumption from vehicles charging typically will not generate localized criteria pollutant emissions on the project site or roadways traveled by the electric vehicles.

(O2) – The percent reduction in local criteria pollutants from use of PHEVs in lieu of conventional vehicles (A2) is equal to ($B \times A2_{max}$). See ($A2_{max}$) above, which assumes (E) is set to zero to nullify eVMT activity and vehicle fleet conversion (B_{max}) is set to 100 percent. ($A2_{max}$) is multiplied by the actual conversion of the vehicle fleet (B) to adjust the percent reduction calculated from ($A2_{max}$). Electricity supplied by statewide fossil-fueled or bioenergy power plants will generate criteria pollutants. However, because these power plants are located throughout the state or outside the state,

electricity consumption from vehicles charging typically will not generate localized criteria pollutant emissions.

(O3) – For a well-to-wheels analysis, the fuels produced by facilities within and outside of state will generate criteria pollutants. Because these facilities are dispersed, offsite of the project/site or plan/community, fuel production typically will not generate localized criteria pollutant emissions. Therefore, only the tank-to-wheels (i.e., tailpipe) portion of the vehicle criteria pollutant emissions should be quantified. For BEVs and PHEVs, this can be done using the methodologies described above (O1 and O2, respectively). For vehicles fueled by diesel, biodiesel, renewable diesel, and natural gas, the criteria pollutant emission factor can be outputted by MOVES (see C). The criteria pollutant reductions from use of gasoline hybrid or flex fuel vehicles cannot be readily quantified within MOVES as these fuel types are not inputs the user can specify.



Fuel Savings (Increased Electricity)

(P1 and Q1) – The use of BEVs in lieu of conventional vehicles would decrease vehicle fuel consumption and increase electricity use. The percent reduction in fuel use (P1) is equal to (B). The absolute increase in electricity use can be calculated using the below formula (Q1).

(P2 and Q2) – The use of PHEVs in lieu of conventional vehicles would decrease vehicle fuel consumption and increase electricity use. The percent reduction in fuel use (P2) is equal to $(B \times A2_{max})$. The absolute increase in electricity use (Q2) is equal to $(H \times Q1)$.

(P3 and Q3) – For gasoline, gasoline hybrid, flex fuel, diesel, biodiesel, renewable diesel, and natural gas, the percent reduction in fuel use of the existing (conventional fuel) vehicle is equal to (B). The absolute increase in the cleaner fuel/vehicle energy can be calculated using the below formula (P3).

BEV Electricity Use Increase Formula

$$Q1 = B \times H \times I$$

Electricity Use Increase Calculation Variables

ID	Variable	Value	Unit	Source
Output				
Q1	Increase in electricity from electric vehicles	[ ]	kWh per year	calculated
User Inputs				
H	BEV efficiency	Table T-30.1	kWh per mile	U.S. EPA 2025
I	Average annual VMT of all vehicles in fleet	[ ]	miles per year	user input

ID	Variable	Value	Unit	Source
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (H) – BEV energy efficiency varies by vehicle type. The average values are provided in Table T-30.1 in the Appendix. If the user can provide a project-specific value, they should replace the default in the GHG reduction formula.

Cleaner Vehicle Energy Use Increase Formula

$$P3 = B \times R \times \frac{S}{T}$$

Cleaner Vehicle Energy Use Increase Variables

ID	Variable	Value	Unit	Source
Output				
P3	Increase in vehicle fuel use in fleet	[ ]	megajoules (MJ)	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
S	Energy density for cleaner fuel/vehicle	Table T-30.2	MJ per gal	U.S. EPA 2025
T	Fuel efficiency for cleaner fuel/vehicle	Table T-30.2	mpg	

Further explanation of key variables:

- (S and T) – The statewide average values for fuel efficiency and energy density of typical vehicle and fuel types are provided in Table T-30.2 (U.S. EPA 2025) for the following states: Arizona, Colorado, New Mexico, Oregon, and Washington. If the user can provide a project-specific value, then the user should replace in the fuel use reduction formula one or more of these values that produces the energy consumption value (MJ).
- Please refer to the GHG Calculation Variables table above for definitions of variables that have been previously defined.

Sources

- Argonne National Laboratory. 2025. *Research and Development (R&D) GREET Life Cycle Assessment Model.* Accessed March 2025. https://www.energy.gov/eere/rd-greet-life-cycle-assessment-model.
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T-40. Establish a School Bus Program



GHG Mitigation Potential



Up to 79% of GHG emissions from school commute vehicle travel

Co-Benefits (icon key on pg. 31)

Climate Resilience

Establishing a school bus program can take more cars off the road, resulting in less traffic and better allowing emergency responders to access a hazard site during an extreme weather event.

Health and Equity Considerations

Shifting children's trips to school from private car trips to bus, bicycling or walking trips promotes consistent physical activity. Prioritize service for students who live further away from schools with limited access to sustainable modes of transportation.

Measure Description

This measure requires establishing or expanding a school bus program. Busing provides a practical way to transport students to school while also offering reductions in GHG emissions when there is high enough ridership. When districts establish busing programs, they directly replace automobile trips to take students to and from school.

Subsector

School Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Establishing or expanding a school bus program requires capital investment to purchase school buses or operating expenses associated with using contracted transportation service, along with increased staffing to direct the program. Total costs vary depending on the type and capacity of buses, as well as on the routes and frequency of service. Electric school buses can cost more initially but offer long-term cost benefits through lower maintenance costs and fuel efficiency. Familes of students who may more easily be able to travel without a car may also observe cost savings from reduced vehicle usage or ownership.

Expanded Mitigation Options

Use electric buses to achieve greater emissions reductions compared to conventional diesel buses with the same number of passengers. Because diesel school buses have much higher emissions per mile than a typical light-duty vehicle and take a much longer route than a direct drive to school, they need to transport a high number of students to make up for the bus emissions. The circumstances change, however, with the introduction of electric buses; even a small capacity electric bus of five students leads to emission reductions relative to the average passenger vehicle.

GHG Reduction Formula

$$A = -\frac{B \times C \times D \times \left(\frac{H}{E} - \frac{G \times I}{F}\right)}{\frac{H}{E}}$$

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel among students	0–79	%	calculated
User Inputs				
B	Percentage of students across the school who begin riding the bus as a result of the program	0–100	%	user input
C	Percentage of students served by bus system (regardless of whether they ride)	0–100	%	user input
Constants, Assumptions, and Available Defaults				
D	Percentage of new bus riders who drove or were driven beforehand	79	%	FHWA 2023
E	Average student occupancy of cars driving to school	1.58	students/car	FHWA 2023
F	Average student occupancy of school buses	Table T-40.1	students/bus	Wang 2019
G	Adjustment for ratio of bus touring distance to driving distance	3.42	unitless	FHWA 2023; Duran 2013
H	Light-duty emission factor	Table T-30.2	grams CO_2e/mile	U.S. EPA 2024
I	School bus emission factor	Table T-30.2	grams CO_2e/mile	U.S. EPA 2024

Further explanation of key variables:

- (B) – This is the percentage of students at the school who can ride the bus and who begin riding the bus after the implementation of the program. For a new program, this is equal to the percentage of all students who ride. For a program change, this is equal to the difference in percentage of students who ride before and after program implementation.
- (C) – This is the percentage of students for whom the bus program provides service. If one neighborhood is served, then this is the percentage of students at the school who live in that neighborhood.

- (D) – If a district is conducting surveys as part of their Safe Routes to Schools (SR2S) or bus program expansion, it is recommended to include a question that assesses what fraction of new riders were driving before bus service was introduced. This eliminates any over counting from riders who biked, walked or took some other form of transit prior to the service's introduction.
- (E) – This constant is from NHTS and represents the average occupancy of school trips taken by car in the Pacific division. NHTS does not consider the driver an occupant if they are dropping someone off; however, students driving themselves to school are included in this occupancy value.
- (F) – This constant represents an estimate of the average occupancy of school buses based on research from Wang 2019 combined with 2024 data from the *School Bus Fleet* magazine. Local values should be used if they are available, especially because low occupancy bus programs may have higher post-project emissions than students being driven.
- (G) – This constant was derived from NHTS data and school bus drive cycle data from Duran 2013. The average school trip taken in a private vehicle is 9.3 miles long in the Pacific Census division, while the average school bus tour is 31.7 miles. Thus, the ratio of bus touring distance to driving distance is 3.42. If the average bus tour for the school district is shorter, than this ration may be smaller or larger than 3.42.
- (H) – These light duty emissions factors are used throughout the Handbook and represent the emissions of cars taking students to school. The emission factors for light-duty autos or light-duty trucks is most appropriate.
- (I) – The school bus emission factor is taken from the most recent version of MOVES and is used to determine the new emissions from the school buses added in this program. If a different type of vehicle is used for the program (such as a van or other light-duty vehicle), users should select the appropriate emission factor for that vehicle type as found in Table T-30.2 in the Appendix.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions (A) is capped at 79 percent. The benefits are unlikely to be this high; this level assumes that buses have an occupancy of 19.9 students, all buses are electric, and all students ride the bus.

Subsector Maximum

($\sum A_{max_{T\text{-}40\ \&\ T\text{-}56}} \leq 79\%$) This measure is in the School Programs subsector. This subcategory includes Measures T-40 and T-56 at the Project/Site scale of application. The school trip VMT reduction from the combined implementation of all measures within this subsector is capped at 79 percent. The reduction percentage for this measure is applicable to the School Programs subsector, which includes school commute trips. If users would like to apply the reduction percentage to community-wide emissions, the reductions can be converted to community-scale reductions by multiplying the reduction percentage by 1.64 percent (FHWA 2023).

Example GHG Reduction Quantification

A school district in the Denver area starts a new busing program that serves all students but only 50 percent (B) of eligible students ride. The buses run on diesel, and the average parent drives their child to school in an SUV. This would lead to an decrease in GHG emissions from school-based trips of 13.4 percent.

$$A = -\frac{50\% \times 100\% \times 79\% \times \left(\frac{409.4 \frac{g}{mi}}{1.58 \frac{riders}{veh}} - \frac{3.42 \times 1255 \frac{g}{mi}}{19.9 \frac{riders}{veh}} \right)}{\frac{409.4 \text{ g/mi}}{1.58 \frac{riders}{veh}}} = 13.4\%$$

Quantified Co-Benefits

Improved Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NOx, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption achieved by the measure would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT achieved by the measure would be the same as the percent reduction in GHG emissions (A).

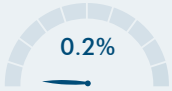
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T-46. Provide Transit Shelters



GHG Mitigation Potential



Up to 0.24% of GHG emissions associated with plan/community VMT

Co-Benefits (icon key on pg. 31)

Climate Resilience

Transit shelters protect passengers from extreme weather, such as high temperatures and heavy precipitation. Providing transit shelters can also incentivize more people to use transit, resulting in less traffic and better allowing emergency responders to access a hazard site during an extreme weather event.

Health and Equity Considerations

Transit shelters can increase shade and provide heat mitigation for waiting passengers. Transit shelters also provide rest areas for people with disabilities and pregnant passengers. Increased access to safe, efficient, comfortable, and well-maintained public transit promotes physical activity and results in reduced health risk.

Measure Description

For this measure, a local government or transit agency provides amenities that make it safer and more comfortable to wait for the bus. The two interventions that have proven to lead to changes in rider perceptions are adding bus shelters and adding real-time arrival information. Research into transit ridership shows that adding these amenities decreases both the real and the perceived wait time for riders, which impacts riders' willingness to ride.

Subsector

Transit

Locational Context

Urban, suburban

Scale of Application

Plan/Community

Implementation Requirements

This measure requires that bus shelters also have benches because the combined effect of shelters and benches was measured in the studies cited.

Cost Considerations

Providing amenities requires capital investment to construct bus shelters and improve passenger communication systems to relay arrival information. Staff and maintenance costs may also increase. A portion of these costs may be offset by increased transit ridership and associated income. Increased ridership also reduces vehicle use, which has cost benefits for both commuters and municipalities.

Expanded Mitigation Options

When adding bus shelters, providing lighting is recommended as it increases rider perceptions of safety at night.

GHG Reduction Formula

$$A1 = B \times \frac{C}{D} \times E \times \frac{F}{G} \times (H - I1) \times J$$ **(for bus shelters only)**

$$A2 = B \times \frac{C}{D} \times E \times \frac{F}{G} \times (H - I2) \times J$$ **(for bus shelters and real-time arrival information)**

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A1, A2	Percent reduction in GHG emissions from vehicle travel in plan/community	0–0.24	%	calculated
User Inputs				
B	Number of transit stops with new bus shelters and benches	[ ]	unitless	user input
C	Average number of boardings per day at each transit station with added amenities	[ ]	boardings/day	user input
D	Average number of boardings per day across the transit agency	[ ]	boardings/day	user input
E	Transit mode share in the core-based statistical area	Table T-3.1	%	FHWA 2017
Constants, Assumptions, and Available Defaults				
F	Percentage of transit users who would otherwise drive	83.3	%	FHWA 2017
G	Average auto occupancy	1.45	riders/vehicle	FHWA 2023
H	Percentage of total travel time spent waiting (transit trips)	24.9	%	FHWA 2023
I1	Percentage of perceived total travel time spent waiting (transit trips with shelters)	20.3	%	Fan 2016
I2	Percentage of total travel time spent waiting (transit trips with shelters and real-time arrival information [RTI])	15.8	%	Watkins 2011
J	Wait time elasticity	-0.54	unitless	Taylor et al. 2009

Further explanation of key variables:

- (B) – This input is the number of bus stops that get equipped with new amenities (either shelters or shelters and real-time information).
- (C) – This input is the average number of boardings per day at the bus stop before the new amenities are added.

- (D) – This input is the average number of boardings per day across the entire transit agency.
- (E) – This is the transit mode share in the city where the bus amenities are being added. It is recommended that users use local data from the NHTS, National Transit Database or the U.S. Census for where the project(s) is located. The user can also use the values for CBSAs in the case where the projects are spread out across multiple cities.
- (F) – This constant is based on the percentage of trips taken by car from NHTS, weighted by transit ridership and number of cars available in the household to account for the fact that some riders do not have a choice to take transit and would ride regardless of the wait time. This value from FHWA 2018 represents pre-COVID-19 pandemic conditions but is the most recent value from FHWA.
- (G) – This is the average car occupancy for trips taken as of the latest version of the NHTS in 2022 for the Pacific and Mountain regions. This value accounts for the effects of the COVID-19 pandemic. Use more localized data if available.
- (H) – This value represents the percentage of the total transit trip travel time that is composed of waiting and is derived from average wait times and travel times in the NHTS in the Pacific and Mountain regions.
- (I1, I2) – This represents the percentage of the total transit trip travel time that is composed of waiting after the addition of transit amenities. This is derived from the average wait times and travel times in the NHTS and the perceived wait time changes found in Fan 2016 and Watkins 2011.
- (J) – This elasticity is sourced from a study (Taylor et al. 2009) that uses data from LA Metro to estimate the effect of wait time and travel time on ridership across the system. Use more localized elasticity data if available.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions (A) is capped at 0.24 percent. This assumes that the CBSA is Seatle-Tacoma-Bellevue,WA, which has a default transit mode share for all trips of 8.4 percent.

Subsector Maximum

($\sum A_{max_{T\text{-}25 \text{ through } T\text{-}29,\ T\text{-}46}} \leq 15\%$) This measure is in the Transit subsector. This subcategory includes Measures T-25 through T-29 and T-46. The VMT reduction from the combined implementation of all measures within this subsector is capped at 15 percent.

Example GHG Reduction Quantification

The user reduces VMT by constructing twelve transit shelters in Tacoma with real time information for a bus system that has an average of 15,000 boardings per day (D) and 300 boardings per day at each of the stops (C) before the project. This leads to a reduction in transportation related GHG emissions of 0.057 percent.

$$A = 12 \times \frac{300}{15{,}000} \times 8.4\% \times \frac{83.3\%}{1.45} \times (24.9\% - 15.8\%) \times -0.54 = 0.057\%$$

Quantified Co-Benefits

Improved Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NOx, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption achieved by the measure would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT achieved by the measure would be the same as the percent reduction in GHG emissions (A).

Sources

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T-55. Infill Development



GHG Mitigation Potential



Up to 22% of GHG emissions from project/site residential VMT

Co-Benefits (icon key on pg. 31)



Climate Resilience

Infill development increases density, which can put people closer to resources they may need to access during an extreme weather event. Infill development can also shorten commutes, decreasing the time people are on the road and exposed to hazards, such as extreme heat or flooding. Screening and management of climate risks should still be considered, especially if infill occurs in a hazardous area, to preserve the benefits of density without introducing new risks.

Health and Equity Considerations

Living in compact areas with greater accessibility provides residents with health benefits, such as better access to health-promoting goods and services and more opportunities to be physically active.

For jurisdictions, taking equity into consideration enables consideration of affordable housing balance and inclusion of measures to reduce gentrification displacement, ensuring stable mixed income areas are developed appropriately.

Measure Description

This measure accounts for the VMT reduction achieved by infill housing development programs that allow residents to live closer to downtown areas where there is greater access to jobs and activities. Residents living at infill development projects typically do not need to travel as far to access essential destinations. This leads to lower VMT and associated GHG emissions compared to similar projects located farther from a downtown area.

Subsector

Land Use

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

To ensure that the development would only proceed with implementation of this measure, the applicable projects would have to be commercial, public, low-density residential or industrial lots that are rezoned as high-density residential or mixed-use. GHG reductions from this measure cannot be credited unless the project site is currently a low-density residential, public, commercial, or industrial lot that is being rezoned into either high-density residential or mixed-use.

Cost Considerations

Depending on the location, siting housing projects in infill locations can increase housing and development costs. However, the costs of providing public services, such as health care, education, policing, and transit, are generally lower in more dense areas where things are in closer proximity. Infrastructure for water and electricity also operates more efficiently when the service and transmission area is reduced. Local governments may provide approval streamlining benefits or financial incentives for infill residential projects.

Expanded Mitigation Options

Pair with Measure T-2, *Increase Job Density*, to promote further densification and yield increased co-benefits from a highly walkable and bikeable area, including VMT reductions, improved public health, and social equity.

GHG Reduction Formula

$$A = \frac{-B+C}{C} \times D$$

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from project VMT in study area	0–22	%	calculated
User Inputs				
B	Distance to downtown for proposed project	[ ]	miles	user input
C	Distance to downtown of conventional development	[ ]	miles	user input
Constants, Assumptions, and Available Defaults				
D	Elasticity of VMT with respect to distance to downtown	-0.22	unitless	Ewing et al. 2010; Stevens 2016

Further explanation of key variables:

- (B) – For polycentric metros such as the Seattle-Tacoma-Bellevue metropolitan statistical area (MSA), the downtown area used to measure the distance needs to represent the closest of the relevant polycentric cities. For example, for a development in Lakewood, WA, downtown Tacoma would be the relevant downtown.
- (C) – This variable needs to be estimated for each region or metropolitan planning organization (MPO) where the measure will be applied because it differs greatly based on geographic context. Using geographic information system tools, this distance can be measured using the Census Centers of Population data for each block group to estimate the average distance to the appropriate downtown within a region weighted by population. For example, applying this technique to the Denver–Aurora–Lakewood, CO MSA using Denver as the centroid yields a population-weighted average distance of 18.1 kilometers, or 11.2 miles.
- (D) – An analysis of three studies in which disaggregate travel data were used found that a 0.22 percent decrease in VMT occurs for every 1 percent decrease in distance to downtown (Ewing et al. 2010).

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions (A) is capped at 22 percent. This would represent an infill project directly in the center of a downtown area.

Subsector Maximum

($\sum A_{max_{T\text{-}1 \text{ through } T\text{-}4,\ T\text{-}55}} \leq 65\%$) This measure is in the Land Use subsector. This subcategory includes Measures T-1 through T-4 and T-55. The VMT reduction from the combined implementation of all measures within this subsector is capped at 65 percent. This measure could not be used in conjunction with Measures T-1, *Increase Residential Density*, or T-3, *Transit-Oriented Development*, due to correlation between distance to downtown and the other measures.

Example GHG Reduction Quantification

The user reduces VMT by rezoning areas near the downtown area to allow for a new mixed-use development. Areas that were undeveloped but already zoned as mixed-use can still achieve reductions, but such reductions can only be attributed to the developer and not to an MPO or city. This requirement ensures the benefits are not counted for projects that could have happened without the rezoning process. In this example, the projects would be located 5 miles from downtown (B) in a metro area where the population-weighted average distance to downtown is 25 miles (C). This would reduce GHG emissions from the project's VMT by 17.6 percent.

$$A = \frac{\text{-5 mi} + \text{25 mi}}{\text{25 mi}} \times \text{-0.22} = \text{-17.6\%}$$

Quantified Co-Benefits

Successful implementation of this measure could achieve improved air quality, energy and fuel savings, VMT reductions, enhanced pedestrian or traffic safety, improved public health and enhanced energy security. This section defines the methods for quantifying improved air quality, energy and fuel savings, and VMT reductions.

Improved Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NO_X, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption achieved by the measure would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT achieved by the measure would be the same as the percent reduction in GHG emissions (A).

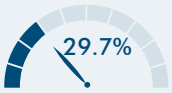
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T-56. Active Modes of Transportation for Youth



GHG Mitigation Potential



Up to 29.7% of GHG emissions from school commute vehicle travel

Co-Benefits (icon key on pg. 31)

Climate Resilience

Planning that promotes more active modes of transportation for youth allows children to travel to a safe place more easily during emergencies. This measure could also take more cars off the road, resulting in less traffic and better allowing emergency responders to access a hazardous site during an extreme weather event. Furthermore, increasing youth active transportation modes can have health benefits, improving community resilience.

Health and Equity Considerations

Shifting children's trips to school from private car trips to bus, bicycling, or walking trips promotes consistent physical activity in children. Prioritize underserved areas with lower rates of vehicle ownership or fewer transit options.

Measure Description

This measure accounts for reductions in VMT achieved by projects that provide infrastructure to support any form of active transport among youth. Trips to school and extracurricular activities represent most of the everyday travel taken by youth. Thus, ensuring that children can use active transportation whenever possible can serve to reduce VMT and allow them to get the necessary exercise to live healthy lives.

Safe Routes to Schools (SR2S) provides federal funding for new sidewalks, bike lanes, off-street pathways, and street crossings to help children use active modes of transportation to get to school, bringing health benefits to children, in addition to reductions in VMT from mode-shifts away from private vehicle trips. This is a blanket measure that can cover projects related to all forms of active transport among youth. Methods for this measure were influenced by methodology from CARB (CARB 2023).

Subsector

School Programs

Locational Context

Urban, suburban

Scale of Application

Project/Site

Implementation Requirements

Specific projects that are implemented need not be funded by SR2S or be located at a school; however, one advantage of the program is the requirement for student travel surveys, which provide critical before and after project data, to quantify the effects of the program.

Cost Considerations

Depending on the improvement, capital and infrastructure costs may be high. Eligible projects may be able to utilize federal funding through their state's SR2S program. In addition, the local municipality may achieve cost savings through a reduction of cars on the road leading to lower infrastructure and roadway maintenance costs.

Expanded Mitigation Options

When paired with Measure T-40, *Establish a School Bus Program*, students who live beyond walking or biking distance from their school will have an option for lower-emissions transportation to get to school.

GHG Reduction Formula

$$A = C \times F \times \frac{B\text{-}D}{G \times E \times (1\text{-}C) + C \times D \times F}$$

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from vehicle travel among students within walking/biking distance	0–29.7	%	calculated
User Inputs				
B	Known or estimated percentage of students within 2 miles who are driven to school after project implementation	0–100	%	Use survey data – see tools from SR2S
Constants, Assumptions, and Available Defaults				
C	Percentage of students living within 2 miles of the school	Table T-56	%	FHWA 2017, ODOT 2025
D	Percentage of students within 2 miles who are driven to school before measure implementation	Table T-56	%	FHWA 2017, ODOT 2025
E	Percentage of students who are driven more than 2 miles to school	66	%	FHWA 2023
F	Average driving distance for students who could walk or bike to school	2	miles	Assumption
G	Average driving distance for students who cannot walk or bike to school (> 2 miles)	8.66	miles	FHWA 2023

Further explanation of key variables:

- (B) – This is the percentage of students who could walk or bike to school who are driven to school after the project implementation. An informed estimate could be used if calculating reductions for a future project; however, survey data after the fact will provide the most accurate result.
- (C) – This represents the fraction of students who live within walking or biking distance to school, and is available in the Appendix Table T-56.1 using data from the 2017 National Household Travel Survey. The assumption that students are not willing to bike or walk longer than 2 miles is a simplification that makes it easier to exclude students who could not have benefited from infrastructure or programming that encourages walking and biking to school. Estimates were also produced for one mile as well, which may be more relevant for walking-based programs or infrastructure improvements. If survey data are available, users should select a value that is representative of the school, school district, or youth center where the project is being implemented.
- (D) – This represents the percentage of students who live within 2 miles from school but are driven to school nonetheless and is available in the Appendix Table T-56.2. This value is from the 2017 National Household Travel Survey by MSA, but a local-specific

value should be used if that is available for the school or school district. It should be noted that some metros (like the Portland MSA) had less than 100 respondents who took school trips under 2 miles, and may not be representative of the whole region.

- (E) – This represents the percentage of students outside of the 2-mile radius who are driven to school. This value is derived from 2022 NHTS data, but a local value should be used instead if it is available.
- (F) – This value represents the average driving distance for students who could walk or bike to school. This is based on the earlier assertion that students would not be willing to travel more than 2 miles by bike or on foot to school. If survey data are available, users should select a value that is representative of the school, school district, or youth center where the project is being implemented. In the Appendix, we have also provided data at the one-mile level, which may be more appropriate for programs focused specifically on walking.
- (G) – Using 2022 NHTS data, it is estimated that the average driving distance for students who cannot walk or bike to school is 8.66 miles. If more local data is available for the school area, use that value instead.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The percent reduction in GHG emissions (A) is capped at 29.7 percent. The benefits are unlikely to be this high because this level assumes that all students who could walk or bike to school start doing so.

Subsector Maximum

($\sum A_{max_{T\text{-}40\ \&\ T\text{-}56}} \leq 79\%$) This measure is in the School Programs subsector. This subcategory includes Measures T-40 and T-56 at the Project/Site scale of application. The school trip VMT reduction from the combined implementation of all measures within this subsector is capped at 79 percent. The reduction percentage for this measure is applicable to the School Programs subsector, which includes school commute trips. If users would like to apply the reduction percentage to community-wide emissions, the reductions can be converted to community-scale reductions by multiplying the reduction percentage by 1.64 percent (FHWA 2023).

Example GHG Reduction Quantification

A school installs a new raised pedestrian crossing in combination with an outreach program that brings children to school as part of a walking school bus. After this program is implemented, the percentage of students within 2 miles of school who are driven to school drops to 20 percent (B). This would lead to a reduction in GHG emissions from school trips of 7.2 percent.

$$A = 43\% \times 2 \text{ mi} \times \frac{20\% - 51\%}{8.66 \text{ mi} \times 66\% \ (1-43\%) + 43\% \times 51\% \times 2 \text{ mi}} = -7.2\%$$

Quantified Co-Benefits

Improved Air Quality

The percent reduction in GHG emissions (A) would be the same as the percent reduction in NOx, CO, NO_2, SO_2, and PM. Reductions in VOC emissions can be calculated by multiplying the percent reduction in GHG emissions (A) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* for further discussion.

Energy and Fuel Savings

The percent reduction in vehicle fuel consumption achieved by the measure would be the same as the percent reduction in GHG emissions (A).

VMT Reductions

The percent reduction in VMT achieved by the measure would be the same as the percent reduction in GHG emissions (A).

Sources

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Energy



The GHG emissions from energy use come from power generation that provides the energy used to operate a building or source. Power is typically generated by either a remote, central electricity generating plant, onsite generation by fuel combustion, or onsite solar, wind, or other renewable power. Because the emissions from central electricity generation are not emitted where the electricity is being used, these types of emissions are referred to as *indirect* emissions. As such, measures that reduce electricity consumption result in reductions of criteria pollutants where the electricity is generated (i.e., power plants). Electricity-reducing measures are, therefore, not considered to result in local air quality co-benefits at the project site, although they could contribute to regional air quality improvements.

Because the emissions from onsite fuel combustion are emitted where the fuel is being consumed, these types of emissions are referred to as *direct* emission. Measures that reduce residential natural gas use (e.g., from cooktops and for space and water heating) reduce onsite fuel combustion and improve local air quality. Direct use of onsite solar or wind power generated electricity does not result in emissions.

Energy sector emissions can be reduced through energy efficiency improvements, renewable energy generation, building electrification, and CH_4 recovery and reuse at industrial facilities (landfills and wastewater treatment plants). These types of measures are discussed below. This section also provides guidance for combining emission reductions from energy measures and accounting for statewide legislation that may reduce future emissions reductions achieved by energy measures. The measure factsheets and quantification methods for individual measures follow. Use the graphic on the following page to click on an individual measure to navigate directly to the measure's factsheet.

Measures to Improve Efficiency

Energy sector emissions can be reduced by lowering the amount of electricity and natural gas required for building operations. This can be achieved by designing a more energy-efficient building structure and/or installing energy-efficient appliances.[16] Emissions reductions from energy efficiency improvements should be quantified based on the amount of expected energy savings that would be achieved over existing energy codes and regulations. Existing

[16] This Handbook does not account for potential "rebound effects" of energy efficiency measures. *Rebound effect* is the phenomenon that an increase in energy efficiency may lead to fewer energy savings because energy use will increase due to consumer and market responses. While rebound effects have been documented in literature, they are difficult to precisely and reliably quantify.

consumption values are determined using the U.S. Energy Information Administration's (U.S. EIA) 2020 Residential Energy Consumption Survey (RECS) and 2018 Commercial Buildings Energy Consumption Survey (CBECS), and other literature sources (e.g., ENERGY STAR program). Quantified measures that target energy efficiency improvements described in this section include Measures E-1 through E-9 and E-26.

Note that many of the energy efficiency measures in the CAPCOA Handbook rely on California-specific energy end-use databases, such as the California Commercial End-Use Survey (CEUS) and Residential Appliance Saturation Study (RASS). Equivalent end-use databases are not available for the western states. Accordingly, this Western States Handbook is supported by the U.S. EIA's RECS and CBECS. The RECS and CBECS are national-scale surveys with data tabulated by geography and for specific characteristics (e.g., housing type, energy consumption end-uses). Differences in data provided by the RECS and CBECS verses the CEUS and RASS influence the resolution and/or methodology of some measures for this Western States Handbook when compared to the CAPCOA Handbook. Implications for specific measures are discussed further in the individual measure quantification methodologies.

Energy

ENERGY EFFICIENCY IMPROVEMENTS

- E-1. Implement a Plan to Improve Building Energy Efficiency
- E-2. Require Energy Efficient Appliances
- E-3-A. Require Energy Efficient Residential Boilers
- E-3-B. Require Energy Efficient Commercial Packaged Boilers
- E-4. Install Cool Roofs and/or Cool Walls in Residential Development
- E-5. Install Green Roofs in Place of Dark Roofs
- E-6. Encourage Residential Participation in Existing Demand Response Program(s)
- E-7. Require Higher Efficacy Public Street and Area Lighting
- E-8. Replace Incandescent Traffic Lights with LED Traffic Lights
- E-9. Utilize a Combined Heat and Power System
- E-21. Install Cool Pavement

RENEWABLE ENERGY GENERATION

- E-10-A. Establish Onsite Renewable Energy Systems—Generic
- E-10-B. Establish Onsite Renewable Energy Systems—Solar Power
- E-10-C. Establish Onsite Renewable Energy Systems—Wind Power
- E-11. Procure Electricity from Lower Carbon Intensity Power Supply
- E-26. Biomass Energy

BUILDING DECARBONIZATION

- E-12. Install Electric Water Heater in Place of Gas Storage Tank Heater in Residences
- E-13. Install Electric Cooking Appliances in Place of Gas Appliances
- E-14. Limit Wood Burning Devices and Natural Gas/Propane Fireplaces in Residential Development
- E-15. Require All-Electric Development
- E-16. Require Zero Net Energy Buildings
- E-17. Require Renewable-Surplus Buildings

METHANE RECOVERY

- E-18. Establish Methane Recovery in Landfills
- E-19. Establish Methane Recovery in Wastewater Treatment Plants

Measures to Increase Renewable Energy Generation

Different modes of electricity generation have different GHG emission intensities. Fossil fuel-based generation emits GHGs from fuel combustion, with the emissions quantity depending on the quantity and type of fuel used. Renewable energy generation, on the other hand, typically has significantly fewer emissions, and most types of renewable sources — such as solar photovoltaic (PV) systems — have zero associated GHG emissions. Renewable energy generation reduces emissions by avoiding an equivalent amount of grid energy. To calculate this, the amount of energy generated by the renewable system(s) must be quantified and then multiplied by the electricity provider-specific emission factor for the type of energy (e.g., electricity, natural gas) being replaced.[17] An exception to typical renewable energy sources is biomass or biofuels, which result in comparable direct emissions as fossil fuels when combusted; however, these fuels have lower upstream emissions than fossil fuels and result in GHG reductions when considering the entire lifecycle of the energy source. Thus, the methodology used to quantify emission reductions from the biomass measure (Measure E-21) is based on a lifecycle approach that accounts for upstream emissions associated with various fuel types. Consequently, users are cautioned in how these reductions are compared to operational emissions inventories, which may not include lifecycle emissions.

Quantified measures that target renewable energy generation described in this section include Measures E-10-A through E-11 and E-21.

Measures for Building Decarbonization

Building decarbonization, also termed *beneficial electrification* or *building electrification*, involves shifting from fossil fuels (e.g., natural gas) to electricity as the power source for heating, cooking, and appliances. In a fully electrified building, gas-powered water heaters, gas-powered ovens and cooktops, gas-powered clothes washers and dryers, and space heating that normally uses natural gas, propane, or heating oil are all replaced by electric alternatives, which are usually two to three times more efficient than traditional appliances. Displacing emissions-intensive fossil fuel energy with less emissions-intensive electricity results in a net emission reduction. Further, the emission reduction increases if the electricity for these end uses is generated by solar, wind, or other sources of zero-carbon electricity. These zero-carbon sources can be provided on a project site or integrated into the electricity providers' renewable energy mix. In future years, building decarbonization measures will become increasingly effective at reducing GHG emissions because electricity provided by retail sellers of electricity will be procured from increasing amounts of renewable energy sources.

Emissions reductions achieved through building electrification are quantified based on the direct emissions avoided by the displaced fuel plus the indirect emissions added by the increased use of electricity. To calculate this, the avoided energy (i.e., negative value) generated by the fossil-fueled appliance(s) must be quantified and then multiplied by the appropriate fuel emission factor. The additional energy (i.e., positive value) generated by the electric alternative

[17] The quantification methods do not account for potential future renewable energy curtailment (i.e., the deliberate reduction in power output below what could have been generated to balance supply and demand), which could reduce expected emissions savings from certain renewable energy measures.

appliance(s) must be quantified and then multiplied by the electricity provider-specific emission factor.[18] The sum of these two emissions represents the net emission reduction. Quantified measures that target building decarbonization described in this section include Measures E-12 through E-17.

Measures for Methane Recovery

Decomposition of waste and organic material in landfills and at wastewater treatment facilities generates CH_4. Capturing CH_4 through recovery systems directly reduces GHG emissions. Additional reductions can be achieved if the captured CH_4 is combusted to generate electricity for onsite energy needs, which displaces the associated indirect GHG emissions from electricity production. Emissions reductions from CH_4 recovery systems that include electricity generation are quantified using similar methods as described above for measures to increase renewable energy generation. Quantified measures that target CH_4 recovery described in this section include Measures E-18 and E-19.

Combining Emissions Reductions from Energy Measures

The total reductions claimed by a user for energy measures should not exceed 100 percent of project energy emissions, unless a measure would result in additional excess energy capacity that would be sold to an electricity provider or other project. This may include renewable energy generation systems tied into the grid. These additional emission reductions may be used to offset other categories of emissions, with the approval of the agency reviewing the project. In these cases of excess capacity, the quantified excess emissions must be carefully verified to ensure that any credit allowed for these additional reductions is truly additional.[19]

Reduced Effectiveness of Energy Measures in Future Years

All five western states have adopted Renewables Portfolio Standards (RPS) that place binding requirements on retail electric suppliers to procure a minimum percentage of generation from eligible renewable resources. Colorado, New Mexico, Oregon, and Washington have also adopted Clean Energy (or Electricity) Standards (CES), which are similar to an RPS, but often rely on a broader set of technologies and may have less defined enforcement mechanisms (Barbose 2024). The below table summarizes current (as of March 2025) state RPS and CES targets.

[18] One method for determining energy consumption for an electric alternative appliance is to convert the natural gas consumption, typically measured in therms, into British thermal units, which can then be converted into the electricity energy consumption metric of kWh. However, this method does not account for the differing energy efficiencies of natural gas versus electricity or potential differences in the technical specifications of the associated appliances. Accordingly, the Handbook does not use this basic conversion method. Instead, the Handbook recommends using actual reported energy consumption for electric alternative appliances.

[19] For more detailed information on offset verification protocols, visit https://www.climateactionreserve.org/how/future-protocol-development/criteria/.

State	Applicability	RPS Target	CES Target
AZ	IOUs and Co-ops	15% by 2025	—
CO	IOUs	30% by 2020	Non-municipal utilities serving >500,000 customers—reduce GHG emissions by 80% by 2030 (from 2005). Statewide achieve 100% clean energy by 2040.
	Co-ops serving ≥ 100,000	20% by 2020	
	Co-ops serving ≤ 100,000	10% by 2020	
	Municipal	10% by 2020	
NM	IOUs	20% by 2020 40% by 2025 50% by 2030 80% by 2040	100% clean energy by 2045
	Co-ops	10% by 2020 40% by 2025 50% by 2030 80% by 2050	100% clean energy by 2050
OR	Large IOUs (those with 3% or more of state load)	20% by 2020 27% by 2025 35% by 2030 45% by 2035 50% by 2040	Two largest IOUs—reduce GHG emissions by 80% by 2030, 90% by 2035, and 100% by 2040 (from baseline).
	Co-ops	20% by 2020 25% by 2025	
	Medium-to-large utilities (serving 1.5% to 3% of state load)	5% by 2020 10% by 2025 25% by 2035	
	Small utilities (those with less than 1.5% of state load)	5% by 2025	
WA	Utilities serving ≥ 25,000	15% by 2020	All retail sales of electricity must be carbon neutral by 2030; achieve 100% clean energy by 2045.

AZ = Arizona; CO = Colorado; NM = New Mexico; OR = Oregon; WA = Washington; RPS = Renewables Portfolio Standard; CES = Clean Energy (or Electricity) Standard; IOU = investor-owned utility; GHG = greenhouse gas.

Sources: Lawrence Berkely National Laboratory (LBNL). 2024. RPS and CES Nominal Percentage Targets XLXS. Accessed January 30, 2025. https://eta-publications.lbl.gov/sites/default/files/rps_and_ces_nominal_percentage_targets_august_2024.xlsx.
Clean Air Task Force. 2025. "Clean Electricity Standards: Tracking Clean Energy in U.S. States." Accessed January 30, 2025. https://www.catf.us/us/state-policy/clean-electricity-standards/.

As retail sellers of electricity procure increasing amounts of renewable energy to displace fossil fuels in their energy generation mix, the emission factors of electricity providers will decrease over time. Because some energy measures reduce electricity consumption or displace grid energy, the annual GHG reduction from these measures will be less in future years. As noted above, however, the shift to a larger portfolio of renewable energy will make building decarbonization

measures more effective. Further, if the electricity provider for a project already has carbon-free electricity, then energy reduction measures would not reduce electricity emissions as they would already be zero or near zero. Users should take care to appropriately account increasing decarbonization of electricity generation. Where available, utility emission factors are presented in Tables E-4.5 through E-4.9 in the Appendix, *Emissions Factors and Data Tables*.[20, 21]

Similarly, measures that reduce building energy consumption may become less effective over time because of increasingly stringent local and state energy standards. The table below summarizes current (as of March 2025) state energy codes. Note that local municipalities may have additional (or more stringent) standards than mandated at the state level.

State	Residential	Non-Residential
AZ	As a "home rule state," Arizona does not have mandatory statewide energy codes. Many local jurisdictions within the state have adopted iterations of the International Building Code as standards.	
CO[a]	Local jurisdictions must adopt and enforce the Model Low Energy and Carbon Code and Model Electric Ready and Solar Ready Code. As a "home rule state," local jurisdictions may amend these codes as deemed appropriate for local conditions, but those amendments must not decrease the effectiveness of the code.	
NM	2021 New Mexico Residential Energy Conservation Code	2021 New Mexico Commercial Energy Conservation Code
OR	2023 Oregon Residential Specialty Code	2025 Oregon Energy Efficiency Specialty Code (effective July 1, 2025)
WA	2021 WA State Energy Code – Residential	2021 WA State Energy Code – Commercial

AZ = Arizona; CO = Colorado; NM = New Mexico; OR = Oregon; WA = Washington

Sources: U.S. Department of Energy. 2025. "State Portal." Accessed January 30, 2025. https://www.energycodes.gov/state-portal.

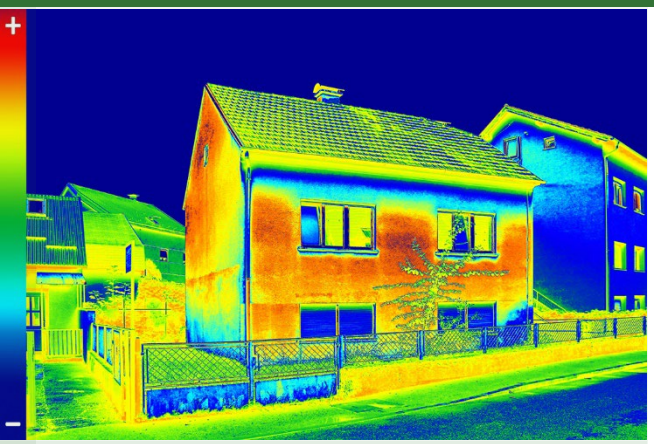
[a]CO has proposed a draft Model Green Code that address building attributes such as energy and water use efficiency, electrification, low carbon building materials, and other strategies.

Strengthening of local and state requirements, including provisions for zero net energy (ZNE) buildings (i.e., energy efficiency improvements and onsite renewable energy), will improve energy efficiency and reduce energy consumption in new construction. Some measures in this Handbook may become obsolete if they are made mandatory for all new buildings as part of future local or state standards. As such, users should take care to determine whether the measures in this Handbook still exceed applicable local and/or state requirements at the time of project implementation. If the user's project exceeds the requirements of local and/or state codes, then they can take credit for the resulting reductions.

[20] Future year emission factors for selected New Mexico utilities were provided by New Mexico Energy Conservation and Management and for some utilities reflect compliance with the state's mandatory RPS targets and attainment of the CES, as well as implementation of utility utility-specific renewable procurement or GHG reduction plans (Table E-4.7). Future year emission factors for Arizona (Table E-4.5) and Washington (Table E-4-9) utilities (where available) were forecasted for the Handbook and account for implementation of legislatively mandated RPS targets. Attainment of Washington's CES targets (on an emissions or clean energy basis) and utility-specific targets will further reduce the intensity of utility emission factors beyond those presented in Tables E-4.5 and E-4.9. Base year factors for selected Colorado and Oregon utilities are provided in Tables E-4.6 and E-4.8, respectively. Refer to the footnotes in Tables E-4.5 through E-4.9 for additional information.

[21] The default electricity provider emission factors reflect the annual average emissions intensity of delivered electricity. Depending on the time of day and load, measures that reduce electricity consumption may offset emissions from marginal power sources, yielding emissions reductions that differ from those estimated with average annual emission factors.

E-1. Implement a Plan to Improve Building Energy Efficiency



GHG Mitigation Potential



Up to 99% of GHG emissions from building electricity and/or natural gas use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Increased energy efficiency can reduce the strain on the overall grid, particularly the risk of power outages during peak loads. Increased efficiency can also reduce energy costs, particularly if extreme heat would otherwise increase these costs.

Health and Equity Considerations

More energy efficient buildings can help residents save money on utility costs and reduce exposure to extreme heat, supporting greater resilience to climate health impacts. This can be especially critical for low-income and vulnerable residents.

Measure Description

This measure will develop and implement a plan to improve building energy efficiency beyond minimum requirements of applicable building energy standards in place at the time of construction. GHGs are emitted because of activities in residential and commercial buildings that use electricity and natural gas as energy sources. By committing to construct buildings that are more efficient than required by regulation, the building's energy use is reduced, thereby decreasing GHG emissions. All states except Arizona have minimum statewide energy efficiency standards. As a "home rule state," Arizona does not have mandatory statewide energy codes, but many local jurisdictions within the state have adopted iterations of the International Building Code as standards. Local municipalities in other states (including Colorado as another "home rule state") may have additional (or more stringent) standards than mandated at the state level.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Energy efficiency improvements must exceed minimum requirements of any applicable state or local energy codes in place at the time of construction.

Cost Considerations

In order to make buildings even more energy efficient, developers will face greater upfront costs to purchase higher-quality materials, which may be passed on to the property owner. However, property owners will realize cost savings from reduced energy and reduced stress on HVAC and other equipment, which in turn can reduce the need for maintenance and associated costs. Property owners will also avoid potential retrofitting costs in the future if efficiency standards are made more stringent.

Expanded Mitigation Options

Not applicable.

Introduction

Measure E-1 has been rewritten from the CAPCOA Handbook for this Western States Handbook. Measure E-1 in the CAPCOA Handbook requires new buildings to exceed the energy efficiency requirements of the building energy standards of the 2019 version of California's Building Energy Efficiency Standards, known as Title 24. The Title 24 standards are not applicable outside of California. As discussed above in this chapter, many of the western states and their local jurisdictions have adopted similar energy efficiency codes. Given the diversity of standards and requirements among these codes across the western states, Measure E-1 was generalized to include an energy efficiency performance standard. Similar to the CAPCOA Handbook measure, users may define a performance standard that commits to a percentage improvement beyond an applicable energy code. When applied in this way, the user should ensure the underlying electricity and natural gas emissions come only from end-use categories subject to the energy code.

GHG Reduction Formula

$$A = -((B \times D) + (C \times E))$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Reduction in GHG emissions from improved energy efficiency	[ ]	MT CO_2e	calculated
User Inputs				
B	Percent improvement over baseline building electricity consumption	0–100	% expressed as a whole number	user input
C	Percent improvement over baseline building natural gas consumption	0–100	% expressed as a whole number	user input
D	Baseline GHG emissions from building electricity consumption	[ ]	MT CO_2e	user input
E	Baseline GHG emissions from building natural gas consumption	[ ]	MT CO_2e	user input
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (A) – The output provides the reduction in GHG emissions that could be achieved through a minimum percentage reduction in building energy consumption. At the project/site level, attainment of the performance standard should be validated through identification and modeling of project-specific actions. Many of the energy efficiency measures identified in this chapter may be used to attain a minimum percentage reduction in building energy consumption. At the plan/community level, the reductions

quantified by this measure may be used to programmatically inform future plans or policy development.

- (B, C) – The energy efficiency plan should identify the percentage improvement in building electricity and/or natural gas consumption.
- (D, E) – Baseline GHG emissions from electricity and natural gas consumption should be quantified using accepted and standard models. If the measure performance standard (B, C) identifies a minimum percentage reduction below a certain state or local energy code, the user must ensure the baseline GHG emissions estimates are reflective of buildings constructed to that code.

GHG Calculation Caps or Maximums

Measure Maximum

(B_{ma}, C_{max}) The percentage improvement over baseline building electricity and/or natural gas consumption is capped at 100.

It is assumed that the energy demand of the user's project is currently being met by grid electricity that requires *some* amount of fossil fuel-based energy generation and/or onsite natural gas, both of which emit GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per MWh) greater than zero and/or the project consumes natural gas onsite for building energy. For all-electric projects that are served by electricity providers already with a renewable portfolio of 100 percent, this measure could have no reduction in GHG emissions. If the electricity provider is using renewable energy credits (REC) to meet a 100 percent renewable portfolio goal, then some emissions reductions may be achieved. This measure would still result in the co-benefits of reduced electricity use and enhanced energy security.

Mutually Exclusive Measures

Users may not individually credit other energy efficiency measures that will be used to achieve the percentage reduction in building energy consumption (B, C). For example, if the user adopts a 5 percent reduction in building electricity consumption for this measure (B), and they implement Measure E-2, *Require Energy Efficient Appliances*, as a mechanism to achieve that standard, the user may not take credit for both Measures E-1 and E-2.

Example GHG Reduction Quantification

The user is evaluating the effectiveness of near-term targets identified in a local climate action plan. The plan requires a 7 percent and 5 percent reduction in baseline electricity and natural gas consumption, respectively, for new residential development constructed between 2025 and 2027. Baseline electricity and natural gas consumption is defined through compliance with the state's 2025 energy efficiency standard (which took effect on January 1, 2025, and would apply to all new residential construction through December 31, 2027). The user is evaluating application of the climate action plan targets to the construction of 800 single family homes in 2025. Project-specific modeling indicates that operation of these units under baseline conditions (i.e., compliance with the 2025 energy

efficiency standard) would generate 3,800 MT CO_2e per year from building electricity consumption (D) and 7,400 MT CO_2e per year from building natural gas consumption (E). Based on the performance standards and user provided baseline emissions modeling, the measure would reduce building GHG emissions by 636 MT CO_2e.

A = -((7% × 3,800 MT CO2e) + (5% × 7,400 MT CO2e)) = -636 MT CO2e

Quantified Co-Benefits

Improved Air Quality

Electricity supplied by fossil-fueled or bioenergy power plants generates criteria pollutants. However, because these power plants are located throughout individual states, the reduction in electricity use from this measure will not reduce localized criteria pollutant emissions at the project site. The reduction in natural gas consumption from this measure would result in local improvements in air quality because building natural gas combustion occurs on the project site (e.g., space heating, water heating).

Energy and Fuel Savings

Electricity and natural gas savings are the same as the percentage improvement over baseline building electricity and natural gas consumption (B, C).

Sources

- None.

E-2. Require Energy Efficient Appliances



GHG Mitigation Potential



Up to 10% of GHG emissions from building electricity

Co-Benefits (icon key on pg. 31)

Climate Resilience

Increased energy efficiency can reduce the strain on the overall grid, particularly the risk of power outages during peak loads. Increased efficiency can also reduce energy costs, particularly if extreme heat would otherwise increase these costs.

Health and Equity Considerations

The use of ENERGY STAR appliances can increase upfront purchase costs; thus, it should be clearly explained to occupants or buyers that these costs can be offset by reduced operational utility costs. This can be particularly beneficial for low-income residents.

Measure Description

This measure will require installation of ENERGY STAR-certified appliances that exceed the energy efficiency of conventional appliances. By committing to more efficient appliances, the building's energy use is reduced, thereby decreasing GHG emissions.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site

Implementation Requirements

This measure can be used for commercial refrigerators. It can also be used for residential refrigerators, clothes washers, dishwashers, and ceiling fans. This measure will only result in reductions associated with electricity use and does not apply to natural gas as no ENERGY STAR appliances that use natural gas were evaluated.

Cost Considerations

More energy-efficient appliances are typically more expensive than less efficient ones, leading to greater upfront costs. However, the replacement of less efficient appliances with more efficient models reduces energy consumption and thereby reduces long-term energy costs.

Expanded Mitigation Options

None.

GHG Reduction Formula

$$A = (E_1 \times F_1) + (E_2 \times F_2) + (E_3 \times F_3) + (E_4 \times F_4)$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from building electricity	0–10	%	calculated
User Inputs				
B	Building/housing type	[ ]	text	user input
$C_{1,2,3...}$	ENERGY STAR appliance(s) installed	[ ]	text	user input
Constants, Assumptions, and Available Defaults				
D	U.S. EIA Census Region/Division or Climate Zone	Figures E-2.1 through E-2.3	integer	U.S. EIA 2025a, 2025b, 2025c
$E_{1,2,3...}$	Percent reduction in electricity for ENERGY STAR appliance compared to conventional appliance	Table E-2.1	%	ENERGY STAR 2025a, 2025b, 2025c; U.S. DOE 2025
$F_{1,2,3...}$	Percent of total building electricity by appliance	Tables E-2.2 through E-2.5	%	U.S. EIA 2022, U.S. EIA 2023

Further explanation of key variables:

- (A) – The output provides the percentage reduction in GHG emissions from building electricity. To determine the percentage reduction in GHG emissions from building energy (i.e., electricity plus natural gas), the user would need to know the percentage of total GHG emissions from electricity. For example, if 40 percent of building energy emissions come from electricity, the percentage reduction in GHG emissions from building energy could be calculated as follows.

  $$A_{energy} = (40\% \times A_{electricity})$$

  Further, to determine the percentage reduction in GHG emissions for a project with multiple buildings, the user would need to know the percentage of total building energy emissions from each building. For example, if 67 percent of building energy emissions come from Building 1 and 33 percent come from Building 2, the percentage reduction in GHG emissions from all building energy could be calculated as follows.

  $$A_{energy_total} = (67\% \times A_{energy_1}) + (33\% \times A_{energy_2})$$

- (B) – The percentage of total building electricity by appliance (F) is provided for several housing and building types from the RECS and CBECS, respectively. National-scale data are used to inform these percentages. Users may elect to apply the housing and building-specific percentages or use aggregated factors specific to their selected U.S.

EIA census region/division or climate zone (D). Please refer to the discussion under (D) and (F) for additional information.

- (D) – The RECS and CBECS provide energy consumption data aggregated to four U.S. census regions and nine divisions. All western states are in the "West" region, which includes the Pacific and Mountain (North and South) divisions. Refer to Figure E-2.1 in the Appendix. The RECS and CBECS also aggregate data across various climate zones, as shown in Figures E-2.2 and E-2.3. The percentage of total building electricity by appliance (F) is provided for U.S. census regions/divisions and climate zones applicable to the western states. Users should select the appropriate geographic region for their analysis. Note that national averages are also provided for the percentage of total building electricity by appliance (F), as discussed further below. Users electing to apply the national average factors would not need to select a U.S. EIA census region/division or climate zone (D) for the analysis.

  The U.S. EIA census regions/divisions and climate zone included in this Western States Handbook are different from the electricity zones used in the CAPCOA Handbook. The CAPCOA Handbook electricity zones are defined by the California Energy Commission and relate to the underlying end-use consumption data provided by the RASS and CEUS (either directly or by proxy, as shown in Table E-1.1 in the CAPCOA Handbook). The geographic resolution provided by the RECS and CBECS differs from the RASS and CEUS. Whereas energy consumption details from the RASS and CEUS can be separated by distinct climate regions within California, data from the RECS and CBECS used in this Western States Handbook[22] are provided by larger U.S. census region/divisions and national climate zones.
- (E) – See Table E-2.1 for the percentage reduction in ENERGY STAR appliance electricity use compared to conventional appliances that meet the minimum federal efficiency standards.
- (F) – The RECS and CBECS provide energy consumption end-use data at various levels of aggregation. These data have been organized into the following tables in the Appendix to provide defaults for the percentage of total building electricity by appliance:
  - Table E-2.2 – disaggregated by residential housing type based on aggregated national average consumption data.
  - Table E-2.3 – disaggregated by principal non-residential building activity based on aggregated national average consumption data.
  - Table E-2.4 – aggregated for all residential housing types based on disaggregated U.S. census region/division and climate zone consumption data.
  - Table E-2.5 – aggregated for all non-residential building activities based on disaggregated U.S. census region/division and climate zone consumption data.

Users should determine how they want to analyze the measure benefits based on project data and considering the advantages and disadvantages of the available RECS and CBECS defaults. For example, users seeking to analyze measure benefits for specific residential or

[22] Some datasets within the RECS and CBECS are available at the state-level. While state-level data are more geographically refined than data aggregated to the U.S. census region/division or national climate zone, the state database does not provide end-use consumption characteristics at the necessary level of detail to support measure quantification across this Handbook. For example, relevant to this measure, the state RECS database (Table CE5.1 ST – Detailed electricity end uses by state – consumption – totals) only provides end-use electricity consumption for refrigerators and clothes washers. It does not include end-use electricity consumption for ceiling fans or dishwashers, which is provided by U.S. census region/division and national climate zone (Table CE5.1a Detailed household site electricity end-use consumption).

non-residential building types (B) should use Tables E-2.2 and E-2.3, respectively. The user should take note that the percentages in Tables E-2.2 and E-2.3 are based on national-average energy consumption data. Thus, while the data is tailored to specific housing and building types, it may not reflect climate conditions of the project area. Users seeking more geographically tailored results that are not specific to an individual housing or building type should use Table E-2.4 or Table E-2.5.

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the electricity demand of the project's appliances is currently being met by grid electricity that requires *some* amount of fossil fuel-based energy generation, which emits GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per MWh) greater than zero. For projects that are served by electricity providers already with a renewable portfolio of 100 percent, this measure could have no reduction in GHG emissions. If the electricity provider is using REC to meet a 100 percent renewable portfolio goal, then some emissions reductions may be achieved. This measure would still result in the co-benefits of reduced electricity use and enhanced energy security.

Mutually Exclusive Measures

Users implementing this measure to achieve performance standards set under Measure E-1, *Implement a Plan to Improve Building Energy Efficiency*, may not take credit for GHG reductions quantified for both measures, unless the reductions quantified by this measure exceed the minimum Measure E-1 performance standard. For example, if the user adopts a 5 percent reduction in building electricity consumption under Measure E-1 and this measure achieves a 7 reduction, they may account for an additional 2 percent reduction in building electricity consumption under this measure. Refer to Measure E-1 for additional discussion.

Example GHG Reduction Quantification

The user reduces building energy by requiring the builder supply appliances that exceed the energy efficiency of conventional appliances. In this example, the user's project includes Building 1, a grocery store, and Building 2, a single-family home (B). The user would commit to ENERGY STAR commercial refrigerators in the grocery store and ENERGY STAR residential refrigerators, clothes washers, dishwashers, and ceiling fans in the single-family housing (C). The user elects to analyze reductions for each building using national average defaults from Tables E-2.1 and E-2.2. GHG emissions from the grocery store and single-family home from electricity would be reduced by 9.6 percent and 1.9 percent, respectively.

$A_{electricity_1} = -20\% \times 48\% = -9.6\%$ grocery store electricity emissions

$A_{electricity_2} = (-9\% \times 7.8\%) + (-25\% \times 0.6\%) + (-12\% \times 0.8\%) + (-60\% \times 1.7\%) = -1.9\%$ housing electricity emissions

The percentage reduction in GHG emissions from building energy (i.e., electricity plus natural gas) per building can also be calculated if the user knows the percentage of total GHG emissions from each energy source. In this example, 60 percent of the grocery store's energy emissions come from electricity and 50 percent of the single-family home's energy emissions come from electricity. GHG emissions from the grocery store and single-family home would be reduced by 5.8 percent and 1.0 percent, respectively.

A_{energy_1} = (60% × -9.6%) = -5.8% grocery store energy emissions
A_{energy_2} = (50% × -2.8%) = -1.4% housing energy emissions

Further, the percentage reduction in GHG emissions for the project can be calculated if the user knows the percentage of total building energy emissions from each building. In this example, 67 percent of building energy emissions come from the grocery store and 33 percent come from the single-family home. The percentage reduction in GHG emissions from all building energy would be 4.3 percent.

A_{energy_total} = (67% × -5.8%) + (33% × -1.4%) = -4.3% building energy emissions

Quantified Co-Benefits

Energy and Fuel Savings

The percentage reduction in electricity use achieved by the measure is the same as the percentage reduction in GHG emissions from electricity ($A_{electricity}$).

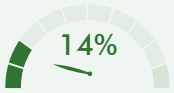
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- U.S. EIA. 2023. *Residential Energy Consumption Survey* (RECS). Table CE2.1 Annual household site fuel consumption in the U.S.—totals and averages, 2020. Table CE5.1a Detailed household site electricity end-use consumption, part 1—totals, 2020. Table CE5.1b Detailed household site electricity end-use consumption, part 2—totals, 2020. Accessed January 2025. https://www.eia.gov/consumption/residential/data/2020/.
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E-3-A. Require Energy Efficient Residential Boilers



GHG Mitigation Potential



Up to 14% of GHG emissions from boiler fuel consumption

Co-Benefits (icon key on pg. 31)

Climate Resilience

If the boilers are electric, increased energy efficiency can reduce the strain on the overall grid, particularly the risk of power outages during peak loads. Increased efficiency can also reduce energy costs.

Health and Equity Considerations

If the boilers use natural gas, propane, or home heat oil, a more efficient model can directly reduce fuel combustion in the home and thus help reduce indoor air pollution, supporting improvements to public health.

Measure Description

This measure requires installation of a residential boiler with a higher energy efficiency than what is required by regulation. Improving boiler efficiency decreases fuel consumption for the same amount of energy output, thereby reducing the associated GHG emissions.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site

Implementation Requirements

This measure is only appropriate for residential boilers. A *residential boiler*, as defined in the Code of Federal Regulations (C.F.R.), means a product that utilizes only single-phase electric current, or single-phase electric current or DC current in conjunction with natural gas, propane, or home heating oil and that (1) is designed to be the principal heating source for the living space of residence; and (2) has a heat input rate of less than 300,000 British Thermal Units (BTUs) per hour.

Cost Considerations

More energy-efficient boilers are typically more expensive than less efficient ones, leading to greater upfront costs. However, the use of more efficient models reduces energy consumption and thereby reduces long-term energy costs. Boilers with improved insulation—a metric in improved energy efficiency—are also less likely to freeze and burst, potentially avoiding cold weather repair costs and water damage.

Expanded Mitigation Options

Pair with Measure E-12, *Install Electric Water Heater in Place of Gas Storage Tank Heater in Residences*, to reduce energy use from both space heating and water heating to yield increased GHG reductions.

GHG Reduction Formula

A = D

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from boiler fuel consumption	1.2–14.0	%	calculated
User Inputs				
B	Boiler type	[ ]	text	user input
C	Annual fuel utilization efficiency of boiler with measure	83–96	%	user input
Constants, Assumptions, and Available Defaults				
D	Boiler fuel savings with measure compared to minimum requirement	Table E-3-A.1	%	U.S. DOE 2015

Further explanation of key variables:

- (C) – The U.S. Department of Energy's (U.S. DOE) 2016 Conservation Standards for Residential Boilers (10 CFR 430) set increased energy efficiency requirements for residential boilers, effective January 2021. The annual fuel utilization efficiency (AFUE) is a common metric for determining residential boiler efficiency as it represents the ratio of the total useful heat delivered to the heat value from the annual amount of fuel consumed. The project boiler AFUE must exceed the minimum AFUE required by the standards to result in GHG emission reductions. Boiler efficiency should be obtainable from manufacturer specifications.
- (D) – The U.S. DOE calculated the average annual fuel use and savings of boilers at various AFUEs above the minimum requirement of the standards based on historical consumption data. This information is summarized in Table E-3-A.1 in the Appendix.

GHG Calculation Caps or Maximums

Measure Maximum

(C_{max}) The annual fuel utilization efficiency of the proposed boiler is capped at the "Max Tech" percentage for each boiler type, which is presented in Table E-3-A.1 in the Appendix.

Mutually Exclusive Measures

If the user selects Measure E-15, *Require All-Electric Development*, the user cannot also select this measure, given that it calls for use of gas- and oil-fired boilers.

Users implementing this measure to achieve performance standards set under Measure E-1, *Implement a Plan to Improve Building Energy Efficiency*, may not take credit for GHG reductions quantified for both measures, unless the reductions quantified by this measure

exceed the minimum Measure E-1 performance standard. Refer to Measure E-1 for additional discussion.

Example GHG Reduction Quantification

The user reduces boiler fuel use by requiring installation of a boiler with a higher AFUE than what is required by the 2016 Conservation Standards for Residential Boilers. If the boiler is a gas-fired hot water boiler (B) with an AFUE of 96 percent (C), the user would reduce GHG emissions from boiler fuel consumption by 14 percent based on Table E-3-A.1 in the Appendix.

A = -14%

Quantified Co-Benefits

Improved Air Quality

The reduction in fuel consumption (i.e., natural gas or oil) from this measure would result in local improvements in air quality because pollutants from fuel consumption would be reduced at the project site. The percentage reduction in GHG emissions (A) is the same as the percentage reduction in criteria pollutant emissions achieved by the measure.

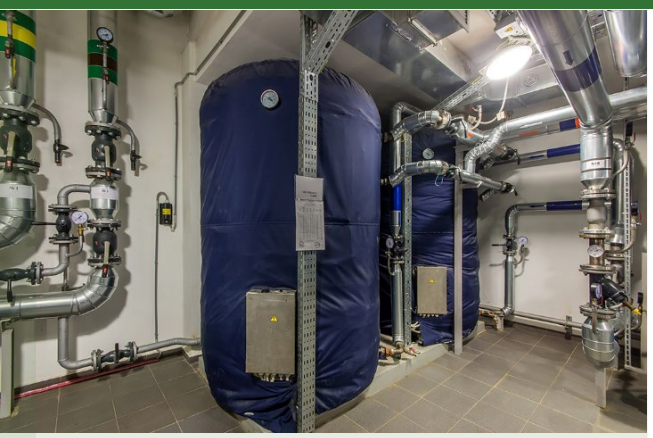
Energy and Fuel Savings

The percentage reduction in fuel consumption achieved by the measure is the same as the percentage reduction in GHG emissions (A).

Source

- U.S. DOE (U.S. Department of Energy). 2015. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Boilers*. March 2015. Accessed January 2021. https://www.regulations.gov/document/EERE-2012-BT-STD-0047-0036.

E-3-B. Require Energy Efficient Commercial Packaged Boilers



GHG Mitigation Potential

16%

Up to 16.0% of GHG emissions from boiler fuel consumption

Co-Benefits (icon key on pg. 31)

Climate Resilience

Increased energy efficiency can reduce the strain on the overall grid, particularly the risk of power outages during peak loads. Increased efficiency can also reduce energy costs.

Health and Equity Considerations

Reduction of fuel combustion in commercial spaces can help reduce indoor pollution.

Measure Description

This measure requires installation of a commercial packaged boiler with higher energy efficiency than what is required by regulation. Improving boiler efficiency decreases fuel consumption for the same amount of energy output, thereby reducing the associated GHG emissions.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site

Implementation Requirements

This measure is only appropriate for a *commercial packaged boiler*, which, as defined in the CFR, means a type of packaged low pressure boiler that is industrial equipment with a capacity (rated maximum input) of 300,000 BTUs per hour or more, which, to any significant extent, is distributed in commerce (1) for heating or space conditioning applications in buildings, or (2) for service water heating in buildings, but does not meet the definition of *hot water supply boiler* (as defined in 10 CFR 431).

Cost Considerations

More energy-efficient boilers are typically more expensive than less efficient ones, leading to greater upfront costs. However, the replacement of less efficient boilers with more efficient models reduces energy consumption and thereby reduces long-term energy costs.

Expanded Mitigation Options

Not applicable.

GHG Reduction Formula

A = D

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from boiler fuel consumption	1.1–16.0	%	calculated
User Inputs				
B	Boiler type	[ ]	text	user input
C	Thermal or combustion efficiency of boiler with measure	83–99	%	user input
Constants, Assumptions, and Available Defaults				
D	Boiler fuel savings with measure compared to minimum requirement	Tables E-3-B.1 and E-3-B.2	%	U.S. DOE 2016

Further explanation of key variables:

- (C) – U.S. DOE's Conservation Standards for Commercial Packaged Boilers (10 CFR 431) were amended in July 2009 to set increased energy efficiency requirements for commercial packaged boilers installed after March 2012. In March 2020, U.S. DOE increased the standards, which will affect boilers installed after January 10, 2023. The minimum thermal efficiency (TE) and combustion efficiency (CE) are the metrics for determining commercial packaged boiler efficiency. TE is the ratio of the heat energy absorbed by the water to the heat energy available in the fuel burned. CE is the ratio of heat energy released by the fuel to the heat energy available in the fuel burned. The project boiler TE or CE must exceed the minimum required by the standards to result in GHG emission reductions. Boiler efficiency should be obtainable from manufacturer specifications.
- (D) – U.S. DOE calculated the average annual fuel use and savings of boilers at various TEs and CEs above the minimum requirement of the 2009 and 2020 standards based on historical consumption data. If the proposed boiler would be installed before January 10, 2023, the user should reference the annual fuel savings relative to the 2009 standards, summarized in Table E-3-B.1 in the Appendix. If the proposed boiler would be installed after January 10, 2023, the user should reference the annual fuel savings relative to the 2020 standards, summarized in Table E-3-B.2 in the Appendix.

GHG Calculation Caps or Maximums

Measure Maximum

(C_{max}) The TE or CE of the proposed boiler is capped at the "Max Tech" percentage for each boiler type, which is presented in Tables E-3-B.1 and E-3-B.2 in the Appendix.

Mutually Exclusive Measures

If the user selects Measure E-15, *Require All-Electric Development*, the user cannot also select this measure, given that it calls for use of gas- and oil-fired boilers. Users implementing this measure to achieve performance standards set under Measure E-1, *Implement a Plan to Improve Building Energy Efficiency*, may not take credit for GHG reductions quantified for both measures, unless the reductions quantified by this measure exceed the minimum Measure E-1 performance standard. Refer to Measure E-1 for additional discussion.

Example GHG Reduction Quantification

The user reduces boiler fuel use by requiring installation of a boiler with a higher CE or TE than is required by the 2009 or 2020 Conservation Standards for Commercial Packaged Boilers. If the proposed boiler is a 350,000 BTU/hour gas-fired hot water boiler installed in 2022 (B) with a TE of 99 percent (C), the user would reduce GHG emissions from boiler fuel consumption by 16 percent based on Table E-3-B.1 in the Appendix.

A = -16%

Quantified Co-Benefits

Improved Air Quality

The reduction in fuel consumption (i.e., natural gas or oil) from this measure would result in local improvements in air quality, because pollutants from fuel consumption would be reduced at the project site. The percentage reduction in GHG emissions (A) is the same as the percentage reduction in criteria pollutant emissions achieved by the measure.

Energy and Fuel Savings

The percentage reduction in fuel consumption achieved by the measure is the same as the percentage reduction in GHG emissions (A).

Source

- U.S. DOE (U.S. Department of Energy). 2016. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Packaged Boilers*. December 2016. Accessed January 2025. https://downloads.regulations.gov/EERE-2013-BT-STD-0030-0083/attachment_1.pdf.

E-4. Install Cool Roofs and/or Cool Walls in Residential Development



GHG Mitigation Potential



Potentially small reduction in GHG from building energy use

Co-Benefits (icon key on pg. 31)



Climate Resilience

Cool roofs and walls absorb less heat and keep buildings cool, increasing the building's adaptive capacity to extreme heat. This also reduces the strain on the electric grid, particularly the risk of power outages during peak loads, and can reduce energy costs. If implemented across a development or throughout a community, cool roofs and walls can reduce the urban heat island effect, building not just individual but also communitywide resilience to extreme heat.

Health and Equity Considerations

Cool roofs and walls can protect the health of vulnerable and low-income residents during heat waves and extreme heat days. In colder climate zones, cool roofs and walls can potentially increase winter heating costs, but the increase may be offset by reduced electricity bills in summer.

Measure Description

This measure will install cool roofs and/or walls in place of dark roofs and/or conventional walls for residential development. Cool roofs have been designed to reflect more sunlight and absorb less heat than a standard roof, keeping buildings cooler in the summertime and thus reducing air-conditioning loads. Complementary to cool roofs, cool walls achieve a similar result through using more reflective paints or materials. This reduces the electricity needed to provide cooling but can potentially increase the energy needed to provide winter heating, thereby reducing associated GHG emissions depending on the project parameters (e.g., climate, level of implementation, carbon intensity of local electricity provider). However, the winter heating penalty may be small with lower levels of winter sunlight due to shorter daylight hours and more overcast skies.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site

Implementation Requirements

Cool roofs can be made of tiles, shingles, coatings, membranes, or metal, among other materials, in a wide range of colors (not just white). Similarly, cool wall paints and materials come in a range of colors, though light-colored paints have the greatest cooling effect. To apply the effectiveness reported by the literature, the albedo of the proposed surface must be at least 0.25 for walls and at least 0.4 for roofs.

Cost Considerations

Installing cool roofs and walls leads to substantial cost savings for relatively low additional input costs. Low-effort residential maintenance options, like painting walls with light-colored or more reflective paint, cost about the same as darker paint colors, and yet immediately reduce the cost of cooling the building. They can also reduce strain on HVAC units and other equipment, which in turn can reduce the need for maintenance and associated costs. Cool roofs can have higher initial costs, depending on the material chosen, but these costs can be offset by lifetime energy savings.

Expanded Mitigation Options

Pair with Measure E-21, *Install Cool Pavement*, to install cool pavements, which will further help reduce the electricity needed to provide cooling. This measure could also be paired Measure E-15, *Require All-Electric Development*, to eliminate the implementation disbenefit of worsened air quality, further discussed below under *Quantified Co-Benefits*.

GHG Reduction Formula

$$H_T = H_N + H_S + H_E + H_W$$

$$L_T = \sum L_z \times \frac{H_z}{H_T}$$

$$A = [((I_R \times G_R \times H_R) + (I_T \times L_T \times H_T)) \times M \times O \times Q \times R]$$

$$-[((J_R \times G_R \times H_R) + (J_T \times L_T \times H_T)) \times N \times P \times Q \times R]$$

GHG Calculation Variables

Many of the values for the variables in this equation can be obtained from the Lawrence Berkeley National Laboratory's (LBNL) Cool Surface Savings Explorer (Explorer) (Levinson et al. 2019). The Explorer is an Excel tool that parses a database containing the results of whole-building model simulations that calculate the building energy changes from the use of cool walls and cool roofs under various scenarios for different building types.

ID	Variable	Value	Unit	Source
Output				
A	Reduction in GHG emissions from building energy	[ ]	MT CO_2e per year	calculated
L_T	Composite solar availability factor of non-roof building sides to be cooled	[ ]	unitless	calculated
H_T	Total area of non-roof building sides to be cooled (N+S+E+W)	[ ]	KSF	calculated
User Inputs				
B	Simulation Region and Building type	[ ]	text	user input
C	Explorer climate zone	Table E-4.1 and Figure E-4.1	integer	user input
D	Building orientation	[ ]	text	user input
E	Building side(s) to be cooled (N, S, E, W & roof)	[ ]	text	user input
F	Albedo of cool surface(s)	0.25–0.60	unitless	user input
G_R	Coverage of cool roof material	0–100	%	user input
H_z	Coverage of cool building side z (N, S, E, W, R [roof])	[ ]	KSF	user input
Constants, Assumptions, and Available Defaults				
I_R	Change in natural gas use of building (roof only)	Savings Explorer	therm per year per m^2	Levinson et al. 2019

ID	Variable	Value	Unit	Source
I_T	Change in natural gas use of non-roof building sides (N+S+E+W)	Savings Explorer	therm per year per m^2	Levinson et al. 2019
J_R	Change in electricity use of building (roof only)	Savings Explorer	kWh per year per m^2	Levinson et al. 2019
J_T	Change in electricity use of non-roof building sides (N+S+E+W)	Savings Explorer	kWh per year per m^2	Levinson et al. 2019
K_z	Wall canyon aspect ratio of building side z (N, S, E, W)	Table E-4.2	unitless	Levinson 2019
L_z	Solar availability factor of building side z (N, S, E, W)	Table E-4.3 and Table E-4.4	unitless	Levinson 2019
M	Carbon intensity of residential natural gas	117	lb CO_2e per mmBTU	U.S. EPA 2020
N	Carbon intensity of electricity provider	Tables E-4.5 through E-4.9	lb CO_2e per MWh	see tables
O	Conversion from therm to mmBTU	0.1	mmBTU per therm	conversion
P	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
Q	Conversion from lb to MT	0.000454	MT per lb	conversion
R	Conversion from KSF to m^2	92.9	m^2 per KSF	conversion

Further explanation of key variables:

- (B) – The simulation region and building type are needed to run the Explorer. Select "United States" as the simulation region. The Explorer provides two types of residential buildings and eight types of commercial buildings, further discussed under (I).
- (C) – The Explorer includes 15 climate zones within the United States simulation region.[23] Table E-4.1 in the Appendix identifies applicable Explorer climate zones within each of the western states. The bolded zones are in-state locations included in the Explorer (e.g., 4C: Seattle, Washington). Non-bolded zones are out-of-state proxy locations that may have similar climate characteristics as portions of the state. Users should ensure that they are selecting the most appropriate Explorer climate zone for their location by referring to Figure E-4.1 in the Appendix (Levison et al. 2019).
- (D) – The building orientation is needed to run the Explorer, further discussed under (I). Building orientation refers to whether the building's longer axis runs east-west or north south.
- (E) – The building side(s) to be cooled is needed to run the Explorer, further discussed under (I). The Explorer provides 16 combinations of sides for the user to choose from.

[23] The Explorer also includes a "California" simulation region, which includes 16 climate zones within California. The California simulation region and associated climate zones are used in the CAPCOA Handbook.

Note that the user cannot select roof at the same time as a wall, so the Explorer will need to be run twice for projects that include both cool walls and cool roofs.

- (F) – The albedo of the cool surface is needed to run the Explorer, further discussed under (I). The energy changes outputted by the Explorer are based on a scenario of a roof with an aged roof albedo of 0.10 and walls with an aged albedo of 0.25. The Explorer provides several options for modified albedo: walls = 0.4, 0.6; roofs = 0.25, 0.4, and 0.6. Users should exercise caution in interpreting their results if the project would have different albedos than provided.
- (G_R) – The coverage of the cool roof material represents the percentage of the roof area that is a cool roof.
- (H_Z) – The area of building side to be cooled represents the area of the building side minus any area that would not be covered in cool materials.
- (I_R, I_T, J_R and J_T) – The change in annual building electricity use and natural gas consumption per square meter of building surface modified can be obtained from the Explorer. Increased cool surfaces would result in a heating penalty (i.e., increase in gas consumption to heat the building and, for select commercial buildings, any electricity that provides auxiliary heat) and a cooling savings (i.e., decrease in electricity to cool and fan the building).[24] Users can run the Explorer to output these values using the following instructions.[25]
  1. Download the tool and database from the ZIP archive online at http://bit.ly/2Kwvtpu. To install, copy the two files to a local folder.
  2. Open the Savings Explorer file. Click the "Launch Simulation Selector" button.
  3. The following inputs should be the same for all projects: simulation region = United States; building vintage = new, property = site energy; metric = savings intensity.
  4. The first query of the Explorer should be done to output energy intensity values for roofs (I_R and J_R). The second query should be done for building sides (I_T and J_T).
     a. The following inputs should be specified based on project-specific information.
        i. Building type (class/category) = (B).
        ii. Explorer climate zone (location) = (C).
        iii. Building orientation = (D).
        iv. Building side(s) to be cooled (cool surfaces) = (E). The first query should be roofs only, if applicable. The second should be the applicable building sides.
        v. Albedo of cool surface(s) = (F).
     b. Once all inputs are specified from #3 and #4, the Explorer will update the variables and results in columns A and B of the workbook.
     c. Sum the results from Column B for cooling, electric heating, and fan. This represents the change in electricity use for cool roofs (J_R). Take the gas heating

[24] As the effects of climate change become more severe, temperatures and solar radiation during the winter may continually increase. The heating penalty may therefore be lower in future years, making this measure more effective at reducing GHG emissions.

[25] See additional instruction in Appendix P, Section 4 of Levinson et al. (2019).



results from Column B, which represents the change in natural gas use for cool roofs (I_R).

5. Repeat #4 for the building sides to output (J_T and I_T).

- (K_z) – Table E-4.2 presents the four canyon aspect ratios used by Levinson (2019) to determine standard solar availability factors (SAF) for each wall direction. The canyon aspect ratio is the ratio of the project wall height to the nearest building separation. The user should select the canyon aspect ratio that best corresponds to each project's cool wall to appropriately look up the SAFs (Lz) in Table E-4.3.
- (L_z) – Tables E-4.3 and E-4.4 present the mean SAFs by cardinal direction and canyon aspect ratio. The SAFs are presented for two scenarios. Table E-4.3 presents the SAFs for a scenario in which the neighboring building has conventional walls. Values are provided for each of the Explorer climate zones listed in Table E-4.1. Table E-4.4 presents the SAFs for a scenario in which the neighboring building has cool walls. Values for cool walls do not differ by Explorer climate zone. The solar availability of the walls at the project building can be lowered by shadows cast by neighboring buildings and raised by sunlight reflected from neighboring buildings. The SAFs are used in the GHG reduction formula to adjust the values for energy use change from Levinson et al. (2019), which were based on model simulations with isolated buildings that were not surrounded by any buildings.
- (M) – The carbon intensity of residential natural gas was calculated in terms of CO_2e by multiplying the U.S. natural gas combustion emission factors for CO_2, CH_4, and N_2O (U.S. EPA 2020) by the corresponding 100-year GWP values from the IPCC's Fifth Assessment Report (IPCC 2013). See Table E-4.10 in the Appendix for more natural gas emission factors.
- (N) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Users should consult their local electricity provider for updated emission factors available at the time of their analysis before proceeding with the defaults provided in these tables. If the project study area is not serviced by a listed electricity provider, or emission factors for the local utility are not available, users may elect to use the appropriate grid average carbon intensity presented in Table E-4.10. Grid electricity emission factors are available for two geographies as defined in the U.S. DOE's GREET model—the Western Electricity Coordinating Council (WECC) and Southwest Power Pool (SPP). Arizona, Colorado, Oregon, and Washington are wholly within WECC. New Mexico is split between WECC and SPP. Refer to Figure E-4.2 in the Appendix.

Note that the GHG intensity factor of most electricity providers will decrease in future years as the electricity providers continue to improve their energy mix to meet clean energy mandates and/or company goals. Accordingly, measures that displace electricity consumption will reduce fewer emissions in future years as the utility resource mix becomes cleaner.

Note that the availability of local utility emission factors differs among western states and from what is provided for California utilities in the CAPCOA Handbook. This Western States Handbook also uses the GREET model to provide future grid emission factors in five-year increments, whereas the CAPCOA Handbook forecasts annual emission factors using U.S. EPA's Emissions & Generation Resource Integrated Database.

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the electricity demand of the user's project is currently being met by grid energy that requires *some* amount of fossil fuel-based energy generation, which emits GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per MWh) greater than zero. For projects that are served by electricity providers already with a renewable portfolio of 100 percent, this measure could have no reduction on GHG emissions. If the electricity provider is using REC to meet a 100 percent renewable portfolio goal, then some emissions reductions may be achieved. In situations where the electricity from the electricity provider is already carbon free, this measure would increase GHG emissions by requiring additional natural gas consumption for building heating. This measure would still result in the co-benefit of reduced electricity use, enhanced energy security, and reduced urban heat island effect.

Mutually Exclusive Measures

If the user selects Measure E-15, *Require All-Electric Development*, they should exercise caution in quantifying the effect of this measure, given that it was developed assuming the residence would be supplied with natural gas (e.g., space heating). Users implementing this measure to achieve performance standards set under Measure E-1, *Implement a Plan to Improve Building Energy Efficiency*, may not take credit for GHG reductions quantified for both measures, unless the reductions quantified by this measure exceed the minimum Measure E-1 performance standard. Refer to Measure E-1 for additional discussion.

Example GHG Reduction Quantification

The user reduces building energy emissions by providing a cool roof and walls in place of dark roofs and walls. In this example, the measure would be implemented in Explorer climate zone 2B, Phoenix, AZ (C) for a single-family home (B) with a fully covered (i.e., 100%) 1 KSF cool roof (G_R), and all building sides of 1 KSF covered in cool materials (H_z or H_N, H_S, H_E, H_W, and H_R). The project is located on a residential street with conventional surrounding buildings and has a canyon aspect ratio of 0.2 for all walls (K_z). Using this information, the SAFs (L_z) can be looked up in Table E-4.3. The electricity and natural gas use changes for the roof (I_R and J_R) and walls (I_T and J_T) can be looked up using the Explorer. The project would begin operation by 2030 and the user elects to use the WECC average emission factor from the Appendix (314 lb CO_2e per MWh) (N). In this example, emissions would be reduced by 1.1 MT CO_2e per year.

$$H_T = \mathbf{1\ KSF} + \mathbf{1\ KSF} + \mathbf{1\ KSF} + \mathbf{1\ KSF} = 4\ KSF$$

$$L_T = \left(0.92 \times \frac{\mathbf{1\ KSF}}{4\ KSF}\right) + \left(0.95 \times \frac{\mathbf{1\ KSF}}{4\ KSF}\right) + \left(0.91 \times \frac{\mathbf{1\ KSF}}{4\ KSF}\right) + \left(0.92 \times \frac{\mathbf{1\ KSF}}{4\ KSF}\right) = 0.93$$

$$A = \left[\left(\left(\frac{-0.025\ therm}{yr \cdot m^2} \times \mathbf{100\%} \times \mathbf{1\ KSF}\right) + \left(\frac{-0.043\ therm}{yr \cdot m^2} \times 0.93 \times 4\ KSF\right)\right) \times \frac{117\ lb\ CO_2e}{mmBTU} \times \frac{0.1\ mmBTU}{therm} \times \frac{0.000454\ MT}{lb} \times \frac{92.9\ m^2}{KSF}\right]$$

$$- \left[\left(\left(\frac{5.143\ kWh}{yr \cdot m^2} \times \mathbf{100\%} \times \mathbf{1\ KSF}\right) + \left(\frac{5.770\ kWh}{yr \cdot m^2} \times 0.93 \times \mathbf{4\ KSF}\right)\right) \times \frac{314\ lb\ CO_2e}{MWh} \times \frac{0.001\ MWh}{kWh} \times \frac{0.000454\ MT}{lb} \times \frac{92.9\ m^2}{KSF}\right] = \frac{-1.1\ MT\ CO_2e}{yr}$$

Quantified Co-Benefits

While the measure will achieve electricity savings, it can increase fuel consumption and potentially worsen ambient air quality. This measure also has direct climate resiliency benefits.

Worsened Air Quality

While not quantified in this Western States Handbook, lowered ambient air temperatures as a result of the reduced urban heat island effects (which can be significant if adoption is widespread) can decrease ozone formation, improving air quality.

If natural gas is used for heating, the increase in natural gas fuel consumption from this measure could result in local worsening of air quality. If electric heating is used at the project site, then there would not be an increase in criteria pollutants or worsened air quality. The increase in criteria pollutant emissions (U) resulting from the measure can be calculated as follows.

Energy Savings (Increased Fuel)

The increase in building natural gas consumption (S) and decrease in electricity use (T) achieved by the measure can be calculated as follows.

Natural Gas Increase Formula

$$S = ((I_R \times \mathbf{G_R} \times \mathbf{H_R}) + (I_T \times L_T \times H_T)) \times R$$

Electricity Reduction Formula

$$T = ((J_R \times \mathbf{G_R} \times \mathbf{H_R}) + (J_T \times L_T \times H_T)) \times R$$

Criteria Pollutant Emission Increase Formula

$$U = O \times V \times S \times W$$

Criteria Pollutant Emission Increase Calculation Variables

ID	Variable	Value	Unit	Source
Output				
U	Increase in criteria pollutant emissions from building energy	[ ]	ton per year	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
V	Criteria pollutant emission factors of natural gas	Table E-4.11	lb per mmBTU	U.S. EPA 1998
W	Conversion from lb to ton	0.0005	tons per lb	conversion

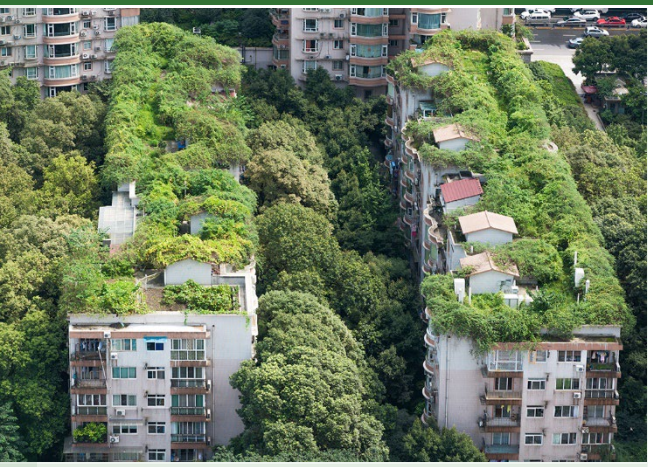
Further explanation of key variables:

- (V) – Table E-4.11 presents the criteria pollutant emission factors of natural gas for residential and commercial uses (U.S. EPA 1998).
- Please refer to the *GHG Calculation Variables* table above for definitions of variables that have been previously defined.

Sources

- IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/.
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E-5. Install Green Roofs in Place of Dark Roofs



GHG Mitigation Potential



Potentially small reduction in GHG emissions from building energy use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Installing green roofs increases resilience by absorbing less heat and keeping buildings cool, increasing the building's adaptive capacity to extreme heat. This also reduces the strain on the overall grid, particularly the risk of power outages during peak loads, and can reduce energy costs. Green roofs have a smaller heat island reduction effect than certified cool roofs but nonetheless are an improvement over conventional roofs.

Health and Equity Considerations

Green roofs provide additional insulation that can keep buildings cooler in the summer and warmer in the winter, reducing energy costs year-round. This can help protect health and increase economic resilience for vulnerable and low-income residents.

Measure Description

This measure will install green roofs in place of dark roofs. Green roofs consist of a layer of vegetation on top of buildings, which provides natural insulation and climate control benefits. This reduces the electricity and natural gas needed to provide cooling and heating, thereby reducing associated GHG emissions.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Green roofs are usually more expensive to install than conventional dark roofs; however, these costs can be quickly offset by reduced energy usage through better insulation, improved stormwater management, and, in some cases, extended lifespan. Green roof maintenance costs include irrigation, weed control, and fertilizer in order to maintain the vegetation; however, green roofs generally cost substantially less than conventional roofs or cool roofs over a 50-year lifecycle.

Expanded Mitigation Options

Use native plants on the roof for improved ecosystem health, drought-tolerant plants for water conservation, or plant an edible garden for enhanced food security.

GHG Reduction Formula

$$A = D \times [(-E \times G \times I \times J) + (-F \times H \times K \times J)]$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Reduction in GHG emissions from building energy	[ ]	MT CO_2e per year	calculated
User Inputs				
B	Building type	[ ]	text	user input
C	Project location (city)	[ ]	text	user input
D	Roof area	[ ]	KSF	user input
Constants, Assumptions, and Available Defaults				
E	Natural gas savings with measure	Table E-5.1	therm per year per KSF	Sailor et al. 2008
F	Electricity savings with measure	Table E-5.1	kWh per year per KSF	Sailor et al. 2008
G	Carbon intensity of natural gas	Table E-4.10	lb CO_2e per mmBTU	U.S. EPA 2020
H	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
I	Conversion from therm to mmBTU	0.1	mmBTU per therm	conversion
J	Conversion from lb to MT	0.000454	MT per lb	conversion
K	Conversion from kWh to MWh	0.001	MWh per kWh	conversion

Further explanation of key variables:

- (B) – The housing and building types are needed to look up the energy savings for residential and office development (E and F). If the user's building type of interest is not presented in Table E-5.1 in the Appendix, they should exercise caution in extrapolating the results from the listed building types.
- (C) – The project location (i.e., city) is used to look up the energy savings for residential and commercial development (E and F). If the user's city of interest is not presented in Table E-5.1, they should use their judgment to select a listed city that has similar climate and precipitation.
- (E and F) – The Green Roof Energy Calculator is a free, web-based tool developed in 2008 by academic researchers on behalf of the U.S. Green Building Council. The purpose of the tool is to enable architects, developers, and others to obtain quick estimates of how green roof design decisions might affect building energy use. To provide the user with a range of energy savings, the tool was run for the two available building types for each included city within the five western states. The runs used

conservative values for the remainder of the tool inputs. These results are summarized in Table E-5.1. If the user can provide project-specific values for tool inputs (i.e., growing media depth, leaf area index, irrigation, percentage of total roof coverage, roof material albedo), then they should run the tool themselves and use the outputted energy savings in place of the values in Table E-5.1 (Sailor et al. 2008). Additionally, the user can consider calculating their energy savings from this measure using U.S. DOE's EnergyPlus, a more complex, robust model that requires more energy expertise and project inputs (U.S. DOE 2020).

- (G) – The carbon intensity of natural gas was calculated in terms of CO_2e by multiplying the U.S. natural gas combustion emission factors for CO_2, CH_4, and N_2O (U.S. EPA 2020) by the corresponding 100-year GWP values from the IPCC's Fifth Assessment Report (IPCC 2013). Table E-4.10 in the Appendix provides natural gas CO_2e emission factors for residential and commercial uses.
- (H) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer to Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the energy demand of the user's project is currently being met by grid electricity that requires *some* amount of fossil fuel-based energy generation and/or onsite natural gas, both of which emit GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per MWh) greater than zero and/or the project consumes natural gas onsite for building energy. For all-electric projects that are served by electricity providers already with a renewable portfolio of 100 percent, this measure could have no reduction in GHG emissions. If the electricity provider is using REC to meet a 100 percent renewable portfolio goal, then some emissions reductions may be achieved. This measure would still result in the co-benefits of reduced electricity use, enhanced energy security, and reduced urban heat island effect.

Mutually Exclusive Measures

If the user selects Measure E-15, *Require All-Electric Development*, they should exercise caution in quantifying the effect of this measure, given that some of the constants and available defaults were developed with the assumption that the building would be supplied with natural gas. One option for including the quantified emissions reduction from this measure alongside those achieved by Measure E-15 would be to exclude all of the natural gas–related effects from this measure. In other words, (E) should be zeroed out in the above equation. Note that doing this may result in an underestimation of emissions reductions; green roofs provide additional insulation that can keep buildings warmer in the winter, as evidenced by Table E-5.1.

Users implementing this measure to achieve performance standards set under Measure E-1, *Implement a Plan to Improve Building Energy Efficiency*, may not take credit for GHG reductions quantified for both measures, unless the reductions quantified by this measure

exceed the minimum Measure E-1 performance standard. Refer to Measure E-1 for additional discussion.

Example GHG Reduction Quantification

The user reduces building energy emissions by providing a green roof in place of a dark roof. In this example, the measure would be implemented in the city of Astoria (C) for a new residential building (B) that has a roof area of 5 KSF. Therefore, the natural gas savings would be 6.6 therms per year per KSF (E), and the additional electricity savings would be 19.1 kilowatt-hours per year per KSF (F). The project would begin operation by 2027 and the user elects to use the WECC average emission factor from the Appendix (585 lb CO_2e per MWh) (H). The mitigated emissions would be reduced by 0.20 MT CO_2e per year.

$$A = \mathbf{5\ KSF} \times \left[\left(\frac{\text{-6.6 therm}}{\text{yr·KSF}} \times \frac{\text{117 lb } CO_2e}{\text{mmBTU}} \times \frac{\text{0.1 MMBtu}}{\text{therm}} \times \frac{\text{0.000454 MT}}{\text{lb}}\right) + \left(\frac{\text{-19.1 kWh}}{\text{yr·KSF}} \times \frac{\text{585 lb } CO_2e}{\text{MWh}} \times \frac{\text{0.001 MWh}}{\text{kWh}} \times \frac{\text{0.000454 MT}}{\text{lb}}\right)\right] = \text{-0.20} \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

In addition to the benefits noted below, the measure also has direct climate resiliency benefits.

Energy and Fuel Savings

The user would decrease the building natural gas consumption (E X D X I) and, depending on the location for the project area, either decrease or increase the electricity use (F X D X K).

Improved Air Quality

The reduction in natural gas fuel consumption from this measure would result in local improvements in air quality because the fuel consumption occurs on site of the project. The reduction in criteria pollutant emissions (L) achieved by the measure can be calculated as follows.

Criteria Pollutant Emission Reduction Formula

$$L = \mathbf{D} \times \text{-}E \times M \times I \times N$$

Criteria Pollutant Emission Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
L	Reduction in criteria pollutant emissions from building energy	[ ]	tons per year	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
M	Criteria pollutant emission factors of natural gas	Table E-4.11	lb per mmBTU	U.S. EPA 1998
N	Conversion from lb to ton	0.0005	tons per lb	conversion

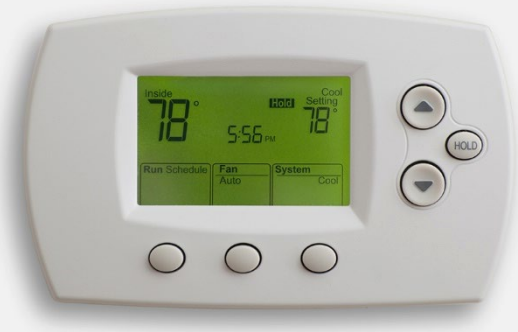
Further explanation of key variables:

- (M) – Table E-4.11 presents the criteria pollutant emission factors of natural gas for residential and commercial uses (U.S. EPA 1998).
- Please refer to the *GHG Calculation Variables* table above for definitions of variables that have been previously defined.

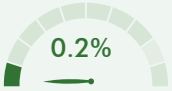
Sources

- IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/.
- Sailor, D., B. Brass, and S. Peck. 2008. *Green Roof Energy Calculator*. Accessed December 2024. https://ucrc.asu.edu/green-roof-energy-calculator.
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E-6. Encourage Residential Participation in Existing Demand Response Program(s)



GHG Mitigation Potential



Up to 0.2% reduction in GHG emissions from residential building electricity

Co-Benefits (icon key on pg. 31)

Climate Resilience

Strategic energy conservation during demand response events reduces the strain on the overall grid, particularly the risk of power outages during peak loads. It can also reduce energy costs, particularly if extreme heat would otherwise increase these costs.

Health and Equity Considerations

Demand response programs can help residents save money on utility costs and reduce exposure to extreme heat, supporting greater resilience to climate health impacts. This can be especially critical for low-income and vulnerable residents.

Measure Description

This measure will require marketing and promotion of the local utility's manual (i.e., behavioral) demand response program(s) to encourage participation from residents in the project area. Buildings contribute to GHG indirectly through electricity consumption. During demand response events, program users shift or conserve electricity, thereby reducing the associated indirect GHG emissions. Methods of engaging customers in demand response efforts include offering time-based rates, such as time-of-use pricing, critical peak pricing, variable peak pricing, real-time pricing, and critical peak rebates. Users are encouraged to respond to time-based rates or other forms of financial incentives with smart phone app, email, phone call, and/or text notifications.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site or Plan/Community

Implementation Requirements

See measure description.

Cost Considerations

The cost of providing the demand response program is borne by the local utility. Property owners will realize cost savings from reduced electricity use.

Expanded Mitigation Options

The electricity reduction cited in the GHG emissions quantification methodology is based on a *manual* demand response program. Residential participation in an *automated* program, which requires smart appliances for the relevant end uses and appliances (e.g., heating and cooling, dishwashers, washing machines), can reduce user fatigue while improving the electricity reduction rates, yielding improved GHG emissions reductions.

GHG Reduction Formula

$$A = -\left(B \times C \times \frac{D}{E}\right)$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from residential electricity	0–0.2	%	calculated
User Inputs				
B	Level of participation	0–100	%	user input
Constants, Assumptions, and Available Defaults				
C	Electricity reduction during demand response event	18 (or user input)	%	Gattaciecca et al. 2020
D	Average number of demand response events	100	hours per year	U.S. DOE 2010
E	Hours in a year	8,760	hours per year	conversion

Further explanation of key variables:

- (A) – The output provides the percentage reduction in GHG emissions from residential building *electricity*. To determine the percentage reduction in GHG emissions from total residential building *energy* (i.e., electricity plus natural gas), the user would need to know the percentage of total GHG emissions from electricity. For example, if 40 percent of building energy emissions come from electricity, the percentage reduction in GHG emissions from total building energy could be calculated as follows.

  $$A_{energy} = (40\% \times A_{electricity})$$

  Further, to determine the percentage reduction in GHG emissions for a project with multiple residential buildings, the user would need to know the percentage of total building energy emissions from each building. For example, if 67 percent of building energy emissions come from Building 1 and 33 percent come from Building 2, the percentage reduction in GHG emissions from all building energy could be calculated as follows.

  $$A_{energy_total} = (67\% \times A_{energy_1}) + (33\% \times A_{energy_2})$$

- (B) – The level of participation refers to the percentage of households in the project area that enroll in the demand response program.
- (C) – OhmConnect is a demand response provider in California that challenges its users to reduce consumption during critical energy periods (i.e., events). OhmConnect measures the users' actual consumption against a calculated historical baseline and rewards them for the difference. A study of California OhmConnect users found that,

on average, users reduced their energy consumption by 0.15 kWh, or 18 percent, during an OhmConnect demand response event relative to what they would have consumed without an event (Gattaciecca et al. 2020). Reductions achieved through demand response events in other jurisdictions may be similar. Users are encouraged to coordinate with their local utility at the time of their analysis to determine if an updated or more locally specific reduction factor is available.

- (D) – It was estimated that demand response for managing peak loads involves, at most, 100 hours a year (U.S. DOE 2010). The user should input a project-specific value in the GHG reduction formula, if available.

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the project's electricity demand is currently being met by grid electricity that requires *some* amount of fossil fuel–based energy generation, which emits GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per MWh) greater than zero. For projects that are served by electricity providers already with a renewable portfolio of 100 percent, this measure could have no reduction in GHG emissions. If the electricity provider is using REC to meet a 100 percent renewable portfolio goal, then some emissions reductions may be achieved. This measure would still result in the co-benefits of reduced electricity use and enhanced energy security.

Example GHG Reduction Quantification

The user reduces residential electricity consumption by providing incentives for expanded participation in an existing demand response program. In this example, the expected level of participation is 100 percent of households in the study area (B). The user would reduce GHG emissions from residential electricity by 0.2 percent.

$$A = -\left(100\% \times 18\% \times \frac{100\ \frac{hr}{yr}}{8{,}760\ \frac{hr}{yr}}\right) = -0.2\%$$

Quantified Co-Benefits

Energy and Fuel Savings

The percentage reduction in residential building electricity achieved by the measure is the same as the percentage reduction in GHG emissions (A).

Sources

- Gattaciecca, J., K. Trumbull, S. Krumholz, K. McKanna, and J. R. DeShazo, University of California, Los Angeles. 2020. *Identifying Effective Demand Response Program Designs for Residential Customers.* California Energy Commission. Publication number: CEC-500-2020-072.

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- U.S. DOE (U.S. Department of Energy). 2010. *The Smart Grid: An Estimation of the Energy and CO_2 Benefits*. January 2010. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-19112.pdf.

E-7. Require Higher Efficacy Public Street and Area Lighting



GHG Mitigation Potential



Potentially moderate reduction in GHG emissions from street lighting

Co-Benefits (icon key on pg. 31)

Climate Resilience

Installation of more efficient lights can reduce the strain on the overall grid and reduce energy costs. Lights with solar charging can also continue to function when the overall grid is down, providing an ongoing safety benefit during extreme weather events.

Health and Equity Considerations

Blue or full spectrum light may increase perceptions of safety but inhibit sleep patterns of nearby residents and reduce night sky visibility. Work with communities to determine appropriate color temperatures.

Measure Description

This measure will require the installation of higher efficacy public street and area lighting in place of typical or existing lamps. Lighting sources contribute to GHG indirectly through the production of the electricity that powers the lights. Installing more efficacious lamps, such as light-emitting diodes (LEDs), will use less electricity while producing the same amount of light, thereby reducing the associated indirect GHG emissions.

Subsector

Energy Efficiency Improvements

Scale of Application

Plan/Community

Implementation Requirements

Users may take credit only if they are retrofitting existing street and area lights. This includes streetlights, pedestrian pathway lights, area lighting for parks and parking lots, and outdoor lighting around public buildings.

Cost Considerations

More energy-efficient lighting options are typically more expensive than less efficient ones, leading to greater installation costs. However, the replacement of less efficient lighting with more efficient bulbs reduces energy consumption and thereby reduces energy costs. Additionally, the rated life of more efficient bulbs is typically longer than less efficient ones, which reduces the frequency of replacement costs.

Expanded Mitigation Options

Incorporation of solar fixtures onto the street and area traffic lights would further reduce grid-supplied electricity consumption and associated emissions.

GHG Reduction Formula

$$A = \frac{-B_1 \times C_1 + B_2 \times C_2}{B_1 \times C_1}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from outdoor street and area lighting	[ ]	%	calculated
User Inputs				
B_1	Number of existing lighting heads to be replaced	[ ]	lighting heads	user input
B_2	Number of proposed new lighting heads	[ ]	lighting heads	user input
C_1	Average power rating of existing lamp type	[ ]	watts	user input
C_2	Average power rating of proposed lamp type	[ ]	watts	user input
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (B_1 and B_2) – The number of existing and proposed lighting heads are required in the GHG reduction formula in case the new type of lamp results in less heads needing to be installed.
- (C_1 and C_2) – Lumens are the measure of the amount of light perceived by the human eye. Luminous efficacy is the amount of visible light emitted for a given amount of power. This measure assumes that the replacement lighting would provide the same number of lumens per area as the existing lighting and that only the power rating would change. See Table E-7.1 in the Appendix for a range of typical power ratings and efficacies of various outdoor lamp types (CLTC 2014). These values are for reference only for providing the user with a list of existing and replacement lighting options. The user should input project-specific values in the GHG reduction formula, if available.

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the electricity demand of the project's lighting is currently being met by grid electricity that requires *some* amount of fossil fuel–based energy generation, which emits GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per MWh) greater than zero. For projects that are served by electricity providers already with a renewable portfolio of 100 percent, this measure could have no reduction in GHG emissions. If the electricity provider is using REC to meet a 100 percent renewable portfolio goal, then some emissions reductions may be achieved. This measure would still result in the co-benefits of reduced electricity use and enhanced energy security.

Example GHG Reduction Quantification

The user reduces the energy consumption of outdoor lighting by installing higher efficacy lighting. If the number of existing and proposed lighting heads are both 100 (B_1 and B_2), the power rating of the existing high-pressure sodium lamps is 120 watts, and the power rating of the proposed LED lamps is 80 watts, the user would reduce GHG emissions from outdoor lighting by 33.3 percent.

$$A = \frac{\text{-100 heads} \times \text{120 watts} + \text{100 heads} \times \text{80 watts}}{\text{100 heads} \times \text{120 watts}} = \text{-33.3\%}$$

Quantified Co-Benefits

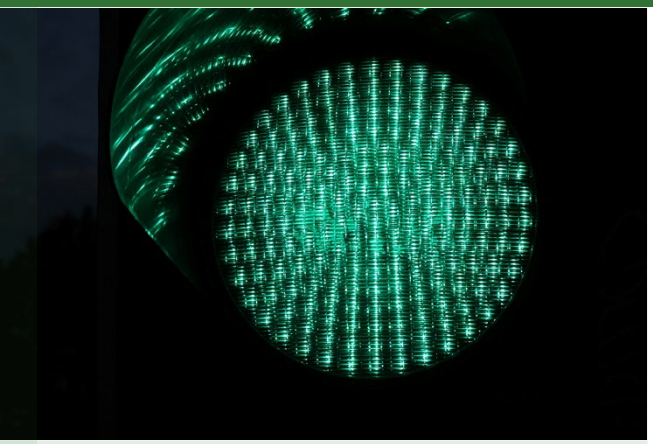
Energy and Fuel Savings

The percentage reduction in electricity achieved by the measure is the same as the percentage reduction in GHG emissions (A).

Source

- CLTC (California Lighting Technology Center). 2014. *2013 Title 24, Part 6: Outdoor Lighting Guide*. University of California, Davis. March 2014. Accessed December 2024. https://cltc.ucdavis.edu/sites/g/files/dgvnsk12206/files/media/documents/2013-title-24-outdoor-lighting-guide-mar15.pdf.

E-8. Replace Incandescent Traffic Lights with LED Traffic Lights



GHG Mitigation Potential



Potentially large reduction in GHG emissions from traffic light electricity use

Co-Benefits (icon key on pg. 31)





Climate Resilience

Installation of more efficient lights can reduce the strain on the overall grid and reduce energy costs.

Health and Equity Considerations

LED signal lights last longer than their incandescent counterparts, potentially improving traffic safety as they burn out less frequently.

Measure Description

This measure will replace incandescent traffic lights with more energy-efficient LED traffic lights. Installing LEDs reduces electricity demand and thus results in a reduction in indirect GHG emissions.

Subsector

Energy Efficiency Improvements

Scale of Application

Plan/Community. Not applicable at the Project/Site-scale, unless the development project requires modification of existing roadway infrastructure, including traffic lights.

Implementation Requirements

New traffic lights are required to be LED and meet minimum federal efficiency standards. Users may take credit only if they are retrofitting existing incandescent traffic lights. Also, this measure may not be suitable in areas that receive substantial snowfall, which may cover and block light, unless the traffic lights are outfitted with winter-ready designs that prevent snow accumulation

Cost Considerations

LED lights, which are much more energy-efficient than incandescent lights, greatly reduce energy consumption and increase cost savings. LED lights are typically more expensive than less efficient incandescent lights and incur greater costs from the initial purchase. However, the rated life of LEDs is typically longer than that of less efficient bulbs, which reduces the frequency of replacement costs.

Expanded Mitigation Options

Incorporation of solar fixtures onto the traffic lights would further reduce grid-supplied electricity consumption and associated emissions.

GHG Reduction Formula

$A = B \times C$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from traffic light electricity use	0–85	%	calculated
User Inputs				
B	Percentage of incandescent traffic lights in project study area to be retrofitted	0–100	%	user input
Constants, Assumptions, and Available Defaults				
C	Percent reduction in power consumption from LED lights compared to incandescent lights	85	%	U.S. DOE 2004

Further explanation of key variables:

- (B) – This methodology assumes that all the existing traffic lights only use incandescent bulbs. If the existing traffic lights are a mix of incandescent and LED bulbs, the LEDs should be excluded from the total number of lights that is used to determine the percentage for this variable.
- (C) – The percentage reduction of 85 percent in power consumption is based on an average incandescent bulb power of 109 watts and an average LED bulb power of 17 watts (U.S. DOE 2004). The user should replace this default with a project-specific percentage reduction in power consumption if the user knows the average wattage of the existing incandescent bulbs and/or the proposed LED bulbs.

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the electricity demand of the project's traffic lights is currently being met by grid electricity that requires *some* amount of fossil fuel–based energy generation, which emits GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per MWh) greater than zero. For projects that are served by electricity providers already with a renewable portfolio of 100 percent, this measure could have no reduction in GHG emissions. If the electricity provider is using REC to meet a 100 percent renewable portfolio goal, then some emissions reductions may be achieved. This measure would still result in the co-benefits of reduced electricity use and enhanced energy security.

Example GHG Reduction Quantification

If the user's project includes incandescent traffic lights, the user can reduce traffic light electricity by replacing the lights with LEDs. If all (i.e., 100 percent) of the incandescent lights are replaced with LED lights (B), the user would reduce GHG emissions from electricity used to power the incandescent traffic lights by 85 percent. The example measure emission reduction is calculated below.

$$A = 100\% \times 85\% = 85\%$$

Quantified Co-Benefits

Energy and Fuel Savings

(C) represents the percentage energy savings for this measure. The project's electricity use from traffic lights in the study area would be reduced by up to 85 percent.

Source

- U.S. DOE (U.S. Department of Energy). 2004. *State Energy Program Case Studies: California Says "Go" to Energy-Saving Traffic Lights*. Accessed January 2021. https://www.nrel.gov/docs/fy04osti/35551.pdf.

E-9. Utilize a Combined Heat and Power System



GHG Mitigation Potential



Potentially small reduction in GHG emissions from CHP energy generation

Co-Benefits (icon key on pg. 31)

Climate Resilience

CHP systems reduce sensitivity to fuel price shocks or scarcity and can contribute to generation capacity, reducing energy costs and the risk of outages. These systems can also provide backup energy to a building if the main grid fails during an extreme weather event.

Health and Equity Considerations

Reduction of natural gas combustion would help improve indoor air quality. However, CHP systems still involve natural gas usage, and thus localized effects of emissions on communities should be reviewed closely.

Measure Description

This measure involves using combined heat and power (CHP) systems in place of separate heat and power (SHP) systems. For the same level of power output, CHP systems use less input energy than traditional SHP generation, resulting in lower CO_2 emissions. In traditional SHP systems, heat created as a by-product is wasted as it is released into the surrounding environment. CHP systems harvest the thermal energy and use it to heat onsite uses or for processes in proximity, which reduces the amount of natural gas or other fuel that would otherwise be combusted for heating or for use in those processes. CHP systems also result in a reduced demand for electricity from the grid, which displaces the CO_2 emissions from the production of electricity from the grid.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site

Implementation Requirements

It is possible that certain CHP systems may not be appropriate for certain locations, where the carbon intensity of the electricity provider is relatively low. In these instances, the emissions reduction will be negative, which indicates an emissions increase.

Cost Considerations

CHP systems are more efficient than systems where heat and power are produced separately. As long as the system is located near to where the power and heat are being used, CHP systems are quick and relatively inexpensive to install. Coupled with the energy savings associated with the improved efficiency, CHP systems represent a long-term potential cost savings.

Expanded Mitigation Options

Not applicable.

GHG Reduction Formula

This section describes how to estimate emissions reductions from utilizing a CHP system to supply energy demands that would otherwise have been provided by separate heat and power systems (e.g., electricity from the grid for uses requiring electricity and boilers for thermal demand). The user should quantify emissions reductions using the U.S. EPA's (2023) CHP Energy and Emission Savings Calculator (CHP Tool), which allows users to estimate the energy savings from displaced electricity and thermal production from 10 CHP technologies: reciprocating engine (rich burn, lean burn, and diesel) microturbine, fuel cell, combustion turbine, boiler/steam turbine, other prime mover, and waste-heat-to-power (power only, and power and thermal).[26]

The user has the option to input project-specific data, such as fuel types, duct burner operation, cooling demand, and boiler efficiencies. The CHP Tool has the capabilities to calculate GHG emissions reduction directly from the use of CHP systems, and the user can choose to use the calculator for that purpose. To ensure consistency with the methods and factors used for other measures in this document, the user can also use the calculator to determine the energy savings and calculate the GHG reductions separately, using the methodology provided in this section.

$$A1 = [(B \times C \times D) + (E \times F) - (G \times F)] \times H$$

$$A2 = \frac{(D + G) - B}{(D + G)}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Reduction in GHG emissions from use of CHP System	[ ]	MT CO_2e	calculated by user or in CHP Tool
A2	Percent reduction in GHG emissions from use of CHP System	[ ]	%	calculated by user or in CHP Tool
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
G	Fuel consumption of CHP system	[ ]	mmBTU per year	calculated in CHP Tool
F	Carbon intensity of commercial natural gas	119	lb CO_2e per mmBTU	U.S. EPA 2020
B	Displaced electricity production from CHP use	[ ]	mmBTU per year	calculated in CHP Tool

[26] Note that the CHP Tool has been updated since publication of the CAPCOA Handbook, which cites the 2020 version of the tool.

ID	Variable	Value	Unit	Source
C	Conversion from mmBTU to kWh	0.2931	MWh per mmBTU	conversion
D	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
E	Displaced thermal production from CHP use	[ ]	mmBTU per year	calculated in CHP Tool
H	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (A1) – The methodology shown for (A1) involves the use of the fuel consumption results provided by the CHP Tool (Table 1 of the Results tab in the CHP Tool). However, the user can also use the CHP Tool to calculate GHG reductions directly (Table 2 of the Results tab in the CHP Tool). The CHP Tool allows the user to choose an electricity emissions factor (the "displaced electricity generation profile") from a pre-determined list, or it allows the user to enter a custom emission factor. If calculating GHG emissions directly in the CHP Tool, the user should enter a custom emission factor that corresponds to the applicable electricity provider for only CO_2 emissions. The CHP Tool does not allow the user to enter a CO_2e factor.
- (D) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.
- (B, E, G) – Standard assumptions to calculate these energy quantities are from the CHP Tool, which can be inputted by the user, are included below. The user should enter project-specific values if available.
  - Operation of 8,760 hours per year.
  - Provides heat only (no cooling).
  - Combusts natural gas fuel (1,028 BTU/ft^3 heat content).
  - No supplementary duct burner.
  - Assumes 4.8 percent transmission loss for displaced electricity (based on Western Interconnect assumptions from the CHP Tool).
  - Assumes thermal demand for a boiler with 80 percent efficiency.

GHG Calculation Caps or Maximums

Measure Maximum

All caps and maximums are indicated in the CHP Tool.

Because the electric power sector is progressively becoming a zero-carbon source, this measure may not achieve GHG reductions for some combinations of CHP system types, sizes, and other variables input into the CHP Tool. In those cases, the CHP Tool will return negative energy savings or emissions reductions, meaning that using a CHP system would result in an increase in energy consumption and emissions relative to using SHP

generation. If considering a CHP system to reduce GHG emissions and save energy, the user should ensure that the CHP set-up actually results in reductions.

Mutually Exclusive Measures

Users implementing this measure to achieve performance standards set under Measure E-1, *Implement a Plan to Improve Building Energy Efficiency*, may not take credit for GHG reductions quantified for both measures, unless the reductions quantified by this measure exceed the minimum Measure E-1 performance standard. Refer to Measure E-1 for additional discussion.

Example GHG Reduction Quantification

The user's project includes a single unit 600 kW microturbine CHP system fueled by natural gas and used for heating-only with no duct burners. The CHP system is assumed to operate for 8,760 hours per year and is displacing a new gas boiler. Parameters for both the microturbine CHP system and the displaced new gas boiler are assumed from the CHP Tool. The electricity that is displaced by the CHP system is derived entirely from a natural gas-based powerplant. The analysis year is 2025 and the user elects to use the SPP average emission factor from the Appendix (821 lb CO_2e per MWh) (D). The energy quantities calculated from the CHP Tool are displaced electricity production (46,957 mmBTU), displaced thermal production (25,258 mmBTU), and a CHP system consumption of (59,831mmBTU). The example scenario results in a 3,262 MT CO_2e reduction.

$$A1 = [\left(46{,}957\ \text{mmBTU} \times 0.2931 \frac{\text{MWh}}{\text{mmBTU}} \times 821 \frac{\text{lb } CO_2e}{\text{MWh}}\right) + \left(25{,}258\ \text{mmBTU} \times 119 \frac{\text{lb } CO_2e}{\text{mmBTU}}\right) - (59{,}831\ \text{mmBTU} \times 119 \frac{\text{lb } CO_2e}{\text{mmBTU}})] \times 0.000454 \frac{\text{MT}}{\text{lb}} = \text{-3,262 MT } CO_2e$$

$$A2 = \frac{(46{,}957\ \text{mmBTU} + 25{,}258\ \text{mmBTU}) - 59{,}831\ \text{mmBTU}}{(46{,}957\ \text{mmBTU} + 25{,}258\ \text{mmBTU})} = 17\%$$

Quantified Co-Benefits

Improved Air Quality

The CHP Tool can calculate reductions in two criteria air pollutants (NO_x and SO_2). To quantify this co-benefit, the user should use the CHP Tool.

Energy and Fuel Savings

To calculate the energy savings for this measure (H), the user should add the displaced electricity production (D) and displaced thermal production (G) from the CHP Tool and then subtract the CHP system energy consumption (B) from the CHP Tool.

Energy Savings Formula

$$H = (D + G) - B$$

Source

- U.S. EPA (U.S. Environmental Protection Agency). 2023. *Combined Heat and Power Energy and Emissions Savings Calculator*. Version 3.5. October 2023. Accessed February 5, 2025. https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator.

E-10-A. Establish Onsite Renewable Energy Systems–Generic



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from building energy use depending on renewable electricity generation compared to building energy consumption

Co-Benefits (icon key on pg. 31)

Climate Resilience

Installing onsite renewable energy systems provides backup generation sources that can contribute to generation capacity and reduce the risk of outages, particularly if an extreme event disrupts the grid. Onsite renewable energy can also reduce energy costs.

Health and Equity Considerations

Onsite renewable energy can provide protection against grid disruptions, which can be critical to protect the health of vulnerable people, such as seniors and those who use electric medical equipment.

Measure Description

This measure requires electricity to be generated from an onsite renewable or zero-emission power system. This displaces the electricity demand that would ordinarily be supplied by the local electricity provider. Electricity generation provided by local electricity providers has varying carbon intensities based on the portfolio of energy sources. Some renewable energy systems, such as fuel cells, may not be completely GHG emissions-free, but may still have lower emissions than the electricity provided by the local electricity provider (unless the electricity provider has a relatively high renewable portfolio), thereby reducing GHG emissions. Zero-emissions power systems, such as PV panels, result in the greatest magnitude of emissions reductions. Onsite renewable systems can also provide back-up power as an alternative to diesel generators in the event of grid power outages or demand response events. Expanding renewable generation capacity onsite in developed areas can also reduce the need to convert or impact undeveloped areas.

Subsector

Renewable Energy Generation

Scale of Application

Project/Site

Implementation Requirements

Renewable energy systems powered by solar and/or wind should be quantified under Measures E-10-B or E-10-C, respectively.

Cost Considerations

Installation costs for onsite renewable energy generation vary greatly depending on the type of energy system and the size of the installation, but overall, installation costs can be high. These costs are recouped by large cost savings as the property owner can use electricity produced on site instead of purchased from the grid, or even a net profit if excess energy is sold to an electricity provider. Additionally, initial installation costs can be partially offset by credits and rebates meant to encourage renewable energy generation.

Expanded Mitigation Options

Pair with Measure E-23, *Use Microgrids and Energy Storage*, in Table 3-2 to store and then deploy surplus electricity generated from the renewable energy system. This would improve the capacity of the system to displace more grid-supplied electricity, further reducing associated emissions.

GHG Reduction Formula

$$A = \frac{-B}{C} \times \frac{E - D}{E}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from electricity use	0–100	%	calculated
User Inputs				
B	Electricity provided by onsite power system with measure	[ ]	kWh per year	user input
C	Total electricity demand	[ ]	kWh per year	user input
D	Carbon intensity of onsite power system	[ ]	lb CO_2e per MWh	user input
Constants, Assumptions, and Available Defaults				
E	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables

Further explanation of key variables:

- (D) – If the onsite power system is a zero-emission source, then the GHG emission reduction (A) is effectively equivalent to the ratio of electricity from the zero-emission system (B) to the total electricity demand (C). If the onsite power system is not a zero-emission source, then the GHG emission reduction calculation needs to consider the GHG intensity factor of the onsite power system (D) and the electricity provider (E).
- (E) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the electricity demand of the project is currently being met by grid energy that requires *some* amount of fossil fuel-based energy generation, which emits GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per kWh) greater than zero. For projects that are served by electricity providers with a renewable portfolio standard of 100 percent, this measure would effectively have no reduction in GHG emissions, although it would still result in the co-benefit of enhanced energy security.

Example GHG Reduction Quantification

If the user's project consumes electricity from a local electricity provider with a non-zero carbon intensity, the user can reduce the project's emissions from electricity consumption by displacing the electricity demand met by the electricity provider with an onsite power system. In this example, the onsite power system would provide 2,000 kWh per year (B) at a carbon intensity of 50 lb CO_2e per megawatt-hour (D). The proposed project would have a total electricity demand of 10,000 kWh per year (C). It would begin operation in 2025 in Whatcom County, Washington. The user elects to use the utility emission factor from the Appendix (851 lb CO_2e per MWh) (E). The user would reduce GHG emissions from electricity use by 19 percent.

Quantified Co-Benefits

$$A = \frac{\frac{\text{-2,000 kWh}}{\text{yr}}}{\frac{\text{10,000 kWh}}{\text{yr}}} \times \frac{\frac{851 \text{ lb } CO_2e}{\text{MWh}} - \frac{\text{50 lb } CO_2e}{\text{MWh}}}{\frac{851 \text{ lb } CO_2e}{\text{MWh}}} = -19\%$$

Successful implementation of this measure would reduce grid electricity, and a portion of this electricity is supplied by fossil-fueled power plants, which generates criteria pollutants. However, because these power plants are located throughout individual states, the reduction in electricity use from this measure will not reduce localized criteria pollutant emissions and are, therefore, not discussed.

Sources

None.

E-10-B. Establish Onsite Renewable Energy Systems–Solar Power



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from building energy use depending on renewable electricity generation compared to building energy consumption

Co-Benefits (icon key on pg. 31)

Climate Resilience

Installing onsite renewable energy systems provides backup generation sources that can contribute to generation capacity and reduce the risk of outages, particularly if an extreme event disrupts the grid. Onsite renewable energy can also reduce energy costs.

Health and Equity Considerations

Solar panels may conflict with tree canopies, which reduces temperatures and improves public health; projects should be carefully designed to minimize these conflicts.

Measure Description

This measure requires electricity to be generated from onsite PV systems, displacing the electricity demand that would ordinarily be supplied by the local electricity provider. Electricity generation provided by local electricity providers has varying carbon intensities based on the portfolio of energy sources. Because PV systems generate zero GHG emissions, this measure displaces the emissions that would have been produced had electricity been supplied by the local electricity provider and thus results in a reduction in GHG emissions. Onsite renewable systems can also provide back-up power as an alternative to diesel generators in the event of grid power outages. Expanding renewable generation capacity onsite in developed areas can also reduce the need to convert or impact undeveloped areas.

Subsector

Renewable Energy Generation

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Installation costs for solar power vary depending on the type and size of the generator; however, initial costs are still considered high. These costs are recouped by large cost savings as the property owner can use electricity produced on site, or even a net profit if excess energy is sold to an electricity provider. Additionally, initial installation costs can be at least partially offset by credits and rebates meant to encourage renewable energy use. Solar power may require the purchase of additional property large enough to host the generators.

Expanded Mitigation Options

Pair with Measure E-23, *Use Microgrids and Energy Storage*, in Table 3-2 to store and then deploy surplus electricity generated from the renewable energy system. This would improve the capacity of the system to displace more grid-supplied electricity, further reducing associated emissions.

GHG Reduction Formula

$$A = \frac{-B}{C}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from electricity use	0–100	%	calculated
User Inputs				
B	Electricity provided by PV system with measure	[ ]	kWh per year	user input
C	Total electricity demand	[ ]	kWh per year	user input
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (B) – The amount of electricity generated by a PV system depends on the size and type of the PV system and the location of the project. The user can use a publicly available solar calculator, such as the NREL PVWatts® Calculator, to estimate the size of the PV system needed to generate the desired amount of electricity. The only input required for this calculator is the location (i.e., zip code). Estimates of the amount of electricity that can be generated from 3, 5, and 10 kilowatt PV systems in the major city within each zip code across the western states are shown in Table E-10-B.1 in the Appendix (NREL 2024). Other calculators include Google's Project Sunroof (Google n.d.) and solar-estimate.org (2021).

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the electricity demand of the user's project is currently being met by grid energy that requires *some* amount of fossil fuel–based energy generation, which emits GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per kWh) greater than zero. For projects that are served by electricity providers with a renewable portfolio standard of 100 percent, this measure would effectively have no reduction in GHG emissions, although it would still result in the co-benefit of enhanced energy security.

Example GHG Reduction Quantification

If the user's project consumes electricity from a local electricity provider with a non-zero carbon intensity, the user can reduce the project's emissions from electricity consumption by displacing the electricity demand met by the electricity provider with an onsite solar

photovoltaic system. If the total electricity demand is 10,000 kWh per year (C), and the solar power system provides 5,000 kWh per year (B), the user would reduce GHG emissions from electricity use by 50 percent. The example measure emission reduction is calculated below.

$$A = \frac{\frac{\text{-5,000 kWh}}{\text{yr}}}{\frac{\text{10,000 kWh}}{\text{yr}}} = \text{-50\%}$$

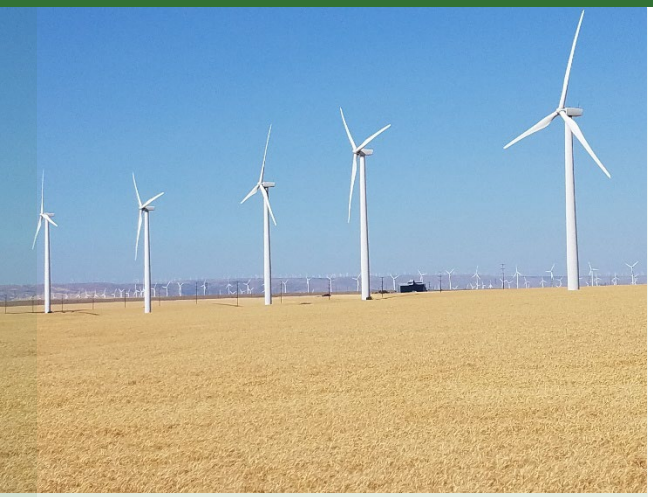
Quantified Co-Benefits

Successful implementation of this measure would reduce grid electricity, and a portion of this electricity is supplied by fossil-fueled power plants, which generates criteria pollutants. However, because these power plants are located throughout individual states, the reduction in electricity use from this measure will not reduce localized criteria pollutant emissions and are, therefore, not discussed.

Sources

- Google. n.d. *Project Sunroof*. Accessed January 2021. https://www.google.com/get/sunroof.
- NREL (National Renewable Energy Laboratory). 2024. *NREL's PVWatts® Calculator*. Version 8.4.0. Accessed December 2024. https://pvwatts.nrel.gov/index.php.
- Solar-Estimate. 2021. *Solar Calculator*. Accessed January 2021. https://www.solar-estimate.org/residential-solar/solar-panel-calculators.

E-10-C. Establish Onsite Renewable Energy Systems–Wind Power



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from building energy, depending on renewable electricity generation compared to building energy consumption

Co-Benefits (icon key on pg. 31)

Climate Resilience

Installing onsite renewable energy systems provides backup generation sources that can contribute to generation capacity and reduce the risk of outages, particularly if an extreme event disrupts the grid. Onsite renewable energy can also reduce energy costs.

Health and Equity Considerations

Consider noise impacts in places with nearby sensitive receptors.

Measure Description

This measure requires electricity to be generated from onsite wind power systems, displacing the electricity demand that would ordinarily be supplied by the local electricity provider. Electricity generation provided by local electricity providers has varying carbon intensities based on the portfolio of energy sources. Since wind turbines generate zero GHG emissions, this measure displaces the emissions that would have been produced had electricity been supplied by the local electricity provider and thus results in a reduction in GHG emissions. Onsite renewable systems can also provide back-up power as an alternative to diesel generators in the event of grid power outages. Expanding renewable generation capacity onsite in developed areas can also reduce the need to convert or impact undeveloped areas. For example, wind power systems can be integrated onto grazing and farmlands with minimal effect on existing land uses.

Subsector

Renewable Energy Generation

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Installation costs for wind power generation vary based on the type and size of the turbine, however, initial costs are still considered high. These costs are recouped by large cost savings as the property owner can use electricity produced on site instead of purchased from the grid, or even at a net profit if excess energy is sold to an electricity provider. Additionally, initial installation costs can be at least partially offset by credits and rebates meant to encourage renewable energy generation.

Expanded Mitigation Options

Pair with Measure E-23, *Use Microgrids and Energy Storage*, in Table 3-2 to store and then deploy surplus electricity generated from the renewable energy system. This would improve the capacity of the system to displace more grid-supplied electricity, further reducing associated emissions.

GHG Reduction Formula

$$A = \frac{-B}{C}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from electricity use	0–100	%	calculated
User Inputs				
B	Electricity provided by wind power system with measure	[ ]	kWh per year	user input
C	Total electricity demand	[ ]	kWh per year	user input
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (B) – The amount of electricity that can be supplied by wind power is highly dependent on location. To implement this measure, users should consider their project's location and other factors that may determine onsite wind power feasibility, such as cost, neighboring land uses, and local ordinances. The U.S. DOE has resources available for wind energy, such as wind speed maps (U.S. DOE n.d.). Additionally, the NREL's Wind Prospector is an interactive mapping tool, where users can determine if their project's location is likely to have suitable wind capacity factors (NREL n.d.).

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the electricity demand of the user's project is currently being met by grid energy that requires *some* amount of fossil fuel–based energy generation, which emits GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per kWh) greater than zero. For projects that are served by electricity providers with a renewable portfolio standard of 100 percent, this measure would effectively have no reduction in GHG emissions, although it would still result in the co-benefit of enhanced energy security.

Example GHG Reduction Quantification

If the user's project consumes electricity from a local electricity provider with a non-zero carbon intensity, the user can reduce the project's emissions from electricity consumption by displacing the electricity demand met by the electricity provider with an onsite wind power system. If the total electricity demand is 10,000 kWh per year (C), and the wind power system

provides 1,000 kWh per year (B), the user would reduce GHG emissions from electricity use by 10 percent. The example measure emission reduction is calculated below.

$$A = \frac{\frac{-1{,}000\ \text{kWh}}{\text{yr}}}{\frac{10{,}000\ \text{kWh}}{\text{yr}}} = -10\%$$

Quantified Co-Benefits

Successful implementation of this measure would reduce grid electricity, and a portion of this electricity is supplied by fossil-fueled power plants, which generates criteria pollutants. However, because these power plants are located throughout individual states, the reduction in electricity use from this measure will not reduce localized criteria pollutant emissions and are, therefore, not discussed.

Sources

- NREL (National Renewable Energy Laboratory). n.d. *Wind Prospector*. Accessed March 4, 2021. https://maps.nrel.gov/wind-prospector/?aL=MlB4Hk%255Bv%255D%3Dt%26VMGtY3%255Bv%255D%3Dt%26VMGtY3%255Bd%255D%3D1&bL=clight&cE=0&lR=0&mC=40.21244%2C-91.625976&zL=4.
- U.S. DOE (U.S. Department of Energy) Office of Energy Efficiency and Renewable Energy. n.d. *Wind Energy in California*. Accessed March 4, 2021. https://windexchange.energy.gov/states/ca#maps.

E-11. Procure Electricity from Lower Carbon Intensity Power Supply



GHG Mitigation Potential



Up to 100% of GHG emissions from electricity use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Procuring electricity from lower carbon intensity power supplies can reduce sensitivity to fuel price shocks or scarcity.

Health and Equity Considerations

Reducing demand for electricity from fossil-fuel sources will help to improve air quality at electrical plants currently using fossil fuels.

Measure Description

This measure will commit the project to procuring electricity with a lower carbon intensity than the primary product offered by the local provider (often an investor-owned utility). This would displace the electricity demand that would ordinarily be supplied by the electricity provider's energy mix. Electricity can have varying carbon intensities based on the electricity providers' portfolio of energy sources. Procurement of electricity of a lower carbon intensity would displace the emissions that would have been produced had the electricity been supplied by the default energy mix and thus results in a reduction in GHG emissions. Green power supply options include utility green power products, community choice aggregation, shared renewables (e.g., community solar), and power purchase agreements.

Subsector

Renewable Energy Generation

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Purchase electricity from a green power supplier, including utility green power products, community choice aggregation, shared renewables (e.g., community solar), and power purchase agreements.

Cost Considerations

The least carbon-intensive fuels are renewable fuels; however, even switching from high carbon-intensity fossil fuels, like coal and petroleum, to lower intensity fossil fuels, like natural gas, represents a cost savings. The costs associated with building renewable energy generating capacity up to a utility scale are high and require constructing large-scale renewable energy plants and power storage facilities. However, the cost of building new carbon intensive power generation plants is similar, if not higher. Renewable energy plants can usually be completed more quickly than a fossil-fueled energy plant, saving construction costs. Renewable energy facilities may also have significant operational cost savings, as many, like solar and wind, do not require fuel inputs.

Expanded Mitigation Options

Procure electricity from a zero-carbon power supply to eliminate all emissions from building electricity.

GHG Reduction Formula

$$A = \frac{B}{C} - 1$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from electricity	0–100	%	calculated
User Inputs				
B	Average carbon intensity of power supply with green power	[ ]	lb CO_2e per MWh	user input
Constants, Assumptions, and Available Defaults				
C	Carbon intensity of electricity provider without measure	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables

Further explanation of key variables:

- (B) – The carbon intensity of the green power supply may be available online directly from the power provider and/or indirectly from the relevant state agencies. If publicly unavailable, the user should request this information from the power provider for the year(s) of interest.
- (C) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.

GHG Calculation Caps or Maximums

Measure Maximum

It is assumed that the electricity demand of the user's project is currently being met by grid energy that requires some amount of fossil fuel-based energy generation, which emits GHGs from fuel combustion. In other words, the electricity provider has an energy intensity factor (lb of CO_2e per kilowatt-hour) greater than zero. For projects that are served by electricity providers already with a renewable portfolio standard of 100 percent, this measure would effectively have no reduction on GHG emissions.

Example GHG Reduction Quantification

The user displaces indirect emissions from electricity by committing the project to procuring power with a lower carbon intensity than the primary local provider. In this example, the green power supply has a carbon intensity of zero (B) because 100 percent of the electricity is from zero-emission energy sources. The project is in the Chelan County PUD territory and would be operational in 2028. The user elects to use the utility emission factor from the

Appendix (189 lb CO_2e per MWh) (C). The user would reduce GHG emissions from electricity by 100 percent.

$$A = \frac{0 \ \frac{\text{lb } CO_2e}{\text{MWh}}}{189 \ \frac{\text{lb } CO_2e}{\text{MWh}}} - 1 = -100\%$$

Quantified Co-Benefits

Successful implementation of this measure would reduce grid electricity, and a portion of this electricity is supplied by fossil-fueled power plants, which generates criteria pollutants. However, because these power plants are located throughout individual states, the reduction in electricity use from this measure will not reduce localized criteria pollutant emissions and are, therefore, not discussed.

Sources

- None.

E-12. Install Electric Water Heater in Place of Gas Storage Tank Heater in Residences



GHG Mitigation Potential



Potentially moderate reduction in GHG emissions from building natural gas

Co-Benefits (icon key on pg. 31)



Climate Resilience

Using electric water heaters that use less fuel can reduce sensitivity to fuel price shocks or scarcity; however, they may decrease resilience if they are the only option available during a power outage. This measure may also power the appliance from the grid rather than from fuel, offering more reliability if the grid has been adapted to climate change or less reliability if the grid has not been adapted.

Health and Equity Considerations

Reduction of natural gas combustion in homes can help reduce indoor air pollution.

Measure Description

This measure requires installation of an electric conventional storage tank water heater in place of a natural gas conventional storage tank water heater in residential developments. An electric storage tank heater displaces natural gas consumption with electricity use, replacing more emissions-intensive natural gas with less emissions-intensive electricity. Other alternative water heater types that are less emissions intensive than natural gas units include solar water heaters with natural gas backup and solar water heaters with electric backup. GHG benefits of these options are not specifically analyzed in this measure, but a solar water heater with electric backup would reduce GHG emissions by displacing natural gas with zero-emission solar energy when water is heated by the system's solar collectors and grid electricity when the back-up function is utilized. A solar water heater with natural gas backup reduces emissions by displacing natural gas with solar energy when water is heated by the solar collectors.

Subsector

Building Decarbonization

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Alternative water heaters analyzed in this measure include electric conventional storage tanks. Additional reductions may be achieved by solar water heaters with natural gas backup or solar water heaters with electric backup.

Cost Considerations

Non-conventional heaters can have high initial and construction costs (e.g., upgrading the electric panel). However, electric storage tank heaters are more energy efficient and cost less to operate once they are installed. They require less fuel, maintenance, and upkeep than natural gas heaters, leading to additional long-term cost savings.

Expanded Mitigation Options

Pair with Measure E-3-A, *Require Energy Efficiency Residential Boilers,* to reduce energy use from both space heating and water heating, yielding increased GHG reductions. Also, a heat pump is another option for an alternative water heater that is highly efficient, though the associated energy reductions were not quantified as part of this measure (see Measure E-25, *Install Electric Heat Pumps*, in Table 3-2).

Introduction

Measure E-12 has been renamed and the GHG reduction formula modified slightly for this Western States Handbook compared to what is presented in the CAPCOA Handbook. Measure E-12 in the CAPCOA Handbook analyzes three alternative types of water heaters—electric conventional storage tanks, solar water heaters with electric backup, and solar water heaters with natural gas backup. Users of the CAPCOA Handbook are directed to use formulas A1 (GHGs) and L1 (criteria pollutants) to analyze the electric alternatives and formulas A2 (GHGs) and L2 (criteria pollutants) to analyze the natural gas backup alternative. As discussed at the beginning of this chapter and under Measure E-2, *Require Energy Efficient Appliances*, residential energy consumption data for the CAPCOA Handbook is sourced from the CEC's RASS, whereas residential energy consumption data for this Western States Handbook is sourced from U.S. EIA's RECS. There are differences among the end-use categories included in the RASS and RECS. Specific to this measure, the RASS includes average natural gas and electricity consumption by the three alternative heater types, thus enabling separate quantification in the CAPCOA Handbook. As discussed further below, the RECS does not differentiate energy consumption among heater types and only gives a single value for electric "water heating" and natural gas "water heating." Based on this available information, Measure E-12 is isolated in this Western States Handbook to installation of an electric water heater in place of a natural gas heater. Thus, formulas A2 and L2 in the CAPCOA Handbook are not presented.

GHG Reduction Formula

$$A = (-E \times C \times G \times I \times J) + (F \times C \times H \times K \times J)$$

GHG Calculation Variables

Based on 2020 survey data, approximately 91 percent of residences within the U.S. EIA "west" climate zone use storage tank heaters, and approximately 64 percent of main water heaters are fueled by natural gas (U.S. EIA 2022). Therefore, for the purposes of this measure, natural gas storage tanks are the type of water heater that the user would be displacing.

ID	Variable	Value	Unit	Source
Output				
A	Reduction in GHG emissions from building energy for electric storage tank heater	[ ]	MT CO_2e per year	calculated
User Inputs				
B	Housing type	[ ]	text	user input
C	Number of dwelling units	[ ]	du	user input
Constants, Assumptions, and Available Defaults				
D	U.S. EIA Census Region/Division or Climate Zone	Figures E-2.1 through E-2.3	integer	U.S. EIA 2025a, 2025b, 2025c

E	Fuel consumption for conventional natural gas storage tank heater	Table E-15.1	therm per year per du	U.S. EIA 2023
F	Electricity use for electric storage tank heater	Table E-15.1	kWh per year per du	U.S. EIA 2023
G	Carbon intensity of residential natural gas	117	lb CO_2e per mmBTU	U.S. EPA 2020
H	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
I	Conversion from therm to 1 million BTU (mmBTU)	0.1	mmBTU per therm	conversion
J	Conversion from lb to metric ton (MT)	0.000454	MT per lb	conversion
K	Conversion from kWh to MWh	0.001	MWh per kWh	conversion

Further explanation of key variables:

- (B) – The housing types are needed to look up the energy use by type of heater (F) in Table E-15.1.
- (D) – The RECS provides energy consumption data aggregated by U.S. census region/division and climate zone. See Figures E-2.1 through E-2.3 in the Appendix. Fuel consumption (E) and electricity use (F) are provided for U.S. census regions/divisions and climate zones applicable to the western states. Users should select the appropriate geographic region for their analysis. Refer Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.
- (E, F) – The U.S. EIA administered the RECS in 2020. Based on the survey, the average natural gas and electricity consumption for "water heating" for each U.S. census region/division and climate zone and housing type is provided in Table E-15.1 in the Appendix. Refer to Measure E-15, *Require All-Electric Development*, for additional information on how the defaults were developed. The RECS does not differentiate energy consumption between primary and secondary water heaters (if present). Thus, the energy intensity values presented in the Appendix for "water heating" are inclusive of total household water heating across all heater types and tank sizes (e.g., 30 gallons or less) included in the survey.[27] If the user can provide a project-specific value, then the user should replace the defaults in the GHG calculation formula.
- (G) – The carbon intensity of residential natural gas was calculated in terms of CO_2e by multiplying the U.S. natural gas combustion emission factors for CO_2, CH_4, and N_2O (U.S. EPA 2020) by the corresponding 100-year GWP values from the IPCC's Fifth

[27] As noted above, this differs from the CAPCOA Handbook, which includes end-use consumption defaults isolated to just "water heaters" by type (see Table E-12.1 in the CAPCOA Handbook). Table E-15.1 in the CAPCOA Handbook also provides energy consumption for the water heating end-use category. When compared to the "NG Storage Tank" water heater type, gas consumption for the water heating end use was 1% to 3% greater, depending on the housing type ("State" climate zone). Electricity consumption for the water heating end use was less than 1% to 6% greater, depending on the housing type ("State" climate zone), compared to the "Electric Storage Tank" water heater type. These data suggest that use of the energy intensity values presented in Appendix A for "water heating" can provide a reasonable approximation of energy savings associated with installing an electric water heater in place of a natural gas version.

Assessment Report (IPCC 2013). See Table E-4.10 in the Appendix for more natural gas emission factors.

- (H) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.

GHG Calculation Caps or Maximums

Measure Maximum

None.

Mutually Exclusive Measures

If the user selects Measure E-15, *Require All-Electric Development*, they may not also take credit for this measure (Measure E-12) or Measure E-13, *Install Electric Cooking Appliances in Place of Gas Appliances,* which electrify select appliances. Measure E-15 accounts for the combined GHG reductions achieved by each of these measures, as well as the electrification of other end uses. To combine the GHG reductions from Measure E-15 with Measure E-12 or Measure E-13 would be considered double counting.

Example GHG Reduction Quantification

The user reduces building energy emissions by installing electric water heaters in place of natural gas storage tank heaters. In this example, 10 single-family detached homes (B and C) would be constructed in coastal Oregon, and the user elects to evaluate energy consumption based on defaults for the U.S. EIA "marine" climate zone (D). Therefore, the fuel consumption for each home's water heating would be 150 therms per year (E), and the electricity consumption would be 1,624 kilowatt-hours per year (F), based on Table E-15.1. The project would begin operation by 2035 and the user elects to use the WECC average emission factor from the Appendix (261 lb. CO_2e per MWh) (H). The mitigated emissions would be reduced by 6 MT CO_2e per year.

$$A = \left(\frac{\text{-150 therm}}{\text{yr·du}} \times \textbf{10 du} \times \frac{\text{117 lb } CO_2e}{\text{MMBtu}} \times \frac{\text{0.1 mmBTU}}{\text{therm}} \times \frac{\text{0.000454 MT}}{\text{lb}}\right) + \left(\frac{\text{1,624 kWh}}{\text{yr·du}} \times \textbf{10 du} \times \frac{\text{261 lb } CO_2e}{\text{MWh}} \times \frac{\text{0.001 MWh}}{\text{kWh}} \times \frac{\text{0.000454 MT}}{\text{lb}}\right) = \text{-6} \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

Energy and Fuel Savings

Energy use conversion from major natural gas appliances to their equivalent electric replacements tends not to be straightforward given that most significant gas appliances (e.g., water heaters, space heaters, ovens and cooktops) have varying input-to-output efficiencies and losses from product to product. Equivalent electric

appliances also have differing efficiencies, and usage patterns for these equivalent appliances may differ in some way. If installing an electric storage tank heater, the user would decrease the building natural gas consumption (E) and increase the electricity use (F).

Improved Air Quality

The reduction in natural gas fuel consumption from this measure would result in local improvements in air quality because the fuel consumption occurs on site of the project. The reduction in criteria pollutant emissions (L) achieved by the measure can be calculated as follows.

Criteria Pollutant Emission Reduction Formula

$$L = -E \times C \times M \times I \times N$$

Criteria Pollutant Emission Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
L	Reduction in criteria pollutant emissions from building energy for electric storage tank heater	[ ]	tons per year	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
M	Criteria pollutant emission factors of natural gas	Table E-4.11	lb per mmBTU	U.S. EPA 1998
N	Conversion from lb to ton	0.0005	tons per lb	conversion

Further explanation of key variables:

- (M) – Table E-4.11 presents the criteria pollutant emission factors of natural gas for residential and commercial uses (U.S. EPA 1998).
- Please refer to the GHG Calculation Variables table above for definitions of variables that have been previously defined.

Sources

- IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/.
- U.S. EIA (U.S. Energy Information Administration). 2022. *Residential Energy Consumption Survey (RECS)*. Table HC8.8 Water heating in homes in the South and West regions, 2020. Accessed January 2025. https://www.eia.gov/consumption/residential/data/2020/.
- U.S. EIA. 2023. *Residential Energy Consumption Survey (RECS)*. Table CE2.1 Annual household site fuel consumption in the U.S.—totals and averages, 2020. Table CE5.1a Detailed household site electricity end-use consumption, part 1—totals, 2020. Table CE5.1b Detailed household site electricity end-use consumption, part

2—totals, 2020. Table CE5.2 Detailed household natural gas and propane end-use consumption—totals, 2020. Accessed January 2025. https://www.eia.gov/consumption/residential/data/2020/.

- U.S. EIA. 2025a. *RECS Terminology*. Accessed February 4, 2025. https://www.eia.gov/consumption/residential/terminology.php.
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E-13. Install Electric Cooking Appliances in Place of Gas Appliances



GHG Mitigation Potential



Potentially small reduction in GHG emissions from building natural gas

Co-Benefits (icon key on pg. 31)

Climate Resilience

Installing cooking appliances that use electricity rather than fuel can reduce sensitivity to fuel price shocks or scarcity. Electric appliances also offer more reliability if the grid has been adapted to climate change or less reliability if the grid has not been adapted.

Health and Equity Considerations

Natural gas appliances are a primary source of residential indoor air pollution (e.g., NOx, CO, and formaldehyde), with the impacts being greater in smaller living spaces and kitchens with inefficient or no vent hoods—disproportionately affecting low-income residents and renters. Replacing natural gas cooking appliances with electric ones thus vastly improves indoor air quality.

Measure Description

This measure requires that residential or commercial developments install electric cooking appliances (i.e., cooktop plus oven, separate cooktops, and separate ovens) in place of gas counterparts. Electric appliances displace natural gas consumption with electricity use, replacing a more emissions-intensive fossil fuel-based source of energy with electricity from the grid that is increasingly transitioning to renewable sources.

Subsector

Building Decarbonization

Scale of Application

Project/Site

Implementation Requirements

The electric cooking appliance must have an electric or induction cooktop and an electric oven. Because induction cooktops are superior in performance to traditional electric cooktops and comparable to gas, the use of induction cooktops is strongly recommended to help overcome any user hesitancy or preference for gas.

Cost Considerations

Electric cooktops are twice as energy efficient as gas cooking appliances, representing a large cost savings from reduced energy consumption. Electric stoves have similar costs as natural gas stoves and are relatively inexpensive to install. Induction cooktops have higher upfront costs compared to gas cooking appliances but similar cost savings (induction cooktops do not radiate heat, which translates into reduced home cooling costs during warm days). Buyer costs include the purchase of magnetic-based pots and pans (e.g., stainless steel or cast iron) specialized for use on induction cooktops.

Expanded Mitigation Options

Limit gas barbecue grills, which would provide additional GHG mitigation and improved localized air quality.

Introduction

Measure E-13 has been renamed for this Western States Handbook. Measure E-13 in the CAPCOA Handbook requires that residential or commercial developments install an electric range (i.e., cooktop plus oven) in place of a gas range. As discussed at the beginning of this chapter and under Measure E-2, *Require Energy Efficient Appliances*, energy consumption data for the CAPCOA Handbook is sourced from the CEC's RASS and CEUS, whereas energy consumption data for this Western States Handbook is sourced from U.S. EIA's RECS and CBECS. There are differences among the end-use categories included in the RASS and RECS and CEUS and CBECS. Specific to this measure, the RASS includes average natural gas and electricity consumption specific to "range/oven," thus enabling separate quantification in the CAPCOA Handbook. As discussed further below, the RECS and CBECS do not differentiate energy consumption among cooking appliances and only give a single value for electric "cooking" and natural gas "cooking." Based on this available information, Measure E-13 is generalized in this Western States Handbook to require installation of all-electric cooking appliances in place of natural gas counterparts. Users may isolate this measure to only electric ranges, consistent with the CAPCOA Handbook, if corresponding energy data for their project are available.

GHG Reduction Formula

$$A = (-E \times C \times G \times I \times J) + (F \times C \times H \times K \times J)$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Reduction in GHG emissions from building energy	[ ]	MT CO_2e per year	calculated
User Inputs				
B	Housing or building type	[ ]	text	user input
C	Number of du or size of commercial building	[ ]	du or 1,000 gross square feet (KSF)	user input
Constants, Assumptions, and Available Defaults				
D	U.S. EIA Census Region/Division or Climate Zone	Figures E-2.1 through E-2.3	integer	U.S. EIA 2025a, 2025b, 2025c
E	Fuel consumption for natural gas cooking appliances	Table E-15.1 or Table E-15.2	therm per year per du or therm per year per KSF	U.S. EIA 2022, 2023
F	Electricity use for electric cooking appliances	Table E-15.1 or Table E-15.2	kWh per year per du or kWh per year per KSF	U.S. EIA 2022, 2023
G	Carbon intensity of natural gas (commercial/residential)	119/117	lb CO_2e per mmBTU	U.S. EPA 2020

H	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
I	Conversion from therm to mmBTU	0.1	mmBTU per therm	conversion
J	Conversion from lb to MT	0.000454	MT per lb	conversion
K	Conversion from kWh to MWh	0.001	MWh per kWh	conversion

Further explanation of key variables:

- (B) – The housing and building types are needed to look up the energy use by type of cooking appliance (E).
- (D) – The RECS and CBECS provide energy consumption data aggregated by U.S. census region/division and climate zone. See Figures E-2.1 through E-2.3 in the Appendix. Fuel consumption (E) and electricity use (F) are provided for U.S. census regions/divisions and climate zones applicable to the western states. Users should select the appropriate geographic region for their analysis. Refer to Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.
- (E and F) – The U.S. EIA administered the RECS in 2020 and the CBECS in 2018. Based on these surveys, the average natural gas and electricity consumption for "cooking" for each U.S. census region/division and climate zone and housing type or building activity is provided in Tables E-15.1 and E-15.2 in the Appendix. The RECS and CBECS do not differentiate energy consumption among individual cooking appliance types. Thus, the energy intensity values presented in the Appendix for "cooking" include ranges (units with both a cooktop and an oven), separate cooktops, and separate ovens. Application of these defaults to quantify GHG benefits thus require the user to replace all natural gas cooking appliances (not just the range) with electric equivalents.[28] If the user can provide a project-specific or an appliance-specific value, then the user should replace the defaults in the GHG calculation formula.
- (G) – The carbon intensity of residential and commercial natural gas was calculated in terms of CO_2e by multiplying the U.S. natural gas combustion emission factors for CO_2, CH_4, and N_2O (U.S. EPA 2020) by the corresponding 100-year GWP values from the IPCC's Fifth Assessment Report (IPCC 2013). See Table E-4.11 in the Appendix for more natural gas emission factors.
- (H) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.

GHG Calculation Caps or Maximums

Measure Maximum

None.

[28] As noted above, this differs from the CAPCOA Handbook, which includes end-use consumption defaults isolated to just "range/oven" (see Table E-15.1 in the CAPCOA Handbook).

Mutually Exclusive Measures

If the user selects Measure E-15, *Require All-Electric Development*, they may not also take credit for Measure E-12, *Install Electric Water Heater in Place of Gas Storage Tank Heater in Residences,* or this measure (Measure E-13), which electrify select appliances. Measure E-15 accounts for the combined GHG reductions achieved by each of these measures, as well as the electrification of other end uses. To combine the GHG reductions from Measure E-15 with Measure E-12 or Measure E-13 would be considered double counting.

Example GHG Reduction Quantification

The user reduces building energy emissions by requiring all-electric cooking appliances in place of natural gas counterparts. In this example, the measure would be implemented for 20 apartments in buildings with 2-4 units (C) in eastern Washington, and the user elects to evaluate energy consumption based on defaults for the U.S. EIA "very cold/cold" climate zone (D). Therefore, the fuel consumption for natural gas cooking would be 7 therms per year per du (E), and the electricity consumption per du would be 112 kilowatt-hours per year (F). The project would begin operation by 2035 and the user elects to use the WECC average emission factor from the Appendix (261 lb. CO_2e per MWh) (G). The mitigated emissions would be reduced by 0.5 MT CO_2e per year.

$$A = \left(\frac{\text{-7 therm}}{\text{yr·du}} \times \textbf{20 du} \times \frac{\text{117 lb } CO_2e}{\text{mmBTU}} \times \frac{\text{0.1 mmBTU}}{\text{therm}} \times \frac{\text{0.000454 MT}}{\text{lb}}\right) + \left(\frac{\text{112 kWh}}{\text{yr·du}} \times \textbf{20 du} \times \frac{\text{261 lb } CO_2e}{\text{MWh}} \times \frac{\text{0.001 MWh}}{\text{kWh}} \times \frac{\text{0.000454 MT}}{\text{lb}}\right) = \text{-0.5} \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

While the measure will achieve fuel savings, it will also increase electricity consumption. For more information on the public health effects of gas cooking appliances, refer to the resources available from the Rocky Mountain Institute (Rocky Mountain Institute 2020).

Fuel Savings (Increased Electricity)

Energy use conversion from major natural gas appliances to their equivalent electric replacements tends not to be straightforward given that most significant gas appliances (e.g., water heaters, space heaters, ovens, and cooktops) have varying input-to-output efficiencies and losses from product to product. Equivalent electric appliances also have differing efficiencies, and usage patterns for these equivalent appliances may differ in some way. If installing an electric cooktop, the user would decrease the building natural gas consumption (E) and increase the electricity use (F).

Improved Air Quality

The reduction in natural gas fuel consumption from this measure would result in local improvements in air quality because the fuel consumption occurs on site of the

project. The reduction in criteria pollutant emissions (L) achieved by the measure can be calculated as follows.

Criteria Pollutant Emission Reduction Formula

$$L = -E \times C \times M \times I \times N$$

Criteria Pollutant Emission Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
L	Reduction in criteria pollutant emissions from building energy	[ ]	tons per year	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
M	Criteria pollutant emission factors of natural gas	Table E-4.11	lb per mmBTU	U.S. EPA 1998
N	Conversion from lb to ton	0.0005	tons per lb	conversion

Further explanation of key variables:

- (M) – Table E-4.11 presents the criteria pollutant emission factors of natural gas for residential and commercial uses (U.S. EPA 1998).
- Please refer to the *GHG Calculation Variables* table above for definitions of variables that have been previously defined.

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E-14. Limit Wood Burning Devices and Natural Gas/Propane Fireplaces in Residential Development



GHG Mitigation Potential



Potentially large reduction in GHG emissions from wood burning devices

Co-Benefits (icon key on pg. 31)



Climate Resilience

Limiting wood burning and natural gas/propane fireplaces and replacing them with electric appliances can reduce sensitivity to fuel price shocks or scarcity; however, they may decrease resilience if they are the only option available during a power outage. This also offers more reliability if the grid has been adapted to climate change or less reliability if the grid has not been adapted.

Health and Equity Considerations

This may increase winter heating costs for some residents in colder climate zones. Eliminating wood burning and combustion of natural gas and propane in homes can help reduce indoor pollution and greatly reduce outdoor air pollution.

Measure Description

This measure requires committing to not installing any wood burning devices (i.e., woodstoves and fireplaces) or natural gas or propane fireplaces in proposed residential developments. This avoids the combustion of biomass, natural gas, and propane, thereby reducing associated biogenic and non-biogenic GHG emissions. The most efficient alternatives to wood burning devices or gas fireplaces are electric fireplace inserts and electric heat pumps.

Subsector

Building Decarbonization

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

This measure may not be applicable in areas where wood burning devices in new development are already prohibited. In such areas, this measure could be applied for informational purposes, to determine the GHG and air quality benefits in new development achieved by restrictions on wood burning devices. However, users should exercise caution in taking credit for any emissions benefit from this measure in areas where the existing baseline already prohibits wood burning devices.

Cost Considerations

Wood, natural gas, and propane fireplaces use more energy and fuel to heat an area than centralized heating systems and have additional costs to purchase fuel for the fireplace. Electric imitation fireplaces meant for cosmetic purposes are less expensive to install and much more energy efficient. For heat production purposes, portable space heaters that run on electricity have the same benefits in cost reduction and allow the owner to use the same device in multiple locations, saving the cost of installing more units.

Expanded Mitigation Options

Consider electrifying all end uses (e.g., space heating, water heating) by implementing Measure E-15, *Require All-Electric Development*.

GHG Reduction Formula

$$A = -\mathbf{D} \times \left[\left(\left((E_1 \times K_1 + E_2 \times K_2 + E_3 \times K_3 + E_4 \times K_4) \times G\right) + F_1 \times L_1 \times H\right) \times N\right) + \left((\mathbf{F_2} \times L_2 + \mathbf{F_3} \times L_3) \times \mathbf{I} \times \mathbf{J} \times M\right)\right] \times O$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Reduction in GHG emissions from wood burning devices	[ ]	MT CO_2e per year	calculated
User Inputs				
B	Project location	[ ]	text	user input
C	Housing type	[ ]	multi-family or single-family	user input
D	Number of du	[ ]	du	user input
F_2	Percent of du with natural gas fireplaces	[ ]	%	user input
F_3	Percent of du with propane fireplaces	[ ]	%	user input
I	Daily usage of fireplace	[ ]	hour per day	user input
J	Annual usage of fireplace	[ ]	day per year	user input
	For locations outside of Oregon, all variables defined below under "Constants, Assumptions, and Available Defaults (Oregon)"			
Constants, Assumptions, and Available Defaults (Oregon)				
E_1	Percent of Oregon du with conventional woodstoves	Table E-14.1	%	Oregon DEQ 2021
E_2	Percent of Oregon du with catalytic woodstoves	Table E-14.1	%	Oregon DEQ 2021
E_3	Percent of Oregon du with non-catalytic woodstoves	Table E-14.1	%	Oregon DEQ 2021
E_4	Percent of Oregon du with pellet woodstoves	Table E-14.1	%	Oregon DEQ 2021
F_1	Percent of Oregon du with wood fireplaces	Table E-14.1	%	Oregon DEQ 2021
G	Oregon wood mass for stove	Table E-14.1	lb per year	Oregon DEQ 2021
H	Oregon wood mass for fireplace	Table E-14.1	lb per year	Oregon DEQ 2021

ID	Variable	Value	Unit	Source
Constants, Assumptions, and Available Defaults (all states)				
K_1	Carbon intensity of conventional woodstove	Table E-14.2	lb biogenic CO_2e per ton wood burned	U.S. EPA 1996a
K_2	Carbon intensity of catalytic woodstove	Table E-14.2	lb biogenic CO_2e per ton wood burned	U.S. EPA 1996a
K_3	Carbon intensity of non-catalytic woodstove	Table E-14.2	lb biogenic CO_2e per ton wood burned	U.S. EPA 1996a
K_4	Carbon intensity of pellet woodstove	Table E-14.2	lb biogenic CO_2e per ton wood burned	U.S. EPA 1996a
L_1	Carbon intensity of wood fireplace	Table E-14.2	lb biogenic CO_2e per ton wood burned	U.S. EPA 1996b
L_2	Carbon intensity of natural gas	Table E-14.2	lb non-biogenic CO_2e per mmBTU	U.S. EPA 2020
L_3	Carbon intensity of propane	Table E-14.2	lb non-biogenic CO_2e per mmBTU	U.S. EPA 2020
M	Heating rate of natural gas and propane	0.06	mmBTU per hour	Liaison Inc. 2025
N	Conversion from lb to ton	0.0005	ton per lb	conversion
O	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (B and C) – The project location and housing type are needed to lookup the percentage of du with various types of woodstoves and fireplaces (E_1 through E_4 and F_1 through F_3).
- (E_1 through E_3, F_1, G, H) – Oregon DEQ provided the percentage of du with various types of woodstoves (E_1 through E_4) and the percentage of du with woodburning fireplaces (F_1). Table E-14.1 in the Appendix presents this information by housing type for each county and statewide. The table also provides the average wood mass for wood stoves (G) and wood fireplaces (H). Residential wood consumption data for other western states is not available. Users outside of Oregon should provide project-specific inputs for these variables. The Oregon data presented in Table E-14.1 may be considered as potential inputs at the discretion of the user. California data presented in Table E-14.1 of the CAPCOA (2024) Handbook may also be considered as a potential reference. Users applying residential wood consumption data from other states should consider similarities in building characteristics and climate when evaluating the reasonableness of the data for their project and location.
- (F_2, F_3) – The percentages of dwelling units with natural gas and propane fireplaces are not included in the Oregon residential wood consumption database, nor are defaults available for other western states. Users in all states should provide project-specific

inputs for these variables. Table E-14.1 of CAPCOA (2024) Handbook includes percentages for California dwelling units that may be considered as potential proxies.

- (I, J) – Daily and annual fireplace usage statsitics are not included in the Oregon residential wood consumption database, nor are defaults available for other western states. Users in all states should provide project-specific inputs for these variables. Table E-14.1 of CAPCOA (2024) Handbook includes average usage for California dwelling units that may be considered as potential proxies.
- (K_1 through L_3) – The carbon intensity of the various woodstoves and fireplace fuels were calculated in terms of CO_2e by multiplying the emission factors for CO_2, CH_4, and N_2O (U.S. EPA 1996a, 1996b, 1998; Abt Associates 2016) by the corresponding 100-year GWP values from the IPCC's Fifth Assessment Report (IPCC 2013).[29] See Table E-14.2 in the Appendix for these emission factors. Note that the methane emission factors have been updated from the CAPCOA (2024) Handbook per Abt Associates (2016), which is used by U.S. EPA in their residential wood combustion nonpoint emissions tool.
- (K_1 through L_1) – GHG emissions from the combustion of wood or biomass are considered biogenic emissions, meaning they are derived from living cells, as opposed to fossil fuels that have been transformed by geological processes. Some protocols do not consider these emissions to be part of an emission inventory. In these instances, users should take care to keep them distinct from non-biogenic emissions caused by natural gas and propane fireplaces (L_2 and L_3).
- (M) – The heating rate of residential gas fireplaces depends on their size. The typical range is from 0.02 to 0.06 mmBTU per hour, with smaller units (up to 400 square feet) having a lower heating rate (0.02 to 0.03 mmBTU per hour) and larger units (1,000 to 2,000 square feet) having a higher heating rate (0.04 to 0.06 mmBTU per hour) (Liaison, Inc. 2025).

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user avoids emission from wood burning devices by eliminating woodstoves and fireplaces from the proposed residential development. In this example, the proposed project would be a 100-unit (D) single-family housing development (C) located in Jackson County, Oregon (B). Based on this information, Table E-14.1 can be used to determine the percentage of du with various types of woodstoves (E_1 through E_4) and wood mass for woodstoves and fireplaces (G, H). The user elects to adopt default assumptions from the CAPCOA (2024) Handbook for the North Coast Unified Air Pollution Control District (APCD) to characterize the percentage of du with various fireplace types (F_1 through F_3), as well as fireplace usage (I, J). Data for the North Coast APCD are considered representative of the project area given similarities in geography and climate (e.g., Jackson County and most of the North Coast APCD are located within the U.S. EIA "marine" climate zone per Figure E-2.2). The mitigated emissions would be reduced by -235 MT CO_2e per year.

[29] The GWP values from the Fifth Assessment Report were used wherever possible; however, in some cases emission factors are provided in terms of CO_2e and it cannot be determined which GWP values were used.

$$A = \text{-100 units} \times \left[\left(\left(\left(\left(4\% \times \frac{4{,}744 \text{ lb } CO_2e}{\text{ton wood}} + 5\% \times \frac{3{,}495 \text{ lb } CO_2e}{\text{ton wood}} + 5\% \times \frac{3{,}540 \text{ lb } CO_2e}{\text{ton wood}} + 1\% \times \frac{2{,}959 \text{ lb } CO_2e}{\text{ton wood}}\right) \times \frac{6{,}610 \text{ lb wood}}{\text{yr}}\right) + 35\% \times \frac{3{,}883 \text{ lb } CO_2e}{\text{ton wood}} \times \frac{4{,}129 \text{ lb wood}}{\text{yr}}\right) \times \frac{0.005 \text{ ton}}{\text{lb}}\right) + \left(\left(55\% \times \frac{117.1 \text{ lb } CO_2e}{\text{mmBTU}} + 0\% \times \frac{136.1 \text{ lb } CO_2e}{\text{mmBTU}}\right) \times \frac{3 \text{ hours}}{\text{day}} \times \frac{82.0 \text{ days}}{\text{yr}} \times \frac{0.06 \text{ mmBTU}}{\text{hour}}\right)\right] \times \frac{0.000454 \text{ MT}}{\text{lb}} = \frac{-235 \text{ MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

Improved Air Quality

The reduction in wood, natural gas, and propane combustion from this measure would result in local improvements in air quality because the combustion occurs on site of the project. The reduction in criteria pollutant emissions (Q) achieved by the measure would be calculated the same way as the GHG reduction equation, except for the following differences.

- (K_1 through L_3) – Use the criteria pollutant emission factors in Table E-14.2 in the Appendix instead of the GHG emission factors (U.S. EPA 1996a, 1998; Abt Associates 2016). Note that several emission factors have been updated from the CAPCOA (2024) Handbook per Abt Associates (2016), which is used by U.S. EPA in their residential wood combustion nonpoint emissions tool.
- (N) – Replace (O) with (N) because criteria pollutant emissions are reported as tons of pollutant per year, whereas GHG emissions are reported in units of metric tons.

Energy and Fuel Savings

The reduction in natural gas and propane fuel consumption (P) achieved by this measure, in units of mmBTU per year, can be calculated as follows.

Fuel Reduction Formula

$$P = \text{-}D \times (F_2 + F_3) \times I \times J \times M$$

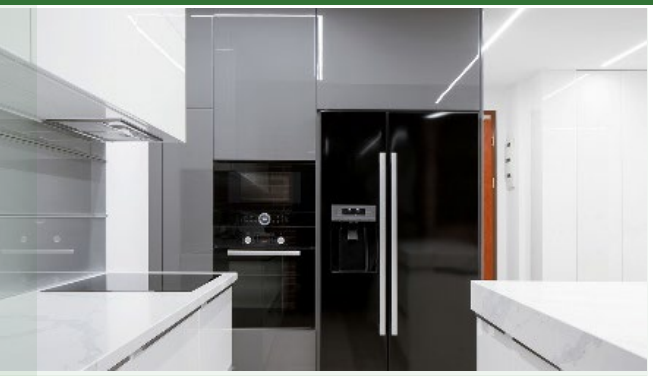
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C000%20Btus.&text=*Based%20on%20natural%20gas%20price,$1.20%20to%20$1.60%20per%20therm.

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E-15. Require All-Electric Development



GHG Mitigation Potential



Potentially large reduction in GHG emissions from building energy use

Co-Benefits (icon key on pg. 31)



Climate Resilience

Requiring all-electric development can reduce sensitivity to fuel price shocks or scarcity and offer more reliability if electricity providers have been adapted to climate change. However, this may decrease resilience if the grid has not been adapted to climate change and if there are no non-electric backup options during a power outage.

Health and Equity Considerations

Elimination of natural gas combustion in homes will improve indoor air quality, as natural gas appliances produce pollutants such as NOx, formaldehyde, and CO. Plans, backups, and contingencies should be in place in the event of extended power failure (consider implementing with Measure E-23, *Use Microgrids and Energy Storage*, in Table 3-2).

Measure Description

This measure requires that residential or commercial developments use all-electric appliances and end uses. Using electric instead of natural gas-powered appliances and end uses replaces a more emissions-intensive fossil fuel source of energy with a less emissions-intensive source of energy, electricity from the grid that is increasingly transitioning to renewable sources.

Subsector

Building Decarbonization

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

It is expected that user's building would electrify the most common natural gas end uses—space heating, water heating, and cooking appliances. Additional natural gas end uses include clothes dryer, pool heat, spa heat, and other, as discussed below under *GHG Calculation Variables*.

Cost Considerations

Although electric appliances for residential and commercial properties sometimes cost more to purchase and install, they are more energy efficient than conventional natural gas appliances. This can lead to long-term cost savings through reduced energy consumption. Electric appliances also usually require less maintenance than conventional appliances.

Expanded Mitigation Options

One of the most efficient ways to provide space heating with electricity is to use heat pumps, which provides increased efficiency relative to traditional electric resistance heating (see Measure E-25, *Install Electric Heat Pumps*, in Table 3-2). The associated energy reduction from heat pumps was not quantified as part of this measure.

Note: Washington State voters approved Initiative 2066 (I-2066) in November 2024. I-2066 prohibits state and local governments from restricting natural gas access in new development and seeks to repeal building codes that incentivize electric heat pumps over natural gas. In March 2025, a King County Superior Court judge ruled I-2066 unconstitutional, and the initiative may be advanced to the State Supreme Court. Local governments in Washington State may be restricted from enforcing all-electric policies, depending on the outcome. However, I-2066 would not limit developers or project proponents from voluntarily pursuing all electric design.

GHG Reduction Formula

$$A = (-E \times C \times G \times I \times J) + (F \times C \times H \times K \times J)$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Reduction in GHG emissions from building energy	[ ]	MT CO_2e per year	calculated
User Inputs				
B	Housing or building type	[ ]	text	user input
C	Number of du or size of commercial building	[ ]	du or KSF	user input
Constants, Assumptions, and Available Defaults				
D	U.S. EIA Census Region/Division or Climate Zone	Figures E-2.1 through E-2.3	integer	U.S. EIA 2025a, 2025b, 2025c
E	Existing fuel consumption for natural gas end uses without measure	Table E-15.1 Table E-15.2	therm per year per du or therm per year per KSF	U.S. EIA 2022, 2023
F	Additional electricity use for equivalent electrified end uses with measure	Table E-15.1 Table E-15.2	kWh per year per du or kWh per year per KSF	U.S. EIA 2022, 2023
G	Carbon intensity of natural gas (commercial/residential)	119/117	lb CO_2e per mmBTU	U.S. EPA 2020
H	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
I	Conversion from therm to mmBTU	0.1	mmBTU per therm	conversion
J	Conversion from lb to MT	0.000454	MT per lb	conversion
K	Conversion from kWh to MWh	0.001	MWh per kWh	conversion

Further explanation of key variables:

- (B) – The housing and building types are needed to look up the energy use for electric and natural gas end uses for residential and commercial development (E and F).
- (D) – The RECS and CBECS provide energy consumption data aggregated by U.S. census region/division and climate zone. See Figures E-2.1 through E-2.3 in the Appendix. Fuel consumption (E) and electricity use (F) are provided for U.S. census regions/divisions and climate zones applicable to the western states. Users should select

the appropriate geographic region for their analysis. Refer to Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.

- (E and F) – The U.S. EIA administered the RECS in 2020. The study yielded energy consumption estimates for 26 electric and 6 natural gas residential end uses. Based on this data for the year 2020, the average energy consumption intensities for natural gas end uses that may be electrified are provided in Table E-15.1. The natural gas end uses included in the RECS and reflected in this measure include space heating, water heating, clothes dryers, cooking, pool heat, hot tub heat, and other.[30] Except for pool heat, there are electric equivalent end uses for each of these end uses. Users should only evaluate the end uses applicable to their project. For example, most residences will not be built with spas. A minimum recommendation is that the primary natural gas end uses that are commonly electrified be included—space heating, water heating, and cooking.

  The data provided in Table E-15.1 are provided by housing type (e.g., single family) and organized by U.S. census regions/division and by climate zone. Consumption data by housing type and geographic region were calculated by combing data from the RECS, which separately provides end-use data 1) disaggregated by residential housing type based on aggregated national average consumption data and 2) aggregated for all residential housing types based on disaggregated U.S. census region/division and climate zone consumption data. The following steps were taken to collate the RECS data.

  1. Identify the percentage of total residential energy consumption by unit type based on the national average consumption. For example, Table CE2.1 of RECS indicates that the single-family detached unit type represents 73% of total electricity consumption for all residential unit types included in the RECS.
  2. Disaggregate the total residential energy consumption by U.S. census region/division and climate zone. This was done by multiplying the national average unit type consumption percentages identified in #1 by the total energy consumption for each U.S. census region/division and climate zone. For example, total residential electricity consumption from Table CE2.1 of RECS for the West census region is 239 billion kWh per year. Seventy-three (73%) of this consumption was apportioned to the single-family detached unit type (175 billion kWh per year). Note that this approach assumes the ratio of energy consumption among the residential unit types at the national level is equal to ratio of energy consumption at the U.S. census region/division and climate zone level.
  3. Identify the percentage of total residential energy consumption by end use for each U.S. census region/division and climate zone. For example, Table CE5.1a of RECS indicates that space heating represents 10% of total electricity consumption for the West census region.
  4. Calculate energy consumption by end use and unit type for each U.S. census region/division and climate zone. This was done by multiplying the unit consumption calculated in #2 by the end-use percentages identified in #3. Continuing the single-family example, space heating for single-family detached units in the West census region would consume 17 billion kWh per year (175 billion kWh per year * 10% of total consumption).

[30] The "other" end-use category represents the difference between total gas consumption per unit and the sum of gas consumption across the 6 RECS end-use categories. Users should exercise caution in applying the average energy consumption data for this category to their project. Note that the end-use categories presented in Table E-15.1 differ from those given in the CAPCOA Handbook due to differences in the underlying course data (U.S. EIA data vs. CEC data).

5. Identify the percentage of total residential units by unit type based on national average data. For example, Table CE2.1 of RECS indicates that the single-family detached unit type represents 62% of the total housing stock among all residential unit types included in the RECS.
6. Disaggregate the number of total residential units by U.S. census region/division and climate zone. This was done by multiplying the national average unit type percentages identified in #5 by the total number of housing units for each U.S. census region/division and climate zone. For example, Table CE2.1 of RECS shows that there are about 28 million residential units in the West census region. Sixty-two (62%) of these units were apportioned to the single-family detached unit type (17 million units). Note that this approach assumes the ratio of unit types at the national level is equal to ratio of unit types at the U.S. census region/division and climate zone level.
7. Calculate the per dwelling unit end-use intensities for each U.S. census region/division and climate zone. This was done by dividing the end use consumption values calculated in #4 by the number of units calculated in #6. Continuing the example, unitized spaced heating electricity consumption for the single-family detached unit type in the West census region is 978 kWh per year (non-rounded value) (rounded equation is (17 billion kWh per year/ 17 million units).

   The U.S. EIA administered the CBECS in 2018. The study yielded energy consumption estimates for 10 electric and 4 natural gas non-residential end uses. Based on this data for the year 2018, the average energy consumption intensities for natural gas end uses that may be electrified are provided in Table E-15.2. The natural gas end uses included in the CBECS and reflected in this measure include space heating, water heating, cooking, and other.[31] Users should only evaluate the end uses applicable to their project. A minimum recommendation is that the primary natural gas end uses that are commonly electrified be included—space heating, water heating, and cooking.

   The data provided in Table E-15.2 are provided by principal building activity (e.g., education) and organized by U.S. census regions/division and climate zone. Consumption data by building activity and geographic region were calculated by combing data from the CBECS, which separately provides end use data 1) disaggregated by non-residential building activity based on aggregated national average consumption data and 2) aggregated for all non-residential building activities based on disaggregated U.S. census region/division and climate zone consumption data. The same steps as described above for the RECS were followed to collate the CBECS data.[32]

   Users should determine how they want to analyze the measure benefits based on project data and considering the advantages and disadvantages of the available

[31] The CBECS "other" end-use category includes wood, coal, solar, and all other energy sources. Users should exercise caution in applying the average energy consumption data for this category to their project. Note that the end-use categories presented in Table E-15.1 differ from those given in the CAPCOA Handbook due to differences in the underlying course data (U.S. EIA data vs. CEC data).

[32] Note that these post-processing steps are unique to this Western States Handbook to process the underlying data from the U.S. EIA's RECS and CBECS to support measure quantification. Separate post-processing steps were conducted for the CAPCOA Handbook to process the CEC data.

RECS and CBECS defaults. If users can provide a project-specific value, then they should replace the defaults in the GHG calculation formula.

- (G) – The carbon intensity of natural gas was calculated in terms of CO_2e by multiplying the U.S. natural gas combustion emission factors for CO_2, CH_4, and N_2O (U.S. EPA 2020) by the corresponding 100-year GWP values from the IPCC's Fifth Assessment Report (IPCC 2013). See Table E-4.11 in the Appendix for more natural gas emission factors.
- (H) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.

GHG Calculation Caps or Maximums

Measure Maximum

None.

Mutually Exclusive Measures

If users select this measure (Measure E-15), they may not also take credit for Measure E-12, *Install Electric Water Heater in Place of Gas Storage Tank Heater in Residences*, or Measure E-13, *Install Electric Cooking Appliances in Place of Gas Appliances,* which electrify select appliances. This measure (Measure E-15) accounts for the combined GHG reductions achieved by each of these measures, as well as the electrification of other end uses. To combine the GHG reductions from this measure (Measure E-15) with Measure E-12 or Measure E-13 would be considered double counting.

Example GHG Reduction Quantification

The user reduces building energy emissions by electrifying the proposed development with electric end uses in place of natural gas end uses. In this example, the measure would be implemented at 20 single-family attached units (C) constructed in Colorado. The user elects to use consumption data for the Mountain North U.S. census division (D). Natural gas end uses without the measure include space heating, water heating, cooking, and clothes dryers, resulting in 798 therms per year per du (E). The electricity consumption to electrify these end uses would be 2,974 kilowatt-hours per year per du (F). The project would begin operation by 2030 and the user elects to use the WECC average emission factor from the

Appendix (314 lb. CO_2e per MWh) (H). The mitigated emissions would be reduced by 76 MT CO_2e per year.

$$A = \left(\frac{-798 \text{ therm}}{\text{yr·du}} \times 20 \text{ du} \times \frac{117 \text{ lb } CO_2e}{\text{MMBtu}} \times \frac{0.1 \text{ MMBtu}}{\text{therm}} \times \frac{0.000454 \text{ MT}}{\text{lb}}\right) + \left(\frac{2{,}974 \text{ kWh}}{\text{yr·du}} \times 20 \text{ du} \times \frac{314 \text{ lb } CO_2e}{\text{MWh}} \times \frac{0.001 \text{ MWh}}{\text{kWh}} \times \frac{0.000454 \text{ MT}}{\text{lb}}\right) = -76 \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

Energy and Fuel Savings

Energy use conversion from major natural gas appliances to their equivalent electric replacements tends not to be straightforward given that most significant gas appliances (e.g., water heaters, space heaters, ovens and cooktops) have varying input-to-output efficiencies and losses from product to product. Equivalent electric appliances also have differing efficiencies, and usage patterns for these equivalent appliances may differ in some way. If electrifying a building, the user would decrease the building natural gas consumption (E) and increase the electricity use (F).

Improved Air Quality

The reduction in natural gas fuel consumption from this measure would result in local improvements in air quality because the fuel consumption occurs on site of the project. The reduction in criteria pollutant emissions (L) achieved by the measure can be calculated as follows.

Criteria Pollutant Emission Reduction Formula

$$L = -E \times C \times M \times I \times N$$

Criteria Pollutant Emission Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
L	Reduction in criteria pollutant emissions from building energy	[ ]	tons per year	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
M	Criteria pollutant emission factors of natural gas	Table E-4.11	lb per mmBTU	U.S. EPA 1998
N	Conversion from lb to ton	0.0005	tons per lb	conversion

Further explanation of key variables:

- (M) – Table E-4.11 presents the criteria pollutant emission factors of natural gas for residential and commercial uses (U.S. EPA 1998).
- Please refer to the *GHG Calculation Variables* table above for definitions of variables that have been previously defined.

Sources

- IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/.
- U.S. EIA (U.S. Energy Information Administration). 2022. *Commercial Buildings Energy Consumption Survey (CBECS) Data*. Table B20: Energy sources, floorspace, 2018. Table E6: Electricity consumption (in kilowatt-hours [kWh]) by end use, 2018. Table E8: Natural gas consumption and conditional energy intensities (in cubic feet) by end use, 2018. Table C25: Natural gas consumption and conditional energy intensity by census region, 2018. Table C29: Natural gas consumption and conditional energy intensity by census division (part 3), 2018. Table C30: Natural gas consumption and conditional energy intensity by climate zone, 2018. Accessed January 2025. https://www.eia.gov/consumption/commercial/data/2018/.
- U.S. EIA. 2023. *Residential Energy Consumption Survey (RECS)*. Table CE2.1: Annual household site fuel consumption in the U.S.—totals and averages, 2020. Table CE5.1a: Detailed household site electricity end-use consumption, part 1—totals, 2020. Table CE5.1b: Detailed household site electricity end-use consumption, part 2—totals, 2020. Table CE5.2: Detailed household natural gas and propane end-use consumption—totals, 2020. Accessed January 2025. https://www.eia.gov/consumption/residential/data/2020/.
- U.S. EIA. 2025a. *RECS Terminology*. Accessed February 4, 2025. https://www.eia.gov/consumption/residential/terminology.php.
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- U.S. EIA. 2025c. *Residential Energy Consumption Survey (RECS) Maps*. Accessed February 4, 2025. https://www.eia.gov/consumption/residential/maps.php.
- U.S. EPA (U.S. Environmental Protection Agency). 1998. "Chapter 1: External Combustion Sources. 1.4, Natural Gas Combustion." In *AP 42*, Fifth Edition, Volume I (July). https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf.
- U.S. EPA. 2020. *Emission Factors for Greenhouse Gas Inventories*. March 2020. Accessed March 2021. https://www.epa.gov/sites/production/files/2020-04/documents/ghg-emission-factors-hub.pdf.

E-16. Require Zero Net Energy Buildings



GHG Mitigation Potential



Potentially large reduction in GHG emissions from building energy use

Co-Benefits (icon key on pg. 31)



Climate Resilience

Requiring ZNE buildings can reduce sensitivity to fuel price shocks or scarcity and offer more reliability if electricity providers have been adapted to climate change or less reliability if the grid has not been adapted. If the development produces and exports emission-free energy, this increases energy resilience and adds generation capacity to the overall grid, reducing risk of outages.

Health and Equity Considerations

As a ZNE building is likely to exclude or limit natural gas combustion, it would likely improve indoor and regional air quality.

Measure Description

This measure requires the user to operate their building at ZNE. A ZNE building foremost reduces GHG emissions by reducing energy use through more efficient design. Further, the building avoids GHG emissions either by using no emissions-generating energy sources or offsetting the building energy emissions by exporting emission-free energy (typically from onsite renewables). The user can evaluate building energy use intensity scenarios using the free online ZeroTool.org. Washington State also maintains a Zero Energy Toolkit with various guidance and resources for zero net energy analysis and design (Washington Department of Commerce 2024).

Subsector

Building Decarbonization

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

The U.S. DOE (2015) commonly defines ZNE buildings as "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."

Cost Considerations

ZNE buildings would have highly variable costs, including building onsite renewable energy, more expensive building materials to improve energy efficiency, and carbon offsets and/or renewable energy credits (RECs). While purchasing RECs may be less costly than building onsite generation, the project would not gain the co-benefits of greater energy resilience and contribution to grid capacity. And while all these costs may be high, the cost savings from reduced energy usage are also substantial.

Expanded Mitigation Options

Instead implement Measure E-17, *Require Renewable Surplus Buildings*, which results in a surplus of renewable energy and therefore increased GHG reductions and co-benefits.

GHG Reduction Formula

A = -100%

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from building energy	100	%	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
	None			

No further explanation of variables.

GHG Calculation Caps or Maximums

Measure Maximum

(A_{max}) The maximum, and, in fact, only percentage reduction in GHG emissions from building energy for this measure is 100 percent. This assumes that the net amount of emissions displaced by onsite renewable energy resources is equal to the number of the emissions generated annually by the building electricity use and onsite fuel consumption.

Mutually Exclusive Measures

If the user selects this measure, they may not also select Measure E-17, *Require Renewable Surplus Buildings*, which represents a unique scenario in which the project produces more renewable energy than what is required to offset the emissions generated from energy consumed by the building and would be considered carbon-negative.

Example GHG Reduction Quantification

The user avoids building energy emissions by committing their project building to be ZNE. The user would reduce GHG emissions from building energy by 100 percent.

Quantified Co-Benefits

Energy and Fuel Savings

The percentage reduction in electricity from an electricity provider and fuel consumption achieved by the measure is the same as the percentage reduction in

GHG emissions (A). This measure, while not resulting in a net reduction in electricity consumption per se, would displace the building electricity from the grid.

Improved Air Quality

Electricity supplied by fossil-fueled or bioenergy power plants generates criteria pollutants. However, because these power plants are located throughout individual states and not typically in close proximity to the ZNE building site, the reduction in electricity use from this measure will not reduce localized criteria pollutant emissions.

For projects that are all electric or replace sources of fossil fuel combustion with electric infrastructure, the reduction in onsite fuel consumption from this measure would result in local improvements in air quality because the building fuel combustion occurs on site of the project (e.g., natural gas for space heating or water heating). The percentage reduction in GHG emissions (A) is the same as the percentage reduction in localized criteria pollutants from building energy achieved by the measure. In other cases, projects may achieve ZNE by offsetting emissions from onsite fuel combustion sources through the export of renewable energy generated to the electric grid. If the project would retain sources of fossil fuel combustion, there would not be a 100 percent reduction in local criteria pollutant emissions. The reduction in criteria pollutant emissions (B) achieved by the measure can be calculated as follows.

Criteria Pollutant Emission Reduction Formula

$$B = -C$$

Criteria Pollutant Emission Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
B	Percent reduction in criteria pollutant emissions from onsite fossil fuel use	[ ]	%	calculated
User Inputs				
C	Percent reduction in onsite fossil fuel use	0–100%	%	user input
Constants, Assumptions, and Available Defaults				
	None			

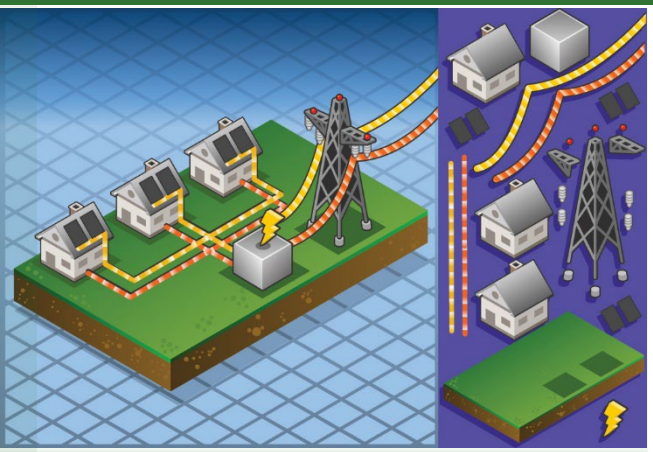
Further explanation of key variables:

- (B and C) – The reduction in criteria pollutant emissions may be less than 100 percent or even 0 percent if the project retains onsite fossil fuel sources (i.e., natural gas, propane) In this situation, the percentage reduction in criteria pollutant emissions is equal to the percentage reduction in onsite fossil fuel use.
- Please refer to the *GHG Calculation Variables* table above for definitions of variables that have been previously defined.

Sources

- U.S. DOE (U.S. Department of Energy). 2015. *A Common Definition for Zero Energy Buildings*. September 2015. Accessed March 31, 2025. https://www.energy.gov/sites/prod/files/2015/09/f26/A%20Common%20Definition%20for%20Zero%20Energy%20Buildings.pdf.
- Washington Department of Commerce. 2024. *Zero Energy Toolkit*. Accessed January 15, 2025. https://www.commerce.wa.gov/seep/zero-energy-toolkit/.

E-17. Require Renewable Surplus Buildings



GHG Mitigation Potential



Potentially large reduction in GHG emissions from building energy use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Requiring renewable surplus buildings can add generation capacity to the overall grid, reducing energy costs and risk of outages.

Health and Equity Considerations

Providing surplus energy back into the grid can reduce the risk of power outages, which underserved communities are more vulnerable to because of disinvestment and historical redlining.

Measure Description

This measure will require that proposed development install onsite renewable energy in an amount that offsets more emissions than the amount generated from the development's electricity use and onsite fuel consumption. Installing zero-emission renewable energy displaces emissions from grid electricity that would otherwise be used, thereby reducing GHG emissions. Implementation of this measure would result in buildings that reduce more GHG emissions than they generate through surplus generation of energy from renewables, sometimes known as *carbon-negative buildings*. The amount of renewable energy required for a building to have net negative GHG emissions is largely determined by the number of emissions from onsite fuel consumption and the carbon intensity of the electricity provider.

Subsector

Building Decarbonization

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Onsite renewable energy should be installed in an amount that offsets more emissions than the amount generated from the development's electricity and onsite fuel consumption. The excess renewable energy must be sold to displace non-zero emission grid electricity.

Cost Considerations

The costs associated with building only renewable-surplus structures are very high, as each building will need to be maximally energy efficient and generate renewable energy on site. However, by definition, energy costs would be entirely eliminated, and surplus energy would be sold back to the electricity provider. This is not only a cost savings, but also an additional revenue stream for each building.

Expanded Mitigation Options

When requiring development with surplus renewable generation, a best practice is to also electrify the building (see Measure E-15, *Require All-Electric Development*) so that emissions from onsite fuel consumption, such as natural gas, are eliminated.

GHG Reduction Formula

$$A = B + [(C - D) \times E \times F \times G]$$

$$A_{\%} = \frac{A - (B + C \times E \times F \times G)}{(B + C \times E \times F \times G)}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	GHG emissions from building energy	[ ]	MT CO_2e per year	calculated
$A_{\%}$	Percent reduction in GHG emissions from building energy	>100	%	calculated
User Inputs				
B	Emissions from building onsite fuel consumption	[ ]	MT CO_2e per year	user input
C	Building electricity use	[ ]	kWh per year	user input
D	Onsite renewable energy production	[ ]	kWh per year	user input
Constants, Assumptions, and Available Defaults				
E	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
F	Conversion from lb to MT	0.000454	MT per lb	conversion
G	Conversion from kWh to MWh	0.001	MWh per kWh	conversion

Further explanation of key variables:

- (B) – Emissions from building onsite fuel combustion may come from natural gas, propane, or other fuels. The user should take care to properly quantify these emissions using accepted methodologies. If the project would be an all-electric development (see Measure E-15), then there would be no onsite fuel consumption, and the value for this variable would be zero.
- (C) – It is assumed that the building electricity comes from a non–zero-emission source (e.g., grid electricity with fossil fuel mix). However, if a project would be all-electric, and the electricity provider supplying the project's electricity sources 100 percent of its electricity from renewable energy sources, then this measure would not reduce building energy emissions, as they would already be zero. The measure would still result in the co-benefit of enhanced energy supply because it adds its energy surplus as additional capacity back to the grid.
- (D) – It is assumed that the onsite renewable energy comes from a zero-emission source (e.g., solar, wind, geothermal, biomass, eligible hydroelectric). See Measures E-10-A through E-10-C for discussion of how to calculate the energy generated from various renewable energy systems. This value should be greater than the value for (C) because the renewable energy generated will need to more than offset the electricity consumed and onsite fuel consumption.

(E) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.

GHG Calculation Caps or Maximums

Measure Maximum

($A_{\%}$) The percentage reduction in GHG emissions from building energy for this measure should be greater than 100 percent. This is based on the requirement that the displaced electricity emissions from the onsite renewable sources must exceed the combined building energy emissions from electricity and onsite fuel consumption.

Mutually Exclusive Measures

If the user selects this measure, they may not also select Measure E-16, *Require Zero Net Energy Buildings*, which represents a unique scenario in which the project produces an amount of renewable energy that displaces an equal number of emissions from building electricity and onsite fuel consumption (i.e., ZNE).

Example GHG Reduction Quantification

The user constructs onsite renewable energy infrastructure that displaces more emissions than the amount generated from electricity and onsite fuel consumption. In this example, a single-family home would be constructed in the Public Service Company of New Mexico's service territory and would begin operation by 2029. The user elects to use the utility emission factor from the Appendix (247 lb. CO_2e per MWh) (E). If the emissions from building onsite fuel consumption are 0.1 MT CO_2e per year (B), the building electricity use is 9,000 KWh per year (C), and the onsite renewable energy production is 16,000 KWh per year (D), the mitigated emissions would be -0.68 MT CO_2e per year.

$$A = \frac{0.1 \text{ MT } CO_2e}{\text{yr}} + \left[\left(\frac{9{,}000 \text{ kWh}}{\text{yr}} - \frac{16{,}000 \text{ kWh}}{\text{yr}}\right) \times \frac{247 \text{ lb } CO_2e}{\text{MWh}} \times \frac{0.000454 \text{ MT}}{\text{lb}} \times \frac{0.001 \text{ MWh}}{\text{kWh}}\right] = \frac{-0.68 \text{ MT} CO_2e}{\text{yr}}$$

$$A_{\%} = \frac{\frac{-0.68 \text{ MT } CO_2e}{\text{yr}} - \left(\frac{0.1 \text{ MT } CO_2e}{\text{yr}} + \frac{9{,}000 \text{ kWh}}{\text{yr}} \times \frac{247 \text{ lb } CO_2e}{\text{MWh}} \times \frac{0.000454 \text{ MT}}{\text{lb}} \times \frac{0.001 \text{ MWh}}{\text{kWh}}\right)}{\frac{0.1 \text{ MT } CO_2e}{\text{yr}} + \frac{9{,}000 \text{ kWh}}{\text{yr}} \times \frac{247 \text{ lb } CO_2e}{\text{MWh}} \times \frac{0.000454 \text{ MT}}{\text{lb}} \times \frac{0.001 \text{ MWh}}{\text{kWh}}}$$

Quantified Co-Benefits

Energy and Fuel Savings

This measure, while not resulting in a net reduction in electricity consumption per se, would completely displace the building electricity from the grid (C) and provide surplus generation capacity from onsite renewable sources (D).

Sources

- None.

E-18. Establish Methane Recovery in Landfills



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from landfill waste decomposition depending on the capture program and system size

Co-Benefits (icon key on pg. 31)

Climate Resilience

Establishing CH_4 recovery provides backup fuels if extreme weather events disrupt main sources of fuel.

Health and Equity Considerations

Combustion of CH_4 may increase local air pollution. Potential effects of combustion emissions on adjacent sensitive receptors should be evaluated during project design.

Measure Description

This measure involves the capture and treatment of landfill gas (LFG) emitted from decomposition of organic waste in landfills. Landfill gas contains about 50 percent CH_4 by volume, which has a GWP 28 times that of CO_2. This measure addresses emissions savings from LFG that is captured and either flared or combusted for energy. Flaring LFG will reduce the amount of CH_4 emitted into the atmosphere. Combusting LFG to generate electricity for onsite energy needs reduces GHG emissions in two ways: it reduces direct CH_4 emissions, and it displaces electricity demand and the associated indirect GHG emissions from electricity production. Municipal solid waste management teams should calculate the GHG savings from both flaring and combustion for energy recovery to see the relative benefits for each option.

Subsector

Methane Recovery

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Landfills that have no current system for capturing CH_4 would face high installation costs for a CH_4 recovery system. Costs would be much lower for landfills that already have a system for trapping or cleaning captured gases. CH_4 reclaimed from waste could represent a large additional revenue stream for landfills if the gases are managed and sold as offsets or RECs on the U.S. Renewable Fuel Standards market.

Expanded Mitigation Options

Additional reductions may be achieved if the LFG is used as transportation fuel or injected into a regional natural gas pipeline for downstream uses. Quantitative methods for these alternatives are not specifically addressed by this measure.

GHG Reduction Formula

$A1 = [(G \times O \times L) + (G \times P \times M)] \times Q$

$B = G \times N$

$A2 = B \times R \times S \times T$

$A3 = A1 + A2$

$C = [D \times [E \times I \times J \times F \times K] \times (1 - H)] \times L$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Emissions from LFG flaring or combustion	[ ]	MT CO_2e	calculated
B	Energy savings from flaring or combustion of LFG for energy	[ ]	mmBTU	calculated
A2	Additional emissions from LFG combustion if energy is generated	[ ]	MT CO_2e	calculated
A3	Total emissions from LFG use (flaring and energy use)	[ ]	MT CO_2e	calculated
C	CH_4 generation potential emissions	[ ]	MT CO_2e	calculated
User Inputs				
D	Municipal solid waste affected by measure	[ ]	tons	user input
E	CH_4 correction factor	0.6–1	unitless	IPCC 2007
F	Fraction of CH_4 in landfill gas	0.4–0.6	unitless	IPCC 2007
G	LFG flared of combusted for energy	[ ]	standard cubic foot (scf)	U.S. EPA 2018
Constants, Assumptions, and Available Defaults				
H	Oxidation rate	0.10	percent	IPCC 2007
I	Disposed organic carbon (DOC)	Table E-18.1	percent	see table
J	Fraction of DOC that is ultimately degraded	0.6	unitless	IPCC 2007
K	Stoichiometric ratio between CH_4 and carbon	16/12	g of CH_4 per g of C	conversion
L	GWP of CH_4	28	unitless	IPCC 2013
M	GWP of N_2O	265	unitless	IPCC 2013
N	Heating value of LFG	0.000485	mmBTU per scf	U.S. EPA 2018

ID	Variable	Value	Unit	Source
O	CH_4 emission factor for LFG combustion	0.001552	g CH_4 per scf	U.S. EPA 2018
P	N_2O emission factor for LFG combustion	0.000306	g N_2O per scf	U.S. EPA 2018
Q	Conversion from g to MT	10^{-6}	MT per g	conversion
R	MWh to mmBTU	3.412142	MWh per mmBTU	conversion
S	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
T	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (C) – The generation potential follows the IPCC 2007 "good practices" guidelines for estimating CH_4 emissions for a landfill that does not have LFG capture technology.
- (D) – This input is the amount of waste that the user will know will have some amount of LFG capture technology.
- (E) – The CH_4 correction factor accounts for CH_4 generation from managed or unmanaged landfills. For example, unmanaged landfills produce less CH_4 from a given amount of waste than managed landfills because a larger fraction of waste decomposes aerobically in the top layers of a landfill.
  - Managed = 1.0
  - Unmanaged (≥5 meter (m) deep) = 0.8
  - Unmanaged (<5 m deep) = 0.4
  - Uncategorized = 0.6
- (F) – The fraction of CH_4 in landfill gas is based on the organic matter content of the landfill. This fraction can range from 0.4 to 0.6, but the default is usually taken as 0.5.
- (I) – DOC values for Colorado, Oregon, and Washington landfills are provided in Table E-18.1 in the Appendix. The values were calculated based on the percentage of landfilled organic waste from Tables S-1.4 through S-1.6 in the Appendix. Users in Arizona and New Mexico are encouraged to contact their local waste management agency for assistance in characterizing the waste stream and calculating the DOC. Alternatively, they may use the national DOC value in Table E-18.1, which was calculated based on the national waste stream composition provided in Table S-1.8.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

In this example, a user decides to implement an LFG capture program and use the LFG to produce energy to offset utility electricity usage. The landfill contains 1,000 short tons of waste (D), is managed and has 0.5 fraction of CH_4 in the LFG (F) with a 75 percent collection

efficiency. Twenty million scf LFG was combusted (G). The project is in Colorado within the Public Service Company of Colorado's service territory. Per Table E-18.1 in the Appendix, the percentage DOC for Colorado landfills is 37.1% (I). The user elects to use the utility emission factor from the Appendix (929 lb CO_2e per MWh) (S). This example scenario results in a total net GHG reduction (A3) of 13,962 MT CO_2e.

$$A1 = \left[\left(\textbf{20,000,000 scf} \times 0.001552\frac{\text{g } CH_4}{\text{scf}} \times 28\right) + \left(\textbf{20,000,000 scf} \times 0.000306\frac{\text{g } N_2O}{\text{scf}} \times 265\right)\right] \times 10^{-6}\ \frac{\text{MT}}{\text{g}} = 2.5 \text{ MT } CO_2e$$

$$B = \textbf{20,000,000 scf} \times 0.000485\frac{\text{MMBtu}}{\text{scf}} = 9{,}700 \text{ MMBtu}$$

$$A2 = 9{,}700 \text{ MMBtu} \times 3.412142\frac{\text{MWh}}{\text{MMBtu}} \times 929\frac{\text{lb}}{\text{MWh}} \times 0.000454\frac{\text{MT}}{\text{lb}} = 13{,}960 \text{ MT } CO_2e$$

$$A3 = 2.6 \text{ MT } CO_2e + 13{,}960 \text{ MT } CO_2e = 13{,}962 \text{ MT } CO_2e$$

$$C = \left[\textbf{1,000 tons} \times \left[1 \times 37.1\% \times 0.6 \times \textbf{0.5} \times \frac{16}{12}\ \frac{\text{g } CH_4}{\text{g C}}\right] \times (1\text{-}0.1)\right] \times 28 = 3{,}740 \text{ MT}CO_2e$$

Quantified Co-Benefits

Energy and Fuel Savings

Energy savings from flaring or combustion of LFG for energy are calculated above as (B).

Sources

- IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar4/wg1/.
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- U.S. EPA (U.S. Environmental Protection Agency). 2018. *Emission Factors for Greenhouse Gas Inventories*. March 2018. Accessed January 2021. https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf.

E-19. Establish Methane Recovery in Wastewater Treatment Plants



GHG Mitigation Potential



Potentially large reduction in GHG emissions from plant operations

Co-Benefits (icon key on pg. 31)





Climate Resilience

Establishing CH_4 recovery provides backup fuels if extreme weather events disrupt main sources of fuel.

Health and Equity Considerations

Combustion of CH_4 may increase air pollution. Potential effects of combustion emissions on adjacent sensitive receptors need to be evaluated during project design.

Measure Description

This measure requires capturing CH_4 from an existing wastewater treatment plant and either (1) combusting or flaring it to prevent escape into the atmosphere or (2) combusting or flaring it and using the heat to generate electricity for onsite energy needs. Using the combusted CH_4 as an energy source reduces GHG emissions by displacing electricity demand and the associated indirect GHG emissions from electricity production. This measure is most applicable to wastewater treatment plants that have anaerobic digestion infrastructure, which facilitates the biological decomposition of the wastewater and produces the CH_4 that is either flared or harnessed for energy.

Subsector

Methane Recovery

Scale of Application

Project/Site

Implementation Requirements

See measure description. Also, this measure may not be appropriate for wastewater treatment plants that use lagoons to process wastewater.

Cost Considerations

Wastewater treatment plants that have no current system for capturing CH_4 would face high installation costs for a CH_4 recovery system. Costs would be lower for plants that already have a system for trapping or cleaning captured gases. CH_4 reclaimed from wastewater treatment could represent a large additional revenue stream for the plants if the gases are managed and sold as offsets or RECs on the U.S. Renewable Fuel Standards market.

Expanded Mitigation Options

Additional reductions may be achieved if the CH_4 is processed and used as a transportation fuel or injected into a regional natural gas pipeline for downstream uses. Captured waste biogas may also be used to support the production of biodegradable biopolymers, which serve as natural alternatives to conventional plastics.

GHG Reduction Formula

$A1 = C \times [D - (E \times F \times G \times H \times (1 - I) \times J \times K \times L)]$ (Emissions Reduction)

$B = (C \times E \times F \times G \times M \times N \times O)$ (Energy Savings, if applicable)

$A2 = B \times P \times Q \times R$ (Additional Emissions Reduction, if applicable)

$A3 = A1 + A2$ (Total Net Emissions Reduction)

$A4 = \frac{A3}{C \times D}$ (% Reduction)

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Emissions reduction from CH_4 flaring or combustion	[ ]	MT CO_2e	calculated
B	Energy savings from CH_4 capture, combustion and energy generation	[ ]	kWh	calculated
A2	Additional emissions reduction if energy is generated	[ ]	MT CO_2e	calculated
A3	Total net emissions reduction	[ ]	MT CO_2e	calculated
A4	Percent reduction in GHG emissions from wastewater	0-100	%	calculated
User Inputs				
C	Wastewater affected by measure	[ ]	liters	user input
Constants, Assumptions, and Available Defaults				
D	Wastewater emission factor	2.85×10^{-6} or 1.93×10^{-6}	MT CO_2 per liter gal per liter	U.S. EPA 2020
E	Conversion from liters to gal	0.26417	sf per gal	conversion
F	Digester gas	0.01	unitless	U.S. EPA 2020
G	Fraction CH_4	0.65	%	U.S. EPA 2020
H	Density of CH_4	662	g CH_4 per m^3 CH_4	U.S. EPA 2020
I	Destruction efficiency	0.99	unitless	U.S. EPA 2020
J	Conversion from ft^3 to m	0.02832	m^3 per ft^3	conversion
K	Conversion from g to MT	$1e^{-6}$	g per MT	conversion
L	GWP of CH_4	28	unitless	IPCC 2013
M	Heating value of CH_4	1,028	BTU per ft^3 CH_4	ICLEI 2013
N	Conversion from kWh to BTU	0.000293	kWh per BTU	conversion
O	Efficiency factor	0.85	unitless	assumption
P	Conversion from kWh to MWh	0.001	MWh per kWh	conversion

ID	Variable	Value	Unit	Source
Q	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
R	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (A1) – The emissions calculated for this variable represent the emissions reduction that is achieved from the combustion of CH_4. Combusting the CH_4 prevents it from entering the atmosphere; however, during the combustion process, some fraction of CH_4 is not fully combusted and can leak into the atmosphere. The formula for this variable accounts for the fraction that is not fully combusted.
- (B) – This variable represents the energy savings that result from the combustion of CH_4 and then using the heat produced to generate energy. If CH_4 will only be combusted or flared but not used for energy, then there would not be energy savings for this measure. The user should set this variable to zero if there will be no energy generation.
- (A2) – The emissions reductions calculated for this variable represent the emissions that are offset from the generation of energy from the captured CH_4 instead of from typical fossil fuel sources. Combusting the CH_4 avoids the need for fossil fuel sources of energy that would have been generated in the absence of this measure.
- (A3) – The net emissions reductions achieved by this measure are calculated in this variable.
- (D) – The factors represent the emissions per liter of wastewater that is treated at facilities with either primary treatment or without primary treatment. These values are as follows.
  - Primary treatment factor: 1.93 x 10-6
  - Without primary treatment factor: 2.85×10^{-6}
- (E) – The digester gas variable represents the amount of digester gas that is generated per gal of wastewater. The value given here is determined by assumptions from the U.S. EPA's GHG inventory, with the amount of digester gas generated per person per day is 1 cubic foot and the amount of wastewater generated per person per day is 100 gallons (gal) (for publicly owned treatment works). Dividing these values (1/100) is equal to 0.01 cubic feet of digester gas per gal of wastewater.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user implements CH_4 capture and energy generation infrastructure at an existing wastewater treatment plant that processes 100 million liters of wastewater per year. The existing plant currently has primary treatment. The project is in Oregon, and user elects to use the WECC average emission factor from the Appendix for the year 2040 (210 lb. CO_2e per MWh) (Q). The example measure emission reduction is calculated below.

$$B = \left(100\times10^{6}\ \text{liters} \times \frac{0.26417\ \text{gal}}{\text{liter}} \times 0.01\frac{\text{ft}^3}{\text{gal}} \times 0.65 \times \frac{1{,}028\ \text{BTU}}{\text{ft}^3\ \text{CH4}} \times \frac{0.000293\ \text{kWh}}{\text{BTU}} \times 0.85\right) = 43{,}962\ \text{kWh}$$

$$A1 = 100\times10^{6}\ \text{liters} \times \left[1.93\times10^{-6}\frac{\text{MT CH}_4}{\text{liter}} - \left(\frac{0.26417\ \text{gal}}{\text{liter}} \times 0.01\frac{\text{ft}^3}{\text{gal}} \times 0.65 \times 662\frac{\text{g CH}_4}{\text{m}^3\ \text{CH}_4} \times (1 - 0.99) \times \frac{0.02832\ \text{m}^3}{\text{ft}^3} \times \frac{10^{-6}\ \text{MT}}{\text{g}} \times 28\right)\right] = 192\ \text{MT CO}_2\text{e}$$

$$A2 = 43{,}962\ \text{kWh} \times 0.001\frac{\text{MWh}}{\text{kWh}} \times \frac{210\ \text{lb CO}_2\text{e}}{\text{MWh}} \times 0.000454\frac{\text{MT}}{\text{lb}} = 4\ \text{MT CO}_2\text{e}$$

$$A3 = 192\ \text{MT CO}_2\text{e} + 4\ \text{MT CO}_2\text{e} = 196\ \text{MT CO}_2\text{e}$$

$$A4 = \frac{196\ \text{MT CO}_2\text{e}}{100\times10^{6}\ \text{liters} \times 1.93 \times 10^{-6}\frac{\text{MT CO}_2\text{e}}{\text{liter}}} = 102\%$$

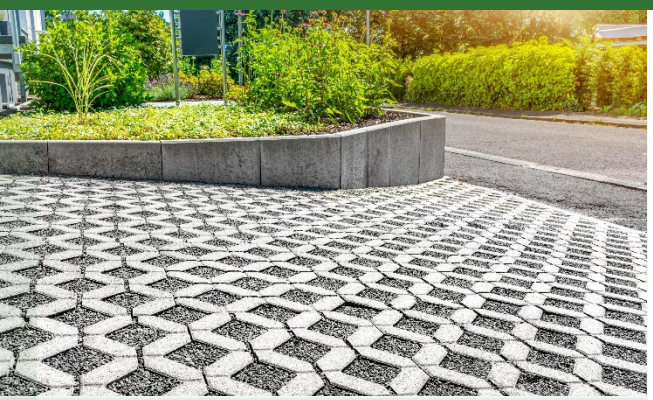
Quantified Co-Benefits

Successful implementation of this measure could achieve energy savings if the user's project includes CH_4-based energy generation infrastructure. This quantified co-benefit is derived in the steps above that are necessary to quantify GHG reductions.

Sources

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- ICLEI (International Council for Local Environmental Initiatives). 2013. "Appendix F: Wastewater and Water Emission Activities and Sources" in *U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions.* https://icleiusa.org/publications/us-community-protocol/.
- U.S. EPA (U.S. Environmental Protection Agency). 2020. "Chapter 7. Waste" in *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018.* https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-chapter-7-waste.pdf.

E-21. Install Cool Pavement



GHG Mitigation Potential

Small

Potentially small reduction in GHG emissions from energy demand

Co-Benefits (icon key on pg. 31)

Climate Resilience

Cool pavement absorbs less heat, reducing the urban heat island effect and building both individual and community-wide resilience to high temperatures.

Health and Equity Considerations

Cool pavements should be prioritized in vulnerable and sensitive communities that experience urban heat island effects, have large amounts of paved areas, and lack sufficient shade. Any disbenefits from cool pavement installation projects such as glare should be addressed during the project's planning phase.

Measure Description

This measure involves installing cool pavement in place of dark pavement. Cool pavement helps to lower ambient outdoor air temperatures when compared to dark-colored, heat-absorbent pavement. This reduces the electricity needed to provide cooling, thereby reducing associated GHG emissions, depending on the project parameters (e.g., climate, carbon intensity of local utility).

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

This measure is only applicable in areas where research is available on the energy savings from cool pavement (see GHG Calculation Variables). Implementation of this measure may result in limited or no GHG reductions for highly developed areas with tall buildings or in urban canyons, such as in a downtown or commercial area, or areas with extensive tree canopy cover. Tall buildings and tree canopies restrict the amount of sunlight reaching the street surface, and thus limited additional cooling would be achieved by the pavement surface.

Furthermore, installing cool pavements in areas with tall buildings or in urban canyons may result in an increased heating demand during the cooler months. Cool pavement installation should be prioritized in paved areas in open spaces with high urban heat island effects, such as major freeways, highways, arterial roads, and parking lots (Altostratus Inc. 2020).

Cost Considerations

The cost of applying cool pavement versus conventional paving materials will vary by region, contractor, time of year, materials chosen, accessibility of the site, local availability of materials, underlying soils, size of the project, traffic conditions, and desired lifetime of the pavement.

Expanded Mitigation Options

Pair with Measures C-1-A , *Use Electric or Hybrid Powered Equipment*, C-1-B, *Use Cleaner-Fuel Equipment*, and C-2, *Limit Heavy-Duty Diesel Vehicle Idling* , to ensure that the construction equipment used during the installation of cool pavement use less fuel, thereby further reducing GHG emissions.

GHG Reduction Formula

$$A = -\left(\frac{B \times D}{E}\right) \times J$$

$$K = \left(\frac{B \times I}{E}\right) \times M$$

$$L = \left(\frac{((A \times F) + (K \times G))}{N}\right)$$

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A	Reduction in electricity demand from the installation of cool pavement	[ ]	MWh/year	calculated
K	Increase in natural gas demand from the installation of cool pavement	[ ]	mmBTU/year	calculated
L	GHG emission reductions from the installation of cool pavement	[ ]	MT CO_2e/year	calculated
User Inputs				
B	Amount of cool pavement that is being constructed	[ ]	ft^2	user input
Constants, Assumptions, and Available Defaults				
C	U.S. EIA Climate Zone	Figure E-2.3	integer	U.S. 2025
D	Cool pavement maximum energy saving per year	Table E-21.1	kWh/year/m^2	LBNL 2017a, 2017b
E	Converting square feet to square meters	10.76	ft^2/m^2	conversion
F	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
G	Natural gas emission factor	Table E-4.11	lbs CO_2e/mmBTU	U.S. EPA 2020
I	Cool pavement maximum additional heating per year	Table E-21.1	therms/year/m^2	LBNL 2017b
J	Converting kilowatt hours to megawatt hours	0.001	MWh/kWh	conversion
M	Converting therms to mmBTU	0.1	mmBTU/therms	conversion
N	Converting pounds to metric tons	2,204.62	lbs/MT	conversion

Further explanation of key variables:

- (B) – The amount of cool pavement that is being constructed should be provided by the user based on project-specific details.

- (C) – This measure relies on the U.S. EIA climate zones defined in Figure E-2.3 in the Appendix. Note that defaults for changes in energy consumption (D, I) are only available for the "warm" and "hot or very hot" climate zones, as discussed further below.
- (D, I) – The LBNL (2017a, 2017b) estimated potential electricity savings and additional heating resulting from changes in surface albedo from installation of cool pavements. The studies were conducted for nine cities/counties in Califonria. All locations except Riverside are in the U.S. EIA's "warm" climate zone. Riverside is in the "hot or very hot" climate zone. Average electricity savings and additional gas consumption among locations in the "warm" climate zone are shown in Table E-21.1.[33] Electricity savings for Riverside are reported for the "hot or very hot" climate zone. Data on potential additional gas consumption for cool pavement installation in Riverside was not quantified in the LBNL studies. Users could consider applying the gas consumption value shown in Table E-21.1 for the "warm" climate zone to approximate a minimum increase in heating. However, please note that additional heating requirements for projects in hot or very hot climates may be greater than for projects located in more mild climates.

  Users should consider their project's location before applying the defaults presented in Table E-21.1. Energy impacts of cool pavements depend heavily on ambient surface temperatures. Thus, it is recommended only those projects located within the U.S. EIA's "warm" or "hot or very hot" climate zones consider the data in Table E-21.1 as potential inputs. Based on Figure E-2.3 in the Appendix, this includes parts of southern New Mexico and Arizona.
- (F) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer Measure E-2, *Install Cool Roofs and/or Cool Walls in Residential Development*, for additional information.

GHG Calculation Caps or Maximums

Measure Maximum

The maximum GHG emission reductions from this measure are tied to the total amount of area that cool pavement can be installed within a supported climate zone and the GHG intensity factors from the utilities serving that area.

Example GHG Reduction Quantification

A city in southern New Mexico ("warm" climate zone [C]) is working on a pilot program that will install cool pavement on a 5-mile, 4-lane stretch of an arterial roadway. The total area of this roadway that would be covered is 1,267,200 square feet (B). The program is in the Public Service Company of New Mexico's service territory and would begin operation by 2030. The user elects to use the utility emission factor from the Appendix (224 lb. CO_2e per

[33] Note the aggregation of data presented in Table E-21.1 differs from the CAPCOA Handbook. The CAPCOA Handbook mapped the nine cities to one of the CEC's climate zones (referred to as Electrification Demand Forecast Zones or "EDFZs" in the CAPCOA Handbook). The EDFZs are specific to regions in California and are thus not applicable to this Western States Handbook. The use of U.S. EIA climate zones results in the elimination of sub-variable "H" from the equations.

MWh) (F). Following the formulas above, this pilot program would result in a reduction of 7.7 $MTCO_2e/yr$ in energy savings.

$$A=-\left(\frac{1{,}267{,}200\ ft^2 \times 1.0030\ kWh/m^2/yr}{10.76\ ft^2/m^2}\right) \times 0.001 MWh/kWh$$

$$A= -118.12\ MWh/yr$$

$$K = \left(\frac{1{,}267{,}200\ ft^2 \times 0.0069\ therms/m^2/yr}{10.76\ ft^2/m^2}\right) \times 0.1\ mmBTU/therms$$

$$K = 81.44\ mmBTU/yr$$

$$L = \left(\frac{((-118.12\ MWh/yr \times 224\ lbs\ CO_2e/MWh) + (81.44\ mmBTU/yr \times 117.32\ lbs\ CO_2e/mmBTU)}{2{,}204.62\ lbs/MT}\right)$$

$$L = -7.7\ MTCO_2e/yr$$

Quantified Co-Benefits

Energy and Fuel Savings

Successful implementation of this measure would achieve electricity savings due to the cooling effects of the pavement.

$$A = -\left(\frac{B \times D}{E}\right) \times J$$

Worsened Air Quality

While the measure would achieve electricity savings, it can increase natural gas consumption (K) during colder months and potentially worsen ambient air quality (U) from natural gas combustion.

Criteria Pollutant Emission Increase Formula

$$K = \left(\frac{B \times I}{E}\right) \times M$$

$$U = \left(\frac{(|K| \times G)}{X}\right)$$

Criteria Pollutant Emissions Increase Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
U	Increase in criteria pollutant emissions from building energy	[ ]	tons per year	calculated
User Inputs				
K	Increase in natural gas demand from the installation of cool pavement	[ ]	mmBTU/year	calculated
Constants, Assumptions, and Available Defaults				
G	Criteria pollutant emission factors of natural gas	Table E-4.11	lbs/mmBTU	U.S. EPA 1998
X	Converting pounds to short tons	2,000	lbs/tons	conversion

Further explanation of key variables:

- (K) – Because K is a negative value in the above equation, the absolute value is used to calculate the positive increase in criteria pollutant emissions.
- (G) – Natural gas GHG emission factors for residential and non-residential uses are found in Table E-4.11 in the Appendix. When choosing between residential or non-residential, it is recommended that users use the emission factor representing the most prominent land use near the cool pavement that is being constructed.

Sources

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U.S. EIA (U.S. Energy Information Administration). 2025. *Commercial Buildings Energy Consumption Survey (CBECS) Maps*. Accessed February 4, 2025. https://www.eia.gov/consumption/commercial/maps.php.
- U.S. EPA (U.S. Environmental Protection Agency). 1998. "Chapter 1: External Combustion Sources. 1.4, Natural Gas Combustion." In *AP 42*, Fifth Edition, Volume I (July). https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf.
- U.S. EPA. 2020. *Emission Factors for Greenhouse Gas Inventories*. March 2020. Accessed March 2021. https://www.epa.gov/sites/production/files/2020-04/documents/ghg-emission-factors-hub.pdf.

E-26. Biomass Energy



GHG Mitigation Potential



Potentially large reduction from electricity generation

Co-Benefits (icon key on pg. 31)



Climate Resilience

Increasing biomass energy generation enhances energy resilience and diversifies fuel supply chains if extreme weather events result in widespread power outages.

Health and Equity Considerations

New biomass processing facilities should be planned in consultation with local members of vulnerable or sensitive communities to ensure that impacts or disbenefits from biomass production and processing are addressed before installation. Non-combustion biomass energy projects, including those that create clean hydrogen, should also be considered.

Measure Description

This measure requires installing new biomass or biofuel electricity generation (or cogeneration). Although the direct combustion emissions for biofuels are generally on-par with other forms of fossil fuel energy, biofuels have a lower life-cycle carbon intensity due to the uptake of carbon from plants used to produce that fuel. A reasonable reference point for this carbon intensity would be the average carbon intensity of the electricity in the utility that would receive power from this new biomass plant.

Subsector

Renewable Energy Generation

Scale of Application

Project/Site or Plan/Community

Implementation Requirements

See measure description.

Cost Considerations

Installation costs for biofuel power generation infrastructure vary greatly depending on the type of biomass or feedstock (i.e., the raw materials needed to produce biofuels), the technology used, and the size of the installation. Overall, installation costs can be high, but initial costs can be partially offset by credits or rebates meant to encourage renewable energy generation. In the long term, using biofuels to generate electricity may result in cost savings due to reduced operational costs and more stable fuel pricing than fossil fuel energy.

Expanded Mitigation Options

Best practice is to site biofuel electricity generation infrastructure in areas where sustainable feedstock is available and can be obtained efficiently. By installing biomass energy generation locally, the carbon intensity of the electricity supply would decrease, reducing GHG emissions from local electricity consumption.

GHG Reduction Formula

$A = B \times C \times D \times (E-F) \times G$

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A	Annual emissions reduction from biomass plant generation	[ ]	MT CO_2e	calculated
User Inputs				
B	Rated peak generation power	[ ]	MW	user input
Constants, Assumptions, and Available Defaults				
C	Hours in a year	8,760	hours	conversion
D	Capacity factor of generation type	Table E-26.1	%	U.S. EIA 2023
E	Lifecycle carbon intensity of biomass sources	Table E-26.2	lb CO_2e per MWh	EPRI 2013
F	Lifecycle carbon intensity electricity	Table E-26.3	lb CO_2e per MWh	U.S. DOE 2024
G	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (B) – This is the rated peak power output of the generators used by the power plant. This is often referred to as the nameplate value.
- (C) – This is the number of hours per year for which the utility intends to operate, not including normal operational breaks, such as maintenance.
- (D) – The capacity factor corrects for the fact that power plants do not always operate at their rated peak power due to a variety of operational and economic factors in order to estimate the actual amount of electricity generation at a utility-scale power plant.
- (E) – For generic projects with known fuels, the biomass lifecycle carbon intensity can be found using the data from the Electric Power Research Institute.
- (F) – This value represents the carbon intensity of electricity displaced by the biomass power plant. Emission factors are available for two geographies as defined in the U.S. DOE's GREET model—WECC and SPP. Arizona, Colorado, Oregon, and Washington are wholly within WECC. New Mexico is split between WECC and SPP. Refer to Figure E-4.2 in the Appendix. Emission factors for WECC and SPP are provided in five year increments between 2025 and 2050 in Table E-26.3. If the analysis year falls within a five-year timeperiod, users should select the earlier timeperiod. For example, if the analysis year is 2037, users should use the emission factor for 2035. Alternatively, users may interpolate an emission factor for their specific analysis year based on the data provided in Table E-26.3. Note that only a single lifecycle carbon intensity value is given for Californa in the CAPCOA Handbook, which is sourced from the CEC.

GHG Calculation Caps or Maximums

Measure Maximum

None.

Mutually Exclusive Measures

Users implementing this measure to achieve performance standards set under Measure E-1, *Implement a Plan to Improve Building Energy Efficiency*, may not take credit for GHG reductions quantified for both measures, unless the reductions quantified by this measure exceed the minimum Measure E-1 performance standard. Refer to Measure E-1 for additional discussion.

Example GHG Reduction Quantification

In this example, a user installs a new 1-MW (B) biomass plant which burns dedicated woody crops that they intend to operate year-round. In 2030, the lifecycle carbon intensity of power for WECC is estimated to be 356 lb. CO_2e/ MWh (F). The new plant, because it will burn wood, is estimated to have a capacity factor of 59 percent (D) and a mean carbon intensity of 189.6 lb. CO_2e/MWh (E).

Quantified Co-Benefits

$$A = 1\ MW \times 8{,}760\ hrs \times 59\% \times \left(189.6\ \frac{lb\ CO_2e}{MWh} - 356\ \frac{lb\ CO_2e}{MWh}\right) \times 0.000454\ \frac{MT}{lb} = -391\ \frac{MT\ CO_2e}{year}$$

Energy and Fuel Savings

The energy savings of traditional fossil fuels (H) can be calculated as follows.

Natural Gas Reduction Formula

$$H = \frac{-B \times C \times D \times I}{J}$$

Natural Gas Reduction Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
H	Natural gas saved	[ ]	therms	Calculated
Constants, Assumptions, and Available Defaults				
I	Heat Rate	9,697,506 (AZ) 10,072,457 (CO) 9,189,381 (NM) 8,166,247 (OR) 8,162,258 (WA)	BTU/MWh	U.S. EPA 2025
J	Conversion from BTU to therms	100,000	BTU/therm	Conversion

Further explanation of key variables:

- (I) – This value represents the average amount of energy needed to produce a MWh of electricity across all combustion sources in each state as of 2023. Data were obtained by dividing the state annual heat input from combustion (mmBTU) by the state annual combustion net generation (MWh) (U.S. EPA 2025). Note that the heat rate for California in the CAPCOA Handbook is sourced from the CEC.

Sources

- EPRI (Electric Power Research Institute). 2013. *Literature Review and Sensitivity Analysis of Biopower Life-Cycle Assessments and Greenhouse Gas Emission*. Accessed August 2023. https://www.epri.com/research/products/000000000001026852.
- U.S. DOE (U.S. Department of Energy). 2024. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model*. 2024 Release. Accessed January 28, 2025. https://greet.anl.gov/.
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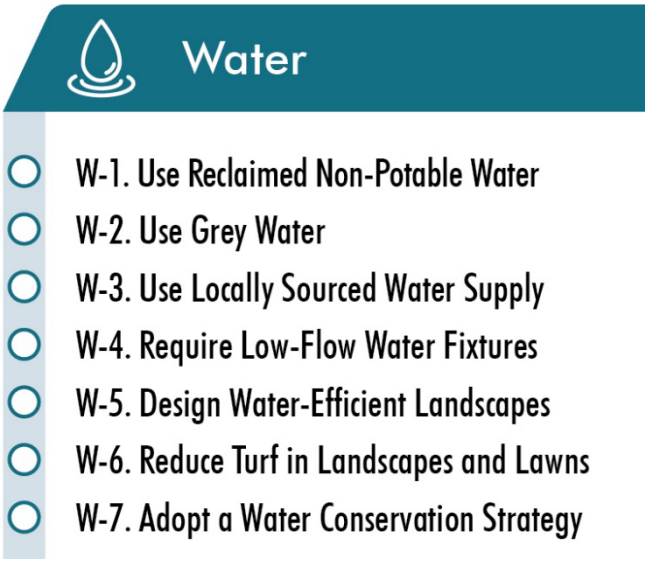
Water



Energy used to pump, treat, and convey water generates GHG emissions and is the primary source of GHG emissions within the water sector. The amount of energy required depends on both the volume of water and energy intensity associated with the water source. For example, it generally takes less energy to pump and convey water from a local source than to transport water across long distances. Water supply across the western states is diverse and often composed of many sources, including groundwater, surface water, and reservoirs, with some water transport occurring over long distances and over varied terrain. Treating water so that it is potable for human use and processing wastewater also generates GHG emissions.

Indirect GHG emissions associated with water use can be decreased by reducing water demand and/or by using a less energy-intensive water source. A project can reduce its indoor water demand by installing low-flow and high-efficiency water fixtures and appliances, such as toilets, showerheads, faucets, clothes washers, and dishwashers. A reduction in outdoor water demand can be achieved by designing water-efficient landscapes that include plants with relatively low watering needs; minimizing areas of water-intensive turf; and installing smart irrigation systems to avoid excessive water use. These and other strategies could be combined into a water conservation strategy with a water reduction performance target. Less energy-intensive water sources include reclaimed and grey water, as well as locally sourced water (e.g., nearby groundwater basins, nearby surface water, and gravity-dominated systems).

Emission reductions achieved by reduced water demand will be directly proportional to the decrease in demand. Use of less energy-intensive water sources will decrease energy-related emissions, but these systems may also require energy to successfully operate. Resources and methods to quantify emissions reductions from measures that reduce water demand and/or target use of a less energy-intensive water source are described in this section. Use the graphic on the right to click on an individual measure to navigate directly to the measure's factsheet.



W-1. Use Reclaimed Non-Potable Water



GHG Mitigation Potential



Potentially small reduction in GHG emissions from outdoor water use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Using reclaimed non-potable water conserves water and energy resources, which will become more strained under climate change, and provides a backup water source should extreme events disrupt current sources. This could also reduce costs associated with obtaining fresh potable water from distant sources.

Health and Equity Considerations

The project should provide appropriate education on non-potable water for project residents/employees.

Measure Description

This measure requires use of reclaimed water for outdoor uses. Reclaimed water is water reused for non-potable uses (e.g., landscape irrigation) after wastewater treatment instead of returning the water to the environment (i.e., discharging into rivers and other bodies of water). Using water after it has been treated requires substantially less energy to deliver it to users than fresh water from distant sources and, therefore, reduces GHG emissions. The use of reclaimed water is typically designated for non-potable uses, such as landscaping and other outdoor uses.

Although wastewater treatment processes have improved, few reclaimed water projects for household or potable uses have been installed. Furthermore, the treatment of wastewater to produce potable water (often through reverse osmosis) is usually energy-intensive and thus may not result in reduction in energy consumption and associated GHG emissions.

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Initial costs of altering a system, whether it is irrigation, plumbing, or cleaning, to use reclaimed non-potable water will vary with the source of the water and the use; however, all applications will have costs associated with installing water collection and distribution infrastructure. Using reclaimed water could also yield cost savings from reduced energy and chemical use during the water treatment process.

Expanded Mitigation Options

This measure does not include treatment of wastewater for potable uses, although the approach to assessing the potential change in GHG emissions would be the same.

GHG Reduction Formula

$A1 = C1 \times (D - E)$ (Energy savings)

$B1 = A1 \times F \times G \times H$ (Emissions reduction)

$B2 = C2 \times \frac{D-E}{D}$ (Percent emissions reduction)

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Energy savings from using reclaimed water	[ ]	kWh	calculated
B1	GHG reduction from using reclaimed water	[ ]	MT CO_2e	calculated
B2	% GHG reduction from outdoor water use	[ ]	%	calculated
User Inputs				
C1	Amount of water to be used from reclaimed sources	[ ]	acre-feet (AF)	user input
C2	Percentage of water from reclaimed water (relative to total outdoor water demand)	[ ]	%	user input
E	Fraction of electricity for water extraction and conveyance	[ ]	kWh per AF	user input
Constants, Assumptions, and Available Defaults				
D	Electricity for municipally provided water (total water supply)	Table W-1.1	kWh per AF	see table W-1.1
F	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
G	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
H	Conversion from pounds (lb) to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (C1) – The amount of water to be used from reclaimed water must be provided by the user.
- (D, E) – Total water supply energy-intensity factors for Arizona counties are provided in Table W-1.1 in the Appendix, *Emission Factors and Data Tables*. Following wastewater treatment, reclaimed water would be pre-treated (to meet standards) and distributed back to an end use (e.g., city park). Accordingly, users in Arizona can determine the fraction of energy for municipally provided water by consulting Table W-1.1 and subtracting the fraction of electricity for water extraction and conveyance (user inputs).

  Users outside Arizona could consider applying factors from one of the Arizona counties (or the statewide average), as appropriate. Alternatively, the national average energy-intensity factor (419 kWh per acre-foot) may be applied (Paraschiv et al., 2023), or as appropriate, users may consult the CAPCOA (2024) Handbook. Table W-1.1 in the

CAPCOA Handbook provides region-wide water energy-intensity factors for 10 hydrologic regions in California by process, including extraction and conveyance.

- (G) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Users should consult their local electricity provider for updated emission factors available at the time of their analysis before proceeding with the defaults provided in these tables. If the project study area is not serviced by a listed electricity provider, or emission factors for the local utility are not available, users may elect to use the appropriate grid average carbon intensity presented in Table E-4.10. Grid electricity emission factors are available for two geographies as defined in the U.S. DOE's GREET model—the Western Electricity Coordinating Council (WECC) and Southwest Power Pool (SPP). Arizona, Colorado, Oregon, and Washington are wholly within WECC. Portions of New Mexico are located in both WECC and SPP. Refer to Figure E-4.2 in the Appendix.

  Note that the GHG intensity factor of most electricity providers will decrease in future years as the electricity providers continue to improve their energy mix to meet their Renewable Portfolio Standards (RPS) requirements and/or company goals. Accordingly, measures that displace electricity consumption through water conservation will reduce fewer emissions in future years as the utility resource mix becomes cleaner.

  Note that the availability of local utility emission factors differs among Western States and from what is provided for California utilities in the CAPCOA Handbook. This Western States Handbook also uses the GREET model to provide future grid emission factors in five-year increments, whereas the CAPCOA Handbook forecasts annual emission factors using U.S. EPA's Emissions & Generation Resource Integrated Database.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions from water-related electricity by using reclaimed water for non-potable uses in place of fresh water. In this example, the project is in Pima County, Arizona, and includes the use of 31 AF per year of reclaimed water (C1), which represents 80 percent of the project's total outdoor water demand (C2). The electricity provider for the project area is Tuscon Electric Power Co., and the user elects to use the utility emission factor in the Appendix (1,076 lb CO_2e per MWh) (G). A user input value of 232 kWh per AF is used for the fraction of electricity for water extraction and conveyance (E).

$$A1 = 31\ \frac{AF}{yr} \times \left(358\frac{kWh}{AF} - 232\frac{kWh}{AF}\right) = 3{,}906\ \frac{kWh}{yr}$$

$$B1 = 3{,}906\ \frac{kWh}{yr} \times 0.001\frac{MWh}{kWh} \times 1{,}076\frac{lb\ CO_2e}{MWh} \times 0.000454\frac{MT}{lb} = 1.91\ \frac{MT\ CO_2e}{yr}$$

$$B2 = 80\% \times \frac{\left(358\frac{kWh}{AF} - 232\frac{kWh}{AF}\right)}{358\frac{kWh}{AF}} = 28\%$$

Quantified Co-Benefits

Energy and Fuel Savings

Energy savings (A1) are derived in the steps above that are necessary to quantify GHG reductions.

Water Conservation

This measure would not necessarily change water consumption, but it would result in conservation of fresh water sources by using reclaimed water. This quantity of freshwater savings is equal to the amount of reclaimed water (C1).

Sources

- CAPCOA (California Air Pollution Control Officers Association). 2024. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Designed for Local Governments, Communities, and Project Developers*. Final Draft. October 2024.
- Paraschiv, S., L. Paraschiv, and A. Serban. 2023. "An Overview of Energy Intensity of Drinking Water Production and Wastewater Treatment." *Energy Reports* 9, no. 11 (October): 118-123.

W-2. Use Grey Water



GHG Mitigation Potential



Potentially small reduction in GHG emissions from outdoor water use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Using grey water conserves water resources, which will become more strained under climate change, and provides a backup water source should extreme events disrupt current sources. This could also reduce costs associated with obtaining fresh potable water from distant sources.

Health and Equity Considerations

The project should provide appropriate education on grey water for project residents and employees.

Measure Description

This measure requires the use of grey water for outdoor uses. Grey water is water from sinks, showers, tubs, and washing machines that has not contacted biological pathogens. Grey water offsets freshwater that would need to be extracted or sourced for the same demand, resulting in water and GHG emissions savings. The energy associated with grey water use is essentially negligible as it is used on site for a second time and does not require major pumping equipment or further treatment.

Scale of Application

Project/Site

Implementation Requirements

Grey water should only be used for non-potable applications, such as landscaping and other outdoor uses, because grey water does not undergo water treatment before being used for the second time.

Cost Considerations

Initial costs of altering the plumbing of a property to use grey water will vary with the property type; however, all applications will have costs associated with installing water collection, storage, and distribution infrastructure. These costs would be offset by reductions in freshwater use, as well as reductions in energy and chemical use needed for water treatment and waste management.

Expanded Mitigation Options

For grey water sourced from sinks, it is best practice not to use water with greasy and oily substances, such as runoff from kitchen sinks with leftover oils, meat scraps, and dairy products.

GHG Reduction Formula

$A1 = (D \times E + D \times F) \times G \times H$ (Water savings, if not known by user)

$B = A1 \times ((I + J) - K)$ (Energy savings)

$C1 = B \times L \times M \times N$ (Emissions reduction)

$C2 = A2$ (Percent emissions reduction)

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Outdoor water savings from using grey water	[ ]	AF per year	calculated
B	Energy savings from using grey water	[ ]	kWh per year	calculated
C1	GHG reduction from using grey water	[ ]	MT CO_2e per year	calculated
C2	% GHG reduction from outdoor water use	[ ]	%	calculated
User Inputs				
A2	Percentage of water from grey water sources (relative to total outdoor water demand)	[ ]	%	user input
D	Number of residents in homes with grey water systems	[ ]	occupants	user input
Constants, Assumptions, and Available Defaults				
E	Gal per day per occupant from showers, bathtubs, and lavatories	Table W-2.1	gal per day per occupant	see table
F	Gal per day per occupant for laundry	Table W-2.1	gal per day per occupant	see table
G	Days per year	365	days per year	conversion
H	Conversion from gal to AF	3.07×10^{-6}	AF per gal	conversion
I	Electricity required for municipally provided water (total water supply)	Table W-1.1	kWh per AF	see table
J	Electricity required for wastewater treatment following municipal use	Table W-2.2	kWh per AF	see table
K	Fraction of electricity for grey water	0	kWh per AF	assumption
L	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
M	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
N	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (A1) – If the user knows how much grey water will be used for their project, that amount should be used to determine GHG reductions. If it is unknown, however, the formula for A1 can be used to estimate the volume of grey water for residential uses.
- (I) – Available water energy-intensity factors are provided in Table W-1.1 in the Appendix). Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information. Because grey water is reused on site, it avoids energy after initial water consumption for at least one use cycle (i.e., wastewater treatment and extraction, conveyance, pre-treatment, and distribution energy for an equivalent volume of water).
- (J) – Wastewater treatment energy-intensity factors for Arizona and Washington are provided in Table W-2.2 in the Appendix. Users outside of these states could consider applying either the Arizona or Washington factor to estimate electricity consumption for wastewater treatment, as appropriate. Alternatively, the national average energy-intensity factor (530 kWh per acre-foot) may be applied (Paraschiv et al., 2023), or as appropriate, users may consider the California factor of 418 kWh per acre-foot cited in the CAPCOA (2024) Handbook.
- (K) – Onsite grey water treatment methods can vary from simple chlorine or ultraviolet (UV) filtration to more complex methods (e.g., membrane bioreactors). The default assumption of 0 kWh/AF assumes simple filtration. Users should revise this value if their project requires electricity for grey water treatment.
- (M) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions from water-related electricity by using grey water for non-potable uses in place of fresh water. In this example, the project is in Pima County, Arizona, and includes 300 residents (D). The user applies the greywater flow rates (E, F) under the Uniform Plumbing Code from Table W-2.1 in the Appendix and calculates that these residents would produce about 13.4 AF of water, which is equal to 20 percent of the project's total water demand (A2). Per Tables W-1.1 and W-2.2, the water and wastewater energy-intensity factors are 358 kWh per AF (I) and 439 kWh per AF (J), respectively. The electricity provider for the project area is Tucson Electric Power Company, and the user has elected to use the utility emission factor in the Appendix (1,076 lb CO_2e per MWh) (L).

$$A1 = \left(\mathbf{300} \times 25\frac{\text{gal}}{\text{day·resident}} + \mathbf{300} \times 15\frac{\text{gal}}{\text{day·resident}}\right) \times 365\frac{\text{days}}{\text{year}} \times \left(3.07\times10^{-6}\frac{\text{AF}}{\text{gal}}\right) = 13.4\ \frac{\text{AF}}{\text{yr}}$$

$$B = 13.4\ \frac{\text{AF}}{\text{yr}} \times \left(\left(358\frac{\text{kWh}}{\text{AF}} + 439\frac{\text{kWh}}{\text{AF}}\right) - 0\frac{\text{kWh}}{\text{AF}}\right) = 10{,}715\ \frac{\text{kWh}}{\text{yr}}$$

$$C1 = 10{,}715\ \frac{\text{kWh}}{\text{yr}} \times 0.001\frac{\text{MWh}}{\text{kWh}} \times 1{,}076\ \frac{\text{lb } CO_2e}{\text{MWh}} \times 0.000454\frac{\text{MT}}{\text{lb}} = 5.2\ \frac{\text{MT } CO_2e}{\text{yr}}$$

C2 = **20%**

Quantified Co-Benefits

Energy and Fuel Savings

Energy savings (B) are derived in the steps above that are necessary to quantify GHG reductions.

Water Conservation

This measure would not necessarily change water consumption, but it would result in conservation of fresh water sources by using grey water. This quantity of freshwater savings is equal to the amount of grey water (A1).

Sources

- CAPCOA (California Air Pollution Control Officers Association). 2024. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Designed for Local Governments, Communities, and Project Developers*. Final Draft. October 2024.
- Paraschiv, S., L. Paraschiv, and A. Serban. 2023. "An Overview of Energy Intensity of Drinking Water Production and Wastewater Treatment." *Energy Reports* 9, no. 11 (October): 118-123.

W-3. Use Locally Sourced Water Supply



GHG Mitigation Potential



Potentially moderate reduction in GHG emissions from water use

Co-Benefits (icon key on pg. 31)



Climate Resilience

Using locally sourced water provides fewer opportunities for extreme events to disrupt the water source due to shorter traveling times. This could also reduce energy costs associated with obtaining fresh potable water from distant sources.

Health and Equity Considerations

Locally sourced water may have more contaminants than imported options. For potable uses, carefully consider the water quality of the proposed source.

Measure Description

This measure requires use of local water supplies instead of more distant water supplies. Locally sourced water is typically less energy intensive because it does not need to be moved across long distances (unless locally sourced water requires extensive pretreatment to address water quality concerns). Using locally sourced water can thus avoid the higher GHG emissions from energy consumed to pump and move water through larger infrastructure systems.

Scale of Application

Plan/Community

Implementation Requirements

See measure description.

Cost Considerations

Prioritizing locally sourced water reduces energy costs associated with the transportation of water to the use location. However, regions that are not already large-scale water producers will most likely require significant investment in water extraction, processing, management, and potentially reuse in order to meet demand.

Expanded Mitigation Options

Install onsite water collection systems, such as rain barrels or cisterns, for even more local water supply, reducing the associated energy and GHG emissions from water transmission.

GHG Reduction Formula

$A1 = \mathbf{C1} \times (D - \mathbf{E})$ (Energy savings)

$B1 = A1 \times F \times G \times H$ (Emissions reduction)

$B2 = \mathbf{C2} \times \frac{D - \mathbf{E}}{D}$ (Percent emissions reduction)

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Energy savings from using local water	[ ]	kWh	calculated
B1	GHG reduction from using local water	[ ]	MT CO_2e	calculated
B2	% GHG reduction from outdoor water use	[ ]	%	calculated
User Inputs				
C1	Amount of water to be obtained from local sources	[ ]	AF	user input
C2	Percentage of water from local sources (relative to total water demand)	[ ]	%	user input
E	Electricity required to treat and distribute local water	[ ]	kWh/AF	user input
Constants, Assumptions, and Available Defaults				
D	Electricity for municipally provided water (total water supply)	Table W-1.1	kWh per AF	see table
F	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
G	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
H	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (E) – The water energy-intensity factor for the local water source must be defined by the user.
- (D) – Available water energy-intensity factors are provided in Table W-1.1 in the Appendix. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.
- (G) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions from water-related electricity by using locally sourced water. In this example, the project is in western Colorado and uses 46 AF per year of water. The user chooses to supply 100 percent of the water for the project (C1, C2) from an alternative local source that has a water energy-intensity of 350 kWh per AF (E). The user assumes the national default from the Appendix for the baseline water energy-intensity factor (419 kWh per AF) (D). The electricity provider for the project area is Holy Cross Electric Association and the user elects to use the utility emission factor in the Appendix (957 lbs CO_2e per MWh) (G).

$$A1 = 46\ \frac{AF}{yr} \times \left(419\frac{kWh}{AF} - 350\ \frac{kWh}{AF}\right) = 3{,}192\ \frac{kWh}{yr}$$

$$B1 = 3{,}192\ \frac{kWh}{yr} \times 0.001\frac{MWh}{kWh} \times 957\ \frac{lb\ CO_2e}{MWh} \times 0.000454\frac{MT}{lbs} = 1.4\ \frac{MTCO_2e}{yr}$$

$$B2 = 100\% \times \frac{419\frac{kWh}{AF} - 350\frac{kWh}{AF}}{419\frac{kWh}{AF}} = 17\%$$

Quantified Co-Benefits

Energy and Fuel Savings

Energy savings (A1) are derived in the steps above that are necessary to quantify GHG reductions.

Sources

- None.

W-4. Require Low-Flow Water Fixtures



GHG Mitigation Potential



Potentially small reduction in GHG emissions from indoor water use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Using low-flow water fixtures conserves water resources, which will become more strained under climate change.

Health and Equity Considerations

Low-flow and high-efficiency water fixtures can help reduce water utility bill costs for project residents.

Measure Description

This measure requires use of low-flow or high-efficiency water fixtures in residential and non-residential buildings. Low-flow and high-efficiency fixtures may include toilets, urinals, showerheads, faucets, clothes washers, and dishwashers. These fixtures use less water than their traditional counterparts and, therefore, reduce energy and indirect GHG emissions that result from sourcing and transporting fresh water.

Scale of Application

Project/Site

Implementation Requirements

Install low-flow or high-efficiency fixtures that exceed state standards in any of the following: toilets, urinals, showerheads, faucets, clothes washers, and dishwashers.

Cost Considerations

Low-flow water fixtures tend to be slightly more expensive to purchase and install than less efficient models; however, these costs are almost immediately offset by large savings in water and energy consumption. Low-flow water fixtures may also have cost implications for local water utilities, depending on rate structures and other considerations.

Expanded Mitigation Options

Install low-flow or high-efficiency water fixtures that perform better than the minimum efficiency standard established through WaterSense or ENERGY STAR, reducing the associated energy use and GHG emissions.

GHG Reduction Formula

$$A1 = \sum \left(\mathbf{D1} \times Ez \times \frac{Fz\text{-}Gz}{Fz} \right) \text{ or } = \sum \left(\mathbf{D1} \times \mathbf{Hz} \right) \quad \text{(Water savings)}$$

$$A2 = \frac{A1}{\mathbf{D1}} \text{ or } = \frac{\mathbf{D1} - \mathbf{D2}}{\mathbf{D1}} \quad \text{(Percent emissions reduction)}$$

$$B = A1 \times I \times (J + K) \quad \text{(Energy savings)}$$

$$C = B \times L \times M \times N \quad \text{(Emissions reduction)}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Indoor water savings with low-flow fixtures	[ ]	gal	calculated
A2	% reduction in indoor water, energy, and GHG emissions with low-flow fixtures	[ ]	%	calculated
B	Energy savings with low-flow fixtures	[ ]	kWh	calculated
C	GHG reduction with low-flow fixtures	[ ]	MT CO_2e	calculated
User Inputs				
D1	Existing indoor water use	[ ]	gal	user input
D2	Mitigated indoor water use	[ ]	gal	user input (if known)
Hz	% savings of water for end use z (e.g., toilet)	1–100	%	user input (if known)
Constants, Assumptions, and Available Defaults				
Ez	% of indoor water used for end use z (e.g., toilet)	Table W-4.1 Table W-4.2	%	Pacific Institute 2003 and Water Research Foundation 2016
Fz	Current state standard water flow rate for end use z (e.g., toilet)	Table W-4.3 Table W-4.4	variable units	see tables
Gz	Reduced flow rate for end use z (e.g., toilet)	Table W-4.3 Table W-4.4	variable units	EnergyStar 2021a, 2021b, and 2023; U.S. EPA 2024
I	Conversion from gal to AF	3.07×10^{-6}	AF per gal	conversion
J	Electricity for municipally provided water (total water supply)	Table W-1.1	kWh per AF	see table
K	Electricity required for wastewater treatment following municipal use	Table W-2.2	kWh per AF	see table

ID	Variable	Value	Unit	Source
L	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
M	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
N	Conversion from lb to MT	0.000454	MT per lb	conversion
z	End use or type of fixture (e.g., toilet)	N/A	-	-

Further explanation of key variables:

- (Ez) – For residential uses, the percentages of indoor water that is typically used for the most common end uses are shown in Table W-4.1 in the Appendix. For non-residential uses, the percentages of total and indoor water that is typically used for the most common end uses are shown in Table W-4.2 in the Appendix. To calculate the water savings for this measure relative to total or indoor use, the user should multiply the savings rate from a given fixture (e.g., kitchen faucet) by the percentage of water that is used in kitchen faucets for a typical residential or non-residential use.
- (Fz) – The current (2025) federal and state plumbing codes for water use flow rates for common fixtures are provided in Table W-4.3 (for residential uses) and Table W-4.4 (for non-residential uses) in the Appendix. The user can use a specific existing flow rate if the flow rate for the end use or fixture differs from the cited codes. Note that cities and local jurisdictions may have more stringent flow criteria than the cited state and federal standards.
- (Gz) – The reduced water use flow rates for common fixtures are provided in Table W-4.3 (for residential uses) and Table W-4.4 (for non-residential uses). The user can use a specific reduced flow rate if the flow rate for the end use or fixture differs from the rates shown in Tables W-4.3 or W-4.4. The reduced flow rates reflect current U.S. EPA WaterSense and U.S. DOE EnergyStar labels. Note that the CAPCOA Handbook also references voluntary standards from the 2019 California Green Building Code. Because the California standard is not applicable outside of California, this Western States Handbook also provides the WaterSense standards as additional reduced flow rates for user consideration.
- (Hz) – This variable is the percent water savings from using a fixture with improved water efficiency, relative to the existing rate for that fixture. If the user knows what the percent savings is for their fixtures, the equation above with variable Hz can be used.
- (J) – Available water energy-intensity factors are provided in Table W-1.1 in the Appendix. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.
- (K) – For this measure, water conservation would affect indoor water consumption. Because indoor water is sent to wastewater treatment plants, it is necessary to account for the energy that would be avoided at the wastewater treatment plant. Available wastewater treatment energy-intensity factors are provided in Table W-2.2. Refer to Measure W-2, *Use Grey Water*, for additional information.
- (M) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are

presented in Table E-4.10. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions from water-related electricity by requiring low-flow fixtures. In this example, the project is a non-residential office use located in Maricopa County, Arizona, with a total indoor water demand of 10 million gal per year (D1). The user is proposing to upgrade toilets and urinals with U.S. EPA WaterSense certified fixtures. Accordingly, the following assumptions are obtained from Tables W-4.2 and W-4.4 in the Appendix:

- Percent of indoor water used for toilets (Ez) = 48 percent.
- Percent of indoor water used for urinal (Ez) = 11 percent.
- Current state standard water flow rate for toilets (Fz) = 1.6 gal per flush.
- Current state standard water flow rate for urinal (Fz) = 1.0 gal per flush.
- Reduced water flow rate for toilets (Fz) = 1.28 gal per flush.
- Reduced water flow rate for toilets (Fz) = 0.5 gal per flush.

Per Tables W-1.1 and W-2.2, the water and wastewater energy-intensity factors are 444 kWh per AF (J) and 439 kWh per AF (K), respectively. The electricity provider is Salt River Project, and the user elects to use the utility emission factor in the Appendix for 2023 (1,015 lb CO_2e per MWh) (M).

$$A1 = \left[\left(10\times10^{6}\ \frac{\text{gal}}{\text{yr}} \times 48\%(\text{toilet}) \times \frac{1.6(\text{toilet})-1.28(\text{toilet})}{1.6(\text{toilet})}\right) + \left(10\times10^{6}\ \text{gal} \times 11\%(\text{urinal}) \times \frac{1.0(\text{urinal})-0.5(\text{urinal})}{1.0(\text{urinal})}\right)\right]$$

$$= 1{,}510{,}000\ \frac{\text{gal}}{\text{yr}}$$

$$A2 = \frac{1{,}510{,}000\ \text{gal}}{10\times10^{6}\ \text{gal}} = 15\%$$

$$B = 1{,}510{,}000\ \frac{\text{gal}}{\text{yr}} \times \left(3.07\times10^{-6}\ \frac{\text{AF}}{\text{gal}}\right) \times \left(444\ \frac{\text{kWh}}{\text{AF}} + 439\ \frac{\text{kWh}}{\text{AF}}\right) = 4{,}094\ \frac{\text{kWh}}{\text{yr}}$$

$$C = 4{,}094\ \frac{\text{kWh}}{\text{yr}} \times 0.001\ \frac{\text{MWh}}{\text{kWh}} \times 1{,}015\ \frac{\text{lb } CO_2e}{\text{MWh}} \times 0.000454\ \frac{\text{MT}}{\text{lb}} = 1.9\ \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

Energy and Fuel Savings

Energy savings (B) are derived in the steps above that are necessary to quantify GHG reductions.

Water Conservation

Water savings (A1) are derived in the steps above that are necessary to quantify GHG reductions.

Sources

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W-5. Design Water-Efficient Landscapes



GHG Mitigation Potential



Potentially small reduction in GHG emissions from outdoor water use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Designing water-efficient landscapes conserves water resources, which will become more strained under climate change. In addition, native landscaping can help support biodiversity and pollinators.

Health and Equity Considerations

Water-efficient landscaping can lower utility costs for project residents and reduce pesticide and fertilizer run-off, which can affect water quality.

Measure Description

This measure requires the use of water-efficient landscapes. Users can achieve water savings by reducing the landscaped area, planting vegetation with minimal water needs (e.g., native species), choosing vegetation appropriate for the climate of the project site or community, choosing complementary plants that have similar water needs or that can provide shade and/or water to each other, or using efficient irrigation systems. Designing water-efficient landscapes for a project site or throughout a community reduces water consumption and thus the corresponding energy and indirect GHG emissions that result from sourcing and transporting fresh water.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Although none of the western states have adopted statewide outdoor water conservation ordinances, many local jurisdictions have established standards. For example, the Bernalillo County Water Conservation Ordinance (Section 30-241 through 30-251) sets restrictions on landscape planting for covered residential and non-residential structures. The Gilbert, Arizona, water conservation ordinance likewise sets standards for efficient irrigation systems (Section 66-3651 through 66-384). Each of Arizona's seven Active Management Areas (i.e., Tucson, Santa Cruz, Prescott, Pinal, Phoenix, Douglas, and Willcox) maintain water management plans, which identify low water use and drought tolerant plant species permitted in covered landscaping areas. Refer to local regulations and standards, if adopted, for specific implementation requirements.

Cost Considerations

Water-efficient landscapes save money not only by having fewer irrigation requirements but also by needing fewer inputs like fertilizer and pesticides and less use of landscaping equipment. Depending on the area of the landscape and the cost of designing it for water efficiency, these cost savings usually recoup the cost of installation and design.

Expanded Mitigation Options

Pair with Measure W-6 for increased outdoor water conservation and GHG reductions. Encourage application of biochar to improve soil quality and enhance carbon sequestration. Incorporate low-impact development practices in the landscape and surrounding area.

Introduction

Measure W-5 has been rewritten from the CAPCOA Handbook for this Western States Handbook. Measure W-5 in the CAPCOA Handbook requires the use of landscapes with lower water demands than required by the California Department of Water Resources' 2015 Model Water Efficient Landscape Ordinance (MWELO). The MWELO is not applicable outside of California. As discussed above in the measure factsheet, many local jurisdictions have established regulations or guidance for water use in outdoor landscapes. Given the diversity of these requirements across the western states, Measure W-5 has been generalized to require design and installation of water-efficient landscapes, which can be achieved through mulitple strategies (e.g., plant selection, irrigation systems).

The methodology for calculating water reductions is based on the U.S. EPA's WaterSense Water Budget Tool (WaterSense Tool). The reduction in water consumption is relative to a "baseline" condition that represents the amount of water required by a site if the landscaped area is watered at 100 percent the reference evapotranspiration rate (ET_o) (i.e., the amount of water lost from a well-maintained expanse of average-height green grass and the surrounding soil). Users can apply this method to evaluate potential water savings of a more water-efficient landscape based on the available irrigation systems included in the measure (e.g., drip-standard). Alternatively, users may adapt the "Baseline" equation to evaluate the effect of specific planting decisions. This is discussed further below under GHG Calculation Variables.

GHG Reduction Formula

$$\text{Baseline} = (\mathbf{B} \times C \times D)$$

$$\text{Reduced} = (1 \div E) \times \left((C \times [F_S \times F_{mc} \times F_d]) - (G \times H)\right) \times \mathbf{B} \times D$$

$$A1 = \text{Baseline} - \text{Reduced} \qquad \text{(Water savings)}$$

$$A2 = A1 \times I \times J \times K \times L \times M \qquad \text{(Emissions reduction)}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Outdoor water savings with water-efficient landscapes	[ ]	gal per year	Calculated
A2	GHG reduction with water-efficient landscapes	[ ]	MT CO_2e per year	Calculated
User Inputs				
B	Landscape area	[ ]	sf	user input
Constants, Assumptions, and Available Defaults				
C	Reference evapotranspiration rate	Table W-5.1	inches per year	WRCC 2025a
D	Conversion from acre-inches/acre to gal/sf	0.62	(gal per sf) per (acre-inch per acre)	conversion
E	Irrigation efficiency	Table W-5.2	unitless	U.S. EPA 2020
F_s	Landscape coefficient—species factor	0 to 1.0 (Table W-5.3)	unitless	U.S. EPA 2014, 2020
F_{mc}	Landscape coefficient—microclimate factor	0.5 to 1.4	unitless	U.S. EPA 2014
F_d	Landscape coefficient—density factor	0.5 to 1.4	unitless	U.S. EPA 2014
G	Annual rainfall (historic average)	Table W-5.4	inches per year	WRCC 2025b, 2025c
H	Effective rainfall factor	25% to 50%	percent	U.S. EPA 2014
I	Conversion from gal to AF	3.07×10^{-6}	AF per gal	conversion
J	Electricity for municipally provided water (total water supply)	Table W-1.1	kWh per AF	see table
K	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
L	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
M	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (Baseline) – Application of the "Baseline" equation assumes the starting landscaped area is watered at 100 percent the reference ET_o rate. If a user has actual water consumption for their project site before implementation of the measure, they may use that value in place of the calculated "Baseline" condition. Alternatively, users may adapt the "Baseline" equation to evaluate the effect of specific planting decisions. Examples include reducing the landscape area (C) or selecting an irrigation system with a higher efficiency (E). Using this approach, the user would model "Baseline" (or "unmitigated") conditions with the "Reduced" equation. The input variables would reflect conditions without implementation of the measure (i.e., with fixed spray irrigation). The resulting water consumption would represent "Baseline" in the formula for A1. The variables for the "Reduced" (or "mitigated") condition would reflect implementation of the measure (i.e., with the more efficient drip irrigation).
- (B) – The user should supply the landscaped area under Baseline and Reduced conditions. If this area differs under the two conditions, the variable can be denoted as B1 (for Baseline) and B2 (for Reduced).
- (C) – The reference ET_o rate corresponding to the user's location affects how much water savings are achieved. Table W-5.1 in the Appendix provides reference ET_o rates from several stations in each western state maintained by the Western Region Climate Center (WRCC).[34] Additional station data in Washington can be downloaded from Washington State University's (WSU) (2025) Historic Average Water Needs Estimate One Crop, at All Stations. Run the database by selecting any crop and irrigation efficiency (these inputs have no impact on the ET_o rate, represented as ETr, or total precipitation, represented as Pt). Additional location-specific data in Arizona can be downloaded from the University of Arizona's Meteorological Network (2025). Obtain data by selecting one of the active stations and clicking "Eto" under Special Reports. Annual ET_o can be obtained at the bottom of the table for December 31 in the "CUM" column (represents the cumulative total for all days in the year). It is recommended that the user obtain data for several historic years and average the values.
- (E) – Irrigation systems are rarely 100 percent effective. For example, nozzle design and wind speed may affect how water is sprayed, resulting in some plants receiving more water and other plants receiving less. The WaterSense Tool conservatively accounts for irrigation efficiency by using "lower-quarter distribution uniformity (DU_{LQ})" values for each type of irrigation equipment. Distribution uniformity is a measure of how evenly water is applied relative to an average. DU_{LQ} is the ratio of the lowest 25 percent water measurements compared to the overall average water measurement for the irrigation system. Table W-5.2 presents the DU_{LQ} efficiency factors by irrigation system type from the WaterSense Tool.
- (F_s, F_{mc}, and F_d) – The landscape coefficient is used to modify the reference ET_o rate (B) to reflect project conditions and is dervied from three factors—a species factor (F_s), a micro-climate factor (F_{mc}), and a planting density factor (F_d).
  - F_s – The species factor ranges from 0 to 1.0. There is little research on water needs of ornamental plants, shrubs, and trees in the western states. Table W-5.3 in the Appendix presents non-species-specific plant factors by water requirnment category for trees, shurbs, ornamental groundcover, and turfgrass from the WaterSense

[34] For information on the city, county, and station latitude and longitude coordinates, visit the WRCC's Station Data Inventory Listing webpage.

Tool. In general, native and well-adapted species would likely have low water use requirements, whereas annuals, tropical plants, and fruit- or vegetable-bearing species would have higher water use requirements. For species-specific plant factors, the user may consider reviewing the University of California Davis's Water Use Classification of Landscape Species (WUCOLS) (2024). The WUCOLS provides plant factors for various vegetation types across six climate regions in California (North-Central Coast, Central Valley, South Coastal, South Inland, High and Intermediate Desert, and Low Desert). These factors may be appliable to locations within the western states with similar climate conditions.

  - F_{mc} – The microclimate factor ranges from 0.5 to 1.4. It accounts for local climate conditions (e.g., amount of sun and wind) and is divided into three categories: low (0.5 to 0.9), average (1.0), and high (1.1 to 1.4). A sheltered landscape with low winds and several hours of shade each day would be characterized as having a "low" microclimate factor. An average microclimate is equal to the reference ET_o conditions. A landscape with raised planters or on a roof terrace would be characterized as having a "high" microclimate factor. The WaterSense Tool defaults to an E_{mc} factor of 1.0.
  - F_d – The planting density factor ranges from 0.5 to 1.4. It accounts for how closely plants are grouped together and is divided into three categories: low (0.5 to 0.9), average (1.0), and high (1.1 to 1.4). Low represents sparsely planted landscapes, medium represents full planting of the same species (e.g., shrub), and high represents mixed landscapes (e.g., shrubs and trees). The WaterSense Tool defaults to an E_d factor of 1.0.

- (G) – Table W-5.3 in the Appendix provides historical average annual rainfall rates from several stations in each western state maintained by the WRCC. Data for additional WRCC stations throughout the western states can be downloaded from WRCC's (2025c) map selection tool. Users can access the data by clicking on their state and navigating to the station closest to their project area. Additional data in Washington and Arizona can also be downloaded from the WSU and University of Arizona resources described above under (C).
- (H) – Not all rainfall can be effectively used by plants, and thus the average annual rainfall (G) must be reduced. The WaterSense Tool allows 25 percent of historical average (defined as a 30-year period) rainfall to be counted toward a plant's needs but notes that effective rainfall may be considered up to 50 percent of average.
- (J) – Available water energy-intensity factors are provided in Table W-1.1 in the Appendix. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.
- (L) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.

GHG Calculation Caps or Maximums

(Baseline > Reduced) Water consumption under the "Baseline" condition must exceed water consumption under the "Reduced" condition to result in water and emissions savings.

Example GHG Reduction Quantification

The user reduces GHG emissions from water-related electricity by requiring water efficient landscaping. In this example, the project will convert a 1,000 square foot (B1) grass field in Tempe, Arizona, to a landscaped area with 800 square feet (B2) of vegetation coverage. The evapotranspiration rate from the Tempe ASU station is 74.29 inches per year (C). The user selects a combination of shrub, tree, and accent plant species from Phoenix's Low Water Use and Drought Tolerant Plant List. The species, microclimate, and density factors for mixed vegetation type drought-tolerant species planted in the same location as the baseline would be 0.2 (F_s), 1.0 (F_{mc}), and 1.1 (F_d), respectively. The landscaped area will use standard drip irrigation with an efficiency of 70% (E). The user obtains historic average annual rainfall (8.62 inches) (G) for the Tempe ASU station from WRCC (2025c). The water energy-intensity factor is 444 kWh per AF (J), and the user elects to use the WECC average emission factor from the Appendix for the analysis year (314 lb CO_2e per MWh) (L).

$$\text{Baseline} = \left(1{,}000\ \text{sf} \times 74.29\ \frac{\text{inch}}{\text{yr}} \times 0.62\ \frac{\frac{\text{gal}}{\text{sf}}}{\frac{\text{acre-in}}{\text{acre}}}\right) = 46{,}060\ \frac{\text{gal}}{\text{yr}}$$

$$\text{Reduced} = (1 \div 70\%) \times \left(\left(74.29\ \frac{\text{inch}}{\text{yr}} \times [0.2 \times 1.0 \times 1.1]\right) - \left(8.62\ \frac{\text{inch}}{\text{yr}} \times 50\%\right)\right) \times 800\ \text{sf} \times 0.62\ \frac{\frac{\text{gal}}{\text{sf}}}{\frac{\text{acre-in}}{\text{acre}}} = 8{,}527\ \frac{\text{gal}}{\text{yr}}$$

$$\text{A1} = 46{,}060\ \frac{\text{gal}}{\text{yr}} - 8{,}527\ \frac{\text{gal}}{\text{yr}} = 37{,}533\ \frac{\text{gal}}{\text{yr}}$$

$$\text{A2} = 37{,}533\ \frac{\text{gal}}{\text{yr}} \times \left(3.07 \times 10^{-6}\ \frac{\text{AF}}{\text{gal}}\right) \times 444\ \frac{\text{kWh}}{\text{AF}} \times 0.001\ \frac{\text{MWh}}{\text{kWh}} \times 314\ \frac{\text{lb CO2e}}{\text{MWh}} \times 0.000454\ \frac{\text{MT}}{\text{lb}} = 0.01\ \frac{\text{MT CO2e}}{\text{year}}$$

Quantified Co-Benefits

Energy and Fuel Savings

Energy savings (MWh per year) can be derived from formula A2 by omitting variables (L) and (M).

Water Conservation

Water savings (A1) are calculated by formula A1.

Sources

- University of Arizona. 2025. "AZMET Weather Data." Accessed March 3, 2025. https://cales.arizona.edu/azmet/az-data.htm.
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- U.S. EPA. 2020. "WaterSense Water Budget Tool Version 1.04." Released June 2020. Accessed March 3, 2025. https://www.epa.gov/watersense/water-budget-tool.
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- WRCC (Western Region Climate Center). 2025a. "Evaporation Stations." Accessed March 3, 2025. https://wrcc.dri.edu/Climate/comp_table_show.php?stype=pan_evap_avg.
- WRCC. 2025b. "Mean Monthly and Annual Precipitation." Accessed March 3, 2025. https://wrcc.dri.edu/Climate/comp_table_show.php?stype=ppt_means.
- WRCC. 2025c. "Cooperative Climatological Data Summaries." Accessed March 3, 2025. https://wrcc.dri.edu/Climate/west_coop_summaries.php.

W-6. Reduce Turf in Landscapes and Lawns



GHG Mitigation Potential



Potentially large reduction in GHG emissions from outdoor water use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Reducing turf conserves water resources, which will become more strained under climate change. Native vegetation that is strategically located around buildings can also reduce ambient temperatures, helping to conserve energy, another resource that may be constrained by climate change.

Health and Equity Considerations

Turf is often used for play. When removing turf for residential or school projects, include play opportunities, build additional public parks nearby, and/or increase access to existing parks or playgrounds. Because turf often requires use of fertilizer (which can be derived from fossil fuels) and herbicides, both of which can affect water quality, removing turf can lead to health benefits. Additionally, the removal of turf and replacement with hardier native species can reduce runoff effects.

Measure Description

This measure would remove or avoid turf grass. Turf grass (i.e., lawn grass) has relatively high water needs compared to most other types of vegetation. Lowering landscaping water demands by reducing turf size would reduce water consumption and thus the corresponding energy and indirect GHG emissions that result from sourcing and transporting fresh water. Some water agencies have instituted turf removal programs that provide rebates for residents who reduce the turf area at their homes.

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Turf maintenance in landscape and lawns has always been significantly more expensive than a lawn filled with hardier species that are native to the region. As turf requires constant input to be maintained, the cost of transitioning turf to a more sustainable landscape is relatively inexpensive, and both a short- and long-term cost savings may be realized.

Expanded Mitigation Options

Additional GHG emissions savings may be achieved through reduced fertilizer use. The methods to calculate these reductions are not included in the quantification method.

GHG Reduction Formula

$A1 = D \times E \times \mathbf{F} \times G$ (Water savings)

$A2 = \frac{\mathbf{F}}{I}$ (Percent emissions reduction)

$B = A1 \times H \times J$ (Energy savings)

$C = B \times K \times L \times M$ (Emissions reduction)

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	Outdoor water savings from turf reduction	[ ]	gal	calculated
A2	% reduction in GHG emissions from outdoor water use	[ ]	%	calculated
B	Energy savings from turf reduction	[ ]	kWh	calculated
C	GHG emissions reduction from turf reduction	[ ]	MT CO_2e	calculated
User Inputs				
F	Area of turf to be removed	[ ]	sf	user input
I	Total turf area	[ ]	sf	user input
Constants, Assumptions, and Available Defaults				
D	Crop coefficient	0.54 to 0.85 (warm-season) 0.60 to 1.04 (cool-season)	unitless	Braun et al. 2022; Romero and Dukes 2008
E	Reference evapotranspiration rate	Table W-5.1	inches per year	WRCC 2025a
G	Conversion factor acre-inches/acre to gal/sf	0.62	(gal per sf) per (acre-inch per acre)	conversion
H	Conversion from gal to AF	3.07×10^{-6}	AF per gal	conversion
J	Electricity required for municipally provided water (total water supply)	Table W-1.1	kWh per AF	see table
K	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
L	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
M	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (D) – Crop coefficients can vary by season and location. The range presented above characterizes a variety of grasses and locations across the United States. Braun et al. (2022) summarizes published literature values for crop coefficients for selected cool-season grasses by climate zone. Romero and Dukes (2008) summarize similar data for both warm- and cool-season grasses. Users are encouraged to review these resources to select a crop coefficient that best characterizes their grass type and climatic region.
- (E) – Table W-5.1 in the Appendix provides reference ET_o rates from several stations in each western state maintained by the WRCC. Refer to Measure W-5, *Design Water Efficient-Landscapes*, for additional information.
- (I) – Available water energy-intensity factors are provided in Table W-1.1 in the Appendix. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.
- (K) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions from water-related electricity by reducing turf grass. In this example, the project is in Douglas, Arizona, which has an ET_o rate of 73.63 inches per day (E). The project will remove 800 sf of turf (F) with warm-season Bermuda grass, and the user has assumed a crop coefficient of 0.68 (D). The project's entire turf area is 1,200 sf (I). The water energy-intensity factor is 358 kWh per AF (J), and the user elects to use the utility emission factor for Arizona Public Service Company from the Appendix (765 lb CO_2e per MWh) (L).

$$A1 = 0.68 \times 73.63 \frac{\text{inch}}{\text{yr}} \times \mathbf{800\ sf} \times 0.62 \frac{\left(\frac{\text{gal}}{\text{sf}}\right)}{\frac{\text{acre·inch}}{\text{acre}}} = 24{,}834 \frac{\text{gal}}{\text{yr}}$$

$$A2 = \frac{\mathbf{800\ sf}}{\mathbf{1{,}200\ sf}} = 67\%$$

$$B = 24{,}834 \frac{\text{gal}}{\text{yr}} \times \left(3.07 \times 10^{-6} \frac{\text{AF}}{\text{gal}}\right) \times 358 \frac{\text{kWh}}{\text{AF}} = 27 \frac{\text{kWh}}{\text{yr}}$$

$$C = 27 \frac{\text{kWh}}{\text{yr}} \times 0.001 \frac{\text{MWh}}{\text{kWh}} \times 765 \frac{\text{lb } CO_2e}{\text{MWh}} \times 0.000454 \frac{\text{MT}}{\text{lb}} = 0.01 \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

Energy and Fuel Savings

Energy savings (B) are derived in the steps above that are necessary to quantify GHG reductions.

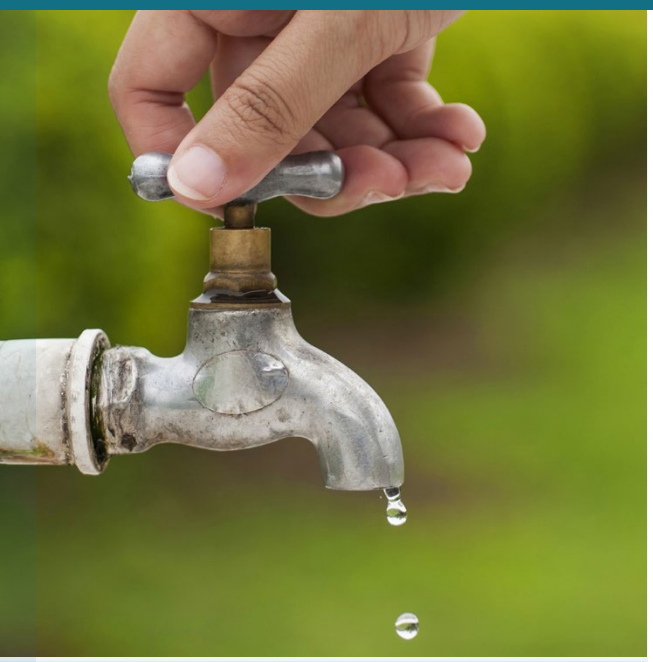
Water Conservation

Water savings (A1) are derived in the steps above that are necessary to quantify GHG reductions.

Sources

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- Romero, C., and M. Dukes. 2008. *Turfgrass Crop Coefficients in the U.S.* Institute of Food and Agricultural Sciences, University of Florida. https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2008/TurfgrassCropCoefficientsInTheU.S..pdf.

W-7. Adopt a Water Conservation Strategy



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from water use

Co-Benefits (icon key on pg. 31)

Climate Resilience

Conserving water reduces the strain on water and energy resources, which is expected to increase under climate change. Depending on reallocation, enhanced water security may support agriculture, which in turn provides enhanced food security.

Health and Equity Considerations

Ensure strategy includes enough water for outdoor use to maintain and enhance urban tree canopy as much as possible. Water conservation can also help to lower utility costs for project residents.

Measure Description

This measure will establish a water conservation strategy to achieve a reduction in water consumption. The water reduction performance standard is flexible to users' needs. The standard in this measure is set as a percent reduction in water consumption relative to a reference condition (e.g., existing conditions, historic year).

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

The strategy should clearly identify the actions that will be undertaken to achieve the performance standard. These actions could include any of the measures presented in this Western States Handbook (Measures W-1 through W-6) or others developed by the user; for example, low-impact development practices to enhance onsite water infiltration and improve stormwater management.

Cost Considerations

A water conservation strategy is a low-cost way to encourage using less water and energy, which in turn saves money. Costs from developing and implementing the strategy are primarily related to staff time and document production. Costs and savings achieved by actions undertaken because of the strategy would vary depending on the action.

Expanded Mitigation Options

Not applicable

GHG Reduction Formula

$$A = (B \times C) \times D \times E \times F \times G$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	GHG reduction from strategy	[ ]	MT CO_2e	calculated
User Inputs				
B	Water consumption for the reference year	[ ]	AF	user input
C	Performance standard for conservation strategy	[ ]	%	user input
Constants, Assumptions, and Available Defaults				
D	Electricity required for municipally provided water (total water supply)	Table W-1.1	kWh per AF	see table
E	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
F	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
G	Conversion from lb to MT	0.000454	MT per lb	conversion

Further explanation of key variables:

- (B) – Water consumption for the project or community for the reference year must be defined by the user.
- (C) – The percent reduction in water consumption relative to the reference condition.
- (D) – Available water energy-intensity factors are provided in Table W-1.1 in the Appendix.
- (F) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Grid average electricity emission factors are presented in Table E-4.10. Refer to Measure W-1, *Use Reclaimed Non-Potable Water*, for additional information.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions by adopting and implementing a water conservation strategy. In this example, the performance standard for the strategy is a 10 percent reduction (C) in existing (2025) water consumption by 2030. Existing water consumption is 1,000 AF per year (B), and the project is in La Paz County, Arizona. The water energy-

intensity factor is 210 kWh per AF (D), and the user elects to use the utility emission factor for Arizona Public Service Company from the Appendix (765 lb CO_2e per MWh) (F).

$$A = \left(1{,}000\frac{AF}{yr} \times 10\%\right) \times 210\frac{kWh}{AF} \times 0.001\frac{MWh}{kWh} \times 765\frac{lb\ CO_2e}{MWh} \times 0.000454\frac{MT}{lb} = 7.3\frac{MT\ CO_2e}{yr}$$

Quantified Co-Benefits

The co-benefits that are quantifiable (energy and fuel savings, water conservation) are calculated as part of the GHG reduction formula. The abbreviated formulas are also shown below.

Energy and Fuel Savings Formula

$$\frac{MWh}{year} = (B \times C) \times D \times E$$

Water Conservation Formula

$$\frac{AF}{year} = B \times C$$

Sources

- None.

Lawn and Landscaping



Landscaping equipment is the primary source of direct GHG emissions in the lawn and landscaping sector. Landscaping equipment traditionally uses gasoline fuel and releases emissions based on the amount of fuel combusted and emission factor of the engine. Equipment emissions can be reduced by requiring use of zero-emission landscaping equipment (including battery-powered and corded electric equipment) over conventional gasoline-fueled counterparts. The exclusive use of grid electricity to power the equipment eliminates onsite gasoline emissions but increases indirect emissions from electricity generation. However, grid-based emissions are typically less than the emissions from the gasoline-fueled equipment (depending on the source of grid power).

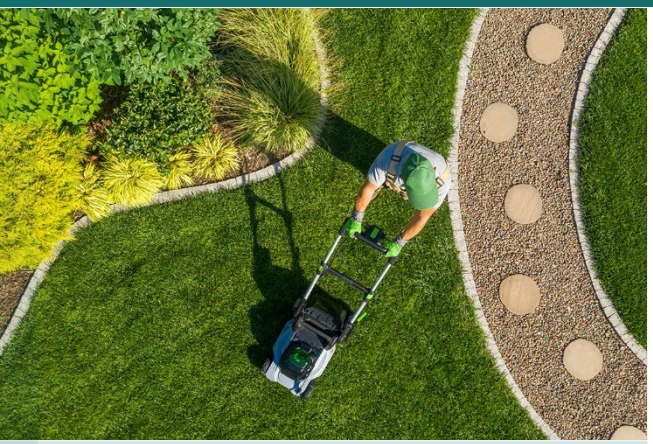
Emissions reductions achieved by zero-emission equipment are determined by finding the difference in emissions between those generated by the replacement power source and those generated by conventional gasoline engines. Emissions for the mitigated scenario may consist of direct emissions from combustion fuel use, and/or indirect emissions from grid electricity. Resources and methods to quantify emissions reductions from a measure requiring zero-emission landscaping equipment are described in this section.

Lawn and Landscaping

- LL-1. Replace Gas-Powered Landscape Equipment with Zero-Emission Landscape Equipment

Additional measures that can be undertaken to reduce emissions within the lawn and landscaping sector include ensuring electric yard equipment compatibility and implementing a yard equipment exchange program. Electric yard equipment compatibility is a supporting action for successful implementation of a measure that restricts gasoline landscaping equipment in favor of zero-emission equipment. A yard equipment exchange program would help facilitate community-scale equipment turnover and engine replacement. Please refer to the *Supporting or Non-Quantified GHG Reduction Measures* section at the end of Chapter 3 for additional information.

LL-1. Replace Gas-Powered Landscape Equipment with Zero-Emission Landscape Equipment



GHG Mitigation Potential



Potentially large reduction in GHG emissions from landscaping equipment

Co-Benefits (icon key on pg. 31)



Climate Resilience

Replacing gas-powered landscape equipment with zero-emission landscape equipment can reduce sensitivity to fuel price shocks or scarcity.

Health and Equity Considerations

Consider implementing programs to help disadvantaged business enterprises convert to electric equipment. Reduction or replacement of gasoline-powered equipment reduces localized air and noise pollution.

Measure Description

This measure requires use of zero-emission landscaping equipment over conventional gasoline-fueled counterparts. Equipment types historically powered by gasoline engines covered by this measure include chainsaws, chippers, lawn mowers, leaf blowers/vacuums, riding mowers, tillers, and trimmers. Replacing gasoline-powered equipment with zero-emission equipment reduces fossil fuel combustion and thus GHG emissions. However, electric equipment results in GHG emissions from the electricity used to charge the equipment. The indirect GHG emissions increase from electricity must be calculated in addition to the GHG emissions reduction from displaced fossil fuel combustion to estimate the total net GHG emissions reduction achieved by this measure on a well-to-wheels basis.

Scale of Application

Project/Site

Implementation Requirements

For this measure to be successfully implemented, it is helpful for electrical outlets on the exterior of buildings to be accessible so that the corded electric landscaping equipment can be more easily used in different areas, and batteries can be charged if indoor charging is not available. Measure LL-3, *Electric Yard Equipment Compatibility,* in Table 3-2 should, therefore, be considered as a supporting action to this measure.

Cost Considerations

Although the environmental benefits of replacing gas powered landscape equipment are high, so too are the costs. Zero-emission equipment is usually more expensive than conventional gasoline-powered equipment. Once the equipment is purchased, however, there are long-term cost savings in avoided fuel inputs and maintenance.

Expanded Mitigation Options

Users may consider an exchange program to expand penetration of this measure, as outlined in Measure LL-2, *Implement Yard Equipment Exchange Program*, in Table 3-2.

GHG Reduction Formula

The formula has been revised from the CAPCOA Handbook to differentiate GHG reductions achieved based on only tailpipe emissions (i.e., tank-to-wheels emissions) from those achieved from total emissions, including upstream fuel emissions (i.e., well-to-wheel emissions). Considering tank-to-wheels, all-electric equipment results in no emissions. Considering well-to-wheels, upstream GHG emissions from the electricity used to charge the equipment and to create liquid fuels must be included to estimate the total net GHG emissions reduction achieved by this measure.

$$A1 = -(C \times D \times E1 \times F) \text{ (tank-to-wheels)}$$

$$A2 = -(C \times D \times E2 \times F) + \left(C \times \frac{D}{G} \times H \times E3 \times I\right) \text{ (well-to-wheels)}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	GHG reduction from using plug-in or battery electric equipment	[ ]	MT CO_2e	calculated
User Inputs				
B	Fuel type of existing equipment	[ ]	text	user input
C	Hours of equipment operation	[ ]	hours	user input
Constants, Assumptions, and Available Defaults				
D	In-use horsepower of equipment[35]	Table LL-1.1	hp	U.S. EPA 2024
E1	Carbon intensity of fossil-fueled equipment (tank-to-wheels)	Table C-1-A.1 or U.S. EPA 2024	kg CO_2e per hp-hour	API 2021; U.S. DOE 2024; U.S. EPA 2018
E2	Carbon intensity of fossil-fueled equipment (well-to-wheels)	Table C-1-A.1	kg CO_2e per hp-hour	API 2021; U.S. DOE 2024; U.S. EPA 2018
E3	Lifecycle carbon intensity electricity	Table E-26.3	lb CO_2e per MWh	U.S. DOE 2024
F	Conversion from kg to MT	0.001	MT per kg	conversion
G	Energy economy ratio	3.8	unitless	CARB 2020
H	Conversion from horsepower to MW	0.0007457	MW per hp	conversion
I	Conversion from lb to MT	0.000454	MT per lb	conversion

[35] Note that in-use horsepower includes the load factor. This is distinct from the rated power of the equipment.

Further explanation of key variables:

- (B) – The fuel type of the existing equipment is used to obtain the carbon intensity of the equipment (E1 or E2).
- (C) – This input represents the hours of operation that the equipment will be used over a user-specified time period.
- (D) – Average in-use hp of various landscaping equipment are provided in Table LL-1.1 in the Appendix, *Emission Factors and Data Tables* (U.S. EPA 2024). The in-use hp values are inclusive of equipment load. Therefore, the GHG reduction equation does not include a multiplier for load factor. Note that the types of equipment presented in Table C-1.B.1 differ from what is presented in the CAPCOA Handbook. This is due to differences in categorization and terminology in the underlying source model (MOVES for this Western States Handbook vs. OFFROAD for the CAPCOA Handbook). If the user can provide an equipment-specific in-use hp, they should replace the default in the GHG calculation formula.
- (E1) – Tank-to-wheels GHG intensity factors for gasoline and diesel-powered landscaping equipment are presented in Table C-1-A.1. Refer to Measure C-1-A.1, *Use Electric or Hybrid Powered Equipment*, for additional information. Note that the CAPCOA Handbook recommends users obtain emission factors from CARB's OFFROAD model. This model reflects activity and data specific to the California fleet and is thus not applicable outside of the state. Accordingly, this Western States Handbook recommends users apply the factors from Table C-1-A.1 or run MOVES. MOVES is maintained by the U.S. EPA and can generate emissions rates at the county-level across the nation.
- (E2) – Well-to-wheels GHG intensity factors for gasoline and diesel-powered landscaping equipment are presented in Table C-1-A.1. Refer to Measure C-1-A.1, *Use Electric or Hybrid Powered Equipment*, for additional information.
- (E3) – Well-to-wheels GHG emission factors for WECC and SPP are provided in five year increments between 2025 and 2050 in Table E-26.3. Refer to Measure E-26, *Biomass Energy*, for additional information.
- (G) – An Energy Economy Ratio (EER) compares the efficiency of different fuels and vehicle technologies. The EER for electric forklifts as a diesel replacement is 3.8 (CARB 2020). If the user can provide an equipment-specific EER, they should replace the default in the GHG calculation formula.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces lawn and landscaping emissions by replacing fossil fuel combustion with electricity consumption, which generates fewer GHG emissions per unit of activity. In this example of a tank-to-wheels calculation, a 22-hp commercial gasoline 4-stroke chipper (B, D) that is used 8 hours per day (C) is replaced by an electric-powered equivalent.

$$A1 = -\left(8\ \frac{\text{hours}}{\text{day}} \times 22\ \text{hp} \times 0.53 \frac{\text{kg } CO_2e}{\text{hp-hour}} \times 0.001 \frac{\text{MT}}{\text{kg}}\right) = -0.09\ \frac{\text{MT } CO_2e}{\text{day}}$$

In this example of a well-to-wheels calculation for the same 22-hp chipper, the analysis year is 2035, and the user elects to use the WECC average carbon intensity factor from the Appendix (297 lb. CO_2e per MWh) (E3).

$$A2 = -\left(8\ \frac{\text{hours}}{\text{day}} \times 22\ \text{hp} \times 0.68 \frac{\text{kg } CO_2e}{\text{hp-hour}} \times 0.001 \frac{\text{MT}}{\text{kg}}\right) + \left(8\ \frac{\text{hours}}{\text{day}} \times \frac{22\ \text{hp}}{3.8} \times 0.0007457 \frac{\text{MW}}{\text{hp}} \times 297 \frac{\text{lb } CO_2e}{\text{MWh}} \times 0.000454 \frac{\text{MT}}{\text{lb}}\right) = -0.11\ \frac{\text{MT } CO_2e}{\text{day}}$$

Measure Co-Benefits

Improved Air Quality

(Tank-to-wheels) Reducing gasoline combustion will also reduce local criteria pollutants. Tank-to-wheels emission savings can be calculated using the same formula used to quantify GHG reductions (A1). Criteria pollutant intensity factors for various landscaping equipment can be obtained from the U.S. EPA's (2024) MOVES.

(Well-to-wheels) The fuels produced by facilities within and outside of state will generate criteria pollutants. Because these facilities are dispersed, offsite of the project/site or plan/community, fuel production (including electricity) typically will not generate localized criteria pollutant emissions. Therefore, only the tank-to-wheels (i.e., tailpipe) portion of the vehicle criteria pollutant emissions should be quantified.

Energy and Fuel Savings

(Tank-to-wheels) Fossil fuel (gasoline) savings are a product of the equipment fuel efficiency (gal consumed per hour) and the equipment operating time (hours). Fuel intensity factors for various landscaping equipment can be obtained from the U.S. EPA's (2024) MOVES. Users should multiply the fuel intensity by the equipment operating hours to quantify fuel savings.

(Well-to-wheels) Fuel savings would be achieved from tank-to-wheels reductions. Additional fuel savings may occur upstream from reduced production and transport, although these likely cannot be attributed to a single project. Increased electricity consumption is calculated as part of the GHG reduction formula (A2). The abbreviated formula is also shown below.

$$MWh = \left(C \times \frac{D}{G} \times H\right)$$

Source

- API (Association of Petroleum Institute). 2021. *Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry*. Released November 2021. Accessed June 2025. https://www.api.org/~/media/files/policy/esg/ghg/2021-api-ghg-compendium-110921.pdf.
- U.S. DOE (U.S. Department of Energy). 2024. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model*. 2024 Release. Accessed January 28, 2025. https://greet.anl.gov/.
- U.S. EPA (U.S. Environmental Protection Agency). 2018. "Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES2014b." Released July 2018. Accessed June 2025. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100UXEN.pdf.
- U.S. EPA. 2024. "Latest Version of Motor Vehicle Emissions Simulator (MOVES)." Released November 2024. Accessed December 2024. https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#guidance.

Solid Waste



CH_4 emissions are generated through the decomposition of organic waste disposed of in a landfill. CO_2 is also generated as materials degrade, but these emissions are considered part of the natural carbon cycle of growth and decomposition. The transportation of waste to a landfilling facility also generates emissions from the combustion of fuel to operate the waste-hauling vehicle. In some cases, organic materials that are landfilled do not completely decompose, allowing for biogenic carbon storage that otherwise would not have occurred. In addition, landfills may capture some of the CH_4 generated by organic materials and combust it to generate electricity, thereby avoiding emissions that otherwise would have been emitted to generate electricity (U.S. EPA 2020).

Emissions associated with landfilling can be avoided through the diversion of waste. Alternate waste management pathways include recycling and composting.

- Recycling is the separation and collection of wastes, their subsequent transformation or remanufacture into usable or marketable products or materials, and the purchase of products made from recyclable materials (U.S. EPA 2020). During recycling, emissions are generated from the transportation of waste to recycling facilities and the operation of machinery to process these materials into new, recycled products. Other emissions may be generated during the recycling process through the purification chemicals or agents. At the same time, recycling offsets emissions associated with the virgin production of materials.
- Composting involves bacterial decomposition of organic matter into compost. Emissions result from the transportation and processing of waste at the compost facility, as well as from the decomposition process. At the same time, compost application can help reduce the use of synthetic fertilizers and increase soil carbon storage.



The methodology used in this Handbook to quantify emission reductions from diverting waste from landfills is based on a lifecycle approach that accounts for upstream and downstream emissions associated with the waste management pathways with and without the measure. This is consistent with the methodology developed by the U.S. Environmental Protection Agency (U.S. EPA) (2020). Additionally, Measure S-3 accounts for up-stream emissions in the food supply chain, such as production- and transportation-related emissions. As a result, users are cautioned in how these reductions are compared to operational emissions inventories, which may not include lifecycle emissions. Additionally, the methodology assumes that all disposed waste will be diverted from the landfill. In reality, recycling and composting programs will likely only result in the diversion of a fraction of disposed waste. Users should consider this when calculating the benefits of implementation of waste diversion programs.

Use the graphic to click on an individual measure to navigate directly to the measure's factsheet.

S-1. Institute or Extend Recycling Services



GHG Mitigation Potential



Potentially small reduction in GHG emissions from waste management pathways

Co-Benefits (icon key on pg. 31)

Climate Resilience

Recycling can reduce upstream material extraction and product manufacturing, preserving resources and reducing energy use.

Health and Equity Considerations

Any new recycling facilities should not be constructed near vulnerable or underserved communities.

Measure Description

This measure will institute or extend recycling services to reduce the volume of landfilled waste. Decomposition of certain types of landfilled waste produces CH_4. Increasing waste diversion from landfills therefore reduces GHG emissions. While the recycling process generates some emissions, it reduces upstream emissions from the manufacturing and production of new raw materials and goods.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Measure success requires consumer education and outreach, as well as convenient access to recycling receptables. Consider implementing an outreach and training program to increase consumer recycling and measure compliance. Ensure recycling bins are placed in convenient locations and accessible to all.

Cost Considerations

Expanding recycling services generates costs of collection, processing, and management of the materials to be recycled, and can include the construction of new facilities to process a certain type of material, or transportation for the materials to reach a plant that can accommodate them. However, expanded recycling also reduces costs associated with new material production, waste processing, landfill management, pollution control, and waste-stream GHG emissions.

Expanded Mitigation Options

Waste reduction is as important, if not more so, as waste diversion. Work with building tenants to audit waste streams to identify opportunities for material reduction. For example, organizations may reduce single-use disposal at large events (e.g., concerts) and venues (e.g., stadiums) through partnerships with organizations that provide reusable cups and dishes.

Introduction

The GHG reduction formula for Measure S-1 has been modified slightly for this Western States Handbook compared to what is presented in the CAPCOA Handbook. The GHG reduction formula in the CAPCOA Handbook presents variables for per-capita residential (E1) and non-residential (E2) waste generation. These separate variables are provided in the CAPCOA Handbook to facilitate measure quantification in the California Emissions Estimator Model, which estimates waste emissions by land-use type. They also reflect the data available from California Department of Resources Recycling and Recovery, which has detailed and separate residential and non-residential waste stream data.

Separation of residential and non-residential per capita waste generation rates is not necessary to quantify GHG reductions achieved by this measure. Accordingly, the GHG reduction formula for this Western States Handbook relies on a single per-capita waste generation rate (E) for the user's entire project. Default per-capita waste generation rates based on total statewide landfilled tonnage divided by the state population are provided in the Appendix, as discussed further below. Users seeking to separately quantify GHG reductions achieved by residential and non-residential components of their project may still do so by providing separate per-capita waste generation rates for variable E in the GHG reduction formula.

GHG Reduction Formula

$A = E \times D$

$B_Z = A \times F_Z$

C = Input B_Z into U.S. EPA WARM

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Waste disposed by project	[ ]	tons	calculated
B	Waste disposed by material type	[ ]	tons	calculated
C	GHG reduction from recycling vs. landfilling waste	[ ]	MT CO_2e	calculated using U.S. EPA WARM
User Inputs				
D	Total project population	[ ]	person	user input
Constants, Assumptions, and Available Defaults				
E	Annual per capita waste disposal rates	Tables S-1.1 through S-1.3	tons per person per year	see tables
F	Percentage of material z in waste stream	Tables S-1.4 through S-1.8	%	see tables

ID	Variable	Value	Unit	Source
z	Material type (e.g., glass)	Tables S-1.4 through S-1.8	text	see tables

Further explanation of key variables:

- (C) – U.S. EPA's (2023) Waste Reduction Model (WARM) calculates GHG emissions associated with various waste management practices, including recycling and landfilling.[36] To estimate the GHG benefit of recycling over landfilling, users input the tonnage of waste by material type into the Tons Landfilled column under the "baseline" scenario. The user then inputs the tonnage of waste by material type into the Tons Recycled column under the "alternative management" scenario. If a material type cannot be recycled, the user should input the tonnage for that material into the Tons Landfilled column under the alternative management scenario. The model calculates emissions under the baseline and alternative management scenarios of manufacturing, transportation, and end-of-life landfilling or recycling of waste and shows the net GHG savings in MT CO_2e.
- (D) – Users should identify the total waste generating population for their project. For residential projects, this would be the total residents. For non-residential projects, this would be the employees and/or visitors. For mixed use projects, this would be the service population (i.e., residents plus employees/visitors). Note that the definition of this variable differs slightly from the CAPCOA Handbook, which requests users provide separate inputs for residential and non-residential populations.

  (E) – Annual solid waste disposal rates for Washington counties are provided in Table S-1.1 in the Appendix. Table S-1.2 provides annual solid waste disposal rates by Oregon wasteshed. Refer to OAR 340-090-0050 for wasteshed designations and boundaries. Statewide per capita waste disposal rates from the U.S. EPA's (2025) State Inventory Tool are provided in Table S-1.3 for Arizona, Colorado, and New Mexico. Note that the definition of this variable differs slightly from the CAPCOA Handbook, which requests users provide separate inputs for residential and non-residential per capita waste generation. Also, the quantification method assumes that all disposed waste for the user selected categories (e.g., paper) will be recycled and diverted from the landfill. Depending on measure penetration and success, users may consider including only a portion of total waste generation in their alternative management scenario for benefits quantification.
- (F) – The composition of disposed waste by material type is provided in Tables S-1.4 through S-1.8 in the Appendix. State data are available for Arizona, Colorado, Oregon, and Washington. Users in New Mexico are encouraged to contact their local waste management agency for assistance in characterizing the waste stream. Alternatively, they may use the national waste stream composition provided in Table S-1.8 to support emissions estimation.

GHG Calculation Caps or Maximums

None.

[36] Note that WARM has been updated since publication of the CAPCOA Handbook, which cites the 2020 version of the tool.

Example GHG Reduction Quantification

The user reduces GHG emissions by diverting waste from a landfill to a recycling center. In this example, the project is a mixed used development with a total waste generating population (i.e., residents plus employees/visitors) of 1,000 (D). It is in the Baker wasteshed in Oregon and is assumed to have a per capita waste disposal rate of 0.82 per Table S-1.2 (E).

The user inputs the tons of waste by material type (B) into U.S. EPA's WARM in the Tons Landfilled column. The project will recycle all paper (B_{paper}), glass (B_{glass}), and mixed plastic ($B_{plastic\ (mixed)}$), which is assumed in the alternative management scenario. Based on WARM, the project would mitigate up to 398 MT CO_2e by diverting its waste from a landfill to a recycling facility.

$$A = 0.82\ \frac{\text{tons}}{\text{yr}\cdot\text{person}} \times 1{,}000\ \text{people} = 821\ \frac{\text{tons}}{\text{yr}}$$

$$B_{paper\ (corrugated)} = 821\frac{\text{tons}}{\text{yr}} \times 3\% = 25\frac{\text{tons}}{\text{yr}}$$

$$B_{paper\ (newspaper)} = 821\frac{\text{tons}}{\text{yr}} \times 0.4\% = 4\frac{\text{tons}}{\text{yr}}$$

$$B_{paper\ (mixed)} = 821\frac{\text{tons}}{\text{yr}} \times 8\% = 63\frac{\text{tons}}{\text{yr}}$$

$$B_{paper\ (office)} = 821\frac{\text{tons}}{\text{yr}} \times 1\% = 8\frac{\text{tons}}{\text{yr}}$$

$$B_{glass} = 821\frac{\text{tons}}{\text{yr}} \times 3\% = 21\frac{\text{tons}}{\text{yr}}$$

$$B_{metals\ (aluminum)} = 821\frac{\text{tons}}{\text{yr}} \times 0.3\% = 2\frac{\text{tons}}{\text{yr}}$$

$$B_{metals\ (mixed)} = 821\frac{\text{tons}}{\text{yr}} \times 3\% = 21\frac{\text{tons}}{\text{yr}}$$

$$B_{plastic\ (LLDPE)} = 821\frac{\text{tons}}{\text{yr}} \times 3\% = 28\frac{\text{tons}}{\text{yr}}$$

$$B_{plastic\ (mixed)} = 821\frac{\text{tons}}{\text{yr}} \times 5\% = 44\frac{\text{tons}}{\text{yr}}$$

$$B_{plastic\ (HDPE)} = 821\frac{\text{tons}}{\text{yr}} \times 2\% = 13\frac{\text{tons}}{\text{yr}}$$

$$B_{food} = 821\frac{\text{tons}}{\text{yr}} \times 17\% = 139\frac{\text{tons}}{\text{yr}}$$

$$B_{yard\ trimmings} = 821\frac{\text{tons}}{\text{yr}} \times 5\% = 38\frac{\text{tons}}{\text{yr}}$$

$$B_{\text{mixed MSW}} = 821\frac{\text{tons}}{\text{yr}} \times 24\% = 200\frac{\text{tons}}{\text{yr}}$$

$$B_{\text{construction (carpet)}} = 821\frac{\text{tons}}{\text{yr}} \times 2\% = 20\frac{\text{tons}}{\text{yr}}$$

$$B_{\text{construction (shingles)}} = 821\frac{\text{tons}}{\text{yr}} \times 4\% = 32\frac{\text{tons}}{\text{yr}}$$

$$B_{\text{construction (flooring)}} = 821\frac{\text{tons}}{\text{yr}} \times 16\% = 129\frac{\text{tons}}{\text{yr}}$$

$$B_{\text{construction (drywall)}} = 821\frac{\text{tons}}{\text{yr}} \times 4\% = 30\frac{\text{tons}}{\text{yr}}$$

$$B_{\text{mixed electronics}} = 821\frac{\text{tons}}{\text{yr}} \times 1\% = 4\frac{\text{tons}}{\text{yr}}$$

Quantified Co-Benefits

None.

Sources

- U.S. EPA (U.S. Environmental Protection Agency). 2023. Current Waste Reduction Model (WARM) Tool, Version 16. Accessed February 2025. https://www.epa.gov/warm/versions-waste-reduction-model#v16.
- U.S. EPA. 2025. State Inventory Tool–Municipal Solid Waste. Version 2025.1. Accessed February 2025. https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool.

S-2. Implement Organics Diversion Program



GHG Mitigation Potential



Potentially small reduction in GHG emissions from management pathways

Co-Benefits (icon key on pg. 31)



Climate Resilience

Organics diversion programs can increase the amount of compost produced, which can go toward gardens and farms and help improve food and crop production. Compost can also help increase soil carbon storage, which can in turn improve biodiversity and groundwater storage.

Health and Equity Considerations

If possible, work with local food banks and shelters to ensure that edible food goes to people first.

Measure Description

This measure will implement an organics diversion program to reduce the volume of organic waste sent to landfills. An organics diversion program lowers the landfill disposal rate of food waste (both edible and non-edible), food soiled paper, yard waste, and non-hazardous wood waste. Decomposition of organic waste in landfills produces CH_4. Increasing organic waste diversion from landfills thus reduces GHG emissions.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Waste management practices to support organics diversion may include construction and management of a composting facility or providing residential and business composting pickup services. Measure success may also require community outreach and education. Provide clearly marked triple bins (waste, recycling, composting) that are accessible to all.

Cost Considerations

Implementing organics diversion services, or utility scale composting, generates costs for collection, processing, and management of the materials to be composted, and can include the construction of new composting facilities or transportation for the materials to reach a plant that can accommodate them. However, expanded composting also reduces costs associated with waste processing, landfill management, pollution control, and waste-stream greenhouse gas emissions. The resulting compost can also take the place of fertilizer, saving costs on land management inputs and increasing agricultural yields.

Expanded Mitigation Options

Diversion of edible food to food banks is another viable organics diversion program but is not specifically captured by the current quantitative method for this measure.

Introduction

The GHG reduction formula for Measure S-2 has been modified slightly for this Western States Handbook compared to what is presented in the CAPCOA Handbook. The GHG reduction formula in the CAPCOA Handbook presents variables for per-capita residential (E1) and non-residential (E2) waste generation. These separate variables are provided in the CAPCOA Handbook to facilitate measure quantification in the California Emissions Estimator Model, which estimates waste emissions by land-use type. They also reflect the data available from the California Department of Resources Recycling and Recovery, which has detailed and separate residential and non-residential waste stream data. Separation of residential and non-residential per capita waste generation rates is not necessary to quantify GHG reductions achieved by this measure.

Accordingly, the GHG reduction formula for this Western States Handbook relies on a single per-capita waste generation rate (E) for the user's entire project. Default per-capita waste generation rates based on total statewide landfilled tonnage divided by the state population are provided in the Appendix, as discussed further below. Users seeking to separately quantify GHG reductions achieved by residential and non-residential components of their project may still do so by providing separate per-capita waste generation rates for variable E in the GHG reduction formula.

GHG Reduction Formula

$A = E \times D$

$B_Z = A \times F_Z$

$C = \text{Input } B_Z \text{ into U.S. EPA WARM}$

Composting can help reduce the use of nitrogen-based fertilizer, which results in GHG emissions during the manufacturing process (which involves use of natural gas) and release of nitrogen dioxide (NO_2) during use. These emissions are not quantified as part of this measure's methodology. Additional GHG reductions may be achieved if the diversion program reduces VMT and associated vehicle emissions. Refer to *Quantified Co-Benefits* below for further discussion.

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Waste disposed by project	[ ]	tons	calculated
B	Waste disposed by material type	[ ]	tons	calculated
C	GHG reduction from recycling vs. composting waste	[ ]	MT CO_2e	calculated using U.S. EPA WARM
User Inputs				
D	Total project population	[ ]	person	user input

ID	Variable	Value	Unit	Source
Constants, Assumptions, and Available Defaults				
E	Annual per capita waste disposal rates	Tables S-1.1 through S-1.3	tons per person per year	see tables
F	Percentage of material z in waste stream	Tables S-1.4 through S-1.8	%	see tables
z	Material type (e.g., glass)	Tables S-1.4 through S-1.8	text	see tables

Further explanation of key variables:

- (C) – U.S. EPA's (2023) WARM calculates the GHG emission impacts associated with various waste management practices, including recycling and composting.[37] To estimate the GHG benefit of composting over landfilling, users input the tonnage of organic waste by material type into the Tons Landfilled column under the "baseline" scenario. The user then inputs the tonnage of organic waste by material type into the Tons Composted column under the "alternative management" scenario. The model calculates emissions under the baseline and alternative management scenarios of manufacturing, transportation and end-of-life landfilling, or diversion of organic waste and shows the net GHG savings in MT CO_2e.
- (D) – Users should identify the total waste generating population for their project. For residential projects, this would be the total residents. For non-residential projects, this would be the employees and/or visitors. For mixed use projects, this would be the service population (i.e., residents plus employees/visitors). Note that the definition of this variable differs slightly from the CAPCOA Handbook, which requests users provide separate inputs for residential and non-residential populations.
- (E) – Annual solid waste disposal rates for Washington counties are provided in Table S-1.1 in the Appendix. Table S-1.2 provides annual solid waste disposal rates by Oregon wasteshed. Refer to OAR 340-090-0050 for wasteshed designations and boundaries. Statewide per capita waste disposal rates from the U.S. EPA's (2025) State Inventory Tool are provided in Table S-1.3 for Arizona, Colorado, and New Mexico. Note that the definition of this variable differs slightly from the CAPCOA Handbook, which requests users provide separate inputs for residential and non-residential per capita waste generation. Also, the quantification method assumes that all disposed waste for the user selected categories (e.g., paper) will be diverted from the landfill. Depending on measure penetration and success, users may consider including only a portion of total waste generation in their alternative management scenario for benefits quantification.
- (F) – The composition of disposed waste by material type is provided in Tables S-1.4 through S-1.8 in the Appendix. State data are available for Arizona, Colorado, Oregon, and Washington. Users in New Mexico are encouraged to contact their local waste

[37] Note that WARM has been updated since publication of the CAPCOA Handbook, which cites the 2020 version of the tool.

management agency for assistance in characterizing the waste stream. Alternatively, they may use the national waste stream composition provided in Table S-1.8 to support emissions estimation.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions by diverting organic waste from a landfill. In this example, the project is a mixed used development with a total waste generating population (i.e., residents plus employees/visitors) of 1,000 (D). It is in the Baker wasteshed in Oregon and is assumed to have a per capita waste disposal rate of 0.82 per Table S-1.2 (E).

The user inputs the tons of waste by material type (B) into U.S. EPA's WARM in the Tons Landfilled column. The project will compost all food waste and yard trimmings, which is assumed in the alternative management scenario. Based on WARM, this business can mitigate up to 62 MT CO_2e by diverting waste from a landfill to compost facility.

$$A = 0.82 \frac{\text{tons}}{\text{yr·person}} \times 1{,}000 \text{ people} = 821 \frac{\text{tons}}{\text{yr}}$$

$$B_{\text{food}} = 821 \frac{\text{tons}}{\text{yr}} \times 17\% = 139 \frac{\text{tons}}{\text{yr}}$$

$$B_{\text{yard trimmings}} = 821 \frac{\text{tons}}{\text{yr}} \times 4.7\% = 38 \frac{\text{tons}}{\text{yr}}$$

Quantified Co-Benefits

VMT Reductions

Organics diversion programs may reduce waste transfer vehicle VMT if the compost facility is closer to the waste generation source than the landfill. The VMT reduction may be calculated using the following formula.

$$G = (H \times I) - (J \times K)$$

VMT Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
G	Reduction in waste transfer vehicle VMT	[ ]	miles/day	calculated
User Inputs				
H	Daily waste transfer trips without the organics diversion program	[ ]	trips/day	user input
I	Waste transfer trip distance without the organics diversion program	[ ]	miles/trip	user input
J	Daily waste transfer trips under the organics diversion program	[ ]	trips/day	user input
K	Waste transfer trip distance under the organics diversion program	[ ]	miles/trip	user input
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (H, J) – The user should take care to properly account for all vehicle trips directly affected by implementation of the measure. This value may be the same with and without the diversion program.
- (I, K) – The user should take care to properly account for the full trip distance of the waste transfer vehicle. Note that if the trip distance increases with implementation of the organics diversion program (i.e., K>I), this measure would result in a VMT increase.

Users may translate VMT reductions (or increases) (G) to GHG emissions using emission factors from the U.S. EPA's MOtor Vehicle Emission Simulator (MOVES). Users should multiply the VMT reductions (or increases) by the appropriate vehicle emission factors for their region. If the organics diversion program also reduces (or increases) the number of vehicle trips (i.e., J<H or J>H), users should quantify the resulting changes in process emissions using MOVES. Note that the CAPCOA Handbook recommends users obtain emission factors from CARB's EMFAC model. This model reflects activity and data specific to the California fleet and is thus not applicable outside of the state. Accordingly, this Western States Handbook recommends users run MOVES, which is maintained by the U.S. EPA and can generate emissions rates at the county-level across the nation.

Improved Air Quality

Composting can produce volatile organic compound (VOC) emissions in and around the composting site. This may result in worsened regional air quality. Increases in VOC emissions may be offset if the organics diversion program reduces waste transfer vehicle VMT. Users may translate VMT reductions (or increases) (G) to criteria pollutant emissions using emission factors from MOVES. Users should multiply the VMT reductions (or increases) by the appropriate vehicle

emission factors in their region. If the organics diversion program also reduces (or increases) the number of vehicle trips (i.e., J<H or J>H), users should quantify the resulting changes in process emissions using MOVES.

Sources

- U.S. EPA (U.S. Environmental Protection Agency). 2023. Waste Reduction Model (WARM), Version 16. Accessed February 2025. https://www.epa.gov/warm/versions-waste-reduction-model#v16.
- U.S. EPA. 2025. State Inventory Tool–Municipal Solid Waste. Version 2025.1. Accessed February 2025. https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool.

S-3. Require Edible Food Recovery Program Partnerships with Food Generators



GHG Mitigation Potential



Potentially large reduction in GHG emissions from edible food waste

Co-Benefits (icon key on pg. 31)

Climate Resilience

Food recovery programs can have health benefits and improve community resilience. Additionally, food recovery conserves resources, reduces waste, and lowers methane emissions.

Health and Equity Considerations

Edible foods diverted from landfills and redistributed for consumption can increase community food security and improve the nutritional status of vulnerable populations.

Measure Description

This measure requires that food service establishments, wholesale providers, and retail sources of edible food waste partner with food recovery programs. Food recovery programs collect edible foods, which would otherwise be landfilled or composted, from commercial production and distribution channels and redistribute the food for consumption by those in need. This measure avoids emissions from the decomposition of non-diverted organic material in landfills. This measure's reductions are lifecycle emissions, as it results in reductions in up-stream and down-stream emissions, such as production and transportation related emissions.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Implementation of this measure requires having data on the following: (1) total edible food recovered, (2) vehicle(s) used for the food recovery and total VMT, and (3) total square footage of the refrigeration systems used and type of refrigerants used. Measure success may be enhanced through consumer education and outreach.

Cost Considerations

Establishing edible food recovery program partnerships with food generators can generate costs from the collection of edible food. Specifically, edible recovery requires the use of vehicles that have maintenance and fuel costs, electricity costs from the use of large refrigeration systems, costs from refrigerant leakages and recharges, and in some cases, labor costs. However, edible food recovery programs can reduce food costs for households within a community and improve food security.

Expanded Mitigation Options

Pair with a lower carbon intensity power source to ensure that the energy supplied to power the electrified equipment has a lower carbon intensity than the local grid, thereby further reducing GHG emissions. Also pair with lower GWP refrigerants, to ensure that refrigeration systems are responsible for less emissions and increase the benefit of this measure.

GHG Reduction Formula

$$A = \sum_{E} \left[\left(\frac{G \times H}{L} \right) + \left(\frac{I \times J \times K}{M} \right) \right]$$

$$B = \sum_{F} \left[\left((N \times O + P) \times \left(\frac{Q}{R \times M} \right) \right) + \left(\frac{S \times T \times U}{M} \right) \right]$$

$$C = - \left(\frac{V \times (1 - (Z1 + Z2))}{W} \right) \times X$$

$$D = C + A + B$$

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A	GHG emissions from transportation vehicles	[ ]	MT CO_2e/year	calculated
B	GHG emission from refrigeration equipment	[ ]	MT CO_2e/year	calculated
C	GHG emission reductions from recovery of edible food	[ ]	MT CO_2e/year	calculated
D	Net GHG emissions from the recovery of edible foods	[ ]	MT CO_2e/year	calculated
User Inputs				
E	Number and type of identical delivery vehicle(s)	[ ]	unitless	user input and Table T-30.2
F	Number and type and number of identical	[ ]	unitless	user input and Table S-3.1

ID	Parameter	Value	Unit	Source
	refrigeration unit(s)			
H	Average miles per year for the delivery vehicle(s)	[ ]	miles/year	user input
I	Leakage rate of the transportation refrigeration unit (TRU), if applicable	[ ]	%	user input
J	TRU refrigerant charge size, if applicable	[ ]	lbs/year	user input
N	Volume of refrigeration compartment	[ ]	ft^3	user input
T	Refrigerant charge size, if known	[ ]	lbs	user input or Table S-3.1
V	Amount of edible food recovered per year	[ ]	lbs	user input
Z2	Percentage of edible food recovered after accounting for consumer loss	[ ]	Percent	user input
Constants, Assumptions, and Available Defaults				
G	Delivery vehicle GHG emission factor	Table T-30.2	g CO_2e per mile	U.S. EPA 2024; U.S. DOE 2021
L	Grams to metric ton conversion factor	1,000,000	g/MT	conversion
K	GWP of refrigerant (default of R-134A is	Table R-1.1; default value is 1,300	unitless	IPCC 2013 and WMO 2018

ID	Parameter	Value	Unit	Source
	assumed for TRU)			
M	Pounds to metric ton conversion factor	2,204.62	lbs/MT	conversion
O	Electricity consumption of refrigeration unit per year per cubic feet	Table S-3.1	kWh/year per ft^3	10 CFR 431.66
P	Constant electricity consumption of a refrigeration unit per year	Table S-3.1	kWh/year	10 CFR 431.66
Q	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	see tables
R	Converting MWh to kWh	1,000	kWh/MWh	conversion
S	Annual average leakage rate per year of the refrigeration unit	Table S-3.1	%	CARB 2020; U.S. EPA 2016
U	GWP of refrigerant	Table R-1.1	unitless	IPCC 2007 and WMO 2018
W	Pounds to short ton conversion factor	2,000	lbs/ton	conversion
X	Edible food waste recovery emission reduction factor (Landfill or Composting)	1.49 to 5.83 (Landfill) 0.926 (Composting)	MT CO_2e/ton (dry)	Perez et al. 2023
Z1	Percentage of edible food that is lost	0.13	unitless	Oregon DEQ 2019

ID	Parameter	Value	Unit	Source
	during the culling/sorting process and at a distribution facility.			

Further explanation of key variables:

- (E) – The user will need to specify how many of the individual delivery vehicle types are being used and run different calculations for each different type of delivery vehicle. The equation cannot be run without specifying (1) the delivery vehicle from Table T-30.2, and (2) the number of delivery vehicles. Note that the types of vehicles listed in Table T-30.2 differ from what is presented in the CAPCOA Handbook. This is because delivery vehicle GHG emission factors (G) are obtained from the MOVES model for this Western States Handbook, whereas the CAPCOA Handbook obtained the factors from the EMFAC model.
- (F) – The type of refrigeration units that are supported for this measure are provided in Table S-3.1 in the Appendix. The user will need to specify how many of the individual refrigeration unit types are being used and run different calculations for each different type of refrigeration unit. The equation cannot be run without specifying the (1) type of refrigeration unit from Table S-3.1, and (2) the number of refrigeration units.
- (G) – This value is used to calculate the emissions generated by delivery vehicles transporting the recovered food. Delivery vehicle GHG emission factors (grams CO_2e per mile) are provided in Table T-30.2 in the Appendix.
- (H) – This input represents the number of miles traveled by the delivery vehicle(s) used to transport the recovered food.
- (I) – This value represents the rate at which refrigerants leak from the transportation refrigeration unit in the delivery vehicle.
- (J) – This value represents the quantity of refrigerants used in the delivery vehicles.
- (K) – This value is the GWP for the refrigerants used in the delivery vehicles. GWP values are provided in Table R-1.1 in the Appendix.
- (N) – This value represents the volume of the refrigeration compartment used to store the recovered food.
- (O) – This value is used to calculate the emissions generated by refrigeration units where the recovered food is stored. The electricity consumption of the refrigeration unit per year per cubic feet are provided in Table S-3.1 in the Appendix.
- (P) – This value is used to calculate the quantity of energy consumed in the refrigeration units. The constant electricity consumption of a refrigeration unit per year are provided in Table S-3.1 in the Appendix.
- (Q) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Users should consult their local electricity provider for updated emission factors available at the time of their analysis before proceeding with the defaults provided in these tables. If the project study area is not serviced by a listed electricity provider, or emission factors for the local utility are not available, users may elect to use the appropriate grid average carbon intensity presented in Table E-

4.10. Grid electricity emission factors are available for two geographies as defined in the U.S. DOE's GREET model—the Western Electricity Coordinating Council (WECC) and Southwest Power Pool (SPP). Arizona, Colorado, Oregon, and Washington are wholly within WECC. New Mexico is split between WECC and SPP. Refer to Figure E-4.2 in the Appendix.

Note that the GHG intensity factor of most electricity providers will decrease in future years as the electricity providers continue to improve their energy mix to meet clean energy mandates and/or company goals. Accordingly, GHG reductions achieved by this measure will change over time as the utility resource mix becomes cleaner.

Note that the availability of local utility emission factors differs among western states and from what is provided for California utilities in the CAPCOA Handbook. This Western States Handbook also uses the GREET model to provide future grid emission factors in five-year increments, whereas the CAPCOA Handbook forecasts annual emission factors using U.S. EPA's Emissions & Generation Resource Integrated Database.

- (S) – This value represents the rate at which refrigerants leak from the refrigeration unit. Table S-3.1 in the Appendix provides average annual leak rates based on published state (California) and federal data (CARB 2020; U.S. EPA 2016). The California data are referenced in the CAPCOA Handbook and are based on a statewide inventory conducted by the California Air Resources Board (CARB). Data specific to the western states are not available, however Washington State currently uses the California data to support statewide emissions analysis (WSDOT 2025). Average annual leak rates from the U.S. EPA national inventory are also provided in this Western States Handbook as additional potential defaults.
- (T) – This value represents the quantity of refrigerants used to store the recovered food. Table S-3.1 provides average charge sizes based on published state (California) and federal data (CARB 2020; U.S. EPA 2016). As noted under variable (S), the California data is from a CARB inventory. The federal data is from U.S. EPA's national GHG inventory.
- (U) – This value is the GWP for the refrigerants used in the refrigeration storage units. GWP values are provided in Table R-1.1 in the Appendix.
- (X) – This value represents the GHG emissions that are reduced from one short ton of recovered dry food from a landfill or from a composting facility.
- (Z1) – This value accounts for the loss rate in edible food being recovered during the cull/sorting process at facilities and the food delivery process at partner agency facilities (Oregon DEQ 2019). These values were estimated based on data provided by food rescue organizations located in Oregon; thus, the values may not be representative of all states.
- (Z2) – This value accounts for the loss rate in edible food after it is delivered or picked-up by its intended recipient. Although no data is available for this input, in a study by the Oregon Department of Environmental Quality, three hypothetical scenarios were considered with a minimum, average, and maximum loss rate of 0.07, 0.14, and 0.20, respectively (Oregon DEQ 2019). Users should use the best information they have available to determine what loss rate is applicable for their project or area, or identify a target loss rate to set as a goal.

GHG Calculation Caps or Maximums

Measure Maximum

None. However, it is possible that the GHG emissions from transportation and refrigeration use exceed the emission reduction from the edible food recovery, resulting in a disbenefit for this measure.

Example GHG Reduction Quantification

A food bank located in the City of Seattle with a 960 cubic feet commercial walk-in refrigerator with solid doors (F, N) is recovering edible food waste from local restaurants. The food bank is estimating that it will be able to recover and donate approximately 25,000 pounds of edible dry food from the local restaurants (V). The food bank will be using a gasoline refrigerated single unit short-haul truck (E) to recover the edible food. The food bank is anticipating that the total distance traveled per day is approximately 20 miles, or approximately 7,300 miles per year (H). The following additional values are used.

- Carbon intensity of 1,010 grams CO_2e per mile for the gasoline refrigerated single unit short-haul truck (G) (Table T-30.2).
- Average yearly leakage rate of 24 percent (I).
- Average yearly refrigerant charge size of 4 lbs (J).
- GWP of 1,300 for R-134A (K) (Table R-1.1).
- Electricity consumption per year per cubic foot of 36.5 kWh/year/ft^3 for the commercial refrigerator with solid doors (O) (Table S-3.1).
- Yearly constant electricity consumption of 744.6 kWh/year (P) (Table S-3.1).
- Seattle City Light's carbon intensity of electricity of 26 lbs CO_2e per MWh (Q).
- Leakage rate of 15 percent for commercial refrigerators (S) (Table S-3.1).
- Average yearly refrigerant charge size of 31.4 pounds (T) (Table S-3.1).
- GWP of 150 for refrigeration unit refrigerants (U) (Table R-1.1).
- The edible food waste recovery emission reduction factor of 1.49 MT CO_2e per ton (X).
- Percentage of edible food recovered and used after accounting for loss and waste pre-consumer(Z1).
- For the consumer-side loss, a goal of 20 percent loss, or 0.20, is identified for this example.

Based on these assumptions, the recovery of the 25,000 pounds of edible food would result in a reduction of 3.74 $MTCO_2e$ per year.

$$A = \sum_{1} \left[\left(\frac{1{,}010 \text{ g } CO_2e/\text{mi} \times 7{,}300 \text{ mi/year}}{1{,}000{,}000 \text{ g/MT}} \right) + \left(\frac{0.24 \times 4 \text{ lbs/yr} \times 1{,}300}{2{,}204.62 \text{ lbs/MT}} \right) \right]$$

$$A = 7.94 \text{ } MTCO_2e/yr$$

$$B=\sum_{1}\left[\left(\left(\mathbf{960ft^3}\times 36.5\ \text{kWh/year/ft}^3\right)+744.6\ \text{kWh/year}\right)\times\left(\frac{26\ \text{lbs}\ CO_2e/\text{MWh}}{2{,}204.62\frac{\text{lbs}}{\text{MT}}\times 1{,}000\ \text{kWh/MWh}}\right)\right]+\left(\frac{0.15\times\mathbf{31.4\ lbs/year}\times 150}{2{,}204.62\ \text{lbs/MT}}\right)$$

$$B=0.75\ MTCO_2e/\text{year}$$

$$C=-\left(\frac{\mathbf{25{,}000\ lbs}\times(1-(0.13+\mathbf{0.20}))}{2{,}000\ \text{lbs/ton}}\right)\times 1.49$$

$$C=-12.48\ MTCO_2e/\text{year}$$

$$D=-12.48\ MTCO_2e/\text{year}+7.99\ MTCO_2e/\text{year}+0.75\ MTCO_2e/\text{year}$$

$$D=-3.74\ MTCO_2e/\text{year}$$

Quantified Co-Benefits

Improved Air Quality

Edible food recovery may improve air quality emissions by reducing the total amount of organic waste that would be flared at a local landfill, by reducing electricity demand, and by reducing transportation emissions from collecting food waste and transporting waste to a landfill.

Criteria Pollutant Emission Reduction Formula

$$A2=\sum_{E}\left[\left(\frac{G\times H}{I}\right)\right]$$

$$B2=\sum_{F}\left((J\times K+L)\times M\right)$$

$$C2=-\left(\left(\frac{N}{O}\right)\times P\right)+\left(\left(\frac{N}{O}\right)\times Q\right)$$

$$D2=C2+A2+B2$$

Criteria Pollutant Emissions Increase Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A2	Air quality emissions from transportation vehicles	[ ]	lbs/year	calculated
B2	Air quality emission from refrigeration equipment	[ ]	lbs/year	calculated
C2	Air quality emission reductions from recovery of edible food	[ ]	lbs/year	calculated
D2	Air quality emissions from the recovery of edible foods	[ ]	lbs/year	calculated

ID	Parameter	Value	Unit	Source
User Inputs				
E	Number and type of identical delivery vehicle(s)	[ ]	unitless	user input and Table T-30.2
F	Number and type of identical refrigeration unit(s)	[ ]	unitless	user input and Table S-3.1
H	Average miles per year for the delivery vehicle(s)	[ ]	miles/ year	user input
J	Volume of refrigeration compartment	[ ]	ft^3	user input
N	Amount of edible food rescued	[ ]	lbs	user input
Constants, Assumptions, and Available Defaults				
G	ROG, NOx, $PM_{2.5}$, and diesel PM_{10} exhaust emission factors	MOVES	g/miles	U.S. EPA 2024
I	Grams to pounds conversion factor	453.6	g/lbs	conversion
K	Electricity consumption of refrigeration unit per year per feet	Table S-3.1	kWh/year per ft^3	10 CFR 431.66
L	Constant electricity consumption of a refrigeration unit per year	Table S-3.1	kWh/year	10 CFR 431.66
M	Electricity air quality emission factor	Table S-3.2	lbs/kWh	U.S. DOE 2025
O	Pounds to short ton conversion factor	2,000	lbs/ton	conversion
P	Avoided transportation for food waste emissions reduction factor	Table S-3.2	lbs/ton	Venkat 2012
Q	Avoided landfill flare emission reduction factor	Table S-3.2	lbs/ton	CARB 2020

Sources

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Natural and Working Lands

Natural and working lands may be a GHG sink or a source of GHG emissions. For example, trees and other vegetation incorporate carbon into their biomass during their growth phase and thereby can remove a finite amount of carbon from the atmosphere. Carbon can also be stored in soils. These types of natural lands (e.g., forests, grasslands) are considered GHG sinks. Other types of lands, on the other hand, such as certain types of agriculture and animal operations, can emit GHGs from a variety of sources and activities.



Measures within the natural and working lands sector aim to enhance the sequestration capacity of the land, reduce the intensity of emissions from GHG sources, or reduce emissions associated with the use of off-road equipment on agricultural land. A project can increase the area available for vegetation by converting previously developed land into vegetated open space. Conversions from one type of vegetated land to another may increase or decrease carbon sequestration, depending on the relative sequestration capacities of the land types. Additional ways to increase sequestration may include planting and maintaining new trees on either developed or undeveloped land. GHG emission from working lands can be reduced through climate-smart farming practices, some of which may increase below- and above-ground carbon storage or reduce excess fertilizer and related emissions. For users in wildfire-prone areas, projects can reduce GHG emissions from wildfire events by managing in specific ways to lessen the potential for severe wildfire activity. Finally, emissions from equipment used on agricultural lands can be reduced by replacing diesel-powered equipment with electric or hybrid-electric equipment and generating on-farm electricity from solar and wind.



Methods to quantify GHG reductions from natural and working lands do not lend to a simplified approach that can be presented in a few pages. Therefore, it is advised that users rely on existing tools to quantify GHG reductions as referenced in this section. Additional measures that can be undertaken to reduce emissions within the natural and working lands sector include establishing a local farmers market or community garden. Please refer to *Supporting or Non-Quantified GHG Reduction Measures* for additional information on these measures.

Use the graphic above to click on an individual measure to navigate directly to the measure's factsheet.

N-1. Create New Vegetated Open Space



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from vegetated open spaces

Co-Benefits (icon key on pg. 31)

Climate Resilience

Creating new vegetated open spaces can reduce the urban heat island effect, mitigate flooding and stormwater flows, and improve water quality, as well as provide recreational spaces that improve health and community resilience. Vegetated open space can also provide wildlife habitat and corridors for wildlife migration in the face of increasing temperatures and changing precipitation patterns.

Health and Equity Considerations

Prioritize open space creation in communities that have the lowest level of access to parks, gardens, and green spaces.

Measure Description

This measure would convert previously developed areas to vegetated open spaces. By creating new vegetated areas from previously settled land, the project would sequester CO_2 that would not have been captured without the land conversion. Trees and other vegetation also incorporate carbon into their biomass during their growth phase (stored carbon).

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Implementation must involve conversion of cleared areas to vegetated open spaces. This measure does not give any GHG reduction for the preservation of existing lands. Ensure the habitat types are native and will thrive in the local climate.

Cost Considerations

Upfront costs of creating more green spaces will depend on how the land is currently being used and how much construction is required to make it suitable. However, vegetated open spaces can achieve cost savings from improved storm water management, and they can reduce the incidence and cost of heat exposure and pollution-related illnesses.

Expanded Mitigation Options

None.

GHG Reduction Formula

The equation and method below can be used to generate a high-level estimate of stored soil carbon plus above and belowground biomass carbon pools, which can serve as an estimate of total CO_2 stored. Note that the CAPCOA Handbook also directs users to the *RePlan: Regional Conservation and Development Planning Tool* (RePlan) as a potential quantification method. RePlan reflects land use data specific to California and is thus not applicable outside of the state. Accordingly, it is not recommended in this Western States Handbook.

$$A = [(B_C \times C_C) + (B_S \times C_S \times D)] \times E$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	CO_2 benefit from new land cover type (soil and above and belowground carbon storage)	[ ]	MT CO_2e per year (over accumulation period)	calculated
User Inputs				
B_C	Hectare (ha) of land by IPCC climate zone and cover type	[ ]	ha	user input and Table N-1.1
B_S	Ha of land by soil type	[ ]	ha	user input and Figure N-1.1
Constants, Assumptions, and Available Defaults				
C_C	Annual above and belowground biomass carbon accumulation by IPCC climate zone and land cover type	Table N-1.2	MT carbon per ha per year	see table
C_S	Annual soil carbon accumulation by soil type and land use type	Table N-1.3	MT carbon per ha per year	IPCC 2006
D	Soil carbon gain from conversion from settlements to vegetated land	30	%	CARB 2020
E	Molecular weight ratio of CO_2 to carbon	44/12	MT CO_2 to MT carbon	assumed

Further explanation of key variables:

- (A) – If the existing land use type currently generates CO_2e or includes soil carbon plus above or belowground stored carbon, those emissions should be added or removed, respectively, from the CO_2e reduction quantified under this measure.
- (B_C) – The climate zones are based on classifications from the Intergovernmental Panel on Climate Change (IPCC) (2006, 2019). The zones are defined by annual mean daily temperature, total annual precipitation, total annual potential evapotranspiration, and elevation. Above and belowground biomass carbon accumulation factors (Cc) are available for six land cover types. The land cover types are broad and include one or

more land cover classes from the Commission for Environmental Cooperation's (2020) North American Environmental Atlas.[38] Table N-1.1 in the Appendix, *Emissions Factors and Data Tables,* identifies the 2019 IPCC climate zones and land cover classes within each western state and crosswalks those to the available land cover type by 2006 IPCC climate zone combinations addressed in this measure. See also the IPCC climate zone map, available online from the IPCC at Publications - IPCC-TFI.

Note that the land cover types and classes presented in this Western States Handbook differ from what is provided in the CAPCOA Handbook. This is due to differences in categorization and terminology in the underlying source documentation (IPCC for this Western States Handbook vs. data from the California Air Resources Board [CARB] for the CAPCOA Handbook).

- (B_S) – The soil types are based on classifications from IPCC guidance (2006). Most of the western states are characterized by high active clay soils. Refer to Figure N-1.1 in the Appendix. Soil types for the user's project area can be obtained from the United States Department of Agriculture's Soil Survey Map.
- (C_C) – Average annual above or belowground stored carbon accumulation rates per ha of land cover type by IPCC climate zone are provided in Table N-1.2 in the Appendix. These rates include above and belowground carbon storage in biomass pools. The rates have been annualized over a 20-year period, per IPCC's (2006) GHG inventory framework and research corroborated by Law et al. (2001). Note that the 20-year annualization factor differs from the CAPCOA Handbook, which applied guidance from CARB. The CARB annualization factors are based on the median project duration (time to harvest from planting) for forests and studies conducted for California grasslands and shrublands.

  As noted under variable (Bc), the annual above or belowground stored carbon accumulation rates provided in this Western States Handbook were developed based on data from the IPCC and other sources. This differs from the CAPCOA Handbook, which relies on state-specific land use inventory data from CARB. While the CARB data presented in the CAPCOA Handbook reflect conditions within California, it may be appropriate to generally characterize portions of the western states based on similarities in climate and land cover types. Where project-specific data is not available, users may consult the CAPCOA (2024) Handbook, Table N-1.1 and Figure N-1.1, as an additional resource for carbon accumulation rates.
- (C_S) – Average annual soil carbon accumulation rates per ha of land use type are provided in Table N-1.3 in the Appendix. The rates have been annualized over a 20-year accumulation period, consistent with IPCC's (2006) GHG inventory framework.

GHG Calculation Caps or Maximums

None. If the existing land use cover currently includes stored carbon, and that value exceeds that of the new land cover type, this measure may result in a GHG emissions increase.

[38] An interactive map view of the Altas is available online: http://www.cec.org/files/atlas/?z=3&x=-93.1641&y=61.9803&lang=en&layers=landcover2020ls&opacities=100&labels=true.

Example GHG Reduction Quantification

The user reduces GHG emissions by converting 20 ha of developed area to Broadleaf Forest (B_C) with an Aridisols (B_S) soil type (high active clay). The project is in the "temperate continental" IPCC climate zone where the resulting annual average above and belowground biomass carbon accumulation per ha is 9.3 MT (C_C). The annual average carbon stock per ha is 2.5 MT (C_S). The resulting CO_2e reduction is 734 MT per year.

$$A = \left[\left(20\ \text{ha} \times 9.3\ \frac{\text{MT carbon}}{\text{ha·yr}}\right) + \left(20\ \text{ha} \times 2.5\ \frac{\text{MT carbon}}{\text{ha·yr}} \times 30\%\right)\right] \times \frac{44}{12}\frac{\text{MT } CO_2}{\text{MT carbon}} = 734\ \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

None quantified. Depending on the land cover type created, successful implementation of this measure could achieve improved air quality, improved public health, and improved ecosystem health.

Sources

- CAPCOA (California Air Pollution Control Officers Association). 2024. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Designed for Local Governments, Communities, and Project Developers*. Final Draft. October 2024.
- CARB (California Air Resources Board). 2020. *Benefits Calculator Tool for Agricultural Lands Conservation*. Accessed March 2021. https://ww2.arb.ca.gov/sites/default/files/classic/cc/capandtrade/auctionproceeds/alc_tool_final_2020.xlsx.
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- IPCC (Intergovernmental Panel on Climate Change). 2019. *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Edited by E. C. Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, S. Ngarize, A. Osako, Y. Pyrozhenko, P. Shermanau, and S. Federici. Switzerland: IPCC.
- IPCC. 2006. *IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme. Edited by H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe. Japan: IGES.
- Law, B. E., P. E. Thornton, J. Irvine, P. M. Anthoni, and S. Van Tuyl. 2001. "Carbon Storage and Fluxes in Ponderosa Pine Forests at Different Developmental Stages." *Global Change Biology* 7 (8): 755-777.

N-2. Expand Urban Tree Planting



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from urban tree planting

Co-Benefits (icon key on pg. 31)

Climate Resilience

Planting trees provides more shade, reducing the urban heat island effect and localized health impacts of higher temperatures. Trees can also help improve stormwater management and air quality and support mental health and social resilience.

Health and Equity Considerations

Tree planting should be prioritized in areas that have lower levels of existing canopy. Tree-planting programs should be designed in collaboration with residents. This ensures not only that community preferences are considered, but that the community feels ownership over the trees and is more likely to participate in long-term tree care. Community programs should consider maintenance costs to ensure homeowners and renters are not disproportionately burdened with additional expenses. Trees should be selected according to local preferences, such as avoiding high-pollen trees that may exacerbate allergies.

Measure Description

This measure requires tree planting in urban areas. Planting trees sequesters CO_2 while the trees are actively growing, thereby reducing GHGs. The amount of CO_2 sequestered depends on the type of tree and the duration of the active growing period. Urban trees may also provide shade, which can reduce the urban heat island effect and the cooling demands of buildings. Buildings that use less electricity for air conditioning reduce energy consumption and associated indirect GHG emission.

The selection of tree type is critical to minimize the use of additional water, especially in locations with dry climates. Trees that have high water demands that are met through GHG-intensive water (such as water transported over long distances) can impact the amount of GHG reductions achieved by this measure. Nonetheless, even during times of drought, trees help provide multiple benefits to communities, and state agencies as well as natural resource organizations have emphasized repeatedly the importance of watering and maintaining trees during droughts.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

See measure description.

Cost Considerations

Upfront costs of planting more urban trees will depend on how the land is currently being used and how much maintenance and assistance will be needed to grow the trees. However, urban trees can reduce the incidence and cost of heat exposure and pollution-related illnesses by reducing the urban heat island effect and filtering pollutants from the air and soil.

Expanded Mitigation Options

Best practices for urban tree planting programs include selecting native tree species that require minimal water and maintenance, planting low-biogenic volatile organic compound emitting and low-allergen trees, and appropriately distancing trees from buildings, especially in high fire areas.

GHG Reduction Formula

Users are directed to the U.S. Forest Service (USFS) (2021) i-Tree Planting tool. The i-Tree Planting tool quantifies increased carbon sequestration from urban tree planting using species-based biomass equations that account for user defined site-specific variables and tree growth rates. The tool also quantifies GHG reductions from energy savings (e.g., kWh), if applicable. The i-Tree Planting tool is available at https://planting.itreetools.org/.

Depending on the scale of the project, users may also wish to consult other i-Tree tools, including i-Tree Design (https://design.itreetools.org/), i-Tree Canopy (https://canopy.itreetools.org/), and i-Tree County (https://county.itreetools.org/). Users may consult the Climate Action Reserves' *Urban Tree Planting Project Protocol* (CAR 2014).

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	CO_2 sequestered over project lifetime	[ ]	lb CO_2	calculated
B	CO_2 reduced from building energy savings over project lifetime	[ ]	lb CO_2	calculated
User Inputs				
C	Project state/province	[ ]	address	user input
D	Project county/division	[ ]	text	user input
E	Project city	[ ]	text	user input
F	Project lifetime	1–99	years	user input
G	Tree mortality over project lifetime	0–100	%	user input
H	Tree species planted by the project	[ ]	species name	user input*
I	Diameter breast height of each tree	[ ]	inches	user input*
J	Distance to the nearest building	[ ]	feet	user input*
K	Direction of tree from the building	[ ]	degrees	user input*
L	Building vintage	[ ]	text	user input*
M	Building climate controls	[ ]	text	user input*
N	Tree condition	[ ]	text	user input*
O	Tree exposure to sunlight	[ ]	text	user input*
Constants, Assumptions, and Available Defaults				
Q	Carbon intensity of electricity provider	Tables E-4.5 through E-4.10	lb CO_2e per MWh	See tables
R	Carbon intensity of natural gas	117	lb CO_2e per mmBTU	TCR 2025

* Inputs provided through a drop-down menu.

Further explanation of key variables:

- (A and B) – The GHG reductions are presented over the project lifetime. If users are seeking an annualized value, they will need to divide this result by the assumed project lifetime (F).
- (F) – Trees sequester CO_2 while the trees are actively growing. The i-Tree Planting tool will project the benefits for up to 99 years into the future. The tool defaults to 40 years.
- (G) – The i-Tree Planting tool will incorporate tree mortality into the projected benefits.
- (I) – The diameter of the trunk measured at 4.5 feet above the ground.
- (J) – For trees that will be planted to shade buildings, enter the distance class to the nearest building (0–19 feet, 20–39 feet, 40–59 feet, > 60 feet). Note that this could be a building on an adjacent site. The i-Tree tool will not calculate shade benefits (i.e., energy savings) for trees more than 60 feet away from the building.
- (K) – General direction of the tree from the building (e.g., north 0 degrees). This input can be ignored if the tree is more than 60 feet from the building.
- (L) – The age of the building affects its energy efficiency and therefore the potential benefits the trees can bring. Available inputs are built after 1980, built 1950–1980, and built before 1950. If the specific age of the building is unknown, the user can input the typical age of buildings for the area where the user is working. This input can be ignored if the tree is more than 60 feet from the building.
- (M) – Trees can only have an impact on energy use in buildings where energy is used to heat or cool. Available inputs are heating and air conditioning (A/C), heat only, A/C only, and none. If the climate controls of the building are unknown, the user can input the option that is most common for the area where the user is working. This input can be ignored if the tree is more than 60 feet from the building.
- (N) – The condition of the trees will affect how well they grow and thus future benefits. Available inputs are excellent, good, fair, poor, critical, dying, and dead. New plantings are likely to be excellent.
- (O) – The exposure to sunlight affects both how the trees grow and the degree to which a new tree adds shade to a building. Available inputs are full sun, partial shade, and full shade.
- (Q) – Available GHG intensity factors for electric utility providers are provided in Tables E-4.5 through E-4.9 in the Appendix. Users should consult their local electricity provider for updated emission factors available at the time of their analysis before proceeding with the defaults provided in these tables. If the project study area is not serviced by a listed electricity provider, or emission factors for the local utility are not available, users may elect to use the appropriate grid average carbon intensity presented in Table E-4.10. Grid electricity emission factors are available for two geographies as defined in the U.S. DOE's Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model—the Western Electricity Coordinating Council (WECC) and Southwest Power Pool (SPP). Arizona, Colorado, Oregon, and Washington are wholly within WECC. New Mexico is split between WECC and SPP. Refer to Figure E-4.2 in the Appendix.

  Note that the GHG intensity factor of most electricity providers will decrease in future years as the electricity providers continue to improve their energy mix to meet clean energy mandates and/or company goals. Accordingly, this measure will achieve fewer emission reductions in future years as the utility resource mix becomes cleaner.

Note that the availability of local utility emission factors differs among western states and from what is provided for California utilities in the CAPCOA Handbook. This Western States Handbook also uses the GREET model to provide future grid emission factors in five-year increments, whereas the CAPCOA Handbook forecasts annual emission factors using U.S. EPA's Emissions & Generation Resource Integrated Database.

- (R) – The carbon intensity of natural gas was calculated in terms of CO_2e by multiplying the U.S. natural gas combustion emission factors for CO_2, CH_4, and N_2O (TCR 2025) by the corresponding 100-year GWP values from the IPCC's Fifth Assessment Report (IPCC 2013). See Table E-4.11 in the Appendix for more natural gas emission factors.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces emissions by planting shade trees at a new home site. In this example, the project is in Denver (city and county) (E, D)/Colorado (C). The analysis year is 2026, and the user elects to use the WECC average emission factor from the Appendix (585 lb. CO_2e per MWh) (Q). The project lifetime is 40 years (F) and the expected tree mortality is 10 percent (G). The project will plant two live oaks (H) with a diameter breast height of 4 inches (I). The trees are 0 to 19 feet from the nearest building (J) and oriented east 90 degrees (K). The building was built between 1950 and 1980 (L) and includes heat and A/C (M). The tree condition is excellent (N) and has full sunlight (O). Based on these inputs to the i-Tree Planting tool, over the project lifetime, the trees would sequester 2,220 lb. of CO_2 and reduce 331 lb. of CO_2 from building energy savings. This totals 2,551 pounds of CO_2, or 64 pounds CO_2 per year (based on a 40-year project lifetime).

Quantified Co-Benefits

The i-Tree tool outputs electricity savings (kWh), fuel savings (mmBTU), avoided runoff (gallons), and criteria pollutant emissions reductions (pounds). All values are over the project lifetime. Note that depending on user inputs, the measure may result in increased fuel consumption (mmBTU) from building shading in the winter.

Sources

- Climate Action Reserve. 2014. *Urban Tree Planting Project Protocol*. Version 2.0, June 2014. https://www.climateactionreserve.org/wp-content/uploads/2014/07/Urban_Tree_Planting_Project_Protocol_V2.0.pdf.
- IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/.
- TCR (The Climate Registry). 2025. 2025 Default Emission Factor Document. February 2025. https://theclimateregistry.org/wp-content/uploads/2025/03/2025-Default-Emission-Factors-Update-3.pdf.
- USFS (U.S. Forest Service). 2021. i-Tree Planting Calculator. Accessed January 2025. https://planting.itreetools.org/.

N-3. Implement Management Practices to Improve the Health and Function of Natural and Working Lands



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from natural and working lands

Co-Benefits (icon key on pg. 31)

Climate Resilience

Improving the health and function of natural and working lands can reduce the urban heat island effect and flooding and improve water quality, as well as provide recreational spaces that improve health and community resilience. Improving natural and working lands can also provide habitat in which wildlife can live and through which it can migrate in the face of increasing temperatures and changing precipitation patterns.

Health and Equity Considerations

Some management practices can reduce the use of pesticides and herbicides, which can reduce exposure to farmworkers and their families.

Measure Description

This measure covers a broad range of management strategies aimed at improving the overall health and functionality of natural and working lands as a mechanism for increasing carbon sequestration and reducing GHG emissions. Management practices may include those that change ecosystem carbon exchange rates (e.g., cultivated land soil conservation, use of biochar) and those that involve land cover changes.

Scale of Application

Plan/Community

Implementation Requirements

Note that this measure is only applicable to users with land management authority.

Cost Considerations

Overall, improved land management reduces net expenses drastically. Practices designed for maximum land health reduce costs related to inputs, irrigation, and damage from extreme weather, and preserve ecosystems and animal life.

Expanded Mitigation Options

See the *GHG Reduction Formula* section below for online tools to quantify GHG reductions from various conservation practices and management strategies. For agricultural applications, consider developing a Carbon Farm Plan to comprehensively evaluate all elements of your land management strategy.

GHG Reduction Formula

Users are directed to the U.S. Department of Agriculture (USDA) (2024) COMET-Planner[39] and USFS (2021) Forest Vegetation Simulator (FVS). COMET-Planner estimates GHG reductions from agricultural conservation practices identified by the Natural Resources Conservation Service as having GHG and/or carbon sequestration benefits on farms and ranches. COMET-Planner should be used to quantify GHG reductions from cropland management, conservation practices on grazing lands, cropland to herbaceous cover, restoration of disturbed lands, and woody plantings. The FVS should be used to quantify GHG reductions from forest management.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces emissions by implementing grazing management to improve irrigated pasture conditions. The user consults COMET-Planner to quantify the estimated reductions. The project is in Grant County in Washington State. The user selects "Grazing Lands" for the class of conservation practice, "Prescribed Grazing" for the conservation practice standard, and "Grazing Management to Improve Irrigated Pasture Condition" for the conservation practice implementation. The practice would be applied to 25 acres. Based on these inputs, the user will reduce GHG emissions by 1 MT CO_2e per year (USDA 2024).

Quantified Co-Benefits

None quantified. Depending on the management strategy, successful implementation of this measure could achieve improved air quality, water conservation, improved public health, and improved ecosystem health.

Sources

- USDA (U.S. Department of Agriculture). 2024. "COMET-Planner." Accessed December 2024. http://comet-planner.com/.
- USFS (U.S. Forest Service). 2021. "Forest Vegetation Simulator." Accessed March 2021. https://www.fs.usda.gov/managing-land/forest-management/fvs.

[39] Note that the CAPCOA Handbook refers users to the COMET-Planner for the CDFA Healthy Soils Program. This version of the tool was developed by the California Department of Food and Agriculture and CARB for use in California.

N-4. Require Best Management Practices for Manure Management



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from manure management practices

Co-Benefits (icon key on pg. 31)

Climate Resilience

Improving manure management can improve water and air quality, thereby improving community health and resilience. Depending on the alternative management practice, it can also increase the amount of compost produced, which can go toward gardens and farms and help improve soil health as well as food and crop production.

Health and Equity Considerations

Fertilizer and manure are major causes of groundwater contamination. Improved manure management can help improve water quality for rural and vulnerable communities.

Measure Description

This measure will require best management practices for the management of manure from livestock. Well-managed pasture systems and aerobic dry composting systems tend to have lower emissions, while anaerobic wet handling systems generate more CH_4. This measure is thus intended for manure collection systems that are currently managed by anaerobic decomposition of manure volatile solids stored in a lagoon or other predominantly liquid anaerobic environment. Using alternative practices to manage manure results in reduced agriculture emissions from livestock by decreasing the amount of volatile manure solids that are stored in wet, anaerobic conditions.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Emission reductions can only be quantified for projects with existing manure management practices that include the anaerobic decomposition of manure volatile solids stored in a lagoon or other predominantly liquid anaerobic environment.

Cost Considerations

Incorporating best practices for manure management may entail initial costs to build the related storage and processing ability. Cost savings come in the form of reduced need for inputs like fertilizer if the manure is used on site and avoided water pollution and greenhouse gas emissions.

Expanded Mitigation Options

See the *GHG Reduction Formula* section below for tools to quantify GHG reductions from various alternative manure management practices.

GHG Reduction Formula

Users are directed to the USDA's (2024) COMET-Farm. COMET-Farm is a decision-support tool that can be used to quantify GHG emissions from major on-farm sources. Specific to animal agriculture, COMET-Farm estimates GHG emissions from enteric fermentation, housing, and manure management for dairy cattle, beef cattle, sheep, swine, and other animals. Manure management pathways include solid manure storage (stacked), composting, aerobic lagoons, anaerobic lagoons, and anaerobic digesters. COMET-Farm requires users to input baseline information about their farm and then create a scenario that includes implementation of their management practice. The tool quantifies GHG emissions under the baseline condition and managed scenario and calculates the change in emissions.

GHG Calculation Caps or Maximums

None. Depending on baseline conditions and the selected management strategy, this measure may result in an emissions increase. Values are reported in COMET-Farm as either positive or negative values. A positive change value indicates that the managed scenario increases emissions from baseline. A negative change value indicates that the managed scenario reduces emissions from baseline. (USDA 2024.)

Example GHG Reduction Quantification

The example GHG reduction quantification is adapted from USDA's (2024) "Animal Ag Dairy Demo" for COMET-Farm. The user's livestock operation in Morrow County, Oregon, currently milks 180 cows with a total population of over 350 animals, including heifer and calves. Under baseline conditions, 90 percent of the manure is flushed with fresh or recycled water to a single-cell lagoon. The remaining 10 percent is deposited in the corrals and collected seasonally. Solids are separated prior to lagoon storage. The managed scenario includes installation of a methane recovery system, which includes a covered lagoon with attached gas collection system. Based on these inputs, the user will reduce GHG emissions by 1,587 MT CO_2e.

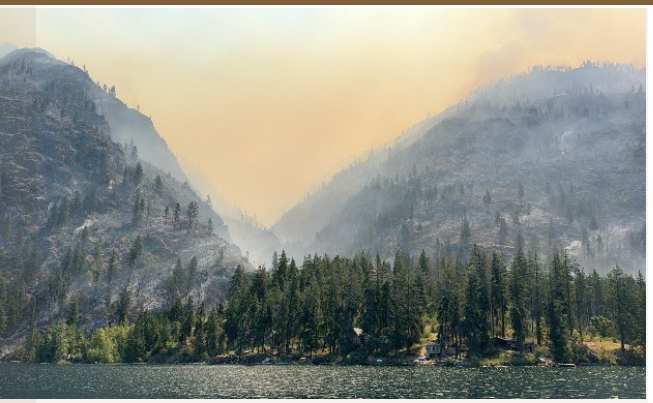
Quantified Co-Benefits

None quantified. Successful implementation of this measure could achieve improved air quality, improved public health, energy and fuel savings, and improved ecosystem health.

Source

- USDA (U.S. Department of Agriculture). 2024. "COMET-Farm." Accessed December 2024. https://comet-farm.com/home.

N-7. Wildfire Resilience and Management



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from natural and working lands

Co-Benefits (icon key on pg. 31)

Climate Resilience

Wildfire resilience and management techniques can reduce wildfire risk, enhance post-wildfire recovery, and improve air quality. This measure could also improve the health and function of natural lands, reduce the urban heat island effect and risk of post-fire flooding, improve water quality, and provide recreational spaces that improve health and community resilience. Increasing wildfire resilience and management can also protect wildlife habitat and migration corridors in the face of increasing temperatures and changing precipitation patterns.

Health and Equity Considerations

Programs to reduce wildfire smoke exposure should consider and address any impacts on vulnerable populations, including outdoor workers and the unhoused, who are disproportionately exposed to wildfire smoke.

Expanding Indigenous cultural burns across forested lands could promote sustainable forest growth and make forests more resilient.

Measure Description

This measure involves implementing fuel treatments in forested and other vegetated areas to minimize the likelihood of severe or catastrophic wildfire behavior, thereby minimizing pyrogenic carbon emissions during a wildfire event. The vast majority of carbon emissions from wildfire events originate from live tree biomass that primarily exists in the overstory canopy. Implementing fuel treatments has the short-term effect of releasing more carbon emissions as understory, ladder fuels, and forest fuel loads are burned. However, in the long term, treated stands produce fewer emissions compared to untreated stands because treated stands produce low to moderate fire severity that does not disturb the carbon stock in the overstory canopy. Untreated stands are far more likely to experience severe behavior that ignites the canopy and releases the stored carbon in the overstory.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

See measure description.

Cost Considerations

The costs of implementing fuel treatment applications in forested woodlands varies widely based on the size and accessibility of the treatment area, the amount and type of surface fuels, the specific treatment method(s) employed, and underlying topographic characteristics. While costs associated with fuel treatment implementation can be significant, particularly for large scale projects, they may be offset by a variety of grant funding available at the federal and state levels for managing surface fuels to minimize wildfire hazards.

Expanded Mitigation Options

This measure can be paired with Measure N-3, *Implement Management Practices to Improve the Health and Function of Natural and Working Lands,* to comprehensively improve the health of natural and working lands. In some cases, this measure could be paired with Measure E-26, *Biomass Energy,* because some types of fuel removed from the understory during measure implementation could provide biomass energy fuel, if facilities are in close proximity.

GHG Reduction Formula

Although this measure is quantifiable, the methods to quantify the measure are complex and require a substantial amount of computation that cannot reasonably be completed manually. For these reasons, no GHG reduction methods are included here, however, users are encouraged to review other tools that may provide an alternative quantification methodology for aspects of this measure. For example, the First Order Fire Effects Model (FOFEM) is a downloadable software tool developed by the U.S. Forest Service that can be used to quantify wildfire-related emissions from uncontrolled and prescribed burn scenarios (U.S. Department of Agriculture 2025). The FOFEM requires several user-specified inputs, and thus it is recommended that users carefully review the model user's guide before proceeding. Certain model inputs, such as the type of vegetation, may be informed by other tools, such as the LANDFIRE database (U.S. Department of Agriculture and U.S. Department of the Interior).

Currently, no tools are available that are applicable to the Western States that quantify the emissions benefits associated with non-fire forest management activities, such as clearcutting or forest thinning.

Quantified Co-Benefits

None quantified. Successful implementation of this measure could achieve improved air quality, improved public health, and improved ecosystem health.

Sources

- Fargione, J. E., S. Bassett, T. Boucher, S. D. Bridgham, R. T. Conant, S. C. Cook-Patton, et al. 2018. "Natural Climate Solutions for the United States." *Science Advances* 4, no. 11. https://www.science.org/doi/10.1126/sciadv.aat1869.
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N-8. Agricultural Equipment Efficiency



GHG Mitigation Potential



Potentially large reduction in GHG emissions from agricultural equipment

Co-Benefits (icon key on pg. 31)



Climate Resilience

Improving agricultural equipment efficiency through use of electric- or hybrid-powered equipment can reduce sensitivity to fuel price shocks or scarcity in conventional fuels. However, using all-electric equipment may decrease resilience if it is the only option available during a power outage. Pairing all-electric equipment with locally generated renewable energy such as solar or wind and storage can increase resilience to power outages and may decrease lifetime costs in electricity.

Health and Equity Considerations

Replacing diesel and gas-powered equipment with electric equipment reduces the risk of pollutant-related health conditions and effects related to noise pollution for the user and surrounding communities.

Measure Description

This measure requires use of electric- or hybrid-powered, off-road agricultural equipment over conventional diesel-fueled counterparts during agricultural activities. Replacing diesel-powered, off-road agricultural equipment with equipment that includes electric or hybrid engines reduces fossil fuel combustion and thus GHG emissions. However, all-electric equipment results in GHG emissions from the electricity used to charge the equipment. The indirect GHG emissions increase from electricity must be calculated in addition to the GHG emissions reduction from displaced fossil fuel combustion to estimate the total net GHG emissions reduction achieved by this measure if using all electric-powered equipment. Variations of this measure are described in Measure C-1-A, *Use Electric or Hybrid Powered Equipment*, Measure M-6, *Off-Road Equipment Efficiency*, and Measure C-1-B, *Use Cleaner-Fuel Equipment*.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Note that while this measure discusses off-road equipment used for agricultural purposes, this measure can also be implemented for other off-road equipment applications (e.g., construction, general purposes).

Cost Considerations

Electric- or hybrid-powered equipment tends to be more expensive to purchase and install than conventional models powered by fossil fuels. These costs may be offset by savings in fuel use and maintenance.

Expanded Mitigation Options

Pair with Measure E-10, *Procure Electricity from Lower Carbon Intensity Power Supply*, to ensure that the energy supplied to power the electrified equipment has a lower carbon intensity than the local grid, thereby further reducing GHG emissions. Consider using portable batteries to support and extend implementation of this measure at more remote sites.

GHG Reduction Formula

The formula has been revised from the CAPCOA Handbook to differentiate GHG reductions achieved based on only tailpipe emissions (i.e., tank-to-wheels emissions) from those achieved from total emissions, including upstream fuel emissions (i.e., well-to-wheel emissions). Considering tank-to-wheels, all-electric equipment results in no emissions. Considering well-to-wheels, upstream GHG emissions from the electricity used to charge the equipment and to create liquid fuels must be included to estimate the total net GHG emissions reduction achieved by this measure.

$$A1 = -(C \times D \times E1 \times F) \text{ (tank-to-wheels for electric equipment)}$$

$$A2 = -(C \times D \times E2 \times F) + \left(C \times \frac{D}{G} \times H \times E3 \times I\right) \text{ (well-to-wheels for electric equipment)}$$

$$A3 = -(C \times D \times E1 \times J \times F) \text{ (tank-to-wheels for hybrid equipment)}$$

$$A4 = -(C \times D \times E2 \times J \times F) \text{ (well-to-wheels for hybrid equipment)}$$

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A1	GHG reduction from using electric equipment (tank-to-wheels)	[ ]	MT CO_2e	calculated
A2	GHG reduction from using electric equipment (well-to-wheels)	[ ]	MT CO_2e	calculated
A3	GHG reduction from using hybrid equipment (tank-to-wheels)	[ ]	MT CO_2e	calculated
A4	GHG reduction from using hybrid equipment (well-to-wheels)	[ ]	MT CO_2e	calculated
User Inputs				
B	Fuel type of existing equipment	[ ]	text	user input
C	Hours of equipment operation	[ ]	hours	user input
D	In-use horsepower of equipment[40]	[ ]	hp	User input
Constants, Assumptions, and Available Defaults				
E1	Carbon intensity of fossil-fueled equipment (tank-to-wheels)	Table C-1-A.1 or U.S. EPA 2024	kg CO_2e per hp-hour	API 2021; U.S. DOE 2024; U.S. EPA 2018
E2	Carbon intensity of fossil-fueled equipment (well-to-wheels)	Table C-1-A.1	kg CO_2e per hp-hour	API 2021; U.S. DOE 2024; U.S. EPA 2018

[40] Note that in-use horsepower includes the load factor. This is distinct from the rated power of the equipment.

E3	Lifecycle carbon intensity electricity	Table E-26.3	lb CO_2e per MWh	U.S. DOE 2024
F	Conversion from kg to MT	0.001	MT per kg	conversion
G	Energy economy ratio	3.8	unitless	CARB 2020
H	Conversion from horsepower to MW	0.0007457	MW per hp	conversion
I	Conversion from lb to MT	0.000454	MT per lb	conversion
J	Percent fuel reduction of hybrid equipment compared to conventional equipment	10	%	Holian and Pyeon 2017

Further explanation of key variables:

- (B) – The fuel type of the existing equipment is used to obtain the carbon intensity of the equipment (E1 or E2).
- (C) – This input represents the hours of operation that the equipment will be used over a user-specified time period.
- (D) – The in-use horsepower of the electric agricultural equipment that is electric will need to be provided by the user. The in-use hp values are inclusive of equipment load. Therefore, the GHG reduction equation does not include a multiplier for load factor.
- (E1) – Tank-to-wheels GHG intensity factors for gasoline and diesel-powered agricultural equipment were derived from Association of Petroleum Institute's (API) (2021) *Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry* and the U.S. DOE's (2024) GREET model. The factors were related to equipment horsepower using the brake specific fuel consumption rates from the U.S. EPA (2018). Table C-1-A.1 in Appendix A presents the resulting tank-to-wheel GHG emission factors for gasoline and diesel agricultural equipment less than 100 horsepower and greater than 100 horsepower. Alternatively, users may obtain tank-to-wheel GHG emission factors from the U.S. EPA's (2024) Motor Vehicle Emission Simulator (MOVES).

  The CAPCOA Handbook recommends users obtain emission factors from CARB's OFFROAD model. This model reflects activity and data specific to the California fleet and is thus not applicable outside of the state. Accordingly, this Western States Handbook recommends users apply the factors from Table C-1-A.1 or run MOVES. MOVES is maintained by the U.S. EPA and can generate emissions rates at the county-level across the nation.
- (E2) – Well-to-wheels GHG emission factors were developed using the methodology discussed above for (E1) and are presented in Table C-1-A.1. Note that MOVES cannot be used to develop alternative well-to-tank GHG emission factors.
- (E3) – Well-to-wheels GHG emission factors for WECC and SPP are provided in five-year increments between 2025 and 2050 in Table E-26.3. Refer to Measure E-26, *Biomass Energy*, for additional information.
- (G) – An Energy Economy Ratio (EER) compares the efficiency of different fuels and vehicle technologies. The EER for electric forklifts as a diesel replacement is 3.8 (CARB

2020). If the user can provide an equipment-specific EER, they should replace the default in the GHG calculation formula.

- (J) – The percent fuel reduction is used in this formula as a proxy for the percent activity reduction that would be expected with hybrid, off-road, heavy-duty equipment. Based on a survey of 12 models of off-road, heavy-duty equipment from 10 different manufacturers, hybrid off-road equipment reduced fuel use by 10 to 45 percent, with an average of 28 percent (Holian and Pyeon 2017). To be conservative, the low end of the range is cited. If the user can provide an equipment-specific hp, the user should replace the default in the GHG calculation formula. If the user knows the make and model of the agricultural equipment, the user should replace the default in the GHG calculation formula.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces agricultural equipment emissions by replacing fossil-fuel combustion with electricity consumption, which generates fewer GHG emissions per unit of activity. In this example of a tank-to-wheels calculation, an agricultural farm is replacing a 70-hp diesel tractor (D) that is used 8 hours per day (C) with an electric-powered equivalent. A 100-hp diesel tractor has an approximate carbon intensity of 0.71 kg CO_2e per hp-hour (E1).

$$A1 = -\left(8\ \frac{\text{hours}}{\text{day}} \times 70\ \text{hp} \times 0.71\ \frac{\text{kg } CO_2e}{\text{hp-hour}} \times 1e^{-3}\ \frac{\text{MT}}{\text{kg}}\right) = -0.4\ \frac{\text{MT } CO_2e}{\text{day}}$$

In this example, of a well-to-wheels calculation, the lifecycle emissions reduction is assessed for the same 70-hp diesel tractor. The project area is in the Western Electricity Coordinating Council, and the corresponding lifecycle carbon intensity for electricity used to power the equipment is 297 lb. CO_2e per MWh for an analysis year of 2035 (E3). The well-to-wheels carbon intensity of the tractor is 0.85 kg CO_2e per hp-hour (E2).

$$A2 = -\left(8\ \frac{\text{hours}}{\text{day}} \times 70\ \text{hp} \times 0.85 \frac{\text{kg } CO_2e}{\text{hp-hour}} \times\ \times 0.001 \frac{\text{MT}}{\text{kg}}\right) + \left(8\ \frac{\text{hours}}{\text{day}} \times \frac{70\ \text{hp}}{3.8} \times 0.0007457 \frac{\text{MWh}}{\text{hp}} \times 297\ \frac{\text{lb. } CO_2e}{\text{MWh}} \times 0.000454\ \frac{\text{MT}}{\text{lb.}}\right) = -0.5 \frac{\text{MT } CO_2e}{\text{day}}$$

Quantified Co-Benefits

Improved Air Quality

(Tank-to-wheels) Reducing fossil-fuel combustion will also reduce local criteria pollutants. Tank-to-wheels emission savings can be calculated using the same formula used to quantify GHG reductions (A1 and A3). Criteria pollutant intensity factors for various off-road equipment can be obtained from the U.S. EPA's (2024) MOVES.

(Well-to-wheels) The fuels produced by facilities within and outside of state will generate criteria pollutants. Because these facilities are dispersed, offsite of the project/site or plan/community, fuel production (including electricity) typically will not generate localized criteria pollutant emissions. Therefore, only the tank-to-wheels (i.e., tailpipe) portion of the vehicle criteria pollutant emissions should be quantified.

Energy and Fuel Savings

(Tank-to-wheels) Fossil fuel savings are a product of the equipment fuel efficiency (gallons consumed per hour) and the equipment operating time (hours). Fuel intensity factors for various off-road equipment can be obtained from the U.S. EPA's (2024) MOVES. Users should multiply the fuel intensity by the equipment operating hours to quantify fuel savings.

(Well-to-wheels) Fuel savings would be achieved from tank-to-wheels reductions. Additional fuel savings may occur upstream from reduced production and transport, although these likely cannot be attributed to a single project. Increased electricity consumption for electric equipment is calculated as part of the GHG reduction formula (A2). The abbreviated formula is also shown below.

$$MWh = C \times \frac{D}{K} \times H$$

Sources

- API (Association of Petroleum Institute). 2021. *Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry*. Released November 2021. Accessed June 2025. https://www.api.org/~/media/files/policy/esg/ghg/2021-api-ghg-compendium-110921.pdf.
- Holian, M., and J. Pyeon. 2017. *Analyzing the Potential of Hybrid and Electric Off-Road Equipment in Reducing Carbon Emissions from Construction Industries*. Mineta Transportation Institute. September 2017. https://transweb.sjsu.edu/research/Analyzing-Potential-Hybrid-and-Electric-Road-Equipment-Reducing-Carbon-Emissions-Construction-Industries.
- U.S. DOE (U.S. Department of Energy). 2024. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model*. 2024 Release. Accessed January 28, 2025. https://greet.anl.gov/.

- U.S. EPA (U.S. Environmental Protection Agency). 2018. "Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES2014b." Released July 2018. Accessed June 2025. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100UXEN.pdf.
- U.S. EPA. 2024. "Latest Version of Motor Vehicle Emissions Simulator (MOVES)." Released November 2024. Accessed December 2024. https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#guidance.

Construction

Equipment and vehicles are the primary sources of downstream GHG emissions in the construction sector. Construction equipment typically operates on construction sites and includes off-road sources like cranes, bulldozers, forklifts, and tractors. Vehicles are used for personnel, material, and equipment transport, as well as onsite material supply movement. Construction equipment and vehicles traditionally use diesel or gasoline fuel and release emissions based on the amount of fuel combusted and the emission certification level of the engine.



Equipment and vehicle emissions can be reduced by using engines that emit fewer pollutants for the same amount of work. This is typically equipment and vehicles powered by electricity or cleaner fuels (e.g., compressed natural gas, renewable diesel). The exclusive use of grid electricity by electric equipment and vehicles eliminates the diesel emissions at the site but increases indirect electricity emissions. However, grid-based emissions are typically less than the emissions from the diesel-fueled equipment (depending on the source of grid power). Hybrid-powered equipment and vehicles would decrease but not eliminate fuel use. Traditional hybrid engines use only combustion fuels. That is, the electricity for hybrid engines is self-generated, so there is no increase in grid-based electrical generation to power the equipment but also limited reduction in fuel-based emissions. On the other hand, if the equipment has plug-in capability, it may draw power from the grid instead of from fuel combustion for a portion of its power. This increases (remote) emissions from the grid and reduces (local) emissions from fuel combustion. However, due to the increased efficiency of electric motors, the increase in grid emissions is typically much smaller than the decrease in local emissions. Likewise, depending on the fuel type, cleaner-fuel equipment and vehicles would decrease but not eliminate combustion emissions.

Construction

- C-1-A. Use Electric or Hybrid Powered Equipment
- C-1-B. Use Cleaner-Fuel Equipment
- C-2. Limit Heavy-Duty Diesel Vehicle Idling
- C-3. Use Local Construction Contractors

Emissions reductions achieved by electric-powered and cleaner-fuel equipment and vehicles are determined by finding the difference in emissions between those generated by the replacement power source and those generated on-site by conventional fossil-fueled engines. In the tank-to-wheels (TTW) case, emissions for the mitigated scenario would consist of direct emissions from combustion fuel use. In the case where well-to-wheel emissions are contemplated, emissions would also include emissions associated with the production of fuels. That is, changes in emissions from electricity generation on the grid and producing liquid fuels consumed by the equipment. Resources and methods to quantify emissions reductions from measures that target cleaner-fuel equipment

are described in this section. Measures that reduce vehicle fuel consumption through idling restrictions and local contractor provisions are also discussed. Use the graphic above to click on an individual measure to navigate directly to the measure's factsheet.

Note that the measures in this chapter address emissions from equipment and vehicle fuel combustion during construction. Additional GHG emissions are generated over the full lifecycle of building materials, starting "upstream" of construction with raw material extraction, transportation, and manufacturing. These upstream emissions can be substantial. For example, the Oregon Department of Environmental Quality (DEQ) estimates that material production accounts for approximately 91 percent of total GHG emissions associated with residential building materials on a lifecycle basis.[41] Thus, while it is important to reduce construction equipment and vehicle fuel combustion emissions through implementation of the measures identified in this chapter, users should also consider policies and programs aimed at reducing the embodied (or lifecycle) carbon of building materials. These are not quantified here, but the following resources are provided for additional information and potential strategies for reducing GHG emissions from building materials:

- U.S. EPA's Sustainable Marketplace, "Reducing Embodied Carbon of Construction Materials": https://www.epa.gov/greenerproducts/reducing-embodied-carbon.
- Oregon DEQ's report, *Opportunities to Reduce Greenhouse Gas Emissions Caused by Oregon's Consumption*: https://www.oregon.gov/deq/mm/Documents/HB3409Sec52CBEReport.pdf.
- The Federal Highway Administration's Infrastructure Carbon Estimator (ICE) version 2.2.8, a planning and pre-engineering analysis tool that provides lifecycle estimates of energy and GHG emissions from the construction and maintenance of transportation infrastructure: https://www.dot.state.mn.us/sustainability/ghg-analysis.html.

[41] Oregon Department of Environmental Quality. 2023. *The Impact of Housing Materials: Reducing Impacts While Meeting Housing Production Goals*. July 2023. Accessed May 16, 2025. https://www.oregon.gov/deq/mm/Documents/housingbriefs.pdf.

C-1-A. Use Electric or Hybrid Powered Equipment



GHG Mitigation Potential



Potentially large reduction in GHG emissions from construction equipment

Co-Benefits (icon key on pg. 31)



Climate Resilience

Using electric- or hybrid-powered equipment can reduce sensitivity to fuel price shocks or scarcity. However, using all-electric equipment may decrease resilience if they are the only option available during a power outage. Battery electric equipment may reduce fire risk (from equipment sparks), particularly in areas that are becoming increasingly dry due to climate change.

Health and Equity Considerations

This measure will reduce air pollution for surrounding communities as well as work related health risks.

Measure Description

This measure requires the use of electric- or hybrid-powered construction equipment over conventional diesel-fueled counterparts. Replacing diesel-powered equipment with electric or hybrid-electric equipment reduces fossil fuel combustion and thus GHG emissions. A variation of this measure is described in Measure C-1-B, *Use Cleaner-Fuel Equipment*. Additionally, similar measures are included in this Western States Handbook for other types of equipment, such as agricultural equipment (see Measure N-8), landscaping (see Measure LL-1), and general off-road equipment (see Measure M-6).

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Note that while this measure discusses off-road equipment used for construction, this measure can also be implemented for other off-road equipment applications (e.g., agriculture, industrial).

Cost Considerations

Electric- or hybrid-powered equipment tends to be more expensive to purchase and install than conventional models powered by fossil fuels. These costs may be offset by savings in fuel use and maintenance.

Expanded Mitigation Options

Pair with Measure E-10, *Procure Electricity from Lower Carbon Intensity Power Supply*, to ensure that the energy supplied to power the electrified equipment has a lower carbon intensity than the local grid, thereby further reducing GHG emissions. Consider using portable batteries to support and extend implementation of this measure at more remote sites.

GHG Reduction Formula

The formulas have been revised from the CAPCOA Handbook to differentiate GHG reductions achieved based on only tailpipe emissions (i.e., tank-to-wheels emissions) from those achieved from total emissions, including upstream fuel emissions (i.e., well-to-wheel emissions). Considering tank-to-wheels, all-electric equipment results in no emissions. Considering well-to-wheels, upstream GHG emissions from the electricity used to charge the equipment and to create liquid fuels must be included to estimate the total net GHG emissions reduction achieved by this measure.

$$A1 = -(C \times D \times E1 \times F) \text{ (tank-to-wheels for electric equipment)}$$

$$A2 = -(C \times D \times E2 \times F) + \left(C \times \frac{D}{G} \times H \times E3 \times I\right) \text{ (well-to-wheels for electric equipment)}$$

$$A3 = -(C \times D \times E1 \times J \times F) \text{ (tank-to-wheels for hybrid equipment)}$$

$$A4 = -(C \times D \times E2 \times J \times F) \text{ (well-to-wheels for hybrid equipment)}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A1	GHG reduction from using electric equipment (tank-to-wheels)	[ ]	MT CO_2e	calculated
A2	GHG reduction from using electric equipment (well-to-wheels)	[ ]	MT CO_2e	calculated
A3	GHG reduction from using hybrid equipment (tank-to-wheels)	[ ]	MT CO_2e	calculated
A4	GHG reduction from using hybrid equipment (well-to-wheels)	[ ]	MT CO_2e	calculated
User Inputs				
B	Fuel type of existing equipment	[ ]	text	user input
C	Hours of equipment operation	[ ]	hours	user input
Constants, Assumptions, and Available Defaults				
D	In-use horsepower of equipment[42]	Table C-1-B.1	hp	U.S. EPA 2024
E1	Carbon intensity of fossil-fueled equipment (tank-to-wheels)	Table C-1-A.1 or U.S. EPA 2024	kg CO_2e per hp-hour	API 2021; U.S. DOE 2024; U.S. EPA 2018
E2	Carbon intensity of fossil-fueled equipment (well-to-wheels)	Table C-1-A.1	kg CO_2e per hp-hour	API 2021; U.S. DOE 2024; U.S. EPA 2018

[42] Note that in-use horsepower includes the load factor. This is distinct from the rated power of the equipment.

ID	Variable	Value	Unit	Source
E3	Lifecycle carbon intensity electricity	Table E-26.3	lb CO_2e per MWh	U.S. DOE 2024
F	Conversion from kg to MT	0.001	MT per kg	conversion
G	Energy economy ratio	3.8	unitless	CARB 2020
H	Conversion from horsepower to MW	0.0007457	MW per hp	conversion
I	Conversion from lb to MT	0.000454	MT per lb	conversion
J	Percent fuel reduction of hybrid equipment compared to conventional equipment	10	%	Holian and Pyeon 2017

Further explanation of key variables:

- (B) – The fuel type of the existing equipment is used to obtain the carbon intensity of the equipment (E1 or E2).
- (C) – This input represents the hours of operation that the equipment will be used over a user-specified time period.
- (D) – Average in-use hp of various construction equipment are provided in Table C-1-B.1 in the Appendix, *Emission Factors and Data Tables* (U.S. EPA 2024). The in-use hp values are inclusive of equipment load. Therefore, the GHG reduction equation does not include a multiplier for load factor. Note that the types of equipment presented in Table C-1.B.1 differ from what is presented in the CAPCOA Handbook. This is due to differences in categorization and terminology in the underlying source model (MOVES for this Western States Handbook vs. OFFROAD for the CAPCOA Handbook). If the user can provide an equipment-specific in-use hp, they should replace the default in the GHG calculation formula.
- (E1) – Tank-to-wheels GHG intensity factors for gasoline and diesel-powered construction equipment were derived from the Association of Petroleum Institute's (API) (2021) *Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry* and the U.S. DOE's (2024) GREET model. The factors were related to equipment horsepower using the brake specific fuel consumption rates from the U.S. EPA (2018). Table C-1-A.1 in Appendix A presents the resulting tank-to-wheel GHG emission factors for gasoline and diesel construction equipment less than 100 horsepower and greater than 100 horsepower. Alternatively, users may obtain tank-to-wheel GHG emission factors from the U.S. EPA's (2024) Motor Vehicle Emission Simulator (MOVES).

  The CAPCOA Handbook recommends users obtain emission factors from CARB's OFFROAD model. This model reflects activity and data specific to the California fleet and is thus not applicable outside of the state. Accordingly, this Western States Handbook recommends users apply the factors from Table C-1-A.1 or run MOVES. MOVES is maintained by the U.S. EPA and can generate emissions rates at the county-level across the nation.
- (E2) – Well-to-wheels GHG emission factors were developed using the methodology discussed above for (E1) and are presented in Table C-1-A.1. Note that MOVES cannot be used to develop alternative well-to-tank GHG emission factors.

- (E3) – Well-to-wheels GHG emission factors for WECC and SPP are provided in five-year increments between 2025 and 2050 in Table E-26.3. Refer to Measure E-26, *Biomass Energy*, for additional information.
- (G) – An Energy Economy Ratio (EER) compares the efficiency of different fuels and vehicle technologies. The EER for electric forklifts as a diesel replacement is 3.8 (CARB 2020). If the user can provide an equipment-specific EER, they should replace the default in the GHG calculation formula.
- (J) – The percent fuel reduction is used in this formula as a proxy for the percent activity reduction that would be expected with hybrid construction equipment. Based on a survey of 12 models of heavy construction equipment from 10 different manufacturers, hybrid construction equipment reduced fuel use by 10 to 45 percent, with an average of 28 percent (Holian and Pyeon 2017). To be conservative, the low end of the range is cited. If the user can provide an equipment-specific hp, the user should replace the default in the GHG calculation formula. If the user knows the make and model of the construction equipment used, the user should replace the default in the GHG calculation formula.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces construction equipment emissions by replacing fossil fuel combustion with electricity consumption, which generates fewer GHG emissions per unit of activity. In this example of a tank-to-wheels calculation, a diesel excavator with an in-use horsepower of 103 (D) that is used 8 hours per day (C) is replaced by an electric-powered equivalent. A 103-hp excavator has a tank-to-wheels carbon intensity of 63 kg CO_2e per hp-hour (E1).

$$A1 = -\left(8\ \frac{\text{hours}}{\text{day}} \times 103\ \text{hp} \times 63\ \frac{\text{kg } CO_2e}{\text{hp-hour}} \times 1e^{-3}\ \frac{\text{MT}}{\text{kg}}\right) = -0.5\ \frac{\text{MT } CO_2e}{\text{day}}$$

In this example, of a well-to-wheels calculation, the lifecycle emissions reduction is assessed for the same 103-hp diesel excavator. The project area is in the Western Electricity Coordinating Council, and the corresponding lifecycle carbon intensity for electricity used to power the equipment is 356 lb. CO_2e per MWh for an analysis year of 2030 (E3). The well-to-wheels carbon intensity of the excavator is 0.76 kg CO_2e per hp-hour (E2).

$$A2 = -\left(8\ \frac{\text{hours}}{\text{day}} \times 103\ \text{hp} \times 0.76\ \frac{\text{kg } CO_2e}{\text{hp-hour}} \times\ \times 0.001\ \frac{\text{MT}}{\text{kg}}\right) + \left(8\ \frac{\text{hours}}{\text{day}} \times \frac{103\ \text{hp}}{3.8} \times 0.0007457\ \frac{\text{MWh}}{\text{hp}} \times 356\ \frac{\text{lb. } CO_2e}{\text{MWh}} \times 0.000454\ \frac{\text{MT}}{\text{lb.}}\right) = -0.6\ \frac{\text{MT } CO_2e}{\text{day}}$$

Quantified Co-Benefits

Improved Air Quality

(Tank-to-wheels) Reducing fossil-fuel combustion will also reduce local criteria pollutants. Tank-to-wheels emission savings can be calculated using the same formula used to quantify GHG reductions (A1 and A3). Criteria pollutant intensity factors for various construction equipment can be obtained from the U.S. EPA's (2024) MOVES.

(Well-to-wheels) The fuels produced by facilities within and outside of state will generate criteria pollutants. Because these facilities are dispersed, offsite of the project/site or plan/community, fuel production (including electricity) typically will not generate localized criteria pollutant emissions. Therefore, only the tank-to-wheels (i.e., tailpipe) portion of the vehicle criteria pollutant emissions should be quantified.

Energy and Fuel Savings

(Tank-to-wheels) Fossil fuel savings are a product of the equipment fuel efficiency (gallons consumed per hour) and the equipment operating time (hours). Fuel intensity factors for various construction equipment can be obtained from the U.S. EPA's (2024) MOVES. Users should multiply the fuel intensity by the equipment operating hours to quantify fuel savings.

(Well-to-wheels) Fuel savings would be achieved from tank-to-wheels reductions. Additional fuel savings may occur upstream from reduced production and transport, although these likely cannot be attributed to a single project. Increased electricity consumption for electric equipment is calculated as part of the GHG reduction formula (A2). The abbreviated formula is also shown below.

$$MWh = C \times \frac{D}{K} \times H$$

Sources

- Association of Petroleum Institute (API). 2021. *Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry*. Released November 2021. Accessed June 2025. https://www.api.org/~/media/files/policy/esg/ghg/2021-api-ghg-compendium-110921.pdf.
- Holian, M., and J. Pyeon. 2017. "Analyzing the Potential of Hybrid and Electric Off-Road Equipment in Reducing Carbon Emissions from Construction Industries." Mineta Transportation Institute. September 2017. Accessed January 2021. https://transweb.sjsu.edu/sites/default/files/1533-analyzing-the-potential-of-hybrid-and-electric-off-road-equipment-in-reducing-carbon-emissions-from-construction-industries-research-brief.pdf.
- U.S. Department of Energy (U.S. DOE). 2024. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model*. 2024 Release. Accessed January 28, 2025. https://greet.anl.gov/.
- U.S. EPA (U.S. Environmental Protection Agency). 2018. "Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES2014b." Released July 2018. Accessed June 2025. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100UXEN.pdf.
- U.S. EPA (U.S. Environmental Protection Agency). 2024. "Latest Version of Motor Vehicle Emissions Simulator (MOVES)." Released November 2024. Accessed December 2024. https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#guidance.

C-1-B. Use Cleaner-Fuel Equipment



GHG Mitigation Potential



Potentially small reduction in GHG emissions from construction equipment

Co-Benefits (icon key on pg. 31)

Climate Resilience

Using cleaner fuel equipment allows for fuel redundancy and can reduce sensitivity to price shocks or scarcity in conventional fuels.

Health and Equity Considerations

Although most alternative fuels reduce both GHG and criteria pollutants, a few may increase criteria pollutant emissions. The most prominent example of this is biodiesel, which generally results in higher NOx emissions, but lower PM emissions compared to conventional diesel.

Measure Description

This measure requires the use of cleaner-fueled construction equipment over conventional diesel- or gasoline-fueled counterparts. Depending on the fuel type, equipment type, and horsepower, equipment may emit fewer GHG for the same amount of work as equivalent diesel- or gasoline-fueled engines. A variation of this measure is described in Measure C-1-A, *Use Electric or Hybrid-Powered Equipment*. Compressed natural gas (CNG) is specifically addressed in the quantification method for this measure, although users could expand to cover additional fuel types, such as biodiesel or renewable diesel.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Note that while this measure discusses off-road equipment used for construction, this measure can also be implemented for other off-road equipment applications (e.g., agriculture, industrial).

Cost Considerations

Except for renewable diesel, which is a "drop-in fuel" that requires no modification to existing diesel engines, equipment powered by cleaner fuels may be more expensive to purchase and install than less clean models. These costs may be offset by savings in fuel use and maintenance. State and local clean fuel programs may also offer grants or incentives, which could help offset costs and make clean fuel equipment cost competitive with fossil fuel versions.

Expanded Mitigation Options

Other cleaner fuels available for use in construction equipment include renewable diesel, biodiesel, and hydrogen fuel cells. These fuels are not specifically captured by the current quantitative method for this measure.

GHG Reduction Formula

$A = ((C \times D \times E2) - (C \times D \times E1)) \times F$ (tank-to-wheels)

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	GHG reduction from using cleaner-fuel equipment	[ ]	MT CO_2e	calculated
User Inputs				
B	Fuel types of existing and cleaner-fuel equipment	[ ]	text	user input
C	Hours of equipment operation	[ ]	hours	user input
E1	Carbon intensity of existing equipment (tailpipe emissions)	[ ]	g CO_2e per hp-hour	U.S. EPA 2024
E2	Carbon intensity of cleaner-fuel equipment (tailpipe emissions)	[ ]	g CO_2e per hp-hour	U.S. EPA 2024
Constants, Assumptions, and Available Defaults				
D	In-use horsepower of equipment	Table C-1-B.1	hp	U.S. EPA 2024
F	Conversion from g to MT	1 e^{-6}	MT per g	conversion

Further explanation of key variables:

- (A) – Depending on the fuel type, equipment type, and horsepower, the cleaner-fuel equipment may emit more GHGs than an equivalent gasoline- or diesel-fueled engine. The user should take care to consider the potential criteria pollutant co-benefits against possible GHG increases from the use of a cleaner fuel.
- (B) – The fuel type of the existing and cleaner-fuel equipment is used to obtain the carbon intensity of the equipment (E1 and E2) from the U.S. EPA's (2024) MOVES.
- (D) – Average in-use hp of various construction equipment are provided in Table C-1-B.1 in the Appendix (U.S. EPA 2024). The in-use hp values are inclusive of equipment load. Therefore, the GHG reduction equation does not include a multiplier for load factor. If the user can provide an equipment-specific in-use hp, they should replace the default in the GHG calculation formula. Note that the types of equipment presented in Table C-1.B.1 differ from what is presented in the CAPCOA Handbook. Refer to Measure C-1-A, *Use Electric or Hybrid Powered Equipment*, for additional information.
- (E1 and E2) – GHG intensity factors for various construction equipment by fuel type can be obtained from the U.S. EPA's (2024) MOVES. Note that the CAPCOA Handbook directs users to the OFFROAD model to obtain GHG intensity factors. Refer to Measure C-1-A, *Use Electric or Hybrid Powered Equipment*, for additional information.

GHG Calculation Caps or Maximums

None. If the emissions rate for the cleaner-fuel equipment exceeds that of the diesel- or gasoline-powered counterpart, this measure may result in a GHG emissions increase.

Example GHG Reduction Quantification

The user reduces construction equipment emissions by replacing gasoline or diesel combustion with CNG or renewable diesel consumption, which may generate fewer GHG emissions per unit of activity, depending on the piece of equipment and horsepower. In this example, a fleet of 194-hp diesel construction equipment (D) that is used 40 hours per day (C) in 2028 is replaced by CNG-fueled equivalents. A 194-hp piece of diesel "other construction equipment" has a carbon intensity of 537 g CO_2e per hp-hour (E1). The CNG-fueled equivalent has a hp of 66 and carbon intensity of 548 g CO_2e per hp-hour (E2).

$$A = \left(\left(40\frac{\text{hours}}{\text{day}} \times 66 \text{ hp} \times 548\frac{\text{g } CO_2e}{\text{hp-hour}}\right) - \left(40\frac{\text{hours}}{\text{day}} \times 194 \text{ hp} \times 537\frac{\text{g } CO_2e}{\text{hp-hour}}\right)\right) \times 1e^{-6}\frac{\text{MT}}{\text{g}} = -3\frac{\text{MT } CO_2e}{\text{day}}$$

Quantified Co-Benefits

Improved Air Quality

Depending on the fuel type, equipment type, and horsepower, the cleaner-fuel equipment may emit more criteria pollutants than an equivalent gasoline- or diesel-fueled engine. Emission changes can be calculated using the same formula used to quantify GHG reductions (A). The carbon intensity factors (E1 and E2) should be replaced in the formula with the corresponding criteria pollutant intensity factors, which can be obtained from the U.S. EPA's (2024) MOVES.

Energy and Fuel Savings

This measure would displace use of fossil fuel (gasoline or diesel) with a cleaner fuel type (CNG). Total fuel consumption is a product of the equipment fuel efficiency (gallons consumed per hour) and the equipment operating time (hours). Fuel intensity factors for various construction equipment can be obtained from the U.S. EPA's (2024) MOVES. Users should multiply the fuel intensity factor by the equipment operating hours to quantify fuel changes for the existing and cleaner-fuel equipment.

Source

- U.S. EPA (U.S. Environmental Protection Agency). 2024. "Latest Version of Motor Vehicle Emissions Simulator (MOVES)." Released November 2024. Accessed December 2024. https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#guidance.

C-2. Limit Heavy-Duty Diesel Vehicle Idling



GHG Mitigation Potential



Potentially small reduction in GHG emissions from construction vehicles

Co-Benefits (icon key on pg. 31)

Climate Resilience

Limiting vehicle idling saves fuel and can reduce sensitivity to price shocks or fuel scarcity.

Health and Equity Considerations

This measure will not only reduce air pollution for surrounding communities but also for onsite workers.

Measure Description

This measure limits heavy-duty vehicle idling beyond current regulatory restrictions. Oregon Vehicle Code (OVC), Chapter 825, Motor Carriers, Section 605 prohibits idling the primary engine of a commercial vehicle with a gross vehicle weight rating that is greater than 10,000 pounds for more than five minutes in any continuous 60-minute period. Legislation was introduced in February 2024 to add Section 402 to Washington State Senate Bill (SB) 6304 that would prohibit vehicles subject to the measure from idling for more than five minutes at any location within 100 feet of a restricted area. Reduction in idling time beyond these or similar regulations would further reduce fuel consumption and thus emissions. Reducing idling benefits the health of construction workers as well as nearby residents and workers.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

The construction site manager should develop an enforceable mechanism that monitors the idling time to ensure compliance with this measure. Note that while this measure discusses heavy-duty vehicles used for construction, this measure can also be implemented for other vehicle applications (e.g., agriculture, industrial).

Cost Considerations

No initial costs are associated with this measure. Restricting vehicle idling time beyond regulation will reduce fuel consumption, leading to long-term cost savings.

Expanded Mitigation Options

Pair with Measure T-30, *Use Cleaner-Fuel Vehicles*, to reduce the carbon intensity of fuels combusted during idling.

GHG Reduction Formula

$$A = (B - D) \times C \times E \times F \times G \times H$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	GHG reduction from idling limit	[ ]	MT CO_2e	calculated
User Inputs				
B	Idle restriction with measure implementation	[ ]	minutes/period	user input
C	Vehicle trips	[ ]	trips	user input
Constants, Assumptions, and Available Defaults				
D	Idle limit without the measure	5	minutes/period	OVC 825.605; WA SB 6304, Section 402 (proposed)
E	Idle periods per trip	2	period/trip	assumption
F	Vehicle idling emission factor	[ ]	g/idle hours	U.S. EPA 2024
G	Conversion from minutes to hour	0.0167	hours per minute	conversion
H	Conversion from g to MT	1 e^{-6}	MT per g	conversion

Further explanation of key variables:

- (A) – Emissions reductions are quantified per vehicle idling period. Daily emissions reductions can be quantified if the number of idling periods per day is known.
- (B) – The measure-imposed idle restriction must exceed the idle limit without the measure (D).
- (C) – Idle restrictions are imposed on vehicles idling at a single location. Vehicles may make multiple trips to that location or make trips to different locations but still be subject to the idling limit. Users should define the number of trips the vehicle will make for the analysis period (e.g., per day, per year).
- (D) – OVC 825.605 prohibits idling the primary engine of a commercial vehicle with a gross vehicle weight rating that is greater than 10,000 pounds for more than five minutes in any continuous 60-minute period. Legislation was introduced in February 2024 to add Section 402 to Washington State SB 6304 that would prohibit vehicles subject to the measure from idling for more than five minutes at any location within 100 feet of a restricted area. Arizona, New Mexico, and Colorado do not currently have statewide idle restrictions, but individual cities or jurisdictions across all five western states may have limitations. The user should determine the appropriate idling limit for their location and vehicle type.

- (E) – The quantification method assumes the vehicle will idle twice per trip at a single location: once during vehicle shutdown from the inbound trip and once during vehicle warmup for the outbound trip. Users should apply a different factor if the number of idle periods per trip is known.
- (F) – GHG intensity factors for diesel-fueled heavy vehicle idling can be obtained from the U.S. EPA's (2024) MOVES. Note that the CAPCOA Handbook recommends users obtain emission factors from CARB's EMFAC model. This model reflects activity and data specific to the California fleet and is thus not applicable outside of the state. Accordingly, this Western States Handbook recommends users run MOVES, which is maintained by the U.S. EPA and can generate emissions rates at the county-level across the nation.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces vehicle idling emissions by enforcing an idling period of 3 minutes (B). In this example, a commercial truck is regulated under OVC 825.605. The idling limit without the measure is therefore 5 minutes at a single location (D). The vehicle will operate at a construction site in Gilliam County, Oregon. The vehicle will make 10 trips to the construction site per day (C). The idling carbon intensity is 7,151 g CO_2e per idle hour (F).

$$A = \left(3 \frac{\text{idle min}}{\text{period}} - 5 \frac{\text{idle min}}{\text{period}}\right) \times 10 \frac{\text{trips}}{\text{day}} \times 2 \frac{\text{period}}{\text{trip}} \times 7{,}151 \frac{\text{g}}{\text{idle·hr}}$$

$$\times 0.0167 \frac{\text{hr}}{\text{min}} \times 1e^{-6} \frac{\text{MT}}{\text{g}} = <-0.1 \frac{\text{MT } CO_2e}{\text{day}}$$

Quantified Co-Benefits

Improved Air Quality

Reducing fossil-fuel combustion from idling restrictions will also reduce local criteria pollutants. The reduction in criteria pollutant emissions can be calculated using the GHG reduction formula, where (F) represents the criteria pollutant intensity factors obtained from the U.S. EPA's (2024) MOVES.

Source

- U.S. EPA (U.S. Environmental Protection Agency). 2024. "Latest Version of Motor Vehicle Emissions Simulator (MOVES)." Released November 2024. Accessed December 2024. https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#guidance.

C-3. Use Local Construction Contractors



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions from construction worker vehicle fleets

Co-Benefits (icon key on pg. 31)

Climate Resilience

Reducing worker commute trip lengths saves fuel and can reduce sensitivity to price shocks or fuel scarcity.

Health and Equity Considerations

As noted under Cost Considerations, using local contractors may boost local economic development and reinvestment.

Measure Description

This measure requires the use of local construction contractors. Contracting construction work with a local company reduces VMT associated with construction employee commute distances and, therefore, reduces emissions from vehicle fuel combustion. Local hire provisions may cover the entire workforce or a percentage of the workforce based on the project size or employment type.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Local hiring requirements should be expressed in the contractor bid specifications. Note that this measure is specific to local hire provisions for employees reporting to the construction site. Measure C-4, *Use Local and Sustainable Building Materials*, requires use of local building materials, which can reduce VMT and emissions from vendor and delivery trips.

Cost Considerations

Local and skilled workforce provisions can promote economic development, channeling some of the economic value of development directly to the community in which it is building. Decreased worker commute times and fuel savings may generate additional discretionary funds. Reduced car use may decrease the need for infrastructure spending on road maintenance.

Expanded Mitigation Options

Local workforce provisions may increase the likelihood of employee commute trips by transit, walking, or biking. Potential GHG reductions from mode shift are not reflected in the quantification methodology. Partner with local transit agencies to provide discounted transit passes to further incentivize alternative transportation.

Consider additional provisions for workforce training to bolster the development of skilled trades and further economic growth. Requirements may include workers who have graduated from a Joint Labor Management apprenticeship training program or who have at least as many hours of on-the-job experience in the appliable craft or are registered in an apprenticeship training program.

GHG Reduction Formula

$$A = (B - D) \times C \times E \times F \times G$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	GHG reduction from using local construction contractors	[ ]	MT CO_2e	calculated
User Inputs				
B	Distance provision of local hiring requirement	[ ]	miles/one-way trip	user input
C	Number of employees	[ ]	employees	user input
Constants, Assumptions, and Available Defaults				
D	Average one-way employee commute trip distance	Table T-11.1	miles/one-way trip	See table
E	Employee trips per day	2	trips per employee	assumption
F	Vehicle emission factor	[ ]	g CO_2e per mile	U.S. EPA 2024
G	Conversion from g to MT	1 e^{-6}	MT per g	conversion

Further explanation of key variables:

- (B) – The local hire provision should specify the maximum average one-way travel distance for contracted staff.
- (C) – The number of employees required to report to the construction site and subject to the provision must be provided by the user.
- (D) – Where available, average vehicle trip lengths are provided in Table T-11.1 in the Appendix. Users should select the most appropriate location for their project site or supply project-specific information.
- (E) – The quantification method assumes all employees will make both an inbound and outbound trip per day.
- (F) – Users should obtain the carbon intensity of employee commute vehicles from the U.S. EPA's (2024) MOVES. Note that the CAPCOA Handbook recommends users obtain emission factors from CARB's EMFAC model. Refer to Measure C-2, *Limit Heavy-Duty Diesel Vehicle Idling*, for additional information. Employee commute vehicles are generally classified as passenger cars and passenger trucks. Users may obtain a weighted carbon intensity of these vehicle types using a 25/75 percent mix of cars and trucks, respectively. Alternatively, users may apply different weightings of vehicle fleet mixes if project-specific information is available.

GHG Calculation Caps or Maximums

(B<D). For implementation of this measure to result in a GHG reduction, the maximum average allowable travel distance must be less than the average countywide vehicle trip length assumed in the calculation.

Example GHG Reduction Quantification

The user reduces employee commute emissions by requiring all contracted employees to be located within a certain distance of a construction project. In this example, the construction project requires 100 employees per day (C) and is in King County, Washington. Per Table T-11.1, the average commute trip length for the Seattle-Tacoma-Bellevue core-based statistical area is 12.17 miles (D). The contractor agreement requires all staff reporting to the construction site to reside no more than 10 miles from the project (B). The weighted average carbon intensity for passenger commute vehicles in King County, Washington, for the analysis year is 218 g per mile (F).

$$A = \left(10 \frac{\textbf{miles}}{\textbf{trip}} - 12.17 \frac{\text{miles}}{\text{trip}}\right) \times 100 \frac{\textbf{employees}}{\textbf{day}} \times 2 \frac{\text{trips}}{\text{employee}}$$

$$\times 218 \frac{\text{g } CO_2e}{\text{mi}} \times 1e^{-6} \frac{\text{MT}}{\text{g}} = -0.1 \frac{\text{MT } CO_2e}{\text{day}}$$

Quantified Co-Benefits

VMT Reductions

Contracting construction work with a local company reduces construction employee commute VMT. The reduction in VMT can be calculated using the GHG reduction formula with the exception that (F and G) should be replaced with a value of 1 or otherwise be removed from the equation.

Energy and Fuel Savings

This measure will achieve vehicle fuel savings by reducing employee commute VMT. Total fuel consumption is a product of the vehicle fuel efficiency (gallons consumed per mile) and miles traveled. Fuel intensity factors can be obtained from the U.S. EPA's (2024) MOVES. Users should multiply the vehicle fuel intensity factor by the VMT reduction (see above) to quantify fuel savings.

Improved Air Quality

Reducing fossil-fuel combustion from a local hire provision will also reduce local criteria pollutants. The reduction in criteria pollutant emissions can be calculated using the GHG reduction formula, where (F) represents the criteria pollutant intensity factors obtained from the U.S. EPA's (2024) MOVES.

Source

- U.S. Environmental Protection Agency (U.S. EPA). 2024. "Latest Version of Motor Vehicle Emissions Simulator (MOVES)." Released November 2024. Accessed December 2024. https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#guidance.

Refrigerants



Refrigerants are substances used in equipment for cooling and heating purposes. Most of the refrigerants used today are hydrofluorocarbons (HFCs) or blends thereof. HFCs are the third generation of synthetic fluorinated chemicals and were used to replace ozone depleting refrigerants. However, HFCs are potent GHGs that often have high GWP values. Different types of refrigeration equipment are used by different types of land uses. For example, an office may use various types of A/C equipment, while a supermarket may use both A/C equipment and refrigeration equipment.

All equipment that uses refrigerants has a charge size (i.e., quantity of refrigerant the equipment contains) and an operational refrigerant leak rate, and each refrigerant has a GWP that is specific to that refrigerant. The GWPs of common refrigerants are presented in Table R-1.1 in the Appendix, *Emissions Factors and Data Tables*. For purposes of calculating refrigerant emissions in this Western States Handbook, the equipment charge sizes and leak rates have been determined for relevant land use and equipment types. This information is presented in Table R-1.2 in the Appendix. Note that the CAPCOA Handbook presents equipment charge sizes and leak rates across four tables (R-1.2 through R-1.5). The equipment information is presented for each of the land use types included in the California Emissions Estimator Model. Table R-1.2 in this Western States Handbook consolidates the equipment charge sizes and leak rates and presents them by the land use types from the U.S. Energy Information Administration's (U.S. EIA) 2020 Residential Energy Consumption Survey (RECS) and 2018 Commercial Buildings Energy Consumption Survey (CBECS).

Refrigerants

- R-1. Use Alternative Refrigerants Instead of High-GWP Refrigerants
- R-2. Install Secondary Loop and/or Cascade Supermarket Systems in Place of Direct Expansion Systems
- R-3. Install Transcritical CO_2 Supermarket Systems in Place of High-GWP Systems
- R-4. Install Microchannel Heat Exchangers in A/C Equipment in Place of Conventional Heat Exchanger
- R-5. Reduce Service Leak Emissions
- R-6. Reduce Operational Leak Emissions
- R-7. Reduce Disposal Emissions

Emissions from equipment can be reduced by decreasing the charge size and/or leak rate, or replacing the baseline refrigerant with a lower GWP refrigerant. The quantification method for all refrigerant measures, except Measure R-7, addresses emissions generated during equipment operation. Measure R-7 reduces emissions from the disposal of refrigeration and A/C equipment at the end of its lifetime. The quantification approach for Measure R-7 includes lifecycle considerations (i.e., downstream emissions) and, as a result, emission reductions from this measure should not be compared to the emission reductions calculated for other refrigeration measures in this Handbook, which do not include lifecycle emissions.

Use the graphic to click on an individual measure to navigate directly to the measure's factsheet.

R-1. Use Alternative Refrigerants Instead of High-GWP Refrigerants



GHG Mitigation Potential



Up to a 100% reduction in GHG emissions during operation

Co-Benefits (icon key on pg. 31)

Climate Resilience

Climate resilience benefits vary by alternative refrigerant; for example, use of NH_3 can reduce energy consumption, thereby reducing the strain on the overall grid, particularly the risk of power outages during peak loads. Reduced energy consumption would also reduce energy costs, especially if extreme heat would otherwise increase these costs.

Health and Equity Considerations

Evaluate the entire lifecycle impact of alternative refrigerants and avoid those that will degrade into persistent chemicals harmful to the environment. Equipment should be installed in locations with adequate space and/or ventilation in accordance with U.S. EPA recommendations.

Measure Description

This measure replaces high-GWP refrigerants with lower-GWP refrigerants (e.g., natural refrigerants such as CO_2, ammonia [NH_3], and hydrocarbons, or next generation low-GWP synthetic refrigerants like hydrofluoroolefin-1234yf) in refrigeration and A/C equipment. When emitted into the atmosphere, high-GWP refrigerants (e.g., HFCs) absorb significantly more heat than CO_2 on a mass basis, resulting in larger global warming effects. Shifting to lower-GWP refrigerants reduces the potency of refrigerant leaks, decreasing GHG emissions on a CO_2e basis.

Scale of Application

Project/Site

Implementation Requirements

Ensure measure implementation exceeds any state or local high-GWP requirements, including timing for use of alternative refrigerants. For example, Colorado's Regulation 22, Colorado Greenhouse Gas Reporting and Emission Reduction Requirements, Part B (5 CCR 1001-26) sets phase-out dates for certain high-GWP compounds.

Cost Considerations

Implementation may require retrofitting existing equipment or purchasing new equipment, which may result in high initial capital costs. Alternative refrigerants, if synthetic and patented, may cost more than conventional refrigerants. Natural, non-patented refrigerants may cost less. Costs differences are expected to decrease over time with increased availability and commercialization of alternative refrigerants. Savings may also be achieved through increased energy efficiency of a refrigerant system using an alternative refrigerant.

Expanded Mitigation Options

Evaluate the entire lifecycle impact of alternative refrigerants and avoid those that will degrade into persistent chemicals harmful to the environment so as to improve local air quality, public health, and ecosystem health. Ensure that the Clean Air Act and other regulations are followed during refrigerant disposal.

GHG Reduction Formula

$$A = \frac{(B \times C \times G) - (D \times E \times F)}{(D \times E \times F)}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from refrigerant emissions	0–100	%	calculated
User Inputs				
B	Total alternative refrigerant charge size	[ ]	kg	user input
C	Annual leak rate of equipment with alternative refrigerant	[ ]	%	user input
Constants, Assumptions, and Available Defaults				
D	HFC refrigerant charge size	Table R-1.2	kg	U.S. EPA 2016
E	Annual leak rate of equipment with HFC refrigerant	Table R-1.2	%	U.S. EPA 2016
F	GWP of HFC refrigerant	Table R-1.1	unitless	IPCC 2013
G	GWP of alternative refrigerant	Table R-1.1	unitless	IPCC 2013 and WMO 2018

Further explanation of key variables:

- (B, D) – The equipment charge size is the total quantity of refrigerant installed in the refrigeration or A/C equipment. The charge size may be the same for equipment using HFC and alternative refrigerants, or it may differ. Default charge sizes for equipment with HFC refrigerants are provided in Table R.1-2 in the Appendix. If the user can provide a project-specific value, they should replace the default quantity of refrigerant installed in the GHG reduction formula. Charge size for alternative refrigerants would vary by equipment type. In the case where the alternative charge size is not known, the corresponding HFC refrigerant charge size may be used as a substitute.
- (C, E) – The average annual leak rates account for operational and servicing leaks from the equipment throughout the year. The leak rate may be the same for equipment using HFC and alternative refrigerants, or it may differ. Default leak rates for equipment with HFC refrigerants are provided in Table R.1-2 in the Appendix. These are average values and may vary with specific systems. Leak rates for alternative refrigerants would vary by equipment type. In the case where the alternative leak rate is unknown, the corresponding HFC refrigerant leak rate may be used as a substitute.
- (F, G) – The GWP measures the contribution to global warming from the release of one unit of the given refrigerant relative to CO_2 on a 100-year time horizon. The GWPs of common refrigerants and alternatives are provided in Table R-1.1 in the Appendix.

GHG Calculation Caps or Maximums

This measure has a maximum GHG emissions reduction of 100 percent.

Example GHG Reduction Quantification

The user reduces high-GWP emissions by replacing a high-GWP refrigerant with a lower-GWP refrigerant alternative. In this example, a 60,000-sf supermarket has a conventional direct expansion system with 1,360 kg (D) of R-404A and a total leak rate of 33 percent (E). The supermarket also has A/C equipment with 13 kg (D) of R-410A and a total leak rate of 8 percent (E). The GWPs of R-404A and R-410A are 3,943 and 1,924 (F), respectively. The user replaces R-404A with R-448, a refrigerant with a GWP of 1,273 (G), and R-410A with R-407C, a refrigerant with a GWP of 1,624 (G). The charge sizes and leak rates for the alternative equipment would be the same as the high-GWP counterpart. Note that the A/C refrigerant transition from R-410A to R-407C is included for illustrative purposes and that this transition in supermarkets is not currently happening in practice. This would reduce GHG emissions from the refrigeration and A/C systems at the supermarket by 65 percent.

$$A = \frac{((\mathbf{1{,}360\ kg} \times \mathbf{33\%} \times 1{,}273)+(\mathbf{13\ kg} \times \mathbf{8\%} \times 1{,}624))-((1{,}360\ \text{kg} \times 33\% \times 3{,}943)+(13\text{kg} \times 8\% \times 1{,}924))}{((1{,}360\ \text{kg} \times 33\% \times 3{,}943)+(13\ \text{kg} \times 8\% \times 1{,}924))} = -68\%$$

Quantified Co-Benefits

Energy and Fuel Savings

Depending on system type and refrigerant selected, successful implementation of this measure could result in energy savings or energy penalties (U.S. EPA 2019). This co-benefit cannot be quantified for the purposes of this general methodology.

Sources

- IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/.
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- WMO (World Meteorological Organization). 2018. *Scientific Assessment of Ozone Depletion: 2018*. Global Ozone Research and Monitoring Project. Report No. 58. Geneva, Switzerland.

R-2. Install Secondary Loop and/or Cascade Supermarket Systems in Place of Direct Expansion Systems



GHG Mitigation Potential



Up to a 100% reduction in GHG emissions during operation

Co-Benefits (icon key on pg. 31)

Climate Resilience

Increased energy efficiency in refrigeration systems can reduce the strain on the overall grid, particularly the risk of power outages during peak loads. Increased efficiency can also reduce energy costs, particularly if extreme heat would otherwise increase these costs.

Health and Equity Considerations

Not applicable

Measure Description

This measure replaces conventional direct expansion systems in supermarkets with indirect systems such as secondary loop and cascade systems. Currently, direct expansion systems are the most used refrigeration system type in supermarkets in the U.S. (U.S. EPA 2016). Whereas direct expansion systems circulate one refrigerant from the machinery room out to the store and back to the machinery room, indirect systems employ a primary and secondary refrigerant or heat transfer fluid (U.S. EPA 2016, 2019). In secondary loop systems, the primary refrigerant remains in the machine room and cools the secondary fluid, which is then pumped throughout the store to cool products. Another type of indirect system is a cascade system, which contains two refrigeration systems that share a common heat exchanger. These systems often use HFCs, NH_3, or hydrocarbons as the primary refrigerant. Often water mixed with glycol is used as the secondary heat transfer fluid in secondary loop systems; CO_2 is often used as the second refrigerant in cascades. By either confining HFCs to the machinery room as the primary refrigerant or removing HFCs entirely (as in NH_3 and hydrocarbon systems), these systems require significantly lower refrigerant charge and have lower leak rates than conventional direct expansion systems (U.S. EPA 2013a, 2019). Decreasing the refrigerant charge and leak rates results in a reduction of potential direct GHG emissions.

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Although both secondary loop and cascade supermarket systems have a higher initial cost over traditional systems, the minimized costs associated with rechanging systems due to reduced leakage and energy efficiency improvements may provide a net cost savings over the lifetime of the systems.

Expanded Mitigation Options

Pair with Measure R-1, *Use Alternative Refrigerants Instead of High-GWP Refrigerants*, for increased GHG reductions in supermarket refrigerant systems.

GHG Reduction Formula

$$A = \frac{[(B \times F \times H) + (C \times F \times I)] - (D \times E \times G)}{D \times E \times G}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from refrigerant emissions	0–100	%	calculated
User Inputs				
B	Equipment charge size of secondary loop and/or cascade system	[ ]	kg	user input
C	Equipment charge size of secondary refrigerant in secondary loop and/or cascade system	[ ]	kg	user input
Constants, Assumptions, and Available Defaults				
D	Equipment charge size of conventional direct expansion system	1,633	kg	U.S. EPA 2013a
E	Annual leak rate of conventional direct expansion system	25	%	U.S. EPA 2013b
F	Annual leak rate of secondary loop and/or cascade system	5–15	%	U.S. EPA 2013a
G	GWP of HFC refrigerant	Table R-1.1	unitless	IPCC 2013 and WMO 2018
H	GWP of HFC refrigerant	Table R-1.1	unitless	IPCC 2013 and WMO 2018
I	GWP of refrigerant	Table R-1.1	unitless	IPCC 2013 and WMO 2018

Further explanation of key variables:

- (B) – The equipment charge size is the total quantity of the primary refrigerant installed in refrigeration or A/C equipment.
- (C) – The equipment charge size is the total quantity of the secondary refrigerant installed in refrigeration or A/C equipment.
- (D) – Based on industry data, the equipment charge size of a conventional direct expansion system is 1,633 kg. If the user can provide a project-specific value, they should replace the default conventional direct expansion system charge size in the GHG reduction formula.

- (E and F) – The average annual leak rates account for operational and servicing leaks from the equipment throughout the year. Leak rates are provided as averages and may vary with specific systems.
- (G, H, and I) – The GWP of the refrigerant measures the contribution to global warming from the release of one unit of the given refrigerant relative to CO_2 on a 100-year time horizon. The GWP of common refrigerants and alternatives is provided in Table R-1.1 in the Appendix.

GHG Calculation Caps or Maximums

This measure has a maximum GHG emissions reduction of 100 percent.

Example GHG Reduction Quantification

The user reduces high-GWP refrigerant emissions by replacing a conventional direct expansion system in a supermarket with a secondary loop system. In this example, the conventional direct expansion system refrigerant is R-404A, which has a GWP of 3,943 (G). The direct expansion system equipment charge size of 1,633 kg (D) is assumed. The charge size for the primary refrigerant (R-407A) in the secondary loop system is 1,145 kg (B) and the GWP is 1,923 (H). The charge size for the heat transfer fluid refrigerant using water is 1,145 kg (C) with a GWP of 0 (I). Implementation of this project would reduce GHG emissions from the refrigeration system at this supermarket by 79 percent.

$$A = \frac{((1{,}145\ \text{kg} \times 15\% \times 1{,}923) + (1{,}145\ \text{kg} \times 15\% \times 0))-(1{,}633\ \text{kg} \times 25\% \times 3{,}943)}{(1{,}633\ \text{kg} \times 25\% \times 3{,}943)} = -79\%$$

Quantified Co-Benefits

Energy and Fuel Savings

Successful implementation of this measure could achieve energy savings. While historically secondary loop and/or cascade systems have reduced energy efficiency, the past 15 years of development have resulted in energy efficiency improvements ranging from 0.5 percent to 35 percent compared to conventional direct expansion systems (U.S. EPA 2013a; Pan et al. 2020). Note that this range of values is a historical average and that, unlike the GHG reduction formula, the energy savings cannot be precisely quantified using a predictive formula for the purposes of this methodology.

Sources

- IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/.
- Pan, M., H. Zaho, D. Liang, Y. Zhu, Y. Lian, and G. Bao. 2020. "A Review of the Cascade Refrigeration System." *Energies* 13, no. 9 (May). Accessed January 2021. https://www.mdpi.com/1996-1073/13/9/2254/pdf.

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- U.S. EPA. 2016. "Advanced Refrigeration." November 2016. Accessed January 2021. https://www.epa.gov/greenchill/advanced-refrigeration.
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- WMO (World Meteorological Organization). 2018. *Scientific Assessment of Ozone Depletion: 2018*. Global Ozone Research and Monitoring Project. Report No. 58. Geneva, Switzerland.

R-3. Install Transcritical CO_2 Supermarket Systems in Place of High-GWP Systems



GHG Mitigation Potential



Up to a 99.9 percent reduction in GHG emissions during operation

Co-Benefits (icon key on pg. 31)

Climate Resilience

Climate resilience benefits vary by climate; in cooler and more dry climates, a CO_2 transcritical system can be at parity or more energy efficient than conventional direct expansion systems. Increased energy efficiency in refrigeration systems can reduce the strain on the overall grid, especially the risk of power outages during peak loads. Increased efficiency can also reduce energy costs, particularly if extreme heat would otherwise increase these costs.

Health and Equity Considerations

Not applicable

Measure Description

This measure replaces conventional direct expansion systems in supermarkets with CO_2 transcritical systems. Whereas direct expansion systems typically use a high-GWP refrigerant, CO_2 transcritical systems use CO_2, which has a GWP of 1 and a lower leakage rate than typical conventional direct expansion systems. By reducing annual leak rates and replacing high-GWP refrigerants with CO_2, these systems result in a reduction of potential direct GHG emissions. CO_2 transcritical systems operate at high pressures but otherwise operate similarly to conventional direct expansion systems. Typically, the charge size of these systems is comparable to conventional direct expansion systems. CO_2 transcritical systems work most efficiently in cooler climates but can also be used in warmer climates (Belusko et al. 2019; U.S. EPA 2019).

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Transcritical CO_2 supermarket systems carry a high initial cost over traditional systems. However, CO_2 systems have a lower operating cost, mainly due to the price of CO_2 being much lower than the price of conventional refrigerants.

Expanded Mitigation Options

Measure is a subset of Measure R-1, *Use Alternative Refrigerants Instead of High-GWP Refrigerants*, which should be selected for increased GHG reductions in supermarket refrigerant systems.

GHG Reduction Formula

$$A = \frac{(E \times G \times \mathbf{B}) - (D \times F \times C)}{D \times F \times C}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from refrigerant emissions	0–99.9	%	Calculated
User Inputs				
B	Equipment charge size of CO_2 transcritical system	[ ]	kg	user input
Constants, Assumptions, and Available Defaults				
C	Equipment charge size of conventional direct expansion system	1,633	kg	U.S. EPA 2019
D	Annual leak rate of conventional direct expansion system	25	%	U.S. EPA 2013
E	Annual leak rate of CO_2 transcritical system	15	%	U.S. EPA 2019
F	GWP of HFC refrigerant	Table R-1.1	unitless	IPCC 2013
G	GWP of alternative refrigerant (CO_2)	1	unitless	IPCC 2013

Further explanation of key variables:

- (B) – The equipment charge size is the total quantity of refrigerant installed in refrigeration or A/C equipment.
- (C) – Based on industry data, the equipment charge size of a conventional direct expansion system is 1,633 kg. If the user can provide a project-specific value, they should replace the default conventional direct expansion system charge size in the GHG reduction formula.
- (D and E) – Based on industry data, the average annual leak rates for the given equipment type are provided. This includes operational and servicing leak rates for the equipment throughout the year. Leak rates are provided as averages and may vary with specific systems.
- (F and G) – The GWP of the refrigerant measures the contribution to global warming from the release of one unit of the given refrigerant relative to CO_2 on a 100-year time horizon. The GWP of common refrigerants and alternatives is provided in Table R-1.1 in the Appendix.

GHG Calculation Caps or Maximums

This measure has a maximum GHG emissions reduction of 99.9 percent.

Example GHG Reduction Quantification

The user reduces high-GWP emissions by replacing a conventional direct expansion system with a CO_2 transcritical system in a supermarket. In this example, the conventional direct expansion system refrigerant is R-404A, which has a GWP of 3,943 (F) and a charge size of 1,633 kg (C). The charge size for a CO_2 transcritical system is also 1,633 kg (B) and it has a 15 percent leak rate (E). Implementation of this project would reduce GHG emissions from the refrigeration system at this supermarket by 99.9 percent.

$$A = \frac{(15\% \times 1 \times \mathbf{1{,}633\ kg}) - (25\% \times 3{,}943 \times 1{,}633\ kg)}{25\% \times 3{,}943 \times 1{,}633\ kg} = -99.9\%$$

Quantified Co-Benefits

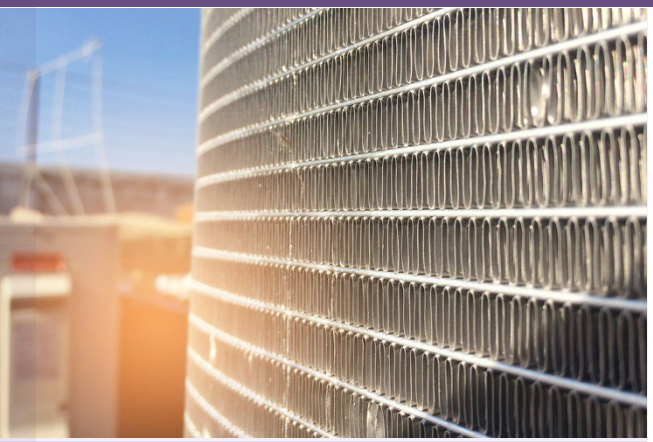
Energy and Fuel Savings

Successful implementation of this measure could achieve energy and fuel savings. Depending on the climate in which a CO_2 transcritical system is installed, energy efficiency can show improvements of up to 10 percent (U.S. EPA 2019). These improvements decrease, or become negative, in warmer and more humid climates (U.S. EPA 2019; Belusko et al. 2019). Note that, unlike the GHG reduction formula, the energy savings cannot be precisely quantified using a predictive formula for the purposes of this methodology.

Sources

- Belusko, M., R. Liddle, A. Alemu, E. Halawa, and F. Bruno. 2019. "Performance Evaluation of a CO_2 Refrigeration System Enhanced with a Dew Point Cooler." *Energies* 12, no. 6 (March). Accessed May 2021. https://www.mdpi.com/1996-1073/12/6/1079.
- IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/.
- U.S. EPA (U.S. Environmental Protection Agency). 2013. *The GreenChill Partnership: Refrigerant Leak Prevention through Regular Maintenance*. September 2013. Accessed January 2021. https://www.epa.gov/sites/production/files/2013-12/documents/gc_preventativemaintenance_20130913.pdf.
- U.S. EPA. 2019. *Global Non-CO_2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation*. U.S. EPA Office of Atmospheric Programs, EPA-430-R-19-012. September 2019. Accessed January 2021. https://www.epa.gov/sites/production/files/2019-09/documents/nonco2_methodology_report.pdf.

R-4. Install Microchannel Heat Exchangers in A/C Equipment in Place of Conventional Heat Exchanger



GHG Mitigation Potential



Up to a 35.0% reduction in GHG emissions during operation

Co-Benefits (icon key on pg. 31)

None

Climate Resilience

Not applicable

Health and Equity Considerations

Microchannel heat exchangers can reduce noise produced by the condenser fan.

Measure Description

This measure replaces conventional heat exchangers in A/C equipment (e.g., unitary A/C) with microchannel heat exchangers (MCHX). Whereas conventional heat exchangers use single or multiple large-diameter tubes to transfer heat in A/C equipment, MCHX use a series of small tubes. A/C equipment using MCHX requires 35 percent to 40 percent less refrigerant than those using conventional heat exchangers (U.S. EPA 2019). The reduction in refrigerant charge in A/C equipment results in a reduction of potential GHG emissions.

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

MCHX have a lower overall equipment cost compared to conventional heat exchangers. Long-term maintenance costs are comparable.

Expanded Mitigation Options

Pair with Measure R-1, *Use Alternative Refrigerants Instead of High-GWP Refrigerants*, for increased GHG reductions in A/C equipment.

GHG Reduction Formula

A = -B

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from refrigerant emissions	35	%	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
B	Assumed charge size reduction due to MCHX	35	%	U.S. EPA 2019

Further explanation of key variables:

- (B) – Based on industry data, the percent reduction in charge size obtained from using MCHX in A/C equipment is provided as an average reduction across A/C equipment.

GHG Calculation Caps or Maximums

This measure has a maximum GHG emissions reduction of 35 percent.

Example GHG Reduction Quantification

The user reduces high-GWP emissions replacing a conventional heat exchanger in A/C equipment with MCHX. Implementation of this project would reduce GHG emissions from the A/C equipment by 35 percent.

A = -35%

Quantified Co-Benefits

None.

Source

- U.S. EPA (U.S. Environmental Protection Agency). 2019. *Global Non-CO_2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation*. U.S. EPA Office of Atmospheric Programs, EPA-430-R-19-012. September 2019. Accessed January 2021. https://www.epa.gov/sites/production/files/2019-09/documents/nonco2_methodology_report.pdf.

R-5. Reduce Service Leak Emissions



GHG Mitigation Potential



Up to 95.0% reduction in GHG emissions during servicing

Co-Benefits (icon key on pg. 31)

None

Climate Resilience

Not applicable

Health and Equity Considerations

Not applicable

Measure Description

This measure reduces emissions of refrigerants during equipment servicing by employing improved refrigerant servicing technologies and practices. It is estimated that recovering refrigerants can reduce emissions in servicing by up to 95 percent (U.S. EPA 2019). Through implementation of refrigerant recovery, overall service GHG emissions can be reduced. Equipment should only be serviced by qualified technicians certified under Section 608 of the Clean Air Act and who also hold an active contractor's license. State refrigerant management programs may also have required service practices that must be followed (e.g., see WAC 173-443-205 for required practices in Washington State). Technicians should make a recovery attempt using refrigerant recovery or recycling equipment for that type of appliance and refrigerant type before opening the appliance to atmospheric conditions. Implementing more widespread and thorough refrigerant recovery practices while servicing refrigeration and A/C systems would go beyond regulatory requirements.

Scale of Application

Project/Site

Implementation Requirements

Require that all appliances are serviced by a qualified technician who must make a recovery attempt using refrigerant recovery or recycling equipment for each appliance and refrigerant type before opening the appliance to atmospheric conditions, in accordance with existing state and federal regulations.

Cost Considerations

Costs associated with reducing service leak emissions may include installation of leak detection systems and increased staff time to monitor and maintain the system. The benefit of reducing leak emissions depends on the price of the refrigerant and the quantity of leaked refrigerant. Because many refrigerants carry a high cost, detecting and repairing leaks is expected to provide a net cost savings and will also allow for quick and accurate servicing.

Expanded Mitigation Options

Not applicable.

GHG Reduction Formula

$$A = \frac{B - C}{C}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from service emissions	0–95.0	%	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
B	Equipment service leak rate with measure	2	%	U.S. EPA 2020
C	Equipment service leak rate without measure	Table R-1.2	%	U.S. EPA 2016

Further explanation of key variables:

- (B) – The updated service leak rate of the equipment after improved technology and/or practices. Leak rates vary between equipment types. A service leak rate of 2 percent can be assumed in the event that project-specific information is unavailable (U.S. EPA 2020). The user should replace this default in the GHG reduction formula if the user is able to provide a project-specific equipment leak rate.
- (C) – The service leak rate of the equipment.

GHG Calculation Caps or Maximums

This measure has a maximum GHG emissions reduction of 95.0 percent.

Example GHG Reduction Quantification

The user reduces service emissions by increasing refrigerant recovery during servicing. In this example, the user operates a commercial A/C and heat pump at a restaurant. The current service leak rate is 4 percent (C). The improved servicing leak rate of the equipment (B) is 2 percent, reducing GHG emissions by 50 percent.

$$A = \frac{2\% - 4\%}{4\%} = -50\%$$

Quantified Co-Benefits

None.

Sources

- U.S. EPA (U.S. Environmental Protection Agency). 2016. *Accounting Tool to Support Federal Reporting of Hydrofluorocarbon Emissions: Supporting Documentation*. October 2016. Accessed May 2021. https://www.epa.gov/sites/production/files/2015-09/documents/hfc_emissions_accounting_tool_supporting_documentation.pdf.
- U.S. EPA. 2019. *Global Non-CO_2 Greenhouse Gas Emissions Projections & Marginal Abatement Cost Analysis: Methodology Documentation*. September 2019. Accessed January 2021. https://www.epa.gov/sites/production/files/2019-09/documents/nonco2_methodology_report.pdf.
- U.S. EPA. 2020. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018." Stationary Refrigeration Leak Repair Requirements. Accessed January 2021. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.

R-6. Reduce Operational Leak Emissions



GHG Mitigation Potential



Up to 99.9% reduction in GHG emissions during operation

Co-Benefits (icon key on pg. 31)

None

Climate Resilience

Not applicable

Health and Equity Considerations

Not applicable

Measure Description

This measure reduces emissions from leakage of refrigerants during operation, decreasing emissions of refrigerants. A typical food retail store leaks an estimated 25 percent of refrigerants, or approximately 1,000 pounds annually (U.S. EPA 2013). Currently, under Section 608 of the Clean Air Act, corrective action must be taken when an appliance with a full charge of 50 or more pounds is discovered to be leaking ozone depleting substances that exceed the applicable trigger rate. The trigger rate for industrial process refrigeration is 30 percent, commercial refrigeration 20 percent, and comfort cooling and all other appliances is 10 percent. Through implementing leak detection technology and preventative maintenance measures, leakages can be resolved before reaching trigger rates, thus significantly reducing GHG emissions (U.S. EPA 2020).

Scale of Application

Project/Site

Implementation Requirements

Under Washington's Refrigerant Management Program, leak inspections are required monthly for large refrigeration systems, quarterly for medium systems, and annually for small systems. When reducing leak emissions, best practices include regularly conducted visual inspections to ensure no leakages occur. If a leak does occur, repairs must be made within 14 days of detection. (WA State Department of Ecology 2025).

Cost Considerations

Costs associated with reducing operational leak emissions may include installation of leak detection systems and increased staff time to monitor and maintain the detection system. The benefit of reducing leak emissions depends on the price of the refrigerant and the quantity of leaked refrigerant. Because many refrigerants carry a high cost, detecting and repairing leaks is expected to provide a net cost savings.

Expanded Mitigation Options

Not applicable.

GHG Reduction Formula

$$A = \frac{B - C}{C}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from leak emissions	0–99.9	%	calculated
User Inputs				
B	Improved equipment leak rate with measure	[ ]	%	user input
Constants, Assumptions, and Available Defaults				
C	Annual equipment leak rate without measure	Table R-1.2	%	U.S. EPA 2016

Further explanation of key variables:

- (B) – The improved leak rate of the equipment after leak detection, leak repair, and leak prevention measures have been implemented. This varies on a case-by-case basis due to differences in equipment and leak control technologies used.
- (C) – The annual operational leak rate of the equipment.

GHG Calculation Caps or Maximums

This measure has a maximum GHG emissions reduction of 99.9 percent.

Example GHG Reduction Quantification

The user reduces operational leak rates by installing leak detection technology and increasing regular maintenance of the equipment. In this example, the user operates refrigeration and condensing units at a supermarket. The current operational leak rate is 25 percent (C), and the updated leak rate of the equipment (B) is decreased to 20 percent annually. Implementation of this project would reduce GHG emissions from the refrigeration and condensing units at this supermarket by 20 percent.

$$A = \frac{(20\% - 25\%)}{25\%} = -20\%$$

Quantified Co-Benefits

None.

Sources

- U.S. EPA (U.S. Environmental Protection Agency). 2013. *The GreenChill Partnership: Refrigerant Leak Prevention through Regular Maintenance*. September 2013. Accessed January 2021. https://www.epa.gov/sites/production/files/2013-12/documents/gc_preventativemaintenance_20130913.pdf.
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- Washington State Department of Ecology. 2025. "Refrigerant Management Program." Accessed January 27, 2025. https://ecology.wa.gov/air-climate/reducing-greenhouse-gas-emissions/hydrofluorocarbons/refrigerant-management-program.

R-7. Reduce Disposal Emissions



GHG Mitigation Potential



Up to a 99.9% reduction in GHG emissions during disposal

Co-Benefits (icon key on pg. 31)

None

Climate Resilience

Not applicable

Health and Equity Considerations

Not applicable

Measure Description

This measure reduces emissions from the disposal of refrigeration and A/C equipment at the end of its lifetime. Safe disposal requirements are included in U.S. EPA regulations (40 C.F.R. 82(F)) under Section 608 of the Clean Air Act. These requirements are designed to minimize refrigerant emissions when equipment is disposed. Refrigerants must be properly recovered using U.S. EPA-certified refrigerant recovery equipment, meaning that a least 90 percent of the refrigerant must be recovered if the compressor is operating, and at least 80 percent must be recovered otherwise (U.S. EPA 2019).

Scale of Application

Project/Site

Implementation Requirements

This measure aims to capture the remaining amount of refrigerant that is not mandated to be recovered. Refrigerants must be reclaimed by a U.S. EPA-certified reclaimer for reuse or destroyed using approved destruction methods (U.S. EPA 2018).

Cost Considerations

The main cost is labor associated with hiring a technician to complete the recovery work.

Expanded Mitigation Options

Smaller equipment tends to have the highest disposal leak rates. Target this measure to small equipment to maximize GHG reductions.

GHG Reduction Formula

$$A = \frac{B - C}{C}$$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Percent reduction in GHG emissions from disposal emissions	0–99.9	%	calculated
User Inputs				
B	Improved equipment disposal emissions rate with measure	[ ]	%	user input
Constants, Assumptions, and Available Defaults				
C	Equipment disposal emissions rate without measure	At least 20	%	U.S. EPA 2018

Further explanation of key variables:

- (B) – The improved disposal emissions rate of the equipment after implementation of improved refrigerant recovery technologies.
- (C) – The disposal emission rate of refrigeration and A/C equipment. Refrigerant must be properly recovered using U.S. EPA-certified refrigerant recovery equipment, meaning that at least 80 percent must be recovered (U.S. EPA 2018). This means the regulated disposal emissions rate would be at least 20 percent. The actual achieved-in practice rate may be much higher than this minimum requirement and could exceed 50 percent. The user should replace this default in the GHG reduction formula if they are able to provide a project-specific value.

GHG Calculation Caps or Maximums

$(B<C)$ In order for implementation of this measure to result in a GHG reduction, the improved equipment disposal emission rate must be less than the 20 percent required by federal and state regulations. For residential equipment, reducing disposal emissions from over 50 percent to 25–30 percent is considered adequate.

Example GHG Reduction Quantification

The user reduces disposal emissions by implementing more technologically advanced refrigerant recovery systems. The initial disposal rate of the equipment (C) is 20 percent, and the improved disposal emission rate with the project (B) is 10 percent. Implementation of this project would reduce disposal emissions by 50 percent.

$$A = \frac{(10\% - 20\%)}{20\%} = -50\%$$

Quantified Co-Benefits

None.

Sources

- U.S. EPA (U.S. Environmental Protection Agency). 2018. *Responsible Appliance Disposal (RAD) Program: Guidance for Existing and Prospective Partners.* August 2018. Accessed January 2021. https://www.epa.gov/sites/production/files/2018-08/documents/rad-guidance-document.pdf.
- U.S. EPA. 2019. *Global Non-CO_2 Greenhouse Gas Emissions Projections & Marginal Abatement Cost Analysis: Methodology Documentation*. September 2019. Accessed January 2021. https://www.epa.gov/sites/production/files/2019-09/documents/nonco2_methodology_report.pdf.

Miscellaneous



This sector includes several measures that will reduce GHG emissions through the implementation of novel or offsite projects defined by the user. The general quantification framework for three measures is outlined in this section, although all require users to identify the expected GHG reductions that will be achieved by the measures. A fourth measure, M-6, *Off-Road Equipment Efficiency*, is a more defined measure and has an identical methodology as Measures C-1-A, *Use Electric or Hybrid Powered Equipment*, in the Construction sector and N-8, *Agricultural Equipment Efficiency*, in the Natural and Working Lands sector. Measure M-6 is included in this sector because it applies to other (i.e., miscellaneous) equipment that is not used for construction or agricultural purposes. Use the graphic below to click on an individual measure to navigate directly to the measure's factsheet. *Supporting or Non-Quantified GHG Reduction Measures* includes two additional measures in the miscellaneous sector that target environmentally responsible purchasing and funding for incentives.



M-1. Establish a Carbon Sequestration Project



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions

Co-Benefits (icon key on pg. 31)

Varies

Climate Resilience

Climate resilience benefits vary by sequestration project; for example, investing in a tree-planting project could provide heat reduction, flood prevention, and ecosystem benefits to areas surrounding the project.

Health and Equity Considerations

Local carbon sequestration projects should be prioritized, if possible, to create local co-benefits in pollution reduction and job creation. Consider including a local hiring provision.

Measure Description

This measure will establish a carbon sequestration project. Carbon emissions are sequestered by embedding the carbon in a structure that will hold the emissions and keep them out of the atmosphere. Sequestration can happen through biological, chemical, or physical processes.

Scale of Application

Project/Site and Plan/Community.

Implementation Requirements

Projects might include (a) geologic sequestration or carbon capture and storage techniques in which CO_2 from point sources, such as power plants and fuel processing plants, is captured and injected underground; (b) novel techniques involving advanced chemical or biological pathways; or (c) technologies yet to be discovered.

Cost Considerations

Carbon sequestration projects can cover a wide range, with the high-cost option being constructing carbon capture and storage facilities. The potential for these projects to achieve long-term costs savings depends on the type and project-specific circumstance.

Expanded Mitigation Options

Not applicable.

GHG Reduction Formula

$A = -B$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	GHG reduction from sequestration project	[ ]	MT CO_2e	calculated
User Inputs				
B	Amount of CO_2e sequestered	[ ]	MT CO_2e	user input
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (B) – The amount of the sequestration must be defined by the user and should be quantified using a published carbon offset protocol.[43]

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions by funding and implementing a carbon sequestration project. In this example, a biomass plant is revitalized to use oxy-combustion technology to capture CO_2 from the biomass waste gasification process. The project achieves an annual emissions reduction of 1,500 MT CO_2e.

$$A = -1{,}500 \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

Depending on the type, a sequestration project could achieve improved air quality, water conservation, or improved ecosystem health. The protocol used to quantify GHG reductions by the user may include methodologies or recommendations for quantifying these co-benefits.

Sources

- None.

[43] Offset protocols for various project types are available on the Climate Action Reserve's website: https://www.climateactionreserve.org/how/protocols/. Washington Department of Ecology has approved four compliance offset protocols under Washington's Cap-and-Invest Program, which are discussed further on Ecology's website: https://ecology.wa.gov/air-climate/climate-commitment-act/cap-and-invest/offsets.

M-2. Establish Offsite Mitigation



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions

Co-Benefits (icon key on pg. 31)

Varies

Climate Resilience

Climate resilience benefits vary by the offsite mitigation project; for example, investing in a community energy efficiency retrofit program could reduce electricity consumption, minimizing risks of a power outage during peak loads. These programs could also reduce energy costs, particularly if extreme heat would otherwise increase these costs. If the program reduces residential or commercial natural gas consumption, it could reduce consumer sensitivity to fuel price shocks or scarcity.

Health and Equity Considerations

Local offsite projects should be prioritized, if possible, to create local co-benefits in pollution reduction and job creation. Consider including a local hiring provision.

Measure Description

This measure will reduce GHG emissions by funding and implementing emissions reduction actions that are not directly associated with the project or located on the project site. These actions could occur within the surrounding community, or elsewhere in the city, county, state, nation, or globe. This measure should only be pursued when all possible onsite measures have been implemented or deemed infeasible. Local reductions (i.e., reductions from GHG reduction projects nearest to the project) should be prioritized, to the extent feasible.

The geographic priority for offsite reductions should be as follows: in the community affected by the project, within nearby communities with existing disproportionate burdens, within the general nearby community, within the region, within the same state of the project, and then outside the state.

All GHG reduction credits (including carbon offsets) purchased for a project should be real, additional, quantifiable, permanent, verifiable, and enforceable. Some states have legislation that further defines acceptable criteria for GHG credits/offsets. For example, Revised Code of Washington (RCW) 70A.65.170(2) outlines criteria for compliance offsets under Washington's Cap-and-Invest Program. Colorado's Regulation 22, Colorado Greenhouse Gas Reporting and Emission Reduction Requirements, Part C (5 CCR 1001-26) likewise outlines criteria for methane credits purchased by gas distribution utilities as part of their clean heat plans. All use of GHG reduction credits should be from sources that follow rigorous protocols and third-party verification.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

This measure should only be pursued as a last resort when all possible onsite measures have been implemented or deemed infeasible.

Cost Considerations

Offsite mitigation projects can cover a wide range, from low-cost options like financing community building energy efficiency improvements to high-cost options like funding utility-scale renewable energy infrastructure. The potential for these projects to achieve long-term costs savings depends on the type and project-specific circumstance.

Expanded Mitigation Options

Not applicable.

GHG Reduction Formula

$A = -B$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	GHG reduction from the offsite mitigation	[ ]	MT CO_2e	calculated
User Inputs				
B	Amount of CO_2e reduced by the mitigation	[ ]	MT CO_2e	user input
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (B) – The amount of the GHG reduction achieved by the offsite mitigation must be defined by the user. Users should establish a method for registering and verifying the quantified GHG emissions reductions and ensure they are real, additional, permanent, and enforceable. These criteria ensure the mitigation would not subsidize or take credit for emissions reductions that would have occurred regardless of the mitigation.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions by funding and implementing offsite mitigation. In this example, the user collaborates with a non-profit organization to fund removal of dead, diseased, and dying trees, which are converted to transportation fuels through pyrolysis. The project achieves an annual emissions reduction of 500 MT CO_2e.

$$A = -500 \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

Depending on the type, offsite mitigation projects may have no co-benefits or achieve a considerable number. For example, offsite mitigation projects that involve removing or retrofitting combustion sources could achieve improved air quality, energy and fuel savings, and improved public health.

Sources

- None.

M-3. Implement an Innovative Strategy for GHG Mitigation



GHG Mitigation Potential

Varies

Variable reduction in GHG emissions

Co-Benefits (icon key on pg. 31)

Varies

Climate Resilience

Climate resilience benefits would vary by the strategy; however, any strategies that reduce costs; improve air, water quality, or public health; increase system redundancy or reliability; reduce water use; or reduce the urban heat island would have resilience benefits.

Health and Equity Considerations

Similar to climate resilience benefits, any health and equity benefits would depend on the specific strategy and actions taken.

Measure Description

This measure will develop and implement a novel strategy to reduce GHG emissions at the project site or off site. This measure may incorporate technologies that have yet to be developed at the time of the publication of this Western States Handbook. Alternatively, this measure may also bring together multiple measures from this Handbook into a cohesive program or mechanism to facilitate the reduction of GHG emissions, such as development of a "VMT bank" that offers community-scale VMT measures that would not otherwise be available to individual land use projects. For example, the San Bernardino County Transportation Authority (2025) in California is piloting a VMT bank that enables the exchange of VMT reduction credits, which can be generated by telecommuting, carpooling, active transportation, or taking transit.

It is recommended that all strategies or projects implemented under this measure meet the same criteria as defined in *Measure M-2, Establish Offsite Mitigation*, which are that the GHG reductions must be real, additional, quantifiable, permanent, verifiable, and enforceable. Quantification of emission reductions achieved by new strategies or projects should be from sources that follow rigorous protocols and third-party verification.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

See measure description.

Cost Considerations

A GHG mitigation strategy may be a low-cost way for a local government to encourage emission reduction activities across many levels of a community. Costs from developing and implementing the strategy are primarily related to staff time and document production. Costs and savings achieved by the strategy would vary depending on the action.

Expanded Mitigation Options

Not applicable.

GHG Reduction Formula

$A = -B$

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	GHG reduction from the strategy	[ ]	MT CO_2e	calculated
User Inputs				
B	Amount of CO_2e reduced	[ ]	MT CO_2e	user input
Constants, Assumptions, and Available Defaults				
	None			

Further explanation of key variables:

- (B) – The amount of the GHG reduction achieved by the mitigation strategy must be defined by the user. To take quantifiable credit for this measure, the user must provide detailed and substantial evidence showing the quantification and verification of the GHG emissions reduction.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces GHG emissions by funding and implementing an innovative GHG reductions strategy. In this example, the lead agency for a new development project collaborates with a local clean air coalition to fund a project that achieves an annual emissions reduction of 2,000 MT CO_2e.

$$A = -2{,}000 \ \frac{\text{MT } CO_2e}{\text{yr}}$$

Quantified Co-Benefits

Depending on the type, mitigation projects may result in none of the identified co-benefits or achieve several of them. For example, mitigation projects that involve removing or retrofitting combustion sources could achieve improved air quality, energy and fuel savings, and improved public health. This quantification methodology does not quantify the co-benefits from these projects.

Sources

- San Bernardino County Transportation Authority. 2025. "SBCTA Developing Pilot VMT Mitigation Bank to Support Sustainable Development." News Release, May 13, 2025. Accessed May 15, 2025. https://www.gosbcta.com/sbcta-developing-pilot-vmt-mitigation-bank-to-support-sustainable-development/.

M-6. Off-Road Equipment Efficiency



GHG Mitigation Potential



Potentially large reduction in GHG emissions from operational equipment

Co-Benefits (icon key on pg. 31)



Climate Resilience

Improving off-road equipment efficiency through use of electric- or hybrid-powered equipment can reduce sensitivity to fuel price shocks or scarcity in conventional fuels. However, using all-electric equipment may decrease resilience if it is the only option available during a power outage.

Health and Equity Considerations

Replacing diesel and gas-powered equipment electric equipment reduces the risk of pollutant-related health conditions and effects related to noise pollution for the user and surrounding communities.

Measure Description

This measure requires use of electric- or hybrid-powered off-road equipment over conventional diesel-fueled counterparts during operational activities. Replacing diesel-powered, off-road equipment with equipment that includes electric or hybrid engines reduces fossil fuel combustion and thus GHG emissions. However, all-electric equipment results in GHG emissions from the electricity used to charge the equipment. The indirect GHG emissions increase from electricity must be calculated in addition to the GHG emissions reduction from displaced fossil fuel combustion to estimate the total net GHG emissions reduction achieved by this measure if using all electric equipment. Variations of this measure are described in Measure C-1-A, *Use Electric or Hybrid Powered Equipment*, Measure N-8, *Agricultural Equipment Efficiency*, and Measure C-1-B, *Use Cleaner-Fuel Equipment*.

Scale of Application

Project/Site and Plan/Community

Implementation Requirements

Note that while this measure discusses off-road equipment used for general purposes, this measure can also be implemented for other off-road equipment applications (e.g., construction, agriculture).

Cost Considerations

Electric- or hybrid-powered equipment tends to be more expensive to purchase and install than conventional models powered by fossil fuels. These costs may be offset by savings in fuel use and maintenance.

Expanded Mitigation Options

Pair with Measure E-10, *Procure Electricity from Lower Carbon Intensity Power Supply*, to ensure that the energy supplied to power the electrified equipment has a lower carbon intensity than the local grid, thereby further reducing GHG emissions. Consider using portable batteries to support and extend implementation of this measure at more remote sites.

GHG Reduction Formula

The formula has been revised from the CAPCOA Handbook to differentiate GHG reductions achieved based on only tailpipe emissions (i.e., tank-to-wheels emissions) from those achieved from total emissions, including upstream fuel emissions (i.e., well-to-wheel emissions). Considering tank-to-wheels, all-electric equipment results in no emissions. Considering well-to-wheels, upstream GHG emissions from the electricity used to charge the equipment and to create liquid fuels must be included to estimate the total net GHG emissions reduction achieved by this measure.

$$A1 = -(C \times D \times E1 \times F) \text{ (tank-to-wheels for electric equipment)}$$

$$A2 = -(C \times D \times E2 \times F) + \left(C \times \frac{D}{G} \times H \times E3 \times I\right) \text{ (well-to-wheels for electric equipment)}$$

$$A3 = -(C \times D \times E1 \times J \times F) \text{ (tank-to-wheels for hybrid equipment)}$$

$$A4 = -(C \times D \times E2 \times J \times F) \text{ (well-to-wheels for hybrid equipment)}$$

GHG Calculation Variables

ID	Parameter	Value	Unit	Source
Output				
A1	GHG reduction from using electric equipment (tank-to-wheels)	[ ]	MT CO_2e	calculated
A2	GHG reduction from using electric equipment (well-to-wheels)	[ ]	MT CO_2e	calculated
A3	GHG reduction from using hybrid equipment (tank-to-wheels)	[ ]	MT CO_2e	calculated
A4	GHG reduction from using hybrid equipment (well-to-wheels)	[ ]	MT CO_2e	calculated
User Inputs				
B	Fuel type of existing equipment	[ ]	text	user input
C	Hours of equipment operation	[ ]	hours	user input
D	In-use horsepower of equipment[44]	[ ]	hp	User input
Constants, Assumptions, and Available Defaults				
		Table C-1-B.1	hp	U.S. EPA 2024
E1	Carbon intensity of fossil-fueled equipment (tank-to-wheels)	Table C-1-A.1 or U.S. EPA 2024	kg CO_2e per hp-hour	API 2021; U.S. DOE 2024; U.S. EPA 2018

[44] Note that in-use horsepower includes the load factor. This is distinct from the rated power of the equipment.

ID	Parameter	Value	Unit	Source
E2	Carbon intensity of fossil-fueled equipment (well-to-wheels)	Table C-1-A.1	kg CO_2e per hp-hour	API 2021; U.S. DOE 2024; U.S. EPA 2018
E3	Lifecycle carbon intensity electricity	Table E-26.3	lb CO_2e per MWh	U.S. DOE 2024
F	Conversion from kg to MT	0.001	MT per kg	conversion
G	Energy economy ratio	3.8	unitless	CARB 2020
H	Conversion from horsepower to MW	0.0007457	MW per hp	conversion
I	Conversion from lb to MT	0.000454	MT per lb	conversion
J	Percent fuel reduction of hybrid equipment compared to conventional equipment	10	%	Holian and Pyeon 2017

Further explanation of key variables:

- (B) – The fuel type of the existing equipment is used to obtain the carbon intensity of the equipment (E1 or E1).
- (C) – This input represents the hours of operation that the equipment will be used over a user-specified time period.
- (D) – The horsepower of the electric off-road equipment that is electric or hybrid will need to be provided by the user. The in-use hp values are inclusive of equipment load. Therefore, the GHG reduction equation does not include a multiplier for load factor.
- (E1) – Tank-to-wheels GHG intensity factors for gasoline and diesel-powered off-road equipment were derived from Association of Petroleum Institute's (API) (2021) *Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry* and the U.S. DOE's (2024) GREET model. The factors were related to equipment horsepower using the brake specific fuel consumption rates from the U.S. EPA (2018). Table C-1-A.1 in Appendix A presents the resulting tank-to-wheel GHG emission factors for gasoline and diesel off-road equipment less than 100 horsepower and greater than 100 horsepower. Alternatively, users may obtain tank-to-wheel GHG emission factors from the U.S. EPA's (2024) Motor Vehicle Emission Simulator (MOVES).

  The CAPCOA Handbook recommends users obtain emission factors from CARB's OFFROAD model. This model reflects activity and data specific to the California fleet and is thus not applicable outside of the state. Accordingly, this Western States Handbook recommends users apply the factors from Table C-1-A.1 or run MOVES. MOVES is maintained by the U.S. EPA and can generate emissions rates at the county-level across the nation.
- (E2) – Well-to-wheels GHG emission factors were developed using the methodology discussed above for (E1) and are presented in Table C-1-A.1. Note that MOVES cannot be used to develop alternative well-to-tank GHG emission factors.

- (E3) – Well-to-wheels GHG emission factors for WECC and SPP are provided in five year increments between 2025 and 2050 in Table E-26.3. Refer to Measure E-26, *Biomass Energy*, for additional information.
- (G) – An Energy Economy Ratio (EER) compares the efficiency of different fuels and vehicle technologies. The EER for electric forklifts as a diesel replacement is 3.8 (CARB 2020). If the user can provide an equipment-specific EER, they should replace the default in the GHG calculation formula.
- (J) – The percent fuel reduction is used in this formula as a proxy for the percent activity reduction that would be expected with hybrid off-road, heavy-duty equipment. Based on a survey of 12 models of off-road, heavy-duty equipment from 10 different manufacturers, hybrid off-road equipment reduced fuel use by 10 to 45 percent, with an average of 28 percent (Holian and Pyeon 2017). To be conservative, the low end of the range is cited. If the user can provide an equipment-specific hp, the user should replace the default in the GHG calculation formula. If the user knows the make and model of the off-road equipment used, the user should replace the default in the GHG calculation formula.

GHG Calculation Caps or Maximums

None.

Example GHG Reduction Quantification

The user reduces off-road equipment emissions by replacing fossil-fuel combustion with electricity consumption, which generates fewer GHG emissions per unit of activity. In this example of a tank-to-wheels calculation, a port is replacing a 100-hp diesel air compressor (D) that is used 8 hours per day (C) with an electric-powered equivalent. A 100-hp air compressor has an approximate tank-to-wheels carbon intensity of 0.7 kg CO_2e per hp-hour (E1).

$$A1 = -\left(8\ \frac{\text{hours}}{\text{day}} \times 100\ \text{hp} \times 0.70\ \frac{\text{kg } CO_2e}{\text{hp-hour}} \times 1e^{-3}\ \frac{\text{MT}}{\text{kg}}\right) = -0.6\ \frac{\text{MT } CO_2e}{\text{day}}$$

In this example, of a well-to-wheels calculation, the lifecycle emissions reduction is assessed for the same 100-hp diesel air compressor. The project area is in the Western Electricity Coordinating Council, and the corresponding lifecycle carbon intensity for electricity used to power the equipment is 651 lb. CO_2e per MWh for an analysis year of 2025 (E3). The well-to-wheels carbon intensity of the air compressor is 0.84 kg CO_2e per hp-hour (E2).

$$A2 = -\left(8\ \frac{\text{hours}}{\text{day}} \times 100\ \text{hp} \times 0.84\ \frac{\text{kg } CO_2e}{\text{hp-hour}} \times \times 0.001\ \frac{\text{MT}}{\text{kg}}\right) + \left(8\ \frac{\text{hours}}{\text{day}} \times \frac{100\ \text{hp}}{3.8} \times 0.0007457\ \frac{\text{MWh}}{\text{hp}} \times 651\ \frac{\text{lb. } CO_2e}{\text{MWh}} \times 0.000454\ \frac{\text{MT}}{\text{lb.}}\right) = -0.6\ \frac{\text{MT } CO_2e}{\text{day}}$$

Quantified Co-Benefits

Improved Air Quality

(Tank-to-wheels) Reducing fossil-fuel combustion will also reduce local criteria pollutants. Tank-to-wheels emission savings can be calculated using the same formula used to quantify GHG reductions (A1 and A3). Criteria pollutant intensity factors for various off-road equipment can be obtained from the U.S. EPA's (2024) MOVES.

(Well-to-wheels) The fuels produced by facilities within and outside of state will generate criteria pollutants. Because these facilities are dispersed, offsite of the project/site or plan/community, fuel production (including electricity) typically will not generate localized criteria pollutant emissions. Therefore, only the tank-to-wheels (i.e., tailpipe) portion of the vehicle criteria pollutant emissions should be quantified.

Energy and Fuel Savings

(Tank-to-wheels) Fossil fuel savings are a product of the equipment fuel efficiency (gallons consumed per hour) and the equipment operating time (hours). Fuel intensity factors for various off-road equipment can be obtained from the U.S. EPA's (2024) MOVES. Users should multiply the fuel intensity by the equipment operating hours to quantify fuel savings.

(Well-to-wheels) Fuel savings would be achieved from tank-to-wheels reductions. Additional fuel savings may occur upstream from reduced production and transport, although these likely cannot be attributed to a single project. Increased electricity consumption for electric equipment is calculated as part of the GHG reduction formula (A2). The abbreviated formula is also shown below.

$$MWh = C \times \frac{D}{K} \times H$$

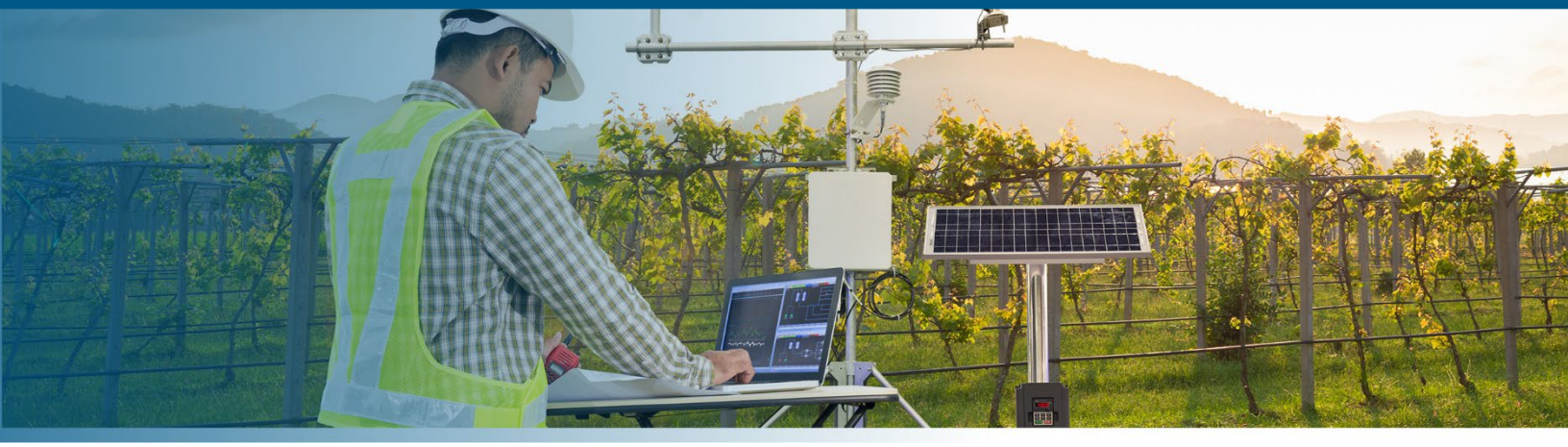
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Emission Factors and Data Tables

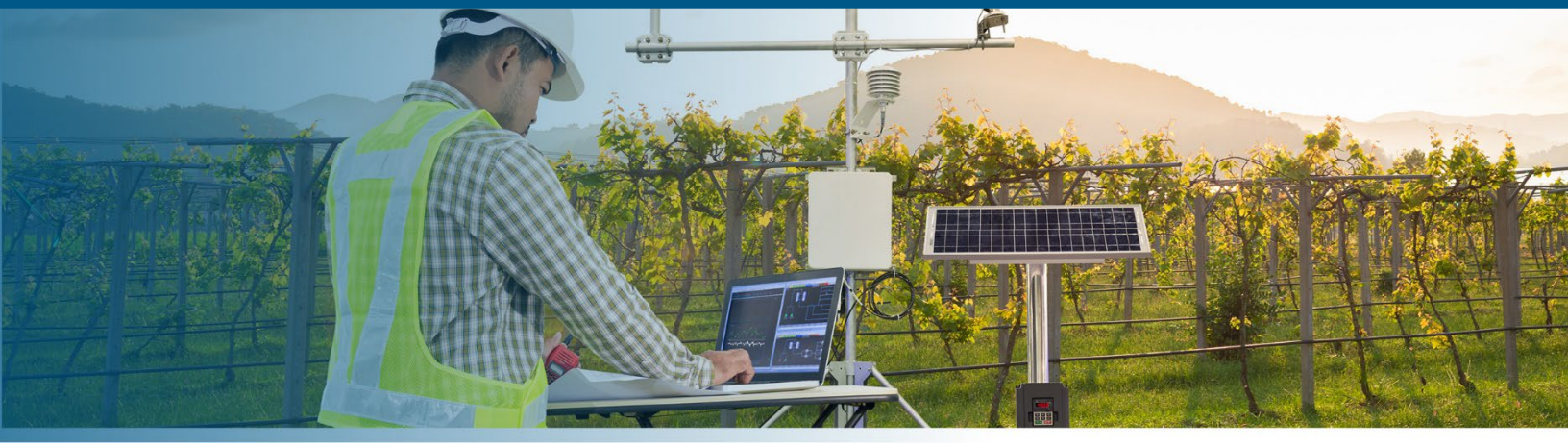
APPENDIX



This document's Appendix has been published as a separate file.

Emission Factors and Data Tables

APPENDIX



Acknowledgments

The structure of this Appendix is derived from the California Air Pollution Control Officers Association (CAPCOA) *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity*, available at CalEEMod.com.

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The CAPCOA *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity* is hosted at CalEEMod.com

ICF has adapted that document here, under permission granted by CAPCOA, to apply to the five western states that contributed to its development. We thank the staff at CAPCOA and the five states: Arizona, Colorado, New Mexico, Oregon, and Washington. The data included here is updated to default values for use by these states as of publication date.

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Release Version

This is Appendix version 1, corresponding to the final version of the Handbook for Analyzing Greenhouse Gas Emission Reductions in Western States, version 1 released August 28, 2025. Each table and figure below is ordered by the first emission reduction measure for which it is used.

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		Mode Share	
Source	Geographic Area	Transit	Vehicle
StateFocus	Denver-Aurora-Centennial, CO	2.73%	97.27%
StateFocus	Colorado Springs, CO	0.68%	99.32%
StateFocus	Fort Collins-Loveland, CO	1.19%	98.81%
StateFocus	Greeley, CO	0.45%	99.55%
StateFocus	Pueblo, CO	0.74%	99.26%
StateFocus	Grand Junction, CO	1.06%	98.94%
StateFocus	Rifle, CO	0.42%	99.58%
StateFocus	Durango, CO	0.02%	99.98%
StateFocus	Edwards, CO	0.23%	99.77%
StateFocus	Canon City, CO	0.03%	99.97%
StateFocus	Montrose, CO	0.02%	99.98%
StateFocus	Breckenridge, CO	0.06%	99.94%
StateFocus	Steamboat Springs, CO	0.09%	99.91%
StateFocus	Fort Morgan, CO	0.00%	100.00%
StateFocus	Alamosa, CO	0.03%	99.97%
StateFocus	Sterling, CO	0.00%	100.00%
Travel Study	Albany MPO, OR	2.7%	87.1%
Travel Study	Bend MPO, OR	3.3%	86.6%
Travel Study	Corvalis MPO, OR	3.3%	79.9%
Travel Study	Eugene/Springfield MPO, OR	4.7%	81.9%
Travel Study	Medford MPO, OR	3.5%	88.2%
Travel Study	Portland Metro, OR	8.6%	77.2%
2023 RTP (Metro)	Portland Metro (2023), OR	3.0%	84.0%
Travel Study	Middle Rogue MPO, OR	2.6%	92.2%
Travel Study	Salem/Keizer MPO, OR	5.4%	83.7%
Travel Study	Walla Walla Valley MPO, OR	0.6%	94.5%
FHWA 2017	Phoenix-Mesa-Scottsdale, AZ	1.41%	95.98%
FHWA 2017	Portland-Vancouver-Hillsboro, OR-WA	2.64%	94.99%
FHWA 2017	Seattle-Tacoma-Bellevue, WA	8.44%	88.74%
FHWA 2017	New Mexico (Statewide)	5.65%	93.03%
2019-2023 ACS	New Mexico (Statewide)	1.00%	N/A

Source (except Colorado, Oregon MPOs, Portland Metro 2023, and New Mexico ACS): Federal Highway Administration. 2017. *National Household Travel Survey–2017 Table Designer*. Annual Person Miles of Travel by TRPTRANS by HH_CBSA/HH_STATE. Accessed February 2025. https://nhts.ornl.gov/.

Colorado: StateFocus Travel Demand Model, provided by Colorado.

Oregon MPOs: 2010 Oregon Travel Study results, provided by Oregon. Results from the 2023-2024 Travel Study have not been released yet; status updates may be available through this resource: https://oregontravelstudy.com/.

State-collected transportation data was not available for Arizona, so all data for Arizona came from national sources such as NHTS, MOVES, or the National Transit Database; local data should be used instead if available.

Portland Metro 2023: MPO provided values sourced from its 2023 Regional Transportation Plan (RTP) in February 2025.
New Mexico: Provided additional estimate based on American Community Survey 2019-2023 data, February 2025.

Table T-8.1. Reduction in Employee Commute Vehicle Miles Traveled by Place Type

Place Type	Reduction in Employee Commute VMT
Urban	-8%
Suburban	-4%
Rural	—

Source: San Diego Association of Governments (SANDAG). 2019. Mobility Management VMT Reduction Calculator Tool–Design Document. June. Accessed January 2021.

— = measure not applicable in this place type; VMT = vehicle miles traveled.

Table T-9.1. Average Transit Mode Share of Work Trips by Geographic Scope

Source	Geographic Area	Transit Mode Share of Work Trips
StateFocus	Denver-Aurora-Centennial, CO	2.82%
StateFocus	Colorado Springs, CO	0.62%
StateFocus	Fort Collins-Loveland, CO	0.89%
StateFocus	Greeley, CO	0.31%
StateFocus	Pueblo, CO	0.49%
StateFocus	Grand Junction, CO	0.98%
StateFocus	Rifle, CO	0.48%
StateFocus	Durango, CO	0.04%
StateFocus	Edwards, CO	0.16%
StateFocus	Canon City, CO	0.01%
StateFocus	Montrose, CO	3.35%
StateFocus	Breckenridge, CO	0.06%
StateFocus	Steamboat Springs, CO	0.17%
StateFocus	Fort Morgan, CO	0.00%
StateFocus	Alamosa, CO	0.01%
StateFocus	Sterling, CO	0.00%
FHWA 2017	Phoenix-Mesa-Scottsdale, AZ	2.54%
Travel Study	Albany MPO, OR	0.3%
Travel Study	Bend MPO, OR	0.9%
Travel Study	Corvalis MPO, OR	2.3%
Travel Study	Eugene/Springfield MPO. OR	4.3%
Travel Study	Medford MPO, OR	2.0%
Travel Study	Portland Metro, OR	13.0%
Travel Study	Middle Rogue MPO, OR	0.0%
Travel Study	Salem/Keizer MPO, OR	2.5%
Travel Study	Walla Walla Valley MPO, OR	1.0%
FHWA 2017	Portland-Vancouver-Hillsboro, OR-WA	4.99%
FHWA 2017	Seattle-Tacoma-Bellevue, WA	14.11%
WA CTR Survey	Clark County, WA	0.88%

Source	Geographic Area	Transit Mode Share of Work Trips
WA CTR Survey	King County, WA	20.21%
WA CTR Survey	Pierce County, WA	1.16%
WA CTR Survey	Snohomish County, WA	2.11%
WA CTR Survey	Spokane County, WA	3.20%
WA CTR Survey	Thurston County, WA	1.41%
WA CTR Survey	Washington (Statewide)	13.04%
FHWA 2017	New Mexico (Statewide)	5.65%[a]
2019-2023 ACS	New Mexico (Statewide)	1.02%

Note: a. Due to the limited number of responses recorded in NHTS data for New Mexico, the transit mode share in New Mexico here is not limited to work trips to get a larger sample size.

Source (except Colorado areas, Washington counties, Oregon MPOs, New Mexico ACS): Federal Highway Administration. 2017. *National Household Travel Survey–2017 Table Designer*. Annual Person Miles of Travel, TRIPPURP (Work), by HH_CBSA/HH_STATE. Accessed February 2025. https://nhts.ornl.gov/.

Colorado areas: StateFocus Travel Demand Model, provided by Colorado February 2025.

Washington (county-level): Commute Trip Reduction Program Survey Cycle 2021-2022, received from Washington State February 2025.

Oregon MPOs: 2010 Oregon Travel Study results, provided by Oregon. Results from the 2023-2024 Travel Study have not been released yet; status updates may be available through this resource: https://oregontravelstudy.com/.

New Mexico: Provided additional estimate based on American Community Survey 2019-2023 data, February 2025.

Table T-10.1. Average One-Way Bicycle and Vehicle Trip Length of All Trips by Geographic Scope

		Trip Length (miles)	
Source	Geographic Area	Bicycle	Vehicle
StateFocus	Denver-Aurora-Centennial, CO	3.71	10.99
StateFocus	Colorado Springs, CO	3.44	10.07
StateFocus	Fort Collins-Loveland, CO	2.89	10.07
StateFocus	Greeley, CO	2.98	14.09
StateFocus	Pueblo, CO	2.61	10.14
StateFocus	Grand Junction, CO	2.65	9.38
StateFocus	Rifle, CO	2.00	13.28
StateFocus	Durango, CO	2.63	13.11
StateFocus	Edwards, CO	2.62	11.85
StateFocus	Canon City, CO	2.19	13.09
StateFocus	Montrose, CO	2.29	12.61
StateFocus	Breckenridge, CO	2.56	11.05
StateFocus	Steamboat Springs, CO	2.08	12.36
StateFocus	Fort Morgan, CO	1.93	13.05
StateFocus	Alamosa, CO	1.53	8.78
StateFocus	Sterling, CO	1.73	11.48
FHWA 2017	Phoenix-Mesa-Scottsdale, AZ	2.6	10.4
Travel Study	Albany MPO, OR	0.86	6.92
Travel Study	Bend MPO, OR	1.44	6.39
Travel Study	Corvalis MPO, OR	1.25	5.55
Travel Study	Eugene/Springfield MPO, OR	1.55	5.8
Travel Study	Medford MPO, OR	1.86	5.15
2023 RTP (Metro)	Portland Metro, OR	1.85	6.07
Travel Study	Portland Metro, OR	3.14	6.14
Travel Study	Middle Rogue MPO, OR	1.91	6.2
Travel Study	Salem/Keizer MPO, OR	1.3	5.79
Travel Study	Walla Walla Valley MPO, OR	0.0	8.85
FHWA 2017	Portland-Vancouver-Hillsboro, OR-WA	3.5	10.8
FHWA 2017	Seattle-Tacoma-Bellevue, WA	2.8	8.3
FHWA 2017	New Mexico (Statewide)	0.6	7.5

Source (except Colorado, Oregon MPOs, and Portland Metro): Federal Highway Administration. 2017. *National Household Travel Survey–2017 Table Designer*. Annual Person Miles of Travel divided by Annual Person Trips, by TRPTRANS by HH_CBSA/HH_STATE. Accessed February 2025. https://nhts.ornl.gov/.

Colorado areas: StateFocus Travel Demand Model, provided by Colorado February 2025.

Oregon MPOs: 2010 Oregon Travel Study results, provided by Oregon. Results from the 2023-2024 Travel Study have not been released yet as of this publication; status updates may be available through this resource: https://oregontravelstudy.com/.

Portland Metro: MPO provided values sourced from their 2023 Regional Transportation Plan (RTP) in February 2025.

Table T-10.2. Average Bicycle and Vehicle Mode Share of Work Trips by Geographic Scope

		Mode Share	
Source	Geographic Area	Bicycle	Vehicle
StateFocus	Denver Regional Council of Governments, CO	4.32%	95.68%
StateFocus	Grand Valley MPO, CO	5.29%	94.71%
StateFocus	North Front Range MPO, CO	4.49%	95.51%
StateFocus	Pikes Peak Area Council of Governments, CO	4.31%	95.69%
StateFocus	Pueblo MPO, CO	5.07%	94.93%
FHWA 2017	Phoenix-Mesa-Scottsdale, AZ	0.1%	96.8%
Travel Study	Albany MPO, OR	1.3%	82.7%
Travel Study	Bend MPO, OR	5.7%	84.4%
Travel Study	Corvalis MPO, OR	13.9%	78.1%
Travel Study	Eugene/Springfield MPO, OR	8.8%	82.5%
Travel Study	Medford MPO, OR	5.4%	89%
Travel Study	Portland Metro, OR	5.5%	76.1%
Travel Study	Middle Rogue MPO, OR	0.6%	97.0%
Travel Study	Salem/Keizer MPO, OR	2.4%	90.6%
Travel Study	Walla Walla Valley MPO, OR	0.0%	93.2%
FHWA 2017	Portland-Vancouver-Hillsboro, OR-WA	1.5%	93.5%
FHWA 2017	Seattle-Tacoma-Bellevue, WA	1.0%	84.2%
WA CTR Survey	Clark County, WA	0.67%	95.52%
WA CTR Survey	King County, WA	3.95%	67.51%
WA CTR Survey	Pierce County, WA	0.65%	96.60%
WA CTR Survey	Snohomish County, WA	0.89%	94.56%
WA CTR Survey	Spokane County, WA	0.84%	92.17%
WA CTR Survey	Thurston County, WA	1.71%	83.01%
FHWA 2017	Washington (Statewide)	2.73%	77.60%
FHWA 2017	New Mexico (Statewide)	0.00%	78.18%
ACS 2019-2023	New Mexico (Statewide)	0.64%	89.11%

Source (except Colorado, Washington counties, Oregon MPOs, and New Mexico ACS): Federal Highway Administration. 2017. *National Household Travel Survey–2017 Table Designer*. Annual Person Miles of Travel by TRIPPURP (Work) by HH_CBSA/HH_STATE. Accessed February 2025. https://nhts.ornl.gov/.

Colorado: StateFocus Travel Demand Model, provided by Colorado.

Washington (county-level): Commute Trip Reduction Program Survey Cycle 2021-2022, received from Washington State February 2025.

Oregon MPOs: 2010 Oregon Travel Study results, provided by Oregon. Results from the 2023-2024 Travel Study have not been released yet as of this publication; status updates may be available through this resource: https://oregontravelstudy.com/.

New Mexico: Provided additional estimate based on American Community Survey 2019-2023 data, February 2025.

Table T-11.1. Average One-Way Vehicle Commute Trip Length by Geographic Scope

Source	State	Geographic Area	Vehicle Trip Length (miles)
StateFocus	CO	Denver-Aurora-Centennial, CO	11.7
StateFocus	CO	Colorado Springs, CO	10.7
StateFocus	CO	Fort Collins-Loveland, CO	11.9
StateFocus	CO	Greeley, CO	15.4
StateFocus	CO	Pueblo, CO	12.1
StateFocus	CO	Grand Junction, CO	11.9
StateFocus	CO	Rifle, CO	18.5
StateFocus	CO	Durango, CO	16.2
StateFocus	CO	Edwards, CO	14.2
StateFocus	CO	Canon City, CO	14.3
StateFocus	CO	Montrose, CO	16.3
StateFocus	CO	Breckenridge, CO	11.9
StateFocus	CO	Steamboat Springs, CO	13.8
StateFocus	CO	Fort Morgan, CO	14.4
StateFocus	CO	Alamosa, CO	10.3
StateFocus	CO	Sterling, CO	12.2
FHWA 2017	AZ	Phoenix-Mesa-Scottsdale, AZ	13.97
FHWA 2017	OR-WA	Portland-Vancouver-Hillsboro, OR-WA	11.51
Travel Study	OR	Albany MPO, OR	12.11
Travel Study	OR	Bend MPO, OR	7.81
Travel Study	OR	Corvalis MPO, OR	10.84
Travel Study	OR	Eugene/Springfield MPO. OR	8.81
Travel Study	OR	Medford MPO, OR	9.01
Travel Study	OR	Portland Metro, OR	9.97
Travel Study	OR	Middle Rogue MPO, OR	7.40
Travel Study	OR	Salem/Keizer MPO, OR	9.41
Travel Study	OR	Walla Walla Valley MPO, OR	5.53
FHWA 2017	WA	Seattle-Tacoma-Bellevue, WA	12.17
FHWA 2017	NM	New Mexico (Statewide)	10.97

Source (except Colorado and Oregon MPOs): Federal Highway Administration. 2017. *National Household Travel Survey–2017 Table Designer*. Annual Person Miles of Travel divided by Annual Person Trips, by TRPTRANS by TRIPPURP (Work) by HH_CBSA/HH_STATE. Accessed February 2025. https://nhts.ornl.gov/.

Colorado: StateFocus Travel Demand Model, provided by Colorado.

Oregon MPOs: 2010 Oregon Travel Study results, provided by Oregon. Results from the 2023-2024 Travel Study have not been released yet; status updates may be available through this resource: https://oregontravelstudy.com/.

Table T-11.2. Average Emission Factor for Employee Commuter Vehicles

State	Value (g CO2e per mile)
Washington	366.6
Oregon	394.3
Colorado	347.9
New Mexico	360.8
Arizona	380.0

Source (except Colorado, Oregon): U.S. Environmental Protection Agency (EPA). 2024. Motor Vehicle Emission Simulator: MOVES5. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024.

Colorado: Provided value based on state values processed through MOVES5.

Oregon: Provided county-level MOVES 5 input databases. Processed to determine values.

Table T-11.3. Average Emission Factor for Vanpool Vehicles

Data Source	State	Value (g CO2e per mile)
Default MOVES5	WA	734.707
Default MOVES5	OR	732.375
State-provided values	OR	750.100
Default MOVES5	CO	732.369
State-provided values	CO	409.8
Default MOVES5	NM	722.443
Default MOVES5	AZ	748.683

Source (except Colorado): U.S. Environmental Protection Agency (EPA). 2024. Motor Vehicle Emission Simulator: MOVES5. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024.

Colorado: Provided value based on state values processed through MOVES5.

Oregon: Provided county-level MOVES 5 input databases. Processed to determine values.

Table T-11.4. Average Fuel Efficiency of Employee Commuter Vehicle and Vanpool Vehicle

State	Fuel Efficiency of Average Employee Vehicle (gallon of gasoline equivalent per mile)	Fuel Efficiency of Vanpool Vehicle (gallon of gasoline equivalent per mile)
Washington	0.0433	0.0484
Oregon	0.0432	0.0482
Colorado	0.0431	0.0482
New Mexico	0.0426	0.0474
Arizona	0.0449	0.0501

Source: U.S. Environmental Protection Agency (EPA). 2024. Motor Vehicle Emission Simulator: MOVES5. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024.

Table T-11.5. Vanpool Commute Length

Geographic Area	Average Length of One-way Vanpool Commute Trip (miles per trip)
Washington	26.8
Oregon	28.8
Colorado	40.2
Denver Regional Council of Governments	51.56
New Mexico	22.5
Arizona	42.1

Source (all except New Mexico, Denver Regional Council of Governments): U.S. Department of Transportation Federal Transit Administration. *National Transit Database 2023-2024*. Accessed February 2025. https://www.transit.dot.gov/ntd/data-product/monthly-module-adjusted-data-release.

New Mexico: Provided values through correspondence in February 2025.

Denver Regional Council of Governments: Colorado DOT provided values through correspondence in February 2025.

Table T-11.6. Average Vanpool Occupancy

Geographic Area	Average Vanpool Occupancy (including driver) (occupants)
Washington	7.1
Oregon	5.4
Colorado	5.35
Denver Regional Council of Governments	5.07
New Mexico	5.2
Arizona	9.2

Source (Oregon, Colorado, Arizona): U.S. Department of Transportation Federal Transit Administration. *National Transit Database 2023-2024*. Accessed February 2025. https://www.transit.dot.gov/ntd/data-product/monthly-module-adjusted-data-release.

Washington: WSDOT provided values through correspondence in February 2025.

New Mexico: NMDOT provided values through correspondence in February 2025.

Denver Regional Council of Governments: CDOT provided values through correspondence in February 2025.

Table T-14.1. Average Emission Factor of Light-Duty Vehicles

State	Average Well-to-Wheel Emission Factor of Non-Electric Vehicles Accessing the Site (g CO2e per mile)
Washington	524.2
Oregon	523.2
Colorado	521.4
New Mexico	515.6
Arizona	543.4

Source (except Colorado, Oregon): U.S. Environmental Protection Agency (EPA). 2024. Motor Vehicle Emission Simulator: MOVES5. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024. Default database values were used in a state-level MOVES5 run.

Argonne National Laboratory. 2025. Research and Development (R&D) GREET Life Cycle Assessment Model. Accessed March 2025. https://www.energy.gov/eere/rd-greet-life-cycle-assessment-model.

Colorado: CDOT provided values through correspondence in February 2025. Corrected to include GREET upstream emissions from GREET.

Oregon: Provided county-level MOVES 5 input databases. Processed to determine statewide values. Correction was made to include upstream emissions from GREET.

Table T-14.2 Average Light-Duty BEV Efficiency

State	Light-Duty BEV Efficiency (kWh per mile)
Washington	0.396
Oregon	0.392
Colorado	0.397
New Mexico	0.391
Arizona	0.384

Source: U.S. Environmental Protection Agency (EPA). 2024. Motor Vehicle Emission Simulator: MOVES5. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024. For chargers used by heavy-duty vehicles, consult Table T-30.1. All MOVES5 default values.

Table T-15. Commute VMT Fraction

Geographic Area	Percent of Household VMT (Commute Based) (%)
Seattle-Tacoma-Bellevue, WA	39%
Portland-Vancouver-Hillsboro, OR-WA	37%
Spokane-Spokane Valley, WA	35%
Salem, OR	39%
Eugene-Springfield, OR	34%
Kennewick-Richland, WA	38%
Phoenix-Mesa-Chandler, AZ	38%
Denver-Aurora-Lakewood, CO	39%
Tucson, AZ	35%
Albuquerque, NM	37%
Colorado Springs, CO	41%
Greeley, CO	43%
Fort Collins, CO	38%
Prescott Valley-Prescott, AZ	40%
Boulder, CO	34%
Lake Havasu City-Kingman, AZ	37%
Flagstaff, AZ	33%
Las Cruces, NM	34%
Yuma, AZ	36%
Santa Fe, NM	32%
Sierra Vista-Douglas, AZ	30%
Farmington, NM	31%
Pueblo, CO	39%
Grand Junction, CO	34%

Source: Replica Data from spring 2024.

Table T-16.1. Typical Monthly Parking Prices by Facility Type

Facility Type	Monthly Cost per Space
Suburban, Surface	$36
Urban, Surface	$65
Urban, Structure	$133
Urban, Underground	$191

Source: Litman, T. 2020. *Parking Requirement Impacts on Housing Affordability*. Victoria Transport Policy Institute. June 2020. Accessed January 2021. https://www.vtpi.org/park-hou.pdf.

Table T-19.1. Active Transportation Adjustment Factors

Average Daily Traffic (vehicle trips per day)	One-way Facility Length[1]	Adjustment Factor for a Population > 250,000 or a Non-university Town with Population < 250,000	Adjustment Factor for a University Town with Population <250,000
1 to 12,000	≤1	0.0019	0.0104
	1.02 to 2	0.0029	0.0155
	>2	0.0038	0.0207
12,001 to 24,000	≤1	0.0014	0.0073
	1.02 to 2	0.0020	0.0109
	>2	0.0027	0.0145
24,001 to 30,000	≤1	0.0010	0.0052
	1.02 to 2	0.0014	0.0078
	>2	0.0019	0.0104

Source: California Air Resources Board. 2020. Quantification Methodology for the Strategic Growth Council's Affordable Housing and Sustainable Communities Program. September 2020. Accessed March 2025. https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/carb_clean-mobility-qm_draft_july2023.pdf.

< = less than; > = greater than; ≤ = less than or equal to

[1]Measurements of bike facilities should not include the length of crosswalks.

Table T-19.2. Key Destination Credits[1,2]

Number of Key Destinations[3]	Credit within ½ Mile of Facility	Credit within ¼ Mile of Facility
0 to 2	0.0000	0.000
3	0.0005	0.001
4 to 6	0.0010	0.002
≥ 7	0.0015	0.003

Source: California Air Resources Board. 2020. *Quantification Methodology for the California Natural Resources Agency Urban Greening Grant Program*. March 2020. Accessed January 2021. https://ww2.arb.ca.gov/sites/default/files/classic/cc/capandtrade/auctionproceeds/cnra_ug_finalqm.pdf.

≥ = greater than or equal to

[1] The largest value from either credit column that matches the project activities should be used. For example, if there are 3 activity centers within ¼ mile of the facility and 7 activity centers within ½ mile of the facility, the correct value to use is 0.0015.

[2] These metrics should be evaluated for the project location site and surrounding area, which can extend a distance not to exceed a ½ mile. If a shopping center has multiple activity centers, each of those activity centers would count individually. For example, if a bank, grocery store, and post office are all located in a shopping center, they would be input as three activity centers for the purposes of this quantification methodology.

[3] Key destination examples: banks, post offices, grocery stores, medical centers, pharmacies, office parks, places of worship, public libraries, schools, universities, colleges, and light rail stations (park & ride).

Table T-19.3. Growth Factor Adjustment

Facility Type	Growth Factor Adjustment
New Class I Bike Path[1] or Class IV Bikeway[2]	1.54
New Class II Bike Lane[3]	1.0
Conversion from Class II to IV	0.54

Source: California Air Resources Board. 2020. *Quantification Methodology for the Strategic Growth Council's Affordable Housing and Sustainable Communities Program.* September 2020. Accessed March 2021. https://ww2.arb.ca.gov/sites/default/files/classic/cc/capandtrade/auctionproceeds/sgc_ahsc_qm_022521.pdf.

[1] Class I bike paths are physically separated from motor vehicle traffic.

[2] Class IV bikeways are protected on-street bikeways, also called cycle tracks.

[3] Class II bike lanes are striped bicycle lanes that provide exclusive use to bicycles on a roadway.

Table T-19.4. Bike Facility Default Days of Use per Year

		Estimated Yearly Days in Use			
State	WFO	2021	2022	2023	Overall
Arizona	FGZ	298	287	335	307
Arizona	PSR	279	302	337	306
Arizona	TWC	294	295	332	307
Arizona	VEF	330	315	349	331
Colorado	BOU	309	296	308	304
Colorado	GJT	280	272	291	281
Colorado	GLD	335	321	326	327
Colorado	PUB	276	279	298	284
New Mexico	ABQ	266	237	276	260
New Mexico	EPZ	334	333	348	338
New Mexico	MAF	343	349	344	345
Oregon	BOI	357	358	356	357
Oregon	MFR	321	339	339	333
Oregon	PDT	340	326	345	337
Oregon	PQR	328	326	351	335
Washington	OTX	324	310	325	320
Washington	PDT	343	332	360	345
Washington	PQR	342	346	354	347
Washington	SEW	327	337	355	340

Source: National Oceanic and Atmospheric Administration. Storm Events Database 2021-2023. https://www.ncei.noaa.gov/pub/data/swdi/stormevents/csvfiles/. Event types excluded: Astronomical low tide, cold/wind chill, drought, dust devil, frost/freeze, funnel cloud, heat, high surf, lake effect snow, marine dense fog, marine hail, marine high wind, marine strong wind, marine thunderstorm wind, marine tropical depression, rip current, seiche, sleet, tropical depression, waterspout, and winter weather. Days impacted by included events were subtracted from 365 to estimate yearly days in use by weather forecast office (WFO).

Table T-20.1. Bicycle Mode Share of All Trips by Geographic Scope

Source	State	Geographic Area	Bicycle Mode Share
StateFocus	CO	Denver-Aurora-Centennial	2.89%
StateFocus	CO	Colorado Springs	3.52%
StateFocus	CO	Fort Collins-Loveland	3.23%
StateFocus	CO	Greeley	4.38%
StateFocus	CO	Pueblo	3.17%
StateFocus	CO	Grand Junction	3.81%
StateFocus	CO	Rifle	4.62%
StateFocus	CO	Durango	5.45%
StateFocus	CO	Edwards	4.87%
StateFocus	CO	Canon City	3.81%
StateFocus	CO	Montrose	4.94%
StateFocus	CO	Breckenridge	4.50%
StateFocus	CO	Steamboat Springs	5.58%
StateFocus	CO	Fort Morgan	3.69%
StateFocus	CO	Alamosa	4.18%
StateFocus	CO	Sterling	3.54%
FHWA 2017	AZ	Phoenix-Mesa-Scottsdale CBSA	1.54%
FHWA 2017	OR-WA	Portland-Vancouver-Hillsboro CBSA	2.47%
FHWA 2017	WA	Seattle-Tacoma-Bellevue CBSA	1.34%
Travel Study	OR	Albany MPO	1.50%
Travel Study	OR	Bend MPO	3.50%
Travel Study	OR	Corvallis MPO	7.40%
Travel Study	OR	Eugene/Springfield MPO	4.40%
Travel Study	OR	Medford MPO	2.10%
Travel Study	OR	Portland Metro MPO	2.80%
2023 RTP Metro	OR	Portland Metro MPO	5.50%
Travel Study	OR	Middle Rogue MPO	0.60%
Travel Study	OR	Salem/Keizer MPO	1.10%
Travel Study	OR	Walla Walla Valley MPO	0.20%
Provided value	NM	Statewide	0.12%
FHWA 2017	NM	Statewide	2.44%
FHWA 2017	AZ	Statewide	1.45%
FHWA 2017	CO	Statewide	2.50%
FHWA 2017	OR	Statewide	2.30%
FHWA 2017	WA	Statewide	1.15%

Source (except Colorado, Oregon MPOs, Portland Metro 2023, and New Mexico estimate): Federal Highway Administration. 2017. *National Household Travel Survey–2017 Table Designer*. Annual Person Miles of Travel by TRPTRANS by HH_CBSA/HH_STATE. Accessed February 2025. https://nhts.ornl.gov/.

Colorado: StateFocus Travel Demand Model, provided by Colorado.

Oregon MPOs: 2010 Oregon Travel Study results, provided by Oregon. Results from the 2023-2024 Travel Study have not been released yet; status updates may be available through this resource: https://oregontravelstudy.com/.

Portland Metro 2023: MPO provided values sourced from their 2023 Regional Transportation Plan (RTP) in February 2025.

New Mexico: Provided estimated value based on scaling bicycle travel commute mode share to all trips in February 2025.

Table T-22.1. Shared Micromobility Trips per Resident

Source	City	State	Population	Bikeshare	Scooter Share	Overall Shared Micromobility
Ride Report	Phoenix	AZ	1,608,139	0.000010	0.00058	0.00059
Ride Report	Tempe	AZ	180,587	N/A	0.0078	0.0078
Ride Report	Fort Collins	CO	169,810	0.00066	0.0032	0.0038
CDOT	Denver	CO	715,522	N/A	N/A	0.024
Ride Report	Denver	CO	715,522	0.0019	0.017	0.019
Ride Report	Boulder	CO	108,250	0.012	0.0086	0.012
Ride Report	Aurora	CO	386,261	N/A	0.00010	0.00010
Ride Report	Thornton	CO	141,867	N/A	0.00023	0.00023
Ride Report	Brighton	CO	40,083	N/A	0.00048	0.00048
Ride Report	Littleton	CO	45,652	N/A	0.00053	0.00053
Ride Report	Arvada	CO	124,402	N/A	0.00068	0.00068
Ride Report	Colorado Springs	CO	478,961	N/A	0.0013	0.0013
Ride Report	Portland	OR	652,500	0.0022	0.0046	0.0068
City of Seattle	Seattle	WA	737,015	0.0033	0.012	0.016
Ride Report	Spokane	WA	228,989	0.00024	0.0054	0.0055
N/A	Overall Average			0.0066	0.0045	0.0054

Source (all except Seattle and Denver): Ride Report, 2021-2023 data as available by city. Average daily trips divided by number of city residents. https://public.ridereport.com.
Seattle: Scooter and Bike Share Data Dashboard. https://www.seattle.gov/transportation/projects-and-programs/programs/new-mobility-program/scooter-bike-share-data.
Denver: Colorado DOT provided values through correspondence in February 2025.

Table T-22.2. Bikeshare and Scooter Share Average Trip Lengths

City	State	Population	Bikeshare (miles)	Scooter Share (miles)	Overall Shared Micromobility (miles)
Arvada	CO	124,402	N/A	1.09	1.09
Aurora	CO	386,261	N/A	1.32	1.42
Boulder	CO	108,250	2.65	0.98	1.17
Brighton	CO	40,083	N/A	1.13	1.13
Colorado Springs	CO	478,961	N/A	1.32	1.32
Denver	CO	715,522	1.48	1.17	1.20
Fort Collins	CO	169,810	1.51	1.37	1.39
Littleton	CO	45,652	N/A	1.10	1.10
Phoenix	AZ	1,608,139	1.45	1.02	1.02
Portland	OR	652,500	1.88	1.26	1.46
Seattle	WA	737,015	1.50	1.00	N/A
Spokane	WA	228,989	1.28	1.13	1.11
Tempe	AZ	180,587	N/A	1.86	1.86
Thornton	CO	141,867	N/A	1.27	1.27
Overall Average			1.68	1.22	1.27

Source (all except Seattle): Ride Report, 2021-2023 data as available by city. Average daily trips divided by number of city residents. https://public.ridereport.com.

Seattle: Scooter and Bike Share Data Dashboard. https://www.seattle.gov/transportation/projects-and-programs/programs/new-mobility-program/scooter-bike-share-data.

Table T-25.1. Mode Shift Factor by Geographic Scope

Geographic Area	Mode Shift Factor
Arizona	73.5%
Colorado	71.4%
Oregon	62.9%
New Mexico	56.8%
Washington	61.7%
Portland Metro	73.0%

Source (except Colorado and Portland Metro): Federal Highway Administration. 2017. *National Household Travel Survey–2017 Table Designer*. Average Vehicle Occupancy by HH_STATE. Accessed February 2025. https://nhts.ornl.gov/.

Colorado: CDOT provided values through correspondence in February 2025.

Portland Metro: MPO provided values sourced from its 2023 Regional Transportation Plan (RTP) in February 2025.

Table T-26.1. Transit Bus Fuel Economy by Fuel Type

Fuel Type	AZ	CO	NM	OR	WA	Unit
Gasoline	0.155	0.156	0.157	0.156	0.156	gal/mile
Diesel	0.166	0.167	0.170	0.167	0.167	gal/mile
Natural gas[1]	0.143	0.144	0.147	0.144	0.144	gal/mile
Electric[2]	0.521	0.504	0.533	0.510	0.505	kWh/mile

Source: U.S. Environmental Protection Agency (EPA). 2024. Motor Vehicle Emission Simulator: MOVES5. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024.

gal = gallon; kWh = kilowatt hour

[1] Natural gas fuel economy is based on a conversion of natural gas fuel consumption to gallons of gasoline equivalent.

Table T-30.1. Battery Electric Vehicle Efficiency by Vehicle Type

Vehicle Type	AZ (kWh/mile)	CO (kWh/mile)	NM (kWh/mile)	OR (kWh/mile)	WA (kWh/mile)
Combination Long-Haul Truck	3.17	3.29	3.13	3.25	3.28
Combination Short-Haul Truck	2.85	2.94	2.78	2.90	2.94
Other Buses	2.55	2.63	2.48	2.59	2.63
Passenger Car	0.32	0.33	0.32	0.32	0.33
Passenger Truck	0.45	0.46	0.45	0.45	0.46
Refuse Truck	1.82	1.88	1.78	1.86	1.88
School Bus	1.25	1.29	1.21	1.27	1.29
Single Unit Long-haul Truck	0.97	1.01	0.96	1.00	1.01
Single Unit Short-haul Truck	0.93	0.96	0.92	0.95	0.96
Transit Bus	1.92	1.98	1.88	1.96	1.98

Source: U.S. Environmental Protection Agency (U.S. EPA). 2024. Motor Vehicle Emission Simulator: MOVES5. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024. Default values.

Table T-30.2. Vehicle Fuel Efficiency, Energy Density, and Well-to-Wheels Carbon Intensity and Emission Factor by Vehicle Category and Fuel Type

Lifecycle carbon emissions from electricity are not provided for each state, as they vary by utility. To calculate those emission factors in units of grams per mile, take the relevant electricity emissions factor value for power generation measured at the plug from Tables E-4.5 through E-4.10 for the appropriate utility, convert units, and multiply by the fuel efficiency for the relevant vehicle type.

EV Lifecycle Emission Factor (g/mi)=$EF_{Electricity}$ (lb/MWh) ×453.6 g/lb×(1MWh/1000 kWh)×Vehicle Fuel Efficiency (kWh/mi)

Arizona (AZ):

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
Combination Long-Haul Truck	CNG[4]	5.2	mpgge	120.3	MJ/GGE	71.3	1,648.3	2,028.4
	Diesel	6.1	mpg	137.1	MJ/gal	76.5	1,706.7	2,067.0
	EV	3.2	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Combination Short-Haul Truck	CNG[4]	4.7	mpgge	120.3	MJ/GGE	77.4	1,972.6	2,391.7
	Diesel	6.3	mpg	137.1	MJ/gal	76.8	1,685.4	2,039.5
	EV	2.8	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.6	mpg	120.3	MJ/gal	73.7	1,569.8	2,151.6
Other Buses	CNG[4]	4.6	mpgge	120.3	MJ/GGE	81.1	2,125.8	2,556.7
	Diesel	6.1	mpg	137.1	MJ/gal	76.1	1,711.1	2,074.3
	EV	2.5	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.3	mpg	120.3	MJ/gal	72.9	1,668.5	2,293.4
Passenger Car	Diesel	27.1	mpg	137.1	MJ/gal	74.4	376.3	458.0
	E-85	19.7	mpg	93.8	MJ/gal	71.5	340.2	565.5
	EV	0.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	26.4	mpg	120.3	MJ/gal	73.0	332.9	457.4
Passenger Truck	Diesel	18.0	mpg	137.1	MJ/gal	75.5	576.7	700.1
	E-85	15.7	mpg	93.8	MJ/gal	71.5	428.1	711.7

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
	EV	0.4	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	20.6	mpg	120.3	MJ/gal	73.1	427.1	586.6
Refuse Truck	CNG[4]	4.2	mpgge	120.3	MJ/GGE	84.6	2,400.6	2,867.2
	Diesel	6.0	mpg	137.1	MJ/gal	76.6	1,760.3	2,131.3
	EV	1.8	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	6.3	mpg	120.3	MJ/gal	73.7	1,404.8	1,925.2
School Bus	CNG[4]	5.5	mpgge	120.3	MJ/GGE	86.8	1,893.3	2,252.0
	Diesel	8.3	mpg	137.1	MJ/gal	76.5	1,268.2	1,535.9
	EV	1.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	6.7	mpg	120.3	MJ/gal	72.9	1,308.3	1,798.2
Single Unit Long-haul Truck	CNG[4]	5.5	mpgge	120.3	MJ/GGE	82.9	1,808.6	2,167.2
	Diesel	12.4	mpg	137.1	MJ/gal	76.7	850.6	1,029.5
	EV	1.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	9.2	mpg	120.3	MJ/gal	72.9	950.2	1,306.3
Single Unit Short-haul Truck	CNG[4]	5.2	mpgge	120.3	MJ/GGE	86.8	2,026.5	2,410.4
	Diesel	11.4	mpg	137.1	MJ/gal	76.7	923.2	1,117.6
	EV	0.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	8.7	mpg	120.3	MJ/gal	73.4	1,016.0	1,393.8
Transit Bus	CNG[4]	4.8	mpgge	120.3	MJ/GGE	81.4	2,054.1	2,469.1
	Diesel	6.3	mpg	137.1	MJ/gal	76.7	1,662.6	2,012.5
	EV	1.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.2	mpg	120.3	MJ/gal	72.9	1,690.4	2,323.8

Colorado (CO):

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
Combination Long-Haul Truck	CNG[4]	5.2	mpgge	120.3	MJ/GGE	71.2	1,637.9	2,015.9
	Diesel	6.2	mpg	137.1	MJ/gal	76.5	1,700.4	2,059.4
	EV	3.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Combination Short-Haul Truck	CNG[4]	4.8	mpgge	120.3	MJ/GGE	77.0	1,947.8	2,363.4
	Diesel	6.3	mpg	137.1	MJ/gal	76.9	1,674.9	2,026.9
	EV	2.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.7	mpg	120.3	MJ/gal	73.7	1,560.9	2,139.3
Other Buses	CNG[4]	4.6	mpgge	120.3	MJ/GGE	80.7	2,089.8	2,515.7
	Diesel	6.1	mpg	137.1	MJ/gal	76.1	1,697.1	2,057.3
	EV	2.6	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.3	mpg	120.3	MJ/gal	72.9	1,662.1	2,284.5
Passenger Car	Diesel	28.5	mpg	137.1	MJ/gal	74.5	358.8	430.4
	E-85	20.6	mpg	93.8	MJ/gal	71.6	326.2	542.1
	EV	0.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	27.5	mpg	120.3	MJ/gal	73.1	319.1	420.7
Passenger Truck	Diesel	18.9	mpg	137.1	MJ/gal	75.6	548.4	654.9
	E-85	16.3	mpg	93.8	MJ/gal	71.6	410.8	682.8
	EV	0.5	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	21.5	mpg	120.3	MJ/gal	73.1	409.4	523.4
Refuse Truck	CNG[4]	4.3	mpgge	120.3	MJ/GGE	84.1	2,359.0	2,820.2
	Diesel	6.0	mpg	137.1	MJ/gal	76.6	1,746.2	2,114.3
	EV	1.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
School Bus	Gasoline	6.3	mpg	120.3	MJ/gal	73.7	1,397.8	1,915.8
	CNG[4]	5.6	mpgge	120.3	MJ/GGE	86.3	1,858.2	2,212.0
	Diesel	8.4	mpg	137.1	MJ/gal	76.5	1,237.9	1,520.4
	EV	1.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Single Unit Long-haul Truck	Gasoline	6.8	mpg	120.3	MJ/gal	72.9	1,296.4	1,781.9
	CNG[4]	5.6	mpgge	120.3	MJ/GGE	82.6	1,771.7	2,124.4
	Diesel	12.5	mpg	137.1	MJ/gal	76.8	844.3	1,021.9
	EV	1.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Single Unit Short-haul Truck	Gasoline	9.3	mpg	120.3	MJ/gal	72.9	942.3	1,295.4
	CNG[4]	5.2	mpgge	120.3	MJ/GGE	86.5	1,984.2	2,361.2
	Diesel	11.5	mpg	137.1	MJ/gal	76.8	917.6	1,110.4
	EV	1.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Transit Bus	Gasoline	8.8	mpg	120.3	MJ/gal	73.4	1,008.6	1,383.7
	CNG[4]	4.8	mpgge	120.3	MJ/GGE	81.0	2,025.3	2,436.2
	Diesel	6.4	mpg	137.1	MJ/gal	76.7	1,650.2	1,997.4
	EV	2.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.2	mpg	120.3	MJ/gal	72.9	1,683.8	2,314.8

New Mexico (NM):

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
Combination Long-Haul Truck	CNG[4]	5.3	mpgge	120.3	MJ/GGE	70.7	1,600.8	1,973.0
	Diesel	6.2	mpg	137.1	MJ/gal	76.5	1,685.3	2041.0
	EV	3.1	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Combination Short-Haul Truck	CNG[4]	4.8	mpgge	120.3	MJ/GGE	76.2	1,889.0	2,296.7
	Diesel	6.4	mpg	137.1	MJ/gal	76.8	1,653.9	2,001.3
	EV	2.8	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.7	mpg	120.3	MJ/gal	73.6	1,542.2	2,114.1
Other Buses	CNG[4]	4.8	mpgge	120.3	MJ/GGE	79.4	2,003.9	2,418.8
	Diesel	6.2	mpg	137.1	MJ/gal	76.1	1,669.0	2,023.3
	EV	2.5	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.3	mpg	120.3	MJ/gal	72.9	1,649.9	2,267.9
Passenger Car	Diesel	28.8	mpg	137.1	MJ/gal	74.5	354.4	431.2
	E-85	20.9	mpg	93.8	MJ/gal	71.6	321.5	534.3
	EV	0.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	28.0	mpg	120.3	MJ/gal	73.1	314.5	432.0
Passenger Truck	Diesel	19.3	mpg	137.1	MJ/gal	75.6	537.9	652.8
	E-85	16.6	mpg	93.8	MJ/gal	71.6	403.6	670.8
	EV	0.4	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	21.9	mpg	120.3	MJ/gal	73.1	402.1	552.3
Refuse Truck	CNG[4]	4.4	mpgge	120.3	MJ/GGE	82.8	2,266.0	2,715.8
	Diesel	6.1	mpg	137.1	MJ/gal	76.6	1,720.2	2,082.8
	EV	1.8	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
School Bus	Gasoline	6.4	mpg	120.3	MJ/gal	73.6	1,377.3	1,888.1
	CNG[4]	5.8	mpgge	120.3	MJ/GGE	84.9	1,765.7	2,107.4
	Diesel	8.6	mpg	137.1	MJ/gal	76.5	1,226.2	1,485.0
	EV	1.2	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Single Unit Long-haul Truck	Gasoline	6.9	mpg	120.3	MJ/gal	72.9	1,263.8	1,737.1
	CNG[4]	5.8	mpgge	120.3	MJ/GGE	81.8	1,688.7	2,028.1
	Diesel	12.7	mpg	137.1	MJ/gal	76.8	831.0	1,005.9
	EV	1.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Single Unit Short-haul Truck	Gasoline	9.5	mpg	120.3	MJ/gal	72.9	924.3	1,270.7
	CNG[4]	5.5	mpgge	120.3	MJ/GGE	85.4	1,872.4	2,233.0
	Diesel	11.7	mpg	137.1	MJ/gal	76.8	899.4	1,088.5
	EV	0.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Transit Bus	Gasoline	9.0	mpg	120.3	MJ/gal	73.4	983.3	1,349.3
	CNG[4]	4.9	mpgge	120.3	MJ/GGE	80.0	1,958.6	2,361.1
	Diesel	6.5	mpg	137.1	MJ/gal	76.7	1,628.1	1,970.6
	EV	1.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.2	mpg	120.3	MJ/gal	72.9	1,675.1	2,302.9

Oregon (OR):

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
Combination Long-Haul Truck	CNG[4]	5.3	mpgge	120.3	MJ/GGE	71.1	1805.7	2,005.0
	Diesel	6.2	mpg	137.1	MJ/gal	76.5	1722.8	2,055.7
	EV	3.2	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Combination Short-Haul Truck	CNG[4]	4.8	mpgge	120.3	MJ/GGE	76.9	2140.2	2,355.8
	Diesel	6.3	mpg	137.1	MJ/gal	76.9	1734.9	2,024.3
	EV	2.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.7	mpg	120.3	MJ/gal	73.7	1564.6	2,136.7
Other Buses	CNG[4]	4.6	mpgge	120.3	MJ/GGE	80.6	2087.3	2,510.6
	Diesel	6.2	mpg	137.1	MJ/gal	76.1	1724.0	2,054.9
	EV	2.6	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.3	mpg	120.3	MJ/gal	72.9	1693.6	2,281.5
Passenger Car	Diesel	28.3	mpg	137.1	MJ/gal	74.5	374.2	438.5
	E-85	20.5	mpg	93.8	MJ/gal	71.6	338.1	544.4
	EV	0.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	27.4	mpg	120.3	MJ/gal	73.1	340.5	440.1
Passenger Truck	Diesel	18.9	mpg	137.1	MJ/gal	75.6	614.9	666.4
	E-85	16.3	mpg	93.8	MJ/gal	71.6	436.5	682.9
	EV	0.5	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	21.5	mpg	120.3	MJ/gal	73.1	451.1	562.4
Refuse Truck	CNG[4]	4.3	mpgge	120.3	MJ/GGE	84.1	2209.5	2,815.7
	Diesel	6.0	mpg	137.1	MJ/gal	76.6	1790.8	2,112.3
	EV	1.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
School Bus	Gasoline	6.3	mpg	120.3	MJ/gal	73.7	1329.0	1,914.3
	CNG[4]	5.6	mpgge	120.3	MJ/GGE	86.2	1699.0	2,200.3
	Diesel	8.4	mpg	137.1	MJ/gal	76.5	1254.9	1,517.0
	EV	1.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Single Unit Long-haul Truck	Gasoline	6.8	mpg	120.3	MJ/gal	72.9	1296.4	1,777.0
	CNG[4]	5.6	mpgge	120.3	MJ/GGE	82.5	1724.4	2,115.9
	Diesel	12.5	mpg	137.1	MJ/gal	76.8	872.4	1,020.5
	EV	1.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Single Unit Short-haul Truck	Gasoline	9.3	mpg	120.3	MJ/gal	72.9	965.9	1,293.1
	CNG[4]	5.3	mpgge	120.3	MJ/GGE	86.4	1879.3	2,352.4
	Diesel	11.5	mpg	137.1	MJ/gal	76.8	934.7	1,108.3
	EV	0.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Transit Bus	Gasoline	8.8	mpg	120.3	MJ/gal	73.4	1022.6	1,380.2
	CNG[4]	4.8	mpgge	120.3	MJ/GGE	81.0	2052.8	2,435.8
	Diesel	6.4	mpg	137.1	MJ/gal	76.7	1681.4	1,998.3
	EV	2.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.2	mpg	120.3	MJ/gal	72.9	1647.2	2,314.4

Washington (WA):

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
Combination Long-Haul Truck	CNG[4]	5.2	mpgge	120.3	MJ/GGE	71.2	1,638.5	2,016.8
	Diesel	6.2	mpg	137.1	MJ/gal	76.5	1,701.3	2,060.5
	EV	3.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Combination Short-Haul Truck	CNG[4]	4.8	mpgge	120.3	MJ/GGE	77.1	1,949.2	2,365.1
	Diesel	6.3	mpg	137.1	MJ/gal	76.9	1,676.2	2,028.4
	EV	2.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.7	mpg	120.3	MJ/gal	73.7	1,562.4	2,141.4
Other Buses	CNG[4]	4.6	mpgge	120.3	MJ/GGE	80.7	2,092.5	2,518.9
	Diesel	6.1	mpg	137.1	MJ/gal	76.1	1,699.8	2,060.5
	EV	2.6	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.3	mpg	120.3	MJ/gal	72.9	1,664.8	2,288.3
Passenger Car	Diesel	28.3	mpg	137.1	MJ/gal	74.5	360.6	438.8
	E-85	20.5	mpg	93.8	MJ/gal	71.6	328.1	545.1
	EV	0.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	27.4	mpg	120.3	MJ/gal	73.1	320.8	440.6
Passenger Truck	Diesel	18.8	mpg	137.1	MJ/gal	75.6	551.4	669.1
	E-85	16.3	mpg	93.8	MJ/gal	71.6	413.4	687.0
	EV	0.5	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	21.4	mpg	120.3	MJ/gal	73.1	411.9	565.6
Refuse Truck	CNG[4]	4.3	mpgge	120.3	MJ/GGE	84.1	2,361.2	2,822.8
	Diesel	6.0	mpg	137.1	MJ/gal	76.6	1,748.7	2,117.3
	EV	1.9	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10

Vehicle Type	Fuel Type	Fuel Efficiency		Energy Density		Carbon Intensity (CO_2e/MJ)[1]	Tailpipe Emission Factor (g CO_2e /mile)[2]	Lifecycle Emission Factor (g CO_2e /mile)[3]
		Value	Units	Value	Units			
School Bus	Gasoline	6.3	mpg	120.3	MJ/gal	73.7	1,398.1	1,916.2
	CNG[4]	5.6	mpgge	120.3	MJ/GGE	86.4	1,860.9	2,215.2
	Diesel	8.3	mpg	137.1	MJ/gal	76.5	1,257.5	1,522.9
	EV	1.3	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Single Unit Long-haul Truck	Gasoline	6.8	mpg	120.3	MJ/gal	72.9	1,298.6	1,784.9
	CNG[4]	5.6	mpgge	120.3	MJ/GGE	82.6	1,775.3	2,128.6
	Diesel	12.5	mpg	137.1	MJ/gal	76.8	845.2	1,023.0
	EV	1.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Single Unit Short-haul Truck	Gasoline	9.3	mpg	120.3	MJ/gal	72.9	943.3	1,296.7
	CNG[4]	5.2	mpgge	120.3	MJ/GGE	86.6	1,986.7	2,364.0
	Diesel	11.5	mpg	137.1	MJ/gal	76.8	918.9	1,112.0
	EV	1.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
Transit Bus	Gasoline	8.7	mpg	120.3	MJ/gal	73.4	1,009.8	1,385.3
	CNG[4]	4.8	mpgge	120.3	MJ/GGE	81.0	2,027.0	2,438.3
	Diesel	6.4	mpg	137.1	MJ/gal	76.7	1,652.1	1,999.8
	EV	2.0	kWh/mile	3.6	MJ/kWh	0.0	0.0	Modify Tables E-4.5-E-4.10
	Gasoline	5.2	mpg	120.3	MJ/gal	72.9	1,686.5	2,318.5

Source: U.S. Environmental Protections Agency (EPA). 2024. Motor Vehicle Emission Simulator: MOVES5. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Ann Arbor, MI. November 2024.

U.S. Department of Energy. 2024. R&D GREET 2024 Model. Energy Systems and Infrastructure Analysis. Argonne National Laboratory. Argonne, IL. July 2024.

Colorado School Bus Emission Factor (Diesel): CDOT provided value through correspondence in February 2025.

Oregon provided MOVES county input databases, which were used and then aggregated to the state level instead of using national defaults.

[1]Carbon intensity values are derived from MOVES5 state runs and therefore only consider tailpipe emissions. Thus, electric vehicles are shown to have zero carbon intensity. Full lifecycle values will compare emissions from electricity generation and distribution, which can be compared to that from other fuels.

[2]Taillpipe emission factors are also derived from MOVES5 state runs for 2025, which consider the direct emissions from the consumption of fossil fuels from the vehicle and consider emissions from starting, running, and idling.

[3]Lifecycle emissions factors are based off the 2025 tailpipe factors from MOVES5 with additional upstream emissions from R&D GREET 2024 for the same year. They consider emissions from the vehicle's use phase, the fuel's production, distribution, and sales. They do not consider emissions from vehicle manufacturing or vehicle end-of-life activities (such as disposal, reuse and recycling).
[4]CNG is shown in units of GGE, as that is how it is sold at filling stations. This was assumed to be 114,000 BTU.

Table T-40.1. School Bus Occupancy

Location	Average Student Occupancy of School Buses (students per bus)
Arizona	8.76
Colorado	11.7
New Mexico	8.76
Oregon	7.2
Washington	7.3

Source: School Bus Fleet Magazine. 2025. "U.S. State-by-State School Transportation Statistics 2023-24." Accessed February 2025. https://www.schoolbusfleet.com/management/10233821/u-s-state-by-state-school-transportation-statistics-2023-24.

Table T-56.1. Percent of Students within Walking/Biking Distance to School

Location	Percent	Notes
Oregon	33%	One-mile threshold
California	62%	Two-mile threshold
Denver CBSA	31%	One-mile threshold
Phoenix CBSA	26%	One-mile threshold
Portland CBSA	16%	One-mile threshold
Seattle CBSA	12%	One-mile threshold
Denver CBSA	43%	Two-mile threshold
Phoenix CBSA	38%	Two-mile threshold
Portland CBSA	63%	Two-mile threshold
Seattle CBSA	30%	Two-mile threshold

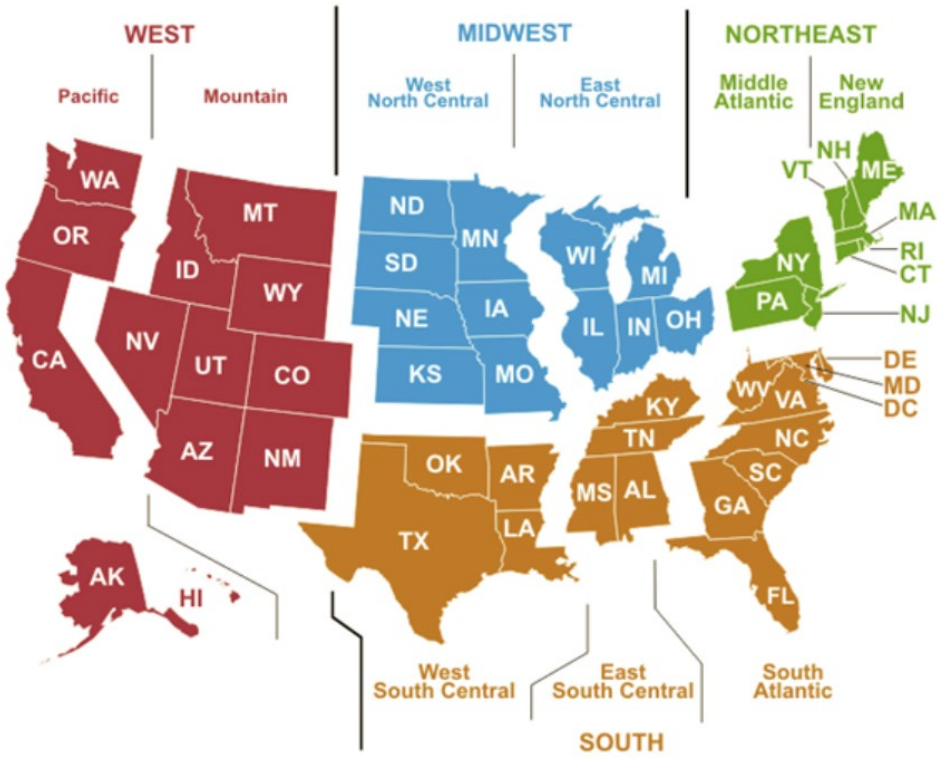
Sources: Data from Oregon provided by ODOT using its travel model. The remaining data are from the *National Household Travel Survey*. Sample sizes for the NHTS are quite small; school surveys will provide much better accuracy.

Table T-56.2. Percent of Students within Walking/Biking Distance Who Are Driven to School

Location	Percent	Notes
Oregon	20%	One-mile threshold
California	51%	Two-mile threshold
Denver CBSA	43%	One-mile threshold
Phoenix CBSA	33%	One-mile threshold
Portland CBSA	50%	One-mile threshold
Seattle CBSA	81%	One-mile threshold
Denver CBSA	51%	Two-mile threshold
Phoenix CBSA	53%	Two-mile threshold
Portland CBSA	65%	Two-mile threshold
Seattle CBSA	50%	Two-mile threshold

Sources: Data from Oregon provided by ODOT using its travel model. California data are from a report by the Safe Routes to Schools Partnership, and the remaining data are from the *National Household Travel Survey*. Sample sizes are quite small; school surveys will provide much better accuracy.

Figure E-2.1. Census Regions and Divisions for U.S. EIA Residential and Non-Residential Energy Data



Region	Division	States
Northeast	New England	Connecticut, Maine, Massachusetts, New Hampshire, Vermont, and Rhode Island
	Middle Atlantic	New Jersey, New York, and Pennsylvania
Midwest	East North Central	Illinois, Indiana, Michigan, Ohio, and Wisconsin
	West North Central	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota
South	South Atlantic	Delaware, the District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia
	East South Central	Alabama, Kentucky, Mississippi, and Tennessee
	West South Central	Arkansas, Louisiana, Oklahoma, and Texas
West	Mountain*	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming
	Pacific	Alaska, California, Hawaii, Oregon, and Washington

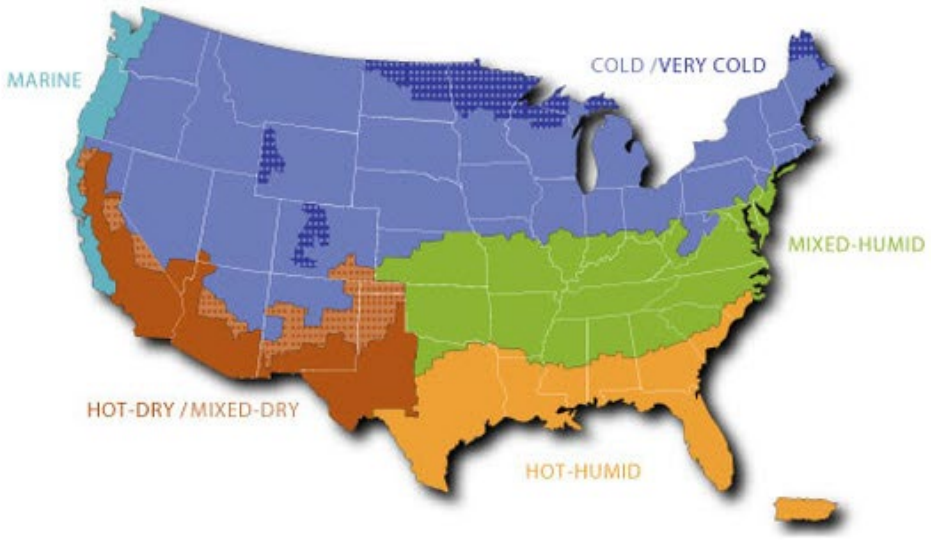
*Mountain South: Arizona, Nevada, and New Mexico; Mountain North: Colorado, Idaho, Montana, Utah, and Wyoming

Sources: U.S. Energy Information Administration (EIA). 2025a. *Residential Energy Consumption Survey (RECS) Terminology*. Accessed February 4, 2025. https://www.eia.gov/consumption/residential/terminology.php.

U.S. Energy Information Administration (EIA). 2025b. *Commercial Buildings Energy Consumption Survey (CBECS) Maps*. Accessed February 4, 2025. https://www.eia.gov/consumption/commercial/maps.php.

Note: The map is applicable to analyses being conducted using end-use energy consumption data from the U.S. EIA's RECS or CBECS. Energy data are provided in Tables E-2.2 through E-2.5 and E-15.1 and E-15.2 for U.S. Census regions and divisions covering the western states.

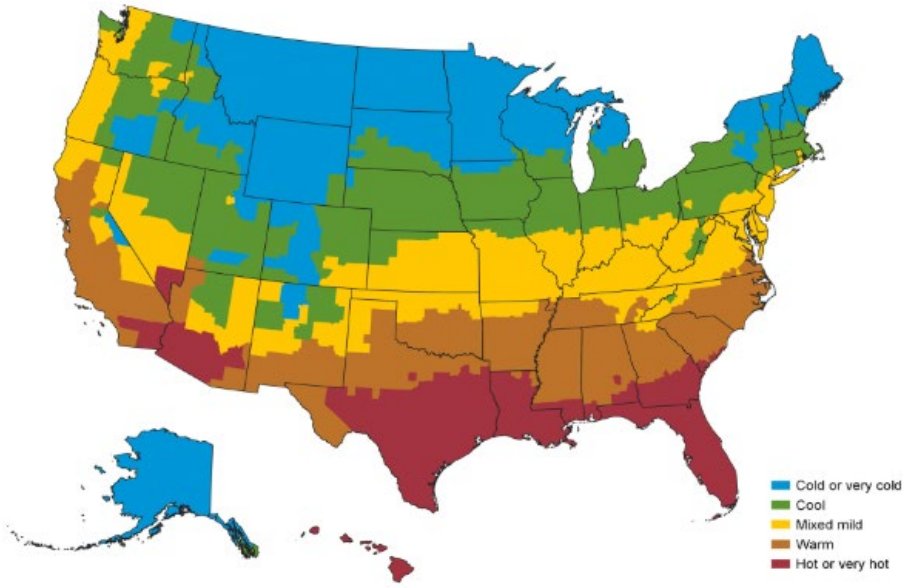
Figure E-2.2. Climate Zones for U.S. EIA Residential Energy Data



Source: U.S. Energy Information Administration (EIA). 2025. *Residential Energy Consumption Survey (RECS) Maps*. Accessed February 4, 2025. https://www.eia.gov/consumption/residential/maps.php.

Note: The map is applicable to analyses being conducted using end-use energy consumption data from the U.S. EIA's RECS. Residential energy data are provided in Tables E-2.2, E-2.4, and E-15.1 for climate zones covering the western states.

Figure E-2.3. Climate Zones for U.S. EIA Non-Residential Energy Data



Source: U.S. Energy Information Administration (EIA). 2025. *Commercial Buildings Energy Consumption Survey (CBECS) Maps*. Accessed February 4, 2025. https://www.eia.gov/consumption/commercial/maps.php.

Note: The map is applicable to analyses being conducted using end-use energy consumption data from the U.S. EIA's CBECS. Non-residential energy data are provided in Tables E-2.3, E-2.5, and E-15.2 for climate zones covering the western states.

Table E-2.1. Electricity Reduction of ENERGY STAR Appliance Compared to Conventional Appliance

Appliance Type	Electricity Reduction (%)
Commercial Refrigerator	-20%
Residential Refrigerator	-9%
Clothes Washer	-25%
Dishwasher	-12%
Ceiling Fan	-60%

Sources: ENERGY STAR. 2025a. "Refrigerators." Accessed February 4, 2025. https://www.energystar.gov/products/refrigerators.

ENERGY STAR. 2025b. "Commercial Refrigerators & Freezers." Accessed February 4, 2025. https://www.energystar.gov/products/commercial_refrigerators_freezers.

ENERGY STAR. 2025c. "Certified Residential Clothes Washers." Accessed February 4, 2025. https://www.energystar.gov/productfinder/product/certified-clothes-washers/results.

ENERGY STAR. 2025d. "Ceiling Fans." Accessed February 4, 2025. https://www.energystar.gov/products/ceiling_fans.

U.S. Department of Energy (DOE). 2025. "Dishwashers." Accessed February 4, 2024. https://www.energy.gov/energysaver/dishwashers#:~:text=An%20ENERGY%20STAR%20certified%20dishwasher,the%20best%20in%20energy%20savings.

Table E-2.2. Percent of Total Residential Building Electricity by Appliance and Housing Type (national average)

Housing Type	Residential Refrigerator	Clothes Washer	Dishwasher	Ceiling Fan
Single-Family Detached	7.8%	0.6%	0.8%	1.7%
Single-Family Attached	8.9%	0.6%	0.8%	1.4%
Apartments in Buildings with 2–4 Units	8.5%	0.5%	0.5%	1.1%
Apartments in Buildings with 5 or More Units	8.8%	0.4%	0.9%	1.3%
Mobile Homes	5.8%	0.6%	0.4%	1.3%

Source: U.S. Energy Information Administration (EIA). 2023. *Residential Energy Consumption Survey (RECS)*. Table CE2.1: Annual household site fuel consumption in the U.S.—totals and averages, 2020. Table CE5.1a: Detailed household site electricity end-use consumption, part 1—totals, 2020. Table CE5.1b: Detailed household site electricity end-use consumption, part 2—totals, 2020. Accessed January 2025. https://www.eia.gov/consumption/residential/data/2020/.

Table E-2.3. Percent of Total Non-Residential Building Electricity for Commercial Refrigerators by Building Type (national data)

Building Type	Commercial Refrigerator
Education	5%
Food Sales	48%
Food Service	26%
Health Care	4%
Inpatient	5%
Outpatient	3%
Lodging	8%
Mercantile	12%
Retail (other than mall)	7%
Enclosed and Strip Malls	15%
Office	3%
Public Assembly	7%
Public Order and Safety	5%
Religious Worship	7%
Service	2%
Warehouse and Storage	11%
Other	1%
Vacant	n/a

Source: U.S. Energy Information Administration (EIA). 2022. *Commercial Buildings Energy Consumption Survey (CBECS)*. Table B20: Energy sources, floorspace, 2018. Table E5: Electricity consumption (in kilowatt-hours [kWh]) by end use, 2018. Accessed January 2025. https://www.eia.gov/consumption/commercial/data/2018/.

Table E-2.4. Percent of Total Residential Building Electricity by Appliance Type and U.S. EIA Census Region/Division and Climate Zone (all housing types)

U.S. EIA Area	Residential Refrigerator	Clothes Washer	Dishwasher	Ceiling Fan
Census Region/Division				
West	9.7%	0.6%	0.9%	1.2%
Mountain	8.4%	0.6%	0.8%	1.4%
Mountain North	9.8%	0.7%	1.2%	1.2%
Mountain South	7.3%	0.5%	0.7%	1.6%
Pacific	10.6%	0.6%	1.0%	1.1%
Climate Zone				
Very Cold and Cold	8.9%	0.6%	0.9%	1.1%
Mixed-Dry and Hot-Dry	10.0%	0.6%	0.8%	1.6%
Marine	9.1%	0.5%	1.0%	0.5%

Source: U.S. Energy Information Administration (EIA). 2023. *Residential Energy Consumption Survey (RECS)*. Table CE2.1: Annual household site fuel consumption in the U.S.—totals and averages, 2020. Table CE5.1a: Detailed household site electricity end-use consumption, part 1—totals, 2020. Table CE5.1b: Detailed household site electricity end-use consumption, part 2—totals, 2020. Accessed January 2025. https://www.eia.gov/consumption/residential/data/2020/.

Table E-2.5. Percent of Total Non-Residential Building Electricity for Commercial Refrigerators by U.S. EIA Census Region/Division and Climate Zone (all building types)

U.S. EIA Area	Commercial Refrigerator
Census Region/Division	
West	11.2%
Mountain	11.6%
Pacific	10.9%
Climate Zone	
Cold or Very Cold	11.5%
Cool	9.4%
Mixed Mild	7.5%
Warm	9.4%
Hot or Very Hot	8.7%

Source: U.S. Energy Information Administration (EIA). 2022. *Commercial Buildings Energy Consumption Survey (CBECS)*. Table B20: Energy sources, floorspace, 2018. Table E5: Electricity consumption (in kilowatt-hours [kWh]) by end use, 2018. Accessed January 2025. https://www.eia.gov/consumption/commercial/data/2018/.

Table E-3-A.1. Average Annual Fuel Use and Savings by Boiler Type for Residential Boilers

	Annual Fuel Use		
AFUE by Boiler Type[1, 2]	Total (mmBTU/yr)[3]	Savings (mmBTU/yr)	Change (%)
Gas-fired[4] Hot Water Boiler			
84% (Standard)	82.1	—	—
85%	81.1	1.0	-1.2%
90%	75.2	6.9	-8.4%
92%	73.6	8.5	-10.4%
96% (Max Tech)	70.6	11.5	-14.0%
Gas-fired Steam Boiler			
82% (Standard)	83.9	—	—
83% (Max Tech)	82.9	1.0	-1.2%
Oil-fired Hot Water Boiler			
86% (Standard)	84.3	—	—
91% (Max Tech)	80.1	4.2	-5.0%
Oil-fired Steam Boiler			
85% (Standard)	82.9	—	—
86% (Max Tech)	81.9	1.0	-1.2%

Source: U.S. Department of Energy (U.S. DOE). 2015. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Boilers*. March 2015. Accessed March 2025. https://www.regulations.gov/document/EERE-2012-BT-STD-0047-0036.

AFUE = Annual fuel utilization efficiency; mmBTU = 1 million British Thermal Units; yr = year

[1] "Standard" refers to the minimum AFUE required by the 2016 Conservation Standards for Residential Boilers.

[2] "Max Tech" refers to the maximum technologically feasible improvement in energy efficiency determined by DOE for each type of boiler.

[3] The average annual fuel use is based on historical consumption data.

[4] Gas-fired boilers refer to boilers that use natural gas and/or propane as fuel.

Table E-3-B.1. Average Annual Fuel Use and Savings for Boilers Installed Before January 10, 2023 for Commercial and Industrial Boilers

	Annual Fuel Use		
CE or TE by Boiler Type[1, 2]	Total (mmBTU/yr)[3]	Savings (mmBTU/yr)	Change (%)
Gas-fired Hot Water Boiler (≥300,000 BTU/hr and ≤2,500,000 BTU/hr)			
80% TE (Standard)	907.7	—	—
81% TE	896.3	11.4	-1.3%
82% TE	885.2	22.6	-2.5%
84% TE	863.7	44.0	-4.8%
85% TE	853.4	54.4	-6.0%
93% TE	815.7	92.0	-10.1%
95% TE	797.3	110.4	-12.2%
99% TE (Max Tech)	762.9	144.8	-16.0%
Gas-fired Hot Water Boiler (≥2,500,000 BTU/hr and ≤10,000,000 BTU/hr)			
82% CE (Standard)	6,008.8	—	—
83% CE	5,929.9	78.9	-1.3%
84% CE	5,853.1	155.7	-2.6%
85% CE	5,778.3	230.5	-3.8%
94% CE	5,442.5	566.3	-9.4%
97% CE (Max Tech)	5,252.2	756.6	-12.6%
Oil-fired Hot Water Boiler (≥300,000 BTU/hr and ≤2,500,000 BTU/hr)			
82% TE (Standard)	807.3	—	—
83% TE	797.4	9.9	-1.2%
84% TE	787.8	19.5	-2.4%
85% TE	778.4	28.9	-3.6%
87% TE	760.2	47.1	-5.8%
88% TE	751.5	55.8	-6.9%
97% TE (Max Tech)	709.5	97.8	-12.1%
Oil-fired Hot Water Boiler (≥2,500,000 BTU/hr and ≤10,000,000 BTU/hr)			
84% CE (Standard)	3,119.1	—	—
86% CE	3,047.7	71.4	-2.3%
88% CE	2,979.5	139.6	-4.5%
89% CE	2,946.5	172.6	-5.5%
97% CE (Max Tech)	2,854.2	264.9	-8.5%
Gas-fired Steam Boiler (≥300,000 BTU/hr and ≤2,500,000 BTU/hr)			
77% TE (Standard)	787.0	—	—
78% TE	776.7	10.3	-1.3%
79% TE	766.7	20.3	-2.6%
80% TE	757.0	30.0	-3.8%
81% TE	747.4	39.6	-5.0%
83% TE (Max Tech)	729.1	57.9	-7.4%

Table E-3-B.1. Average Annual Fuel Use and Savings for Boilers Installed Before January 10, 2023 for Commercial and Industrial Boilers (cont.)

CE or TE by Boiler Type[1, 2]	Annual Fuel Use		
	Total (mmBTU/yr)[3]	Savings (mmBTU/yr)	Change (%)
Gas-fired Steam Boiler (≥2,500,000 BTU/hr and ≤10,000,000 BTU/hr)			
77% TE (Standard)	4,956.9	—	—
78% TE	4,892.1	64.8	-1.3%
79% TE	4,829.0	127.9	-2.6%
80% TE	4,767.5	189.4	-3.8%
81% TE	4,707.6	249.3	-5.0%
82% TE	4,649.1	307.8	-6.2%
84% TE (Max Tech)	4,536.4	420.5	-8.5%
Oil-fired Steam Boiler (≥300,000 BTU/hr and ≤2,500,000 BTU/hr)			
81% TE (Standard)	845.7	—	—
83% TE	825.0	20.7	-2.4%
84% TE	815.0	30.7	-3.6%
86% TE (Max Tech)	795.8	49.9	-5.9%
Oil-fired Steam Boiler (≥2,500,000 BTU/hr and ≤10,000,000 BTU/hr)			
81% TE (Standard)	3,730.3	—	—
83% TE	3,639.0	91.3	-2.4%
85% TE	3,552.1	178.2	-4.8%
87% (Max Tech)	3,469.2	261.1	-7.0%

Source: U.S. Department of Energy (U.S. DOE). 2016. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Packaged Boilers*. December 2016. Accessed January 2025. https://www.regulations.gov/docket?D=EERE-2013-BT-STD-0030.

CE = combustion efficiency; mmBTU = 1 million British Thermal Unit; TE = thermal efficiency; yr = year; BTU = British Thermal Unit; ≥ = greater than or equal to; ≤ = less than or equal to

[1] "Standard" refers to the minimum CE or TE required by the 2012 Conservation Standards for Commercial Packaged Boilers.

[2] "Max Tech" refers to the maximum technologically feasible improvement in energy efficiency determined by DOE for each type of boiler.

[3] The average annual fuel use is based on historical consumption data.

Table E-3-B.2. Average Annual Fuel Use and Savings for Boilers Installed on or After January 10, 2023

	Annual Fuel Use		
CE or TE by Boiler Type[1, 2]	Total (mmBTU/yr)[3]	Savings (mmBTU/yr)	Change (%)
Gas-fired Hot Water Boiler (≥300,000 BTU/hr and ≤2,500,000 BTU/hr)			
84% TE (Standard)	863.7	—	—
85% TE	853.4	10.3	-1.2%
93% TE	815.7	48.0	-5.6%
95% TE	797.3	66.4	-7.7%
99% TE (Max Tech)	762.9	100.8	-11.7%
Gas-fired Hot Water Boiler (≥2,500,000 BTU/hr and ≤10,000,000 BTU/hr)			
85% CE (Standard)	5,778.3	—	—
94% CE	5,442.5	335.8	-5.8%
97% CE (Max Tech)	5,252.2	526.1	-9.1%
Oil-fired Hot Water Boiler (≥300,000 BTU/hr and ≤2,500,000 BTU/hr)			
87% TE (Standard)	760.2	—	—
88% TE	751.5	8.7	-1.1%
97% TE (Max Tech)	709.5	50.7	-6.7%
Oil-fired Hot Water Boiler (≥2,500,000 BTU/hr and ≤10,000,000 BTU/hr)			
88% CE (Standard)	2,979.5	—	—
89% CE	2,946.5	33.0	-1.1%
97% CE (Max Tech)	2,854.2	125.3	-4.2%
Gas-fired Steam Boiler (≥300,000 BTU/hr and ≤2,500,000 BTU/hr)			
81% TE (Standard)	747.4	—	—
83% TE (Max Tech)	729.1	18.3	-2.4%
Gas-fired Steam Boiler (≥2,500,000 BTU/hr and ≤10,000,000 BTU/hr)			
82% TE (Standard)	4,649.1	—	—
84% TE (Max Tech)	4,536.4	112.7	-2.4%
Oil-fired Steam Boiler (≥300,000 BTU/hr and ≤2,500,000 BTU/hr)			
84% TE (Standard)	815.0	—	—
86% TE (Max Tech)	795.8	19.2	-2.4%
Oil-fired Steam Boiler (≥2,500,000 BTU/hr and ≤10,000,000 BTU/hr)			
81% TE (Standard)	3,730.3	—	—
83% TE	3,639.0	91.3	-2.4%
85% TE	3,552.1	178.2	-4.8%
87% (Max Tech)	3,469.2	261.1	-7.0%

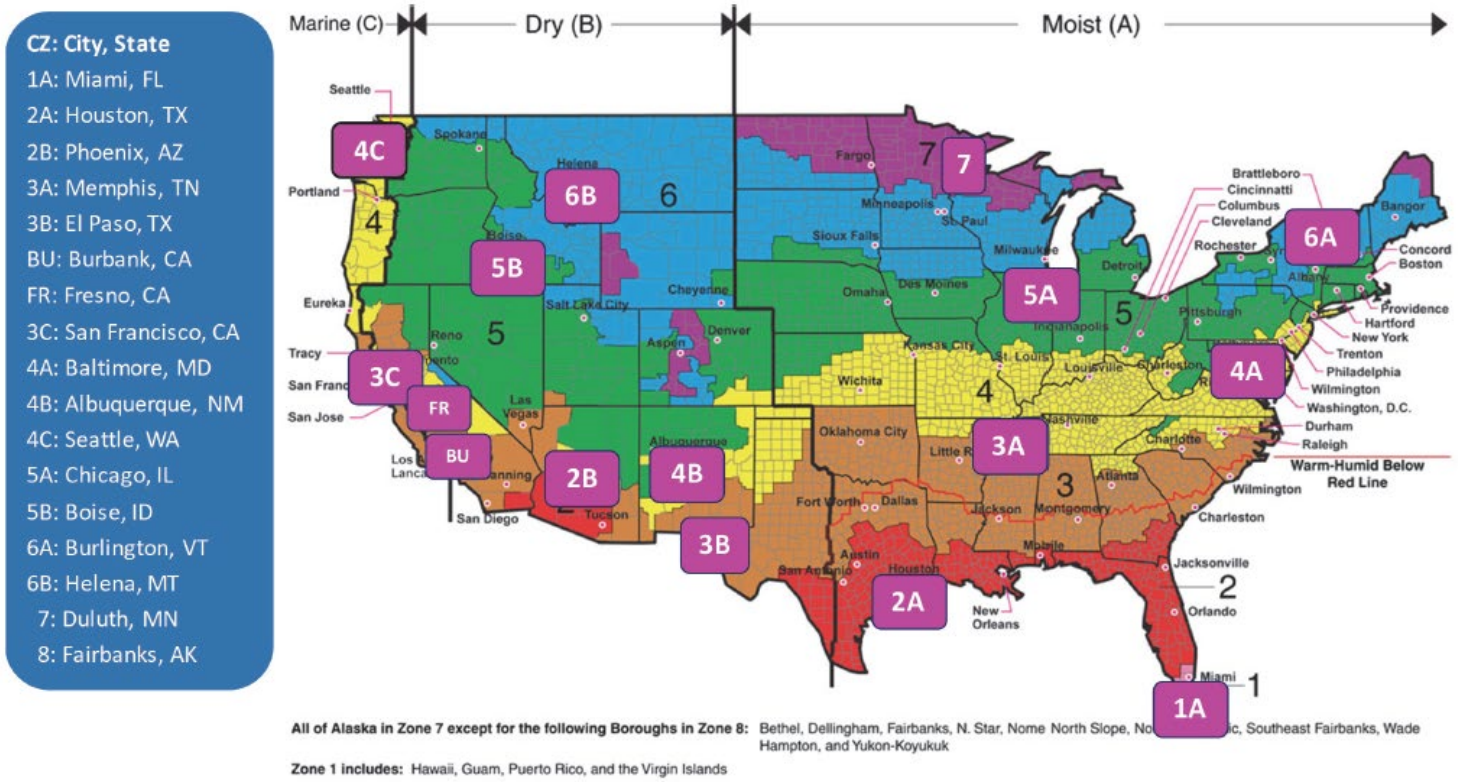
Source: U.S. Department of Energy (U.S. DOE). 2016. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Packaged Boilers.* December 2016. Accessed January 2021. https://www.regulations.gov/docket?D=EERE-2013-BT-STD-0030.

CE = combustion efficiency; mmBTU = 1 million British Thermal Units; TE = thermal efficiency; yr = year; BTU = British Thermal Unit; ≥ = greater than or equal to; ≤ = less than or equal to

[1] "Standard" refers to the minimum CE or TE required by the 2020 Conservation Standards for Commercial Packaged Boilers.

[2] "Max Tech" refers to the maximum technologically feasible improvement in energy efficiency determined by DOE for each type of boiler.[3] The average annual fuel use is based on historical consumption data.

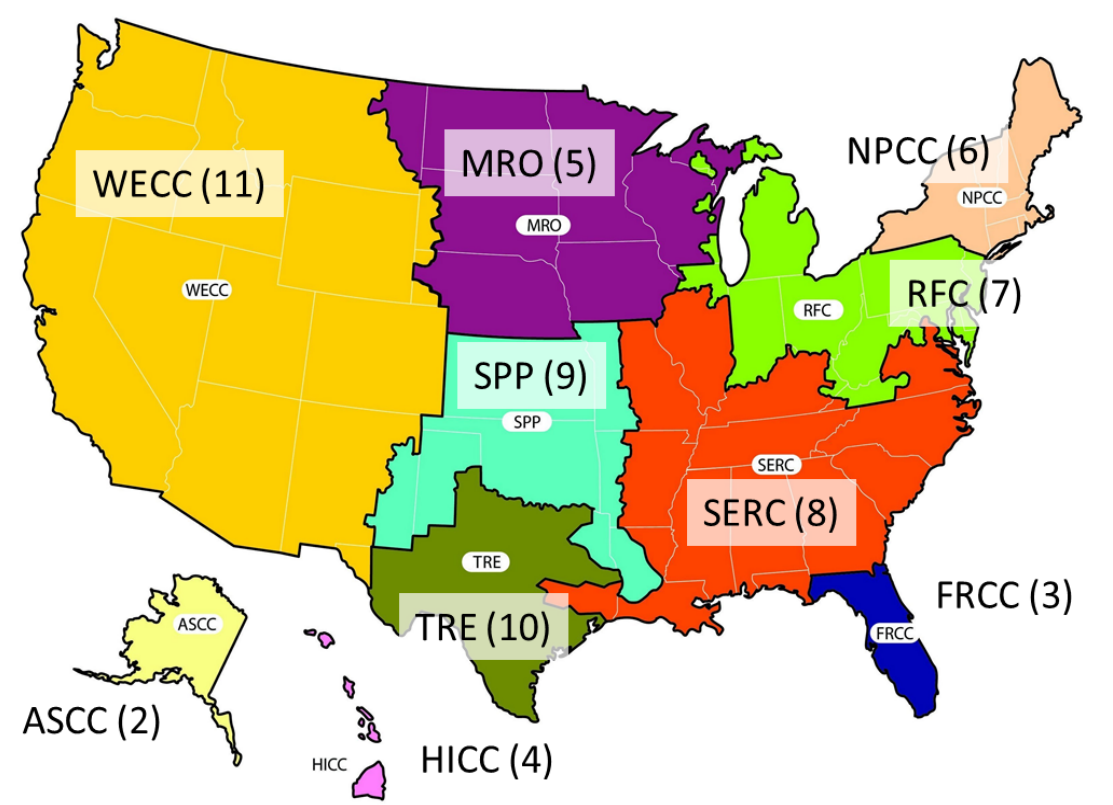
Figure E-4.1. Climate Zones for the Cool Surface Savings Explorer



Source: Levinson, R. 2019. "Using Solar Availability Factors to Adjust Cool-Wall Energy Savings for Shading and Reflection by Neighboring Buildings." *Solar Energy* 180: 717–734. March. https://escholarship.org/content/qt0hf5m90n/qt0hf5m90n.pdf.

Note: The climate zone map is applicable to analyses being conducted using Lawrence Berkeley National Laboratory's Cool Surface Savings Explorer (Explorer) (Levinson et al. 2019). The map shows United States climate zones in which solar availability factors were calculated and included in the Explorer. Climate zone 8 (Fairbanks, AK) is not shown. Table E-4.1 identifies applicable Explorer climate zones within each of the western states.

Figure E-4.2. Electricity Zones for GREET Data



Source: U.S. Department of Energy (U.S. DOE). 2024. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model*. 2024 Release. Accessed January 28, 2025. https://greet.anl.gov/.

Note: The climate zone map is applicable to analyses being conducted using electricity emission factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model (GREET). Table E-4.9 provides the emission factors for the Western Electricity Coordinating Council (WECC) and Southwest Power Pool (SPP), which include the western states.

Table E-4.1. Representative Climate Zones by State for Solar Availability Factors from the Cool Surface Savings Explorer

State	Climate Zone(s)[1]
Washington	**4C: Seattle, WA**
	5B: Boise, ID
	6B: Helena, MT
Oregon	4C: Seattle, WA
	5B: Boise, ID
Colorado	5B: Boise, ID
	6B: Helena, MT
	7: Duluth, MN
Arizona	**2B: Phoenix, AZ**
	2A: Houston, TX
	4B: Albuquerque, NM
	5B: Boise, ID
New Mexico	**4B: Albuquerque, NM**
	3B: El Paso, TX
	5B: Boise, ID

Source: Levinson, R. 2019. "Using Solar Availability Factors to Adjust Cool-Wall Energy Savings for Shading and Reflection by Neighboring Buildings." *Solar Energy* 180: 717-734. March. Accessed January 2021. https://escholarship.org/content/qt0hf5m90n/qt0hf5m90n.pdf.

[1] **Bolded** zones are in-state locations included in the source study. Non-bolded zones are out-of-state proxy locations that may have similar climate characteristics as portions of the state. Refer to Figure E-4.1.

Table E-4.2. Canyon Aspect Ratios from the Cool Surface Savings Explorer

Ratio	Height (ft)	Width (ft)	Neighboring Building Types Represented
0.2	19.7	98.4	Two-story single-family homes across a residential street
1	19.7	19.7	Two-story single-family homes across small backyards
2	19.7	9.8	Two-story single-family homes on the same street side
10	98.4	9.8	Adjacent 10-story office buildings on the same street side

Source: Levinson, R. 2019. "Using Solar Availability Factors to Adjust Cool-Wall Energy Savings for Shading and Reflection by Neighboring Buildings." *Solar Energy* 180: 717-734. March. https://escholarship.org/content/qt0hf5m90n/qt0hf5m90n.pdf.

ft = foot

Table E-4.3. Mean Solar Availability Factors by Canyon Aspect Ratio for Conventional Neighboring Walls by Representative Climate Zones for the Cool Surface Savings Explorer

Cool Surface Savings Explorer Climate Zone[1]	Conventional Neighboring Wall (albedo = 0.25)			
	North	East	South	West
Canyon Aspect Ratio = 0.2				
2A: Houston, TX	0.91	0.91	0.93	0.91
2B: Phoenix, AZ	0.92	0.91	0.95	0.92
3B: El Paso, TX	0.93	0.94	0.95	0.93
4B: Albuquerque, NM	0.93	0.92	0.95	0.92
4C: Seattle, WA	0.91	0.91	0.94	0.90
5B: Boise, ID	0.92	0.91	0.95	0.91
6B: Helena, MT	0.92	0.91	0.95	0.90
7: Duluth, MN	0.91	0.90	0.94	0.90
Canyon Aspect Ratio = 1.0				
2A: Houston, TX	0.65	0.62	0.70	0.62
2B: Phoenix, AZ	0.68	0.61	0.72	0.62
3B: El Paso, TX	0.69	0.64	0.73	0.63
4B: Albuquerque, NM	0.70	0.61	0.71	0.62
4C: Seattle, WA	0.64	0.60	0.64	0.59
5B: Boise, ID	0.67	0.59	0.68	0.60
6B: Helena, MT	0.66	0.59	0.64	0.58
7: Duluth, MN	0.64	0.58	0.63	0.58
Canyon Aspect Ratio = 2.0				
2A: Houston, TX	0.45	0.42	0.47	0.41
2B: Phoenix, AZ	0.49	0.41	0.51	0.41
3B: El Paso, TX	0.50	0.42	0.51	0.42
4B: Albuquerque, NM	0.50	0.41	0.50	0.41
4C: Seattle, WA	0.44	0.40	0.43	0.39
5B: Boise, ID	0.47	0.39	0.47	0.39
6B: Helena, MT	0.46	0.38	0.44	0.37
7: Duluth, MN	0.45	0.38	0.43	0.38
Canyon Aspect Ratio = 10.0				
2A: Houston, TX	0.13	0.11	0.13	0.11
2B: Phoenix, AZ	0.14	0.10	0.14	0.10
3B: El Paso, TX	0.14	0.11	0.15	0.11
4B: Albuquerque, NM	0.14	0.10	0.14	0.11
4C: Seattle, WA	0.12	0.10	0.10	0.10
5B: Boise, ID	0.13	0.10	0.11	0.10
6B: Helena, MT	0.13	0.09	0.10	0.09
7: Duluth, MN	0.12	0.10	0.10	0.10

Source: Levinson, R. 2019. "Using Solar Availability Factors to Adjust Cool-Wall Energy Savings for Shading and Reflection by Neighboring Buildings." *Solar Energy* 180: 717-734. March. https://escholarship.org/content/qt0hf5m90n/qt0hf5m90n.pdf.

[1] Refer to Table E-4.1 and Figure E-4.1 for representative climate zones by state.

Table E-4.4. Mean Solar Availability Factors by Canyon Aspect Ratio for Cool Neighboring Walls from the Cool Surface Savings Explorer

Ratio	Cool Neighboring Wall (albedo = 0.60)			
	North	East	South	West
0.2	1.02	0.95	0.96	0.95
1	0.94	0.72	0.75	0.72
2	0.73	0.52	0.55	0.52
10	0.22	0.15	0.16	0.15

Source: Levinson, R. 2019. "Using Solar Availability Factors to Adjust Cool-Wall Energy Savings for Shading and Reflection by Neighboring Buildings." *Solar Energy* 180: 717-734. March. https://escholarship.org/content/qt0hf5m90n/qt0hf5m90n.pdf.

Table E-4.5. Selected Electric Utility Emission Factors—Arizona (lb CO_2e per MWh)

Utility[1]	2023[2]	2024	2025	2024/2025 Method
Arizona Public Service Co.	814	774	765	forecast[3]
Salt River Project	1,015	871	—	actual
Tucson Electric Power Co.	1,100	1,088	1,076	forecast[3]
UNS Electric, Inc.	1,049	1,037	1,025	forecast[3]

Sources: Pinnacle West Capital Corporation. 2024. *Electric Company ESG/Sustainability Quantitative Information*. Arizona Public Services Co. Accessed February 4, 2024. https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fs22.q4cdn.com%2F464697698%2Ffiles%2Fdoc_downloads%2F2024%2FESG-Template-Pinnacle-West-2024-Final.xlsx&wdOrigin=BROWSELINK.

Salt River Project. 2024. "SRP Power Content Label–Fiscal Year 2023." Accessed February 24, 2025. https://www.srpnet.com/assets/srpnet/pdf/grid-water-management/sustainability-environment/FY23_Sustainability_Power_Content_Label.pdf.

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UNS Energy Corporation. 2024a. *Electric Company ESG/Sustainability Quantitative Information*. Tucson Electric Power Company. June 2024. Accessed February 4, 2024. https://docs.tep.com/wp-content/uploads/TEP-EEI-ESG-2024.pdf.

UNS Energy Corporation. 2024b. *Electric Company ESG/Sustainability Quantitative Information*. Tucson Electric Power Company and UniSource Energy Services (UNS Electric Inc. and UNS Gas Inc.). November 2024. Accessed February 4, 2024. https://docs.tep.com/wp-content/uploads/UNS-EEI-ESG-2024.pdf.

Lawrence Berkely National Laboratory (LBNL). 2024. RPS and CES Percentage Targets XLXS. Accessed January 30, 2025. https://emp.lbl.gov/publications/us-state-renewables-portfolio-clean-0; Clean Air Task Force. 2025. "Clean Electricity Standards: Tracking Clean Energy in U.S. States." Accessed January 30, 2025. https://www.catf.us/us/state-policy/clean-electricity-standards/.

lb. = pounds; MWh = megawatt-hour; CO2e = carbon dioxide equivalent; RPS = renewables portfolio standard

Notes: **Bolded utilities** are subject to the state's RPS.

[1] This table only includes a subset of Arizona electric utilities. A complete list of utilities serving Arizona is available from the U.S. Energy Information Administration (EIA). 2023. "Utility Bundled Retail Sales–Total." Accessed January 25, 2025. https://www.eia.gov/electricity/sales_revenue_price/pdf/table_10.pdf.

[2] Base year (2023) emission factors for each utility were obtained from the sources listed above. For Salt River Project, the 2024 actual (i.e. non-forecasted) emission factor is also available.

[3] Emission factors for utilities subject to the RPS were forecasted according to the following method. Future year emission factors for utilities not subject to the RPS were not forecasted.

- The percent of qualifying RPS load for the 2023 base year was obtained from the sources listed above. The percent of load supplied by non-RPS qualifying sources was calculated as the difference from 100%.
- The 2023 base year emission factor was divided by the percent of non-RPS qualifying sources to calculate an average emission factor for non-RPS qualifying power generation.
- The estimated percent of qualifying RPS load in 2024 and 2025 was obtained from the LBNL.
- The percent of load supplied by non-RPS qualifying sources in 2024 and 2025 was calculated as the difference from 100% and then multiplied by the calculated average emission factor for non-RPS qualifying power generation.
- Because the horizon year for the state's RPS is 2025, emission factors beyond 2025 are not projected.

The forecasting approach holds the non-RPS qualifying power mix constant at 2023 levels. It does not account for utility-specific targets or generation plans. All four utilities listed in this table have a goal of 100% carbon free power by 2050 and have set interim targets to support attainment for this goal (e.g., Arizona Public Service Co. seeks to achieve 65% clean energy by 2030 and eliminate coal-fired generation by 2031). Thus, emission factors for all utilities are expected to be lower than presented in this table. ***Users should consult their local electricity provider for updated emission factors available at the time of their analysis before proceeding with the defaults provided in this table.***

Table E-4.6. Selected Electric Utility Emission Factors—Colorado (lb CO_2e per MWh)

Utility[1]	2022[2]	2023[2]
Holy Cross Electric Assn, Inc.	920	957
Public Service Co. of Colorado	973	929

Sources: Holy Cross Energy. 2024. *2023 CO_2 Emissions Report*. September 2024. Accessed February 24, 2025. https://www.holycross.com/wp-content/uploads/2024/09/HCE_Co2-Report-2023_web-1.pdf.

Holy Cross Energy. 2023. *2022 CO2 Emissions Report*. July 2023. Accessed February 24, 2025. https://www.holycross.com/wp-content/uploads/2023/07/HCE_Co2-Report-2022.pdf.

Xcel Energy. 2023. *Carbon Dioxide (CO2) Emission Intensities*. Accessed February 24, 2025. https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Sustainability%20Report/2023_Xcel_Energy_Carbon_Intensities_Info_Sheet.pdf.

lb. = pounds; MWh = megawatt-hour; CO2e = carbon dioxide equivalent; RPS = renewables portfolio standard

Notes: All utilities listed in this table are subject to the state's RPS.

[1] This table only includes a subset of Colorado electric utilities. A complete list of utilities serving Colorado is available from the U.S. Energy Information Administration (EIA). 2023. *Utility Bundled Retail Sales-Total*. Accessed January 25, 2025. https://www.eia.gov/electricity/sales_revenue_price/pdf/table_10.pdf.)

[2] Emission factors for each utility were obtained from the sources listed above. Because the horizon year for the state's RPS is 2020, future-year emission factors were not projected.

This table does not account for utility-specific emission reduction targets or generation plans. Nor does it account for the state's CES, which requires 1) non-municipal utilities serving more than 500,000 customers to reduce GHG emissions by 80% by 2030 (from 2005) and 2) 100% clean energy (statewide) by 2040. Thus, emission factors for all utilities are expected to be lower than presented in this table. ***Users should consult their local electricity provider for updated emission factors available at the time of their analysis before proceeding with the defaults provided in this table.***

Table E-4.7. Selected Electric Utility Emission Factors—New Mexico (lb CO_2e per MWh)

Utility [1]	2021	2022	2023	2024	2025
El Paso Electric Co. [2]	518	490	462	435	315
Public Service Co. of NM [2]	—	—	395	315	316
Southwestern Public Service Co. [3]	—	—	—	841	731
Tri-State Generation and Transmission Assoc. Inc.[4]	1,459	1,383	1,394	1,263	1,341
Utility	**2026**	**2027**	**2028**	**2029**	**2030**
El Paso Electric Co. [2]	318	321	313	306	299
Public Service Co. of NM [2]	293	285	276	247	224
Southwestern Public Service Co. [3]	651	595	594	587	574
Tri-State Generation and Transmission Assoc. Inc.[4]	1,345	1,304	1,293	1,198	998
Utility	**2031**	**2032**	**2033**	**2034**	**2035**
El Paso Electric Co.[2]	292	283	274	265	257
Public Service Co. of NM[2]	139	36	29	21	16
Southwestern Public Service Co.[3]	561	546	531	514	498
Tri-State Generation and Transmission Assoc. Inc.[4]	947	949	938	893	908
Utility	**2036**	**2037**	**2038**	**2039**	**2040**
El Paso Electric Co.[2]	270	283	294	306	316
Public Service Co. of NM[2]	7	6	8	9	0
Southwestern Public Service Co.[3]	496	507	530	552	573
Tri-State Generation and Transmission Assoc. Inc.[4]	914	890	870	864	821

Sources: New Mexico Energy Conservation and Management (ECAM). 2025. Excel database with utility emission factors, provided to ICF in March 2025.

lb. = pounds; MWh = megawatt-hour; CO_2e = carbon dioxide equivalent; RPS = renewables portfolio standard

Notes: All utilities listed in this table are subject to the state's RPS.

[1] This table only includes a subset of New Mexico electric utilities. A complete list of utilities serving New Mexico is available from the U.S. Energy Information Administration (EIA). 2023. *Utility Bundled Retail Sales-Total.* Accessed January 25, 2025. https://www.eia.gov/electricity/sales_revenue_price/pdf/table_10.pdf.

[2] Future year emission factors account for compliance with the state's RPS and CES and implementation of utility-specific renewable procurement or GHG reduction plans.

[3] Future year emission factors do not account for compliance with the state's RPS or CES (would not accurately reflect member carbon intensity in the regional transmission organization market).

[4] Future year emission factors assume the carbon intensity for the whole generating region and incorporate compliance with Colorado's RPS and New Mexico's RPS.

Users should consult their local electricity provider for updated emission factors available at the time of their analysis before proceeding with the defaults provided in this table.

Table E-4.8. Selected Electric Utility Emission Factors—Oregon (lb CO_2e per MWh)

Utility	2019	2020	2021	2022	2023+[1]
Consumer-Owned Utility					
Ashland Electric Department	45	26	44	35	37
Bandon	45	26	44	35	37
Blachly-Lane Electric Cooperative	82	180	106	75	67
Canby Utility Board	45	26	44	35	37
Cascade Locks	45	26	44	35	37
Central Electric Cooperative	57	115	87	67	62
Central Lincoln PUD	45	26	50	60	56
Clatskanie PUD	118	35	57	50	116
Clearwater Power Company	46	27	47	41	42
Columbia Basin Cooperative	45	26	44	35	37
Columbia Power Cooperative	45	26	44	35	37
Columbia River PUD	45	26	44	35	37
Columbia Rural Electric (Columbia REA)	45	26	44	35	37
Consumers Power	62	99	105	97	93
Coos-Curry Electric Cooperative, Inc.	45	26	44	35	37
Douglas Electric Cooperative	45	26	47	40	41
Drain	45	26	44	35	37
Emerald PUD	319	97	152	137	186
Eugene Water & Electric Board (EWEB)	121	57	88	75	80
Forest Grove Light & Power	41	55	69	60	55
Harney Electric Cooperative	45	26	44	35	37
Hermiston Energy Services	45	26	44	35	37
Hood River Electric Cooperative	45	26	44	35	37
Lane Electric Cooperative	45	26	44	35	37
McMinnville Water & Light	45	25	42	34	36
Midstate Electric Cooperative	45	26	44	35	37
Milton-Freewater City Light & Power	34	20	34	27	29
Monmouth	45	26	44	35	37
Northern Wasco PUD	64	149	338	449	501
Oregon Trail Electric Cooperative	45	26	44	35	37
Salem Electric	45	26	44	35	37
Springfield Utility Board	45	26	44	35	37
Surprise Valley Electrification Corporation	45	26	44	35	37
Tillamook PUD	45	26	44	35	37
Umatilla Electric Cooperative	404	392	751	666	235
Umpqua Indian Utility Co-op	45	26	44	35	37
USDOE ARC	45	26	44	35	37

Utility	2019	2020	2021	2022	2023+[1]
Wasco Electric Cooperative	45	26	44	35	37
West Oregon Electric Cooperative, Inc.	45	26	46	39	39
Electricity Service Supplier					
3 Phases Renewables	0	0	—	—	—
Avangrid Renewables	25	25	22	19	12
Calpine Energy Solutions	944	944	944	944	944
Constellation New Energy	944	944	944	944	944
Shell Energy North America	668	222	605	548	816
Investor-Owned Utility					
Idaho Power Company	545	680	734	774	614
Pacific Power (PacifiCorp)	1,520	1,403	1,321	1,255	1,186
Portland General Electric (PGE)	921	774	694	648	705

Sources: Oregon Department of Environmental Quality 2025. Excel database with utility emission factors, provided to ICF in March 2025.

lb. = pounds; MWh = megawatt-hour; CO_2e = carbon dioxide equivalent; PUD = public utility district; RPS = renewables portfolio standard

[1] Future year emission factors are not available. ***Users should consult their local electricity provider for updated emission factors available at the time of their analysis before proceeding with the defaults provided in this table.***

Table E-4.9. Selected Electric Utility Emission Factors—Washington (lb CO_2e per MWh)

		Forecasted with RPS[2]		
Utility	2022[1]	2023	2024	2025+
Alder Mutual Light	39	—	—	—
Asotin County PUD #1	39	—	—	—
Avista Corp	**740**	**740**	**740**	**740**
Benton County PUD #1	**116**	**116**	**116**	**116**
Benton Rural Electric Assn	39	—	—	—
Big Bend Electric Coop	139	—	—	—
Centralia City Light	193	—	—	—
Chelan County PUD #1	**189**	**189**	**189**	**189**
Cheney Light Department	39	—	—	—
Chewelah Electric Department	39	—	—	—
City of Blaine	39	—	—	—
Clallam County PUD #1	**39**	**38**	**39**	**39**
Clark County PUD #1	**358**	**346**	**320**	**320**
Clearwater Power (WA)	45	—	—	—
Columbia Rural Electric Assn (WA)	141	—	—	—
Consolidated Irrigation District #19	39	—	—	—
Town of Coulee Dam	39	—	—	—
Cowlitz County PUD #1	**103**	**103**	**103**	**103**
Douglas County PUD #1	727	—	—	—

Utility	2022[1]	Forecasted with RPS[2]		
		2023	2024	2025+
Eatonville Electric Department	39	—	—	—
Ellensburg Electric Division	39	—	—	—
Elmhurst Mutual Power & Light	39	—	—	—
Energy Northwest	39	—	—	—
Fairchild Airforce Base	39	—	—	—
Ferry County PUD #1	39	—	—	—
Franklin County PUD #1 [3]	**119**	**119**	**119**	**104**
Grant County PUD #2	800	—	—	—
Grant County PUD #2 (Rate Schedule 13)	0	—	—	—
Grays Harbor County PUD #1	**62**	**62**	**62**	**62**
Inland Power & Light	**40**	**40**	**39**	**39**
Jefferson County PUD #1	39	—	—	—
Kalispel Tribal Utility	39	—	—	—
Kittitas County PUD #1	40	—	—	—
Klickitat County PUD #1	189	—	—	—
Lakeview Light & Power	39	—	—	—
Lewis County PUD #1	**94**	**94**	**94**	**94**
Mason County PUD #1	37	—	—	—
Mason County PUD #3	**38**	**38**	**38**	**38**
McCleary Light & Power	39	—	—	—
Milton Electric Division	39	—	—	—
Modern Electric Water Company	39	—	—	—
Nespelem Valley Elec Coop	39	—	—	—
Northern Lights (WA)	51	—	—	—
Ohop Mutual Light	39	—	—	—
Okanogan County Electric Coop	53	—	—	—
Okanogan County PUD #1	439	—	—	—
Orcas Power & Light Coop	43	—	—	—
Pacific County PUD #2	**120**	**114**	**111**	**120**
Pacific Power (WA)	1,245	—	—	—
Parkland Light & Water	39	—	—	—
Pend Oreille County PUD #1	589	—	—	—
Peninsula Light	**38**	**34**	**34**	**34**
Port Angeles Light Operations	39	—	—	—
Port of Seattle	39	—	—	—
Puget Sound Energy	**851**	**850**	**851**	**851**
Puget Sound Energy Green Direct Program	0	—	—	—
Richland Energy Services	102	—	—	—
Town of Ruston	25	—	—	—

Utility	2022[1]	Forecasted with RPS[2]		
		2023	2024	2025+
Seattle City Light	**29**	**27**	**26**	**26**
Skamania County PUD #1	39	—	—	—
Snohomish County PUD #1	**43**	**43**	**43**	**43**
Steilacoom Electric Utility	39	—	—	—
City of Sumas	39	—	—	—
Tacoma Power	**25**	**25**	**25**	**25**
Tanner Electric Coop	39	—	—	—
Vera Water & Power	86	—	—	—
Wahkiakum County PUD #1	39	—	—	—
Whatcom County PUD #1	39	—	—	—
Yakama Power	39	—	—	—

Sources: Washington State Department of Commerce. 2025. Excel file provided to ICF with utility emission factors. January.

Washington State Department of Commerce. 2025. EIA Reports. Accessed January 2025. https://deptofcommerce.app.box.com/s/y27oz4btzu41qjzorjijhy44xquuoa1u.

lb. = pounds; MWh = megawatt-hour; CO2e = carbon dioxide equivalent; RPS = renewables portfolio standard

Notes: **Bolded utilities** are subject to the state's RPS.

[1] Base year (2022) emission factors for each utility were provided by WSDOT (2025).

[2] Emission factors for utilities subject to the RPS were forecasted according to the following method. Future year emission factors for utilities not subject to the RPS were not forecasted.

- The percent of qualifying RPS load for the 2022 base year was obtained from U.S. EIA. The percent of load supplied by non-RPS qualifying sources was calculated as the difference from 100%.
- The 2022 base year emission factor was divided by the percent of non-RPS qualifying sources to calculate an average emission factor for non-RPS qualifying power generation.
- The percent of qualifying RPS load in 2023 and 2024 was obtained from U.S. EIA. The percent of qualifying RPS load in 2025 was set to 15% per the RPS. Note that many utilities have achieved the 2025 RPS requirement of 15% before 2025.
- The percent of load supplied by non-RPS qualifying sources in 2023, 2024, and 2025 was calculated as the difference from 100% and then multiplied by the calculated average emission factor for non-RPS qualifying power generation.
- Because the horizon year for the state's RPS is 2025, emission factors beyond 2025 are not projected.

The forecasting approach holds the non-RPS qualifying power mix constant at 2022 levels. It does not account for utility-specific targets or generation plans. Nor does it account for the state's CES, which requires that all retail sales of electricity be carbon neutral by 2030 and utilities achieve 100% clean energy by 2045. Thus, emission factors for all utilities are expected to be lower than presented in this table. ***Users should consult their local electricity provider for updated emission factors available at the time of their analysis before proceeding with the defaults provided in this table.***

[3] Franklin PUD's first period of compliance with the renewable requirements was 2022. Its target through 2025 is 3% of load.

Table E-4.10. Grid Average Electricity Emission Factors from GREET (lb per MWh)

Generating Region	2025	2030	2035	2040	2045	2050
WECC	585	314	261	210	203	201
SPP	821	291	275	306	308	320

Source: U.S. Department of Energy (U.S. DOE). 2024. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model*. 2024 Release. Accessed January 28, 2025. https://greet.anl.gov/.

WECC = Western Electricity Coordinating Council; SPP= Southwest Power Pool

Notes: Grid electricity emission factors are available for two geographies as defined in the U.S. DOE's GREET model—the Western Electricity Coordinating Council (WECC) and Southwest Power Pool (SPP). Arizona, Colorado, Oregon, and

Washington are wholly within WECC. New Mexico is split between WECC and SPP. Refer to Figure E-4.2. Emission factors for WECC and SPP are provided in five-year increments between 2025 and 2050. If the analysis year falls within a five-year time period, users should select the earlier time period. For example, if the analysis year is 2037, users should use the emission factor for 2035. Alternatively, users may interpolate an emission factor for their specific analysis year based on the data provided in the table.

Table E-4.11. Natural Gas Emission Factors

	Emission Factor by Land Use Type (lb/mmBTU)	
Pollutant	Residential	Non-Residential
TOG	0.011	0.011
ROG	0.005	0.005
SO_2	0.001	0.001
NO_x	0.092	0.098
PM_{10}	0.007	0.007
$PM_{2.5}$	0.007	0.007
CO	0.039	0.082
CO_2	116.977	117.647
CH_4	0.010	0.010
N_2O	0.000	0.002
CO_2e	117.325	118.549

Sources: U.S. Environmental Protection Agency (U.S. EPA). 1998. "Chapter 1: External Combustion Sources. 1.4, Natural Gas Combustion." In *AP 42*, Fifth Edition, Volume I. July. https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf.

U.S. Environmental Protection Agency (U.S. EPA). 2020. *Emission Factors for Greenhouse Gas Inventories*. March 2020. Accessed March 2021. https://www.epa.gov/sites/production/files/2020-04/documents/ghg-emission-factors-hub.pdf.

TOG = total organic gases; ROG = reactive organic gases; CO = carbon monoxide; SO_2 = sulfur dioxide; NOx = nitrogen oxides; PM_{10} = particulate matter less than or equal to 10 microns; $PM_{2.5}$ = particulate matter less than or equal to 2.5 microns; CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; CO_2 = carbon dioxide equivalent; lb = pound; mmBTU = 1 million British Thermal Units

Table E-5.1. Change in Energy Use for Green Roofs Compared to Dark Roofs by Building Type and City[1]

Building Type	Flagstaff, AZ	Phoenix, AZ	Prescott, AZ	Boulder, CO	Denver, CO	Grand Junction, CO	Albuquerque, NM	Astoria, OR	Portland, OR	Olympia, WA	Seattle, WA	Spokane, WA
Electricity Savings (kWh/yr/KSF)[2]												
Office[3]	343.0	110.8	190.1	216.6	216.2	200.3	206.0	68.2	78.4	101.4	68.1	150.4
Residential[4]	74.6	13.0	-0.8	18.2	27.2	10.4	20.7	19.1	24.6	27.3	12.9	4.6
Gas Savings (therm/yr/KSF)												
Office[3]	1.4	0.03	0.5	1.0	0.9	0.9	0.5	0.3	0.4	0.7	0.4	1.2
Residential[4]	26.6	6.4	18.7	19.4	18.9	18.2	17.8	6.6	6.6	9.5	6.8	15.0

Source: Sailor, D., B. Brass, S. Peck. 2008. *Green Roof Energy Calculator*. Accessed December 2024. https://globalfutures.asu.edu/urban-climate-research-center/green-house-energy-calculator/.

kWh = kilowatt-hour; KSF = thousand square feet; yr = year

[1] The Green Roof Energy calculator was run for the above building types and cities using conservative values for the remaining tool inputs: growing media depth (2 inches), leaf area index (0.5), irrigation (no), green roof coverage (50%), remaining roof material (dark). A "dark roof" is defined as having an albedo of 0.15.

[2] Negative electricity savings represent an increase in electricity use.

[3] The value defined in the Green Roof Energy Calculator is "New Office Bldg."

[4] The value defined in the Green Roof Energy Calculator is "New Residence Bldg."

Table E-7.1. Outdoor Lighting Power Consumption and Efficacy by Lamp Type[1]

La.mp Type	Typical Power Rating (W)	Source Efficacy (LPW)
High-Pressure Sodium	70-400	80-120
Low-Pressure Sodium	55-180	130-170
Ceramic Metal Halide	20-400	75-110
Metal Halide	70-400	40-70
CFL	20-70	80-85
Linear Fluorescent	25-32	80-100
Induction	70-250	50-85
LED	40-250	Up to 130

Source: California Lighting Technology Center. 2014. *2013 Title 24, Part 6 Outdoor Lighting Guide.* University of California, Davis. March 2014. Accessed December 2024. https://cltc.ucdavis.edu/sites/g/files/dgvnsk12206/files/media/documents/2013-title-24-outdoor-lighting-guide-mar15.pdf.

CFL = compact fluorescent lamp; LED = light emitting diode; LPW = lumens per watt; W = watts

[1] Values are based on lamp sizes typically used in outdoor applications. These numbers are subject to change as technologies improve. Source efficacy is based on initial lumen output; system efficacy depends on the specifications of the luminaires and ballasts or drivers employed. Some outdoor applications may be best served by products with characteristics that fall outside of the ranges listed in this table.

Table E-10-B.1. Estimated Electricity Generation from Typical PV Systems by Major City (kilowatt-hours per year)[1]

State	County	Major City	Zip Code	3 kW	5 kW	10 kW
AZ	Apache	Eagar	85925	5,182	8,636	17,269
AZ	Cochise	Sierra Vista	85635	5,438	9,066	18,131
AZ	Coconino	Flagstaff	86001	5,112	8,521	17,038
AZ	Gila	Payson	85541	5,044	8,407	16,811
AZ	Graham	Safford	85546	5,454	9,090	18,177
AZ	Greenlee	Clifton	85533	5,347	8,913	17,823
AZ	La Paz	Parker	85344	5,427	9,043	18,079
AZ	Maricopa	Phoenix	85003	5,294	8,824	17,644
AZ	Mohave	Lake Havasu City	86403	5,312	8,856	17,709
AZ	Navajo	Show Low	85901	5,290	8,817	17,631
AZ	Pima	Tucson	85701	5,362	8,937	17,873
AZ	Pinal	Maricopa	85138	5,284	8,806	17,608
AZ	Santa Cruz	Rio Rico	85648	5,380	8,968	17,935
AZ	Yavapai	Prescott Valley	86314	5,249	8,749	17,492
AZ	Yuma	Yuma	85364	5,410	9,019	18,034
CO	Adams	Thornton	80241	4,798	7,998	15,987
CO	Alamosa	Alamosa	81101	5,316	8,861	17,718
CO	Arapahoe	Aurora	80010	4,825	8,042	16,079
CO	Archuleta	Pagosa Springs	81147	5,036	8,391	16,780
CO	Baca	Springfield	81073	5,003	8,335	16,666
CO	Bent	Las Animas	81054	5,040	8,401	16,801

State	County	Major City	Zip Code	3 kW	5 kW	10 kW
CO	Boulder	Boulder	80301	4,417	7,361	14,718
CO	Broomfield	Broomfield	80020	4,602	7,671	15,343
CO	Chaffee	Salida	81201	5,035	8,390	16,780
CO	Cheyenne	Cheyenne Wells	80810	4,979	8,297	16,594
CO	Clear Creek	Idaho Springs	80452	4,587	7,644	15,285
CO	Conejos	Manassa	81141	5,160	8,602	17,197
CO	Costilla	San Luis	81152	5,302	8,836	17,669
CO	Crowley	Ordway	81034	5,013	8,358	16,713
CO	Custer	Westcliffe	81252	4,960	8,265	16,527
CO	Delta	Delta	81416	4,897	8,160	16,321
CO	Denver	Denver	80202	4,795	7,991	15,978
CO	Dolores	Dove Creek	81324	5,158	8,595	17,187
CO	Douglas	Castle Rock	80104	4,833	8,055	16,106
CO	Eagle	Gypsum	81637	4,652	7,751	15,500
CO	El Paso	Colorado Springs	80902	4,912	8,188	16,371
CO	Elbert	Elizabeth	80107	4,878	8,132	16,259
CO	Fremont	Canon City	81212	4,968	8,279	16,554
CO	Garfield	Rifle	81650	4,717	7,859	15,720
CO	Gilpin	Central City	80427	4,646	7,744	15,488
CO	Grand	Granby	80446	4,451	7,419	14,833
CO	Gunnison	Gunnison	81230	4,962	8,271	16,536
CO	Hinsdale	Lake City	81235	4,657	7,762	15,520
CO	Huerfano	Walsenburg	81089	5,095	8,495	16,984
CO	Jackson	Walden	80480	4,391	7,318	14,629
CO	Jefferson	Arvada	80002	4,559	7,599	15,195
CO	Kiowa	Eads	81036	5,071	8,453	16,897
CO	Kit Carson	Burlington	80807	4,877	8,128	16,253
CO	La Plata	Durango	81301	5,077	8,460	16,915
CO	Lake	Leadville	80461	4,810	8,017	16,028
CO	Larimer	Fort Collins	80521	4,443	7,405	14,806
CO	Las Animas	Trinidad	81082	5,032	8,387	16,770
CO	Lincoln	Limon	80828	4,949	8,247	16,488
CO	Logan	Sterling	80751	4,625	7,710	15,414
CO	Mesa	Grand Junction	81501	4,812	8,023	16,042
CO	Mineral	Creede	81130	5,089	8,484	16,960
CO	Moffat	Craig	81625	4,567	7,615	15,225
CO	Montezuma	Cortez	81321	5,045	8,406	16,813
CO	Montrose	Montrose	81401	4,844	8,070	16,136
CO	Morgan	Fort Morgan	80701	4,731	7,885	15,767
CO	Otero	La Junta	81050	5,082	8,472	16,941
CO	Ouray	Ridgway	81432	4,515	7,527	15,049
CO	Park	Fairplay	80440	5,225	8,711	17,413

State	County	Major City	Zip Code	3 kW	5 kW	10 kW
CO	Phillips	Holyoke	80734	4,684	7,809	15,614
CO	Pitkin	Aspen	81611	4,618	7,697	15,391
CO	Prowers	Lamar	81052	4,994	8,326	16,648
CO	Pueblo	Pueblo	81001	5,016	8,357	16,708
CO	Rio Blanco	Meeker	81641	4,631	7,721	15,435
CO	Rio Grande	Del Norte	81132	5,174	8,620	17,234
CO	Routt	Steamboat Springs	80487	4,299	7,165	14,328
CO	Saguache	Saguache	81149	5,194	8,658	17,312
CO	San Juan	Silverton	81433	4,644	7,739	15,469
CO	San Miguel	Telluride	81435	4,868	8,110	16,216
CO	Sedgwick	Julesburg	80737	4,656	7,764	15,519
CO	Summit	Silverthorne	80498	4,621	7,701	15,399
CO	Teller	Woodland Park	80863	4,842	8,070	16,136
CO	Washington	Akron	80720	4,850	8,084	16,162
CO	Weld	Greeley	80631	4,682	7,805	15,607
CO	Yuma	Yuma	80759	4,766	7,944	15,883
NM	Bernalillo	Albuquerque	87101	5,359	8,934	17,864
NM	Catron	Reserve	87830	5,173	8,620	17,239
NM	Chaves	Roswell	88201	5,301	8,835	17,667
NM	Cibola	Grants	87020	5,327	8,876	17,749
NM	Colfax	Raton	87740	5,207	8,680	17,354
NM	Curry	Clovis	88101	5,274	8,793	17,582
NM	De Baca	Fort Sumner	88119	5,379	8,968	17,928
NM	Dona Ana	Las Cruces	88001	5,499	9,167	18,333
NM	Eddy	Carlsbad	88220	5,314	8,856	17,710
NM	Grant	Silver City	88061	5,324	8,873	17,744
NM	Guadalupe	Santa Rosa	88435	5,371	8,952	17,900
NM	Harding	Roy	87743	5,375	8,960	17,917
NM	Hidalgo	Lordsburg	88045	5,594	9,322	18,642
NM	Lea	Hobbs	88240	5,354	8,924	17,848
NM	Lincoln	Ruidoso	88345	5,169	8,615	17,226
NM	Los Alamos	Los Alamos	87544	5,163	8,605	17,208
NM	Luna	Deming	88030	5,599	9,334	18,661
NM	Mckinley	Gallup	87301	5,327	8,881	17,757
NM	Mora	Wagon Mound	87752	5,250	8,750	17,495
NM	Otero	Alamogordo	88310	5,340	8,899	17,795
NM	Quay	Tucumcari	88401	5,316	8,859	17,718
NM	Rio Arriba	Espanola	87532	5,167	8,610	17,220
NM	Roosevelt	Portales	88130	5,279	8,800	17,598
NM	San Juan	Farmington	87401	5,288	8,811	17,622
NM	San Miguel	Las Vegas	87701	5,288	8,814	17,620
NM	Sandoval	Rio Rancho	87124	5,321	8,870	17,737

State	County	Major City	Zip Code	3 kW	5 kW	10 kW
NM	Santa Fe	Santa Fe	87501	5,306	8,843	17,684
NM	Sierra	Truth Or Consequences	87901	5,450	9,084	18,159
NM	Socorro	Socorro	87801	5,346	8,909	17,815
NM	Taos	Taos	87571	5,083	8,471	16,938
NM	Torrance	Moriarty	87035	5,373	8,955	17,904
NM	Union	Clayton	88415	5,252	8,754	17,503
NM	Valencia	Los Lunas	87031	5,317	8,860	17,717
OR	Baker	Baker City	97814	4,053	6,755	13,506
OR	Benton	Corvallis	97330	3,671	6,117	12,231
OR	Clackamas	Portland	97222	3,329	5,547	11,093
OR	Clatsop	Astoria	97103	3,200	5,332	10,665
OR	Columbia	Saint Helens	97051	3,209	5,352	10,701
OR	Coos	Coquille	97423	3,608	6,010	12,023
OR	Crook	Prineville	97754	4,301	7,167	14,333
OR	Curry	Gold Beach	97444	3,946	6,575	13,149
OR	Deschutes	Bend	97701	4,472	7,453	14,903
OR	Douglas	Roseburg	97470	3,566	5,944	11,887
OR	Gilliam	Condon	97823	4,286	7,142	14,281
OR	Grant	Canyon City	97820	4,090	6,815	13,629
OR	Harney	Burns	97720	4,441	7,403	14,801
OR	Hood River	Hood River	97031	3,876	6,457	12,914
OR	Jackson	Medford	97501	4,112	6,853	13,705
OR	Jefferson	Madras	97741	4,314	7,190	14,376
OR	Josephine	Grants Pass	97526	3,974	6,623	13,245
OR	Klamath	Klamath Falls	97601	4,660	7,768	15,534
OR	Lake	Lakeview	97630	4,589	7,646	15,288
OR	Lane	Eugene	97401	3,562	5,936	11,872
OR	Lincoln	Newport	97365	3,498	5,831	11,660
OR	Linn	Albany	97321	3,638	6,064	12,128
OR	Malheur	Ontario	97914	4,329	7,215	14,429
OR	Marion	Salem	97301	3,568	5,947	11,893
OR	Morrow	Heppner	97836	4,138	6,896	13,790
OR	Multnomah	Portland	97201	3,375	5,625	11,247
OR	Polk	Dallas	97338	3,674	6,123	12,249
OR	Sherman	Moro	97039	4,296	7,160	14,317
OR	Tillamook	Tillamook	97141	3,352	5,585	11,170
OR	Umatilla	Hermiston	97838	4,089	6,815	13,624
OR	Union	La Grande	97850	3,962	6,602	13,201
OR	Wallowa	Enterprise	97828	3,977	6,629	13,254
OR	Wasco	The Dalles	97058	3,998	6,663	13,325
OR	Washington	Hillsboro	97123	3,433	5,721	11,440

State	County	Major City	Zip Code	3 kW	5 kW	10 kW
OR	Wheeler	Fossil	97830	4,238	7,060	14,117
OR	Yamhill	Mcminnville	97128	4,118	6,864	13,723
WA	Adams	Othello	99344	4,118	6,865	13,731
WA	Asotin	Clarkston	99403	3,749	6,248	12,490
WA	Benton	Kennewick	99337	4,154	6,923	13,845
WA	Chelan	Wenatchee	98801	3,981	6,636	13,268
WA	Clallam	Port Angeles	98362	3,361	5,601	11,200
WA	Clark	Vancouver	98662	3,373	5,617	11,233
WA	Columbia	Dayton	99328	4,079	6,797	13,591
WA	Cowlitz	Longview	98632	3,200	5,333	10,663
WA	Douglas	East Wenatchee	98802	3,981	6,636	13,268
WA	Ferry	Republic	99166	3,590	5,983	11,964
WA	Franklin	Pasco	99301	4,061	6,767	13,533
WA	Garfield	Pomeroy	99347	4,054	6,759	13,514
WA	Grant	Moses Lake	98837	4,109	6,843	13,683
WA	Grays Harbor	Aberdeen	98520	3,083	5,143	10,281
WA	Island	Oak Harbor	98277	3,414	5,687	11,374
WA	Jefferson	Port Townsend	98368	3,003	5,005	10,013
WA	King	Seattle	98101	3,282	5,467	10,938
WA	Kitsap	Bremerton	98310	3,256	5,430	10,857
WA	Kittitas	Ellensburg	98926	4,077	6,793	13,583
WA	Klickitat	Goldendale	98620	4,268	7,111	14,217
WA	Lewis	Centralia	98531	3,111	5,183	10,364
WA	Lincoln	Davenport	99122	3,951	6,589	13,176
WA	Mason	Shelton	98584	3,202	5,339	10,673
WA	Okanogan	Omak	98841	3,866	6,441	12,880
WA	Pacific	Raymond	98577	3,107	5,179	10,355
WA	Pend Oreille	Newport	99156	3,484	5,089	11,612
WA	Pierce	Tacoma	98402	3,270	5,450	10,899
WA	San Juan	Friday Harbor	98250	3,475	5,793	11,591
WA	Skagit	Mount Vernon	98273	3,067	5,113	10,224
WA	Skamania	Stevenson	98648	3,325	5,543	11,081
WA	Snohomish	Everett	98201	3,164	5,274	10,546
WA	Spokane	Spokane	99201	3,773	6,286	12,571
WA	Stevens	Colville	99114	3,492	5,280	11,633
WA	Thurston	Olympia	98506	3,170	5,282	10,562
WA	Wahkiakum	Cathlamet	98612	3,084	5,141	10,283
WA	Walla Walla	Walla Walla	99362	3,789	6,315	12,626
WA	Whatcom	Bellingham	98225	3,171	5,283	10,565
WA	Whitman	Pullman	99163	3,914	6,524	13,046
WA	Yakima	Yakima	98901	4,138	6,894	13,783

Source: National Renewable Energy Laboratory (NREL). 2024. *NREL's PVWatts® Calculator*. Version 8.4.0. Accessed December 2024. https://pvwatts.nrel.gov/index.php.

kW = kilowatt; PV = photovoltaic

[1]Default inputs for system information were used to run the simulation.

Table E-14.1. Oregon Woodstove and Fireplace Inventory

		Wood Stoves					Fireplaces[1]				Wood Stoves					Fireplaces[1]	
Housing Type	Location	Conventional (E_1)	Catalytic (E_2)	Non-catalytic (E_3)	Pellet (E_4)	Wood Mass (lb/yr) (G)	Wood (F_1)	Wood Mass (lb/yr) (H)	Housing Type	Location	Conventional (E_1)	Catalytic (E_2)	Non-catalytic (E_3)	Pellet (E_4)	Wood Mass (lb/yr) (G)	Wood (F_1)	Wood Mass (lb/yr) (H)
S	Baker County	5%	7%	7%	2%	7,225	3.8%	4,362	M	Baker County	0.05%	0.07%	0.07%	0.002%	7,225	0.2%	4,362
S	Benton County	3%	4%	4%	1%	6,738	4.1%	4,602	M	Benton County	0.17%	0.22%	0.22%	0.024%	6,738	1.0%	4,602
S	Clackamas County	3%	5%	5%	1%	6,108	5.5%	3,940	M	Clackamas County	0.12%	0.16%	0.16%	0.013%	6,108	0.7%	3,940
S	Clatsop County	4%	5%	5%	2%	7,561	3.6%	4,904	M	Clatsop County	0.12%	0.16%	0.16%	0.014%	7,561	0.6%	4,904
S	Columbia County	5%	6%	6%	2%	7,394	4.4%	4,442	M	Columbia County	0.06%	0.08%	0.08%	0.007%	7,394	0.3%	4,442
S	Coos County	4%	6%	6%	2%	7,352	4.2%	4,599	M	Coos County	0.08%	0.10%	0.10%	0.014%	7,352	0.4%	4,599
S	Crook County	5%	6%	7%	2%	6,929	4.3%	4,179	M	Crook County	0.05%	0.06%	0.06%	0.006%	6,929	0.2%	4,179
S	Curry County	5%	6%	6%	2%	7,689	3.7%	4,877	M	Curry County	0.07%	0.09%	0.09%	0.013%	7,689	0.4%	4,877
S	Deschutes County	4%	5%	5%	2%	6,433	4.8%	3,938	M	Deschutes County	0.09%	0.11%	0.12%	0.009%	6,433	0.5%	3,938
S	Douglas County	5%	6%	6%	2%	7,474	4.2%	4,564	M	Douglas County	0.06%	0.09%	0.09%	0.008%	7,474	0.3%	4,564
S	Gilliam County	6%	8%	8%	3%	7,632	2.9%	5,106	M	Gilliam County	0.02%	0.03%	0.03%	0%	7,632	0.1%	5,106
S	Grant County	6%	8%	8%	3%	7,635	2.9%	5,121	M	Grant County	0.03%	0.04%	0.04%	0%	7,635	0.1%	5,121
S	Harney County	6%	8%	8%	2%	7,668	2.7%	5,294	M	Harney County	0.05%	0.07%	0.07%	0%	7,668	0.2%	5,294
S	Hood River County	4%	6%	6%	2%	7,256	4.4%	4,394	M	Hood River County	0.08%	0.10%	0.10%	0.008%	7,256	0.4%	4,394
S	Jackson County	4%	5%	5%	1%	6,610	5.0%	4,129	M	Jackson County	0.12%	0.15%	0.16%	0.014%	6,610	0.7%	4,129
S	Jefferson County	5%	7%	7%	2%	7,469	3.2%	4,969	M	Jefferson County	0.05%	0.07%	0.07%	0.012%	7,469	0.3%	4,969
S	Josephine County	5%	6%	6%	2%	7,253	4.6%	4,300	M	Josephine County	0.07%	0.09%	0.09%	0.007%	7,253	0.4%	4,300
S	Klamath County	4%	6%	6%	2%	6,588	4.7%	3,993	M	Klamath County	0.07%	0.09%	0.09%	0.011%	6,588	0.4%	3,993
S	Lake County	6%	8%	8%	2%	7,287	3.8%	4,440	M	Lake County	0.03%	0.04%	0.04%	0.003%	7,287	0.1%	4,440
S	Lane County	3%	4%	4%	1%	6,253	5.0%	4,075	M	Lane County	0.14%	0.18%	0.19%	0.009%	6,253	0.8%	4,075
S	Lincoln County	4%	6%	6%	2%	7,608	3.5%	5,083	M	Lincoln County	0.09%	0.12%	0.12%	0.022%	7,608	0.5%	5,083
S	Linn County	4%	5%	6%	2%	7,123	4.4%	4,400	M	Linn County	0.10%	0.13%	0.14%	0.011%	7,123	0.6%	4,400
S	Malheur County	4%	6%	6%	2%	6,963	3.8%	4,471	M	Malheur County	0.08%	0.10%	0.10%	0.015%	6,963	0.4%	4,471
S	Marion County	3%	4%	4%	1%	5,985	5.4%	3,925	M	Marion County	0.14%	0.18%	0.18%	0.008%	5,985	0.8%	3,925
S	Morrow County	5%	7%	7%	2%	7,477	3.2%	4,925	M	Morrow County	0.04%	0.06%	0.06%	0.005%	7,477	0.2%	4,925
S	Multnomah County	2%	3%	3%	1%	4,596	5.4%	3,790	M	Multnomah County	0.21%	0.28%	0.28%	0.003%	4,596	1.2%	3,790
S	Polk County	4%	5%	5%	1%	6,355	5.2%	4,012	M	Polk County	0.12%	0.16%	0.17%	0.013%	6,355	0.7%	4,012
S	Sherman County	6%	8%	8%	3%	7,648	2.8%	5,187	M	Sherman County	0.04%	0.05%	0.05%	0%	7,648	0.1%	5,187
S	Tillamook County	5%	7%	7%	2%	8,057	3.1%	5,298	M	Tillamook County	0.07%	0.09%	0.09%	0.004%	8,057	0.3%	5,298
S	Umatilla County	4%	6%	6%	2%	6,791	4.2%	4,187	M	Umatilla County	0.10%	0.13%	0.13%	0.012%	6,791	0.5%	4,187
S	Union County	5%	6%	6%	2%	7,013	4.0%	4,289	M	Union County	0.09%	0.11%	0.11%	0.007%	7,013	0.5%	4,289
S	Wallowa County	6%	8%	8%	3%	7,651	2.8%	5,205	M	Wallowa County	0.04%	0.05%	0.05%	0.000%	7,651	0.1%	5,205
S	Wasco County	5%	6%	6%	2%	6,939	4.1%	4,257	M	Wasco County	0.09%	0.11%	0.12%	0.017%	6,939	0.5%	4,257
S	Washington County	3%	3%	3%	1%	5,085	5.5%	3,848	M	Washington County	0.19%	0.25%	0.25%	0.010%	5,085	1.1%	3,848
S	Wheeler County	7%	9%	9%	3%	7,609	3.1%	4,986	M	Wheeler County	0.01%	0.01%	0.01%	0%	7,609	0.02%	4,986
S	Yamhill County	4%	5%	5%	2%	6,844	4.7%	4,233	M	Yamhill County	0.10%	0.13%	0.14%	0.008%	6,844	0.6%	4,233
S	Statewide	3%	4%	5%	1%	6,277	5.0%	4,043	M	Statewide	0.14%	0.18%	0.18%	0.009%	6,277	0.8%	4,043

Source: Oregon Department of Environmental Quality 2025. Excel database of appliance usage and inventory statistics, provided to ICF in February 2025.

M = multi-family housing; S = single-family housing; lb = pound; yr = year; hr = hour

[1]Percent of du with natural gas and propane fireplaces not available.

Table E-14.2. Woodstove and Fireplace Emission Factors (pound per ton of dry wood burned, unless noted)

Type	TOG	ROG	CO	SO2	NOx	PM_{10}	$PM_{2.5}$	CO2 (BIO)	CO2 (NBIO)	CH4	N2O	CO_2e
Woodstoves Conventional	83	53	230.8	0.4	2.8	30.6	30.6	2,952	0	64.0	0	4,744
Woodstoves Catalytic	26.6	11.2	92.3	0.3	1.5	15.2	1.52	2,952	0	19.4	0	3,495
Woodstoves Noncatalytic	28	8.9	122.6	0.3	1.7	14.5	14.5	2,952	0	21.0	0	3,540
Woodstoves Pellet	—	2.2	15.9	0.3	3.8	3.06	3.06	2,952	0	0.25	0	2,959
Wood Fireplace	—	18.9	149	0.4	2.6	23.6	23.6	3,400	0	14.4	0.3	3,883
Natural Gas Fireplace (lb/mmBTU)	0.0108	0.0054	0.0392	0.0006	0.0922	0.0075	0.0075	0	11	0.0022	0.0002	117.1
Propane Fireplace (lb/mmBTU)	0.0109	0.0109	0.0820	0.0000	0.1421	0.0077	0.0077	0	135	0.0066	0.0013	136.1

Sources: Abt Associates. 2016. "Residential Wood Combustion: Documentation for EPA's Nonpoint Emissions Estimation Tool." Prepared for the U.S. Environmental Protection Agency. October 2016.

U.S. Environmental Protection Agency (U.S. EPA). 1996a. "Section 1.10 Residential Wood Stoves" in *AP-42*. October 1996. Accessed February 2025. https://www.epa.gov/sites/default/files/2020-09/documents/1.10_residential_wood_stoves.pdf.

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U.S. Environmental Protection Agency (U.S. EPA). 1998. "Section 1.4 Natural Gas Combustion" in *AP-42*. July 1998. Accessed February 2025. https://www.epa.gov/sites/default/files/2020-09/documents/1.4_natural_gas_combustion.pdf.

U.S. Environmental Protection Agency (U.S. EPA). 2020. *Emission Factors for Greenhouse Gas Inventories*. March 2020. Accessed March 2021. https://www.epa.gov/sites/production/files/2020-04/documents/ghg-emission-factors-hub.pdf.

TOG = total organic gases; ROG = reactive organic gases; CO = carbon monoxide; SO_2 = sulfur dioxide; NOx = nitrogen oxides; PM_{10} = particulate matter less than or equal to 10 microns; $PM_{2.5}$ = particulate matter less than or equal to 10 microns; CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; BIO = biogenic; NBIO = non-biogenic; lb = pound; mmBTU = 1 million British Thermal Units

Table E-15.1. Residential Energy Consumption Intensities for Natural Gas End Uses That May Be Electrified by Housing Type and U.S. EIA Census Region/Division and Climate Zone

		Electricity (kWh/unit/year)						Natural Gas (therm/unit/year)						
U.S EIA Area[1]	Housing Type	Space heating[2]	Water heating	Clothes dryers	Cooking[3]	Hot tub heaters	Other[4]	Space heating[2]	Water heating	Clothes dryers	Cooking[3]	Pool heat	Hot tub heat	Other[4]
Census Region/ Division														
West	Single-family detached	978	1,000	432	182	89	720	244	165	6	13	8	1	12
	Single-family attached	667	681	295	124	61	491	202	136	5	11	6	1	10
	Apartments in buildings with 2–4 units	524	535	231	97	48	385	159	108	4	8	5	1	8
	Apartments in buildings with 5 or more units	480	490	212	89	44	353	66	44	2	3	2	<1	3
	Mobile homes	982	1,003	433	183	89	722	69	47	2	4	2	<1	3
Mountain	Single-family detached	981	1,044	599	229	102	841	385	167	4	10	10	1	13
	Single-family attached	669	712	408	156	69	573	318	138	3	8	9	1	11
	Apartments in buildings with 2–4 units	525	559	320	123	55	450	251	109	3	7	7	1	9
	Apartments in buildings with 5 or more units	481	512	294	112	50	412	104	45	1	3	3	<1	4
	Mobile homes	984	1,048	601	230	102	843	109	47	1	3	3	<1	4
Mountain North	Single-family detached	1,144	915	661	254	127	712	576	209	3	9	Q	Q	21
	Single-family attached	780	624	450	173	87	485	477	173	3	8	Q	Q	17
	Apartments in buildings with 2–4 units	612	490	354	136	68	381	376	136	2	6	Q	Q	14
	Apartments in buildings with 5 or more units	561	449	324	125	62	349	156	56	1	3	Q	Q	6
	Mobile homes	1,147	918	663	255	127	714	164	59	1	3	Q	Q	6
Mountain South	Single-family detached	817	1,174	536	204	77	944	192	124	4	11	14	2	15
	Single-family attached	557	800	365	139	52	644	159	103	4	9	12	1	13
	Apartments in buildings with 2–4 units	437	628	287	109	41	505	125	81	3	7	9	1	10
	Apartments in buildings with 5 or more units	401	576	263	100	38	463	52	34	1	3	4	<1	4
	Mobile homes	820	1,178	538	205	77	948	54	35	1	3	4	<1	4

		Electricity (kWh/unit/year)						Natural Gas (therm/unit/year)						
U.S EIA Area[1]	Housing Type	Space heating[2]	Water heating	Clothes dryers	Cooking[3]	Hot tub heaters	Other[4]	Space heating[2]	Water heating	Clothes dryers	Cooking[3]	Pool heat	Hot tub heat	Other[4]
Pacific	Single-family detached	977	971	349	159	89	679	173	164	8	14	6	1	11
	Single-family attached	666	662	238	108	61	463	143	136	6	12	5	1	9
	Apartments in buildings with 2–4 units	523	519	187	85	48	363	113	107	5	9	4	1	7
	Apartments in buildings with 5 or more units	479	476	171	78	44	333	47	44	2	4	2	<1	3
	Mobile homes	980	974	350	159	89	681	49	47	2	4	2	<1	3
Climate Zone														
Very cold and Cold	Single-family detached	1,415	1,091	497	210	80	613	516	137	5	10	5	<1	7
	Single-family attached	964	744	339	143	55	418	427	113	4	9	4	<1	6
	Apartments in buildings with 2–4 units	757	584	266	112	43	328	337	89	3	7	3	<1	5
	Apartments in buildings with 5 or more units	694	535	244	103	39	301	139	37	1	3	1	<1	2
	Mobile homes	1,419	1,095	499	211	80	615	147	39	1	3	1	<1	2
Mixed-dry and Hot-dry	Single-family detached	476	655	343	140	55	600	157	165	8	15	11	1	16
	Single-family attached	324	446	234	96	37	409	130	136	7	12	9	1	13
	Apartments in buildings with 2–4 units	255	350	184	75	29	321	103	108	5	10	7	1	10
	Apartments in buildings with 5 or more units	233	321	168	69	27	295	42	44	2	4	3	<1	4
	Mobile homes	477	657	344	141	55	602	45	47	2	4	3	<1	4
Marine	Single-family detached	1,760	1,624	444	205	120	837	201	150	5	12	Q	1	9
	Single-family attached	1,200	1,107	303	140	82	571	167	124	4	10	Q	1	8
	Apartments in buildings with 2–4 units	942	869	238	110	64	448	132	98	3	8	Q	<1	6
	Apartments in buildings with 5 or more units	864	797	218	101	59	411	54	41	1	3	Q	<1	3
	Mobile homes	1,766	1,629	446	206	120	840	57	43	1	3	Q	<1	3

Sources: U.S. Energy Information Administration (EIA). *Residential Energy Consumption Survey (RECS)*. Table CE2.1: Annual household site fuel consumption in the U.S.—totals and averages, 2020. Table CE5.1a: Detailed household site electricity end-use consumption, part 1—totals, 2020. Table CE5.1b: Detailed household site electricity end-use consumption, part 2—totals, 2020. Table CE5.2: Detailed household natural gas and propane end-use consumption—totals, 2020. Accessed January 2025. https://www.eia.gov/consumption/residential/data/2020/.

yr = year; yr = year; KSF = thousand square feet

Notes: End-use consumption data by housing type and geographic zone were calculated by combining dataset from the RECS. The method includes applying some national averages to regional data. Refer to the Measure E-15 factsheet for additional information.

Q = Data withheld in the RECS because 1) the relative standard error was greater than 50%, 2) the reporting sample had fewer than 20 buildings, or 3) value rounded to zero in the units displayed.

[1] See Figure E-2.1 for map of U.S. census regions/division and climate zones.

[2] Includes main (primary) and secondary space heating.

[3] Includes ranges (units with both a cooktop and an oven), separate cooktops, and separate ovens. Microwaves, small kitchen appliances, and outdoor cooking are excluded.

[4] Difference between total consumption per unit and the sum of consumption across the RECS end-use categories.

Table E-15.2. Non-Residential Energy Consumption Intensities for Natural Gas End Uses That May Be Electrified by Principal Building Activity and U.S. EIA Census Region/Division and Climate Zone

		Electricity (kWh/KSF/year)				Natural Gas (therm/KSF/year)			
U.S. EIA Area[1]	Principal Building Activity	Space heating	Water heating	Cooking	Other[2]	Space heating	Water heating	Cooking	Other[2]
Census Region/ Division									
West	Education	398	199	199	2,308	130	33	58	6
	Food sales	Q	Q	Q	Q	Q	Q	Q	Q
	Food service	1,596	798	798	9,259	632	161	285	31
	Health care	958	479	479	5,556	318	81	143	16
	Inpatient	1,303	652	652	7,559	498	127	225	25
	Outpatient	654	327	327	3,795	125	32	56	6
	Lodging	573	287	287	3,326	226	58	102	11
	Mercantile	750	375	375	4,348	219	56	99	11
	Retail (other than mall)	549	274	274	3,181	133	34	60	7
	Enclosed and strip malls	858	429	429	4,974	258	66	116	13
	Office	541	270	270	3,137	111	28	50	5
	Public assembly	406	203	203	2,357	198	50	89	10
	Public order and safety	534	267	267	3,096	210	53	95	10
	Religious worship	197	99	99	1,145	99	25	45	5
	Service	323	162	162	1,876	234	60	106	12
	Warehouse and storage	233	116	116	1,350	61	15	27	3
	Other	1,930	965	965	11,194	Q	Q	Q	Q
	Vacant	Q	Q	Q	Q	Q	Q	Q	Q
Mountain	Education	470	188	282	1,882	171	32	66	5
	Food sales	Q	Q	Q	Q	Q	Q	Q	Q
	Food service	2,005	802	1,203	8,020	766	143	297	22
	Health care	1,042	417	625	4,169	369	69	143	11
	Inpatient	Q	Q	Q	Q	Q	Q	Q	Q
	Outpatient	650	260	390	2,599	Q	Q	Q	Q
	Lodging	700	280	420	2,800	305	57	119	9
	Mercantile	842	337	505	3,368	240	45	93	7
	Retail (other than mall)	654	262	393	2,618	185	35	72	5
	Enclosed and strip malls	1,030	412	618	4,121	276	52	107	8
	Office	659	264	395	2,635	122	23	48	4
	Public assembly	554	222	332	2,216	301	56	117	9
	Public order and safety	Q	Q	Q	Q	Q	Q	Q	Q
	Religious worship	Q	Q	Q	Q	Q	Q	Q	Q
	Service	342	137	205	1,367	Q	Q	Q	Q
	Warehouse and storage	307	123	184	1,228	150	28	58	4
	Other	Q	Q	Q	Q	Q	Q	Q	Q
	Vacant	Q	Q	Q	Q	Q	Q	Q	Q
Pacific	Education	344	206	138	2,615	92	32	50	6

U.S. EIA Area[1]	Principal Building Activity	Electricity (kWh/KSF/year)				Natural Gas (therm/KSF/year)			
		Space heating	Water heating	Cooking	Other[2]	Space heating	Water heating	Cooking	Other[2]
	Food sales	Q	Q	Q	Q	Q	Q	Q	Q
	Food service	1,317	790	527	10,008	492	170	270	33
	Health care	872	523	349	6,627	274	95	150	18
	Inpatient	1,088	653	435	8,266	415	144	228	28
	Outpatient	643	386	257	4,883	113	39	62	8
	Lodging	486	291	194	3,690	159	55	87	11
	Mercantile	653	392	261	4,962	194	67	106	13
	Retail (other than mall)	480	288	192	3,650	78	27	43	5
	Enclosed and strip malls	735	441	294	5,582	235	81	129	16
	Office	459	275	183	3,486	99	34	54	7
	Public assembly	319	191	128	2,425	128	44	70	9
	Public order and safety	451	270	180	3,424	Q	Q	Q	Q
	Religious worship	138	83	55	1,047	86	30	47	6
	Service	302	181	121	2,292	Q	Q	Q	Q
	Warehouse and storage	192	115	77	1,461	27	9	15	2
	Other	Q	Q	Q	Q	Q	Q	Q	Q
	Vacant	Q	Q	Q	Q	Q	Q	Q	Q
Climate Zone									
Cold or very cold	Education	629	90	270	2,337	324	19	33	10
	Food sales	Q	Q	Q	Q	Q	Q	Q	Q
	Food service	2,457	351	1,053	9,125	Q	Q	Q	Q
	Health care	1,962	280	841	7,289	657	39	66	20
	Inpatient	Q	Q	Q	Q	Q	Q	Q	Q
	Outpatient	Q	Q	Q	Q	Q	Q	Q	Q
	Lodging	967	138	414	3,592	458	27	46	14
	Mercantile	976	139	418	3,625	339	20	34	10
	Retail (other than mall)	797	114	341	2,959	258	15	26	8
	Enclosed and strip malls	Q	Q	Q	Q	Q	Q	Q	Q
	Office	900	129	386	3,342	235	14	24	7
	Public assembly	925	132	396	3,435	412	25	42	12
	Public order and safety	Q	Q	Q	Q	Q	Q	Q	Q
	Religious worship	Q	Q	Q	Q	Q	Q	Q	Q
	Service	549	78	235	2,040	478	28	48	14
	Warehouse and storage	356	51	153	1,322	260	15	26	8
	Other	Q	Q	Q	Q	Q	Q	Q	Q
	Vacant	Q	Q	Q	Q	Q	Q	Q	Q
Cool	Education	547	156	182	1,902	304	27	56	14
	Food sales	3,159	902	1,053	10,980	602	54	110	27
	Food service	2,518	719	839	8,752	1583	143	290	71

U.S. EIA Area[1]	Principal Building Activity	Electricity (kWh/KSF/year)				Natural Gas (therm/KSF/year)			
		Space heating	Water heating	Cooking	Other[2]	Space heating	Water heating	Cooking	Other[2]
	Health care	1,650	471	550	5,735	437	39	80	20
	Inpatient	2,048	585	683	7,119	576	52	106	26
	Outpatient	1,042	298	347	3,622	231	21	42	10
	Lodging	1,055	301	352	3,667	310	28	57	14
	Mercantile	1,154	330	385	4,013	358	32	66	16
	Retail (other than mall)	896	256	299	3,116	198	18	36	9
	Enclosed and strip malls	1,405	402	468	4,886	474	43	87	21
	Office	891	255	297	3,099	201	18	37	9
	Public assembly	657	188	219	2,283	387	35	71	17
	Public order and safety	799	228	266	2,777	288	26	53	13
	Religious worship	195	56	65	677	210	19	38	9
	Service	415	118	138	1,441	279	25	51	13
	Warehouse and storage	350	100	117	1,218	205	18	38	9
	Other	1,581	452	527	5,494	222	20	41	10
	Vacant	327	93	109	1,135	Q	Q	Q	Q
Mixed mild	Education	684	156	187	2,364	258	37	50	17
	Food sales	Q	Q	Q	Q	Q	Q	Q	Q
	Food service	3,470	789	946	11,987	997	144	193	64
	Health care	1,470	334	401	5,078	432	62	84	28
	Inpatient	1,599	363	436	5,523	575	83	111	37
	Outpatient	1,180	268	322	4,076	217	31	42	14
	Lodging	964	219	263	3,330	332	48	64	21
	Mercantile	1,110	252	303	3,835	253	37	49	16
	Retail (other than mall)	882	200	240	3,045	174	25	34	11
	Enclosed and strip malls	1,335	303	364	4,613	324	47	63	21
	Office	975	222	266	3,367	143	21	28	9
	Public assembly	814	185	222	2,811	359	52	69	23
	Public order and safety	1,009	229	275	3,484	253	37	49	16
	Religious worship	451	103	123	1,559	234	34	45	15
	Service	579	132	158	2,000	289	42	56	19
	Warehouse and storage	398	91	109	1,377	142	20	27	9
	Other	2,332	530	636	8,055	276	40	53	18
	Vacant	178	40	48	614	Q	Q	Q	Q
Warm	Education	559	230	230	2,400	105	27	44	10
	Food sales	2,104	866	866	9,035	Q	Q	Q	Q
	Food service	2,511	1,034	1,034	10,782	746	191	311	69
	Health care	1,437	592	592	6,172	342	88	143	31
	Inpatient	1,828	753	753	7,850	442	114	185	41
	Outpatient	1,138	468	468	4,885	160	41	67	15

U.S. EIA Area[1]	Principal Building Activity	Electricity (kWh/KSF/year)				Natural Gas (therm/KSF/year)			
		Space heating	Water heating	Cooking	Other[2]	Space heating	Water heating	Cooking	Other[2]
	Lodging	763	314	314	3,278	171	44	71	16
	Mercantile	935	385	385	4,016	185	48	77	17
	Retail (other than mall)	785	323	323	3,370	104	27	43	10
	Enclosed and strip malls	1,067	440	440	4,584	222	57	93	20
	Office	743	306	306	3,189	108	28	45	10
	Public assembly	755	311	311	3,243	158	41	66	15
	Public order and safety	883	364	364	3,793	217	56	90	20
	Religious worship	266	110	110	1,143	86	22	36	8
	Service	412	170	170	1,770	298	76	124	27
	Warehouse and storage	318	131	131	1,365	65	17	27	6
	Other	1,300	535	535	5,582	105	27	44	10
	Vacant	297	122	122	1,274	Q	Q	Q	Q
Hot or very hot	Education	192	192	256	2,301	41	25	56	11
	Food sales	Q	Q	Q	Q	Q	Q	Q	Q
	Food service	880	880	1,174	10,563	358	218	489	96
	Health care	436	436	581	5,226	215	131	294	58
	Inpatient	582	582	776	6,988	253	154	346	68
	Outpatient	204	204	272	2,448	Q	Q	Q	Q
	Lodging	257	257	343	3,085	82	50	112	22
	Mercantile	316	316	422	3,794	80	49	109	21
	Retail (other than mall)	292	292	389	3,499	68	42	93	18
	Enclosed and strip malls	340	340	453	4,080	84	51	115	23
	Office	267	267	356	3,205	34	21	46	9
	Public assembly	248	248	331	2,980	68	42	94	18
	Public order and safety	Q	Q	Q	Q	Q	Q	Q	Q
	Religious worship	107	107	142	1,278	45	28	62	12
	Service	199	199	266	2,392	Q	Q	Q	Q
	Warehouse and storage	126	126	169	1,517	16	10	22	4
	Other	Q	Q	Q	Q	Q	Q	Q	Q
	Vacant	Q	Q	Q	Q	Q	Q	Q	Q

Sources: U.S. Energy Information Administration (EIA). *Commercial Buildings Energy Consumption Survey (CBECS)*. Table B20: Energy sources, floorspace, 2018. Table E6: Electricity consumption (in kilowatt-hours [kWh]) by end use, 2018. Table E8: Natural gas consumption and conditional energy intensities (in cubic feet) by end use, 2018. Table C25: Natural gas consumption and conditional energy intensity by census region, 2018. Table C29: Natural gas consumption and conditional energy intensity by census division (part 3), 2018. Table C30: Natural gas consumption and conditional energy intensity by climate zone, 2018. Accessed January 2025. https://www.eia.gov/consumption/commercial/data/2018/.

yr = year; yr = year; KSF = thousand square feet

Notes: End-use consumption data by building activity and geographic zone were calculated by combining dataset from the CBECS. The method includes applying some national averages to regional data. Refer to the Measure E-15 factsheet for additional information. See Figure E-2.1 for map of U.S. census regions/division and climate zones.

Q = Data withheld in the CBECS because 1) the relative standard error was greater than 50%, 2) the reporting sample had fewer than 20 buildings, or 3) value rounded to zero in the units displayed.

[1] See Figure E-2.1 for map of U.S. census regions/division and climate zones.

[2] Includes wood, coal, solar, and all other energy sources.

Table E-18.1. Landfill Disposed Organic Carbon (DOC)

Location	Percent Disposed Organic Carbon (DOC)
Colorado[1]	37.1
Oregon[2]	21.6
Washington[3]	16.9
National[4]	31.3

Sources: See footnotes.

[1] Colorado Department of Public Health and Environment. 2018. *Waste Composition of Municipal Solid Waste Disposal.* Accessed February 4, 2025. https://oitco.hylandcloud.com/CDPHERMPop/docpop/docpop.aspx?clienttype=html&docid=3261683.

[2] Oregon Dept. of Environmental Quality. 2025. Excel file provided to ICF with waste disposal rates and waste stream data. February.

[3] Washington State Department of Ecology. 2025. Excel file provided to ICF with waste disposal rates and waste stream data. January.

[4] U.S. EPA. 2020. *Advancing Sustainable Materials Management: 2018* Tables and Figures. December. https://www.epa.gov/sites/default/files/2021-01/documents/2018_ff_fact_sheet_dec_2020_fnl_508.pdf.

Table E-21.1. Available Cool Pavement Maximum Yearly Electricity Savings

EIA Climate Zone[1]	Cooling Savings (kWh/m^2/year)[2]	Additional Heating (therms/m^2/year)[2]
Hot or Very Hot	0.9000	—[3]
Warm	1.0030	0.0069

Sources: Lawrence Berkely National Laboratory (LBNL). 2017a. *Are Cooler Surfaces a Cost-Effect Mitigation of Urban Heat Islands?* April 2017. https://eta-publications.lbl.gov/sites/default/files/cooler_surfaces.pdf.

Lawrence Berkely National Laboratory (LBNL). 2017b. *Energy and Environmental Consequences of a Cool Pavement Campaign.* May 2017. https://eta-publications.lbl.gov/sites/default/files/e-b-cool-pavement-campaign.pdf.

U.S. Energy Information Administration (U.S. EIA). 2025. *Commercial Buildings Energy Consumption Survey (CBECS) Maps.* Accessed February 4, 2025. https://www.eia.gov/consumption/commercial/maps.php.

[1] Users should refer to the EIA climate zone map to see if their project is within one of the applicable zones. See Figure E-2.3.

[2] Values were calculated based on available data from Lawrence Berkely National Laboratory (LBNL) (2017a, 2017b). The LBNL study presents cooling and heating values for nine locations in California. The California locations were mapped to the U.S. EIA climate zones. Average cooling and heating values were then calculated for each of the cross-walked EIA climate zones based on the mapped cities. Note that data are not available for all U.S. EIA climate zones.

[3] Data on potential additional gas consumption for cool pavement installation in the hot or very hot climate zone was not quantified in the LBNL studies. Users could consider applying the gas consumption value for the "warm" climate zone to approximate a minimum increase in heating. However, please note that additional heating requirements for projects in hot or very hot climates may be greater than for projects located in more mild climates.

Table E-26.1. Capacity Factors for Biomass Electricity Generation in the United States

Fuel Type	Capacity Factor[1]
Other Biomass[2]	62%
Wood	59%

Source: U.S. Energy Information Agency (EIA). 2023. Table 6.07.B: "Capacity Factors for Utility Scale Generators Primarily Using Non-Fossil Fuels." *Electric Power Monthly.* Accessed December 2023. https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_6_07_b.

[1] Capacity factors are based on an average of the last five years of generation.

[2] Other biomass includes landfill gas, non-biogenic municipal solid waste, sludge waste, biogenic municipal solid waste, black liquor, and agricultural byproducts.

Table E-26.2. Lifecycle Emission Factors for Biomass Electricity Generation in the United States

Fuel Type	Life Cycle GHG Emission Factors (lbs CO_2e/MWh)[1]		
	Mean	Median	Standard Deviation
Dedicated Woody Crops	189.6	114.7	308.7
Dedicated Herbaceous Crops	617.4	119.1	882
Agricultural Residues	573.3	123.5	882
Forest Residues	374.8	79.4	683.6
Urban Residues	904.1	108	859.9
Mill Residues	202.9	33.1	485.1
Animal Wastes & Processing Residues	1,367.1	286.6	859.9
Other Wastes & Residues	132.3	92.6	108

Source: Electric Power Research Institute (EPRI). 2013. *Literature Review and Sensitivity Analysis of Biopower Life-Cycle Assessments and Greenhouse Gas Emissions*. Accessed December 2023. https://www.epri.com/research/products/1026852.

[1] Emission factors exclude the effects of land use change. Use the mean value.

Table E-26.3. Lifecycle Carbon Intensity Factors from GREET (pounds CO_2e per megawatt-hour)

Year	WECC	SPP
2025	651	905
2030	356	324
2035	297	305
2040	242	340
2045	234	343
2050	232	359

Source: U.S. Department of Energy (U.S. DOE). 2024. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model*. 2024 Release. Accessed January 28, 2025. https://greet.anl.gov/.

WECC = Western Electricity Coordinating Council; SPP= Southwest Power Pool

Notes: Emission factors are available for two geographies as defined in the U.S. DOE's GREET model—the Western Electricity Coordinating Council (WECC) and Southwest Power Pool (SPP). Arizona, Colorado, Oregon, and Washington are wholly within WECC. New Mexico is split between WECC and SPP. Refer to Figure E-4.2. Emission factors for WECC and SPP are provided in five-year increments between 2025 and 2050. If the analysis year falls within a five-year time period, users should select the earlier time period. For example, if the analysis year is 2037, users should use the emission factor for 2035. Alternatively, users may interpolate an emission factor for their specific analysis year based on the data provided in the table.

Table W-1.1. Water Energy Intensity Factors (Total Supply)

State	Region	kWh per AF
AZ	Statewide	419
AZ	Apache County	296
AZ	Cochise County	358
AZ	Coconino County	370
AZ	Gila County	345
AZ	Graham County	358
AZ	Greenlee County	395
AZ	La Paz County	210
AZ	Maricopa County	444
AZ	Mohave County	382
AZ	Navajo County	370
AZ	Pima County	358
AZ	Pinal County	395
AZ	Santa Cruz County	382
AZ	Yavapai County	333
AZ	Yuma County	432
U.S.	Nationwide	419

Sources: Paraschiv, S., L. Paraschiv, and A. Serban. 2023. "An Overview of Energy Intensity of Drinking Water Production and Wastewater Treatment." *Energy Reports* 9 (11):118-123.

Bartos, M., and C. Mikhail. n.d. Supporting Information for *The Conservation Nexus: Valuing Interdependent Water and Energy Savings in Arizona*. Accessed February 21, 2025. https://pubs.acs.org/doi/suppl/10.1021/es4033343/suppl_file/es4033343_si_001.pdf.

kWh = kilowatt-hours; AF = acre feet

Table W-2.1. Greywater Flows (gallons per day per occupant)

	Source	
Flow Source	Oregon	Uniform Plumbing Code
Showers, bathtubs, and lavatories	35	25
Laundry	23	15

Sources: Oregon Department of Land Conservation. 2025. Email message to ICF with greywater data. February 2025.

Uniform Plumbing Code (UPC). Section 1503.8.1.

Table W-2.2. Wastewater Energy Intensity Factors (kWh per AF)

Location	Wastewater Treatment
Arizona	439
Washington	816
National	530

Sources: Bartos, M. and C. Mikhail. n.d. Supporting Information for *The Conservation Nexus: Valuing Interdependent Water and Energy Savings in Arizona*. Accessed February 21, 2025. https://pubs.acs.org/doi/suppl/10.1021/es4033343/suppl_file/es4033343_si_001.pdf.

Paraschiv, S., L. Paraschiv, and A. Serban. 2023. "An Overview of Energy Intensity of Drinking Water Production and Wastewater Treatment." *Energy Reports* 9 (11):118-123.

Washington State Department of Commerce (WA DOC). 2025. Excel file of wastewater treatment electricity provided to ICF. January 2025.

Table W-4.1. Residential Water Consumption Percentages by End Use

End-Use/Fixture (z)	% of Indoor Water Use[1]
Toilet	24%
Showerhead	19%
Bathroom and Kitchen Faucet	19%
Dishwashers	1%
Clothes Washers	16%
Leaks and Other	18%
Bath	3%

Source: Water Research Foundation. 2016. *Residential End Uses of Water, Version 2*. Accessed January 2021. https://www.waterrf.org/research/projects/residential-end-uses-water-version-2.

[1] Indoor water use percentages calculated based on data from the Water Research Foundation 2016.

Table W-4.2. Non-Residential Water Consumption Percentages by End Use

End-Use/Fixture (z)	Office		Hotel		Restaurant		Grocery Store		Non-Grocery Retail Store		K-12 School		Other School	
	Total[1]	Indoor[2]	Total[1]	Indoor[2]	Total[1]	Indoor[2]	Total[1]	Indoor[2]	Total[1]	Indoor[2]	Total[1]	Indoor[2]	Total[1]	Indoor[2]
Restroom	26%	—	51%	—	34%	—	17%	—	26%	—	20%	—	20%	—
Toilets (72% of Restroom)	—	48%	—	46%	—	27%	—	26%	—	46%	—	51%	—	37%
Urinals (17% of Restroom)	—	11%	—	11%	—	6%	—	6%	—	11%	—	12%	—	9%
Faucets (4% of Restroom)	—	3%	—	3%	—	1%	—	1%	—	3%	—	3%	—	2%
Showers (7% of Restroom)	—	5%	—	4%	—	3%	—	2%	—	4%	—	5%	—	4%
Kitchen	3%	—	10%	—	46%	—	9%	—	4%	—	2%	—	1%	—
Faucets (57% of Kitchen)	—	4%	—	7%	—	29%	—	11%	—	6%	—	4%	—	1%
Dishwashers (24% of Kitchen)	—	2%	—	3%	—	12%	—	5%	—	2%	—	2%	—	1%
Ice Making (19% of Kitchen)	—	1%	—	2%	—	10%	—	4%	—	2%	—	1%	—	0%
Laundry	0%	0%	14%	18%	0%	0%	0%	0%	0%	0%	0%	0%	1%	3%
Other	10%	26%	5%	6%	12%	13%	22%	46%	11%	27%	6%	21%	17%	44%
Landscaping	38%	—	10%	—	6%	—	3%	—	38%	—	72%	—	61%	—
Cooling	23%	—	10%	—	2%	—	49%	—	21%	—	*[3]	—	*[3]	—
Total[4]	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Pacific Institute. 2003. *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. November 2023. https://pacinst.org/wp-content/uploads/2013/02/waste_not_want_not_full_report3.pdf.

[1] Water end-use data from Figures E-1, E-2, E-5, E-6, E-7, E-8, and E-9 of Appendix E of the Pacific Institute report.

[2] Indoor end-use data calculated based on the total water use data for the relevant building category and Figure 4-3 and Figure 4-4 of the Pacific Institute report. Figure 4-3 shows the breakdown of restroom water use by end-use in the commercial and industry sector. Figure 4-4 shows the breakdown of kitchen water-use by end-use in the commercial and industry sector; it was assumed that all end-uses except dishwashing and ice making are associated with faucet water use.

[3] No data.

[4] Totals may not add to 100% due to rounding.

Table W-4.3. Residential Baseline and Reduced Flow Rates by Fixture Type

End-Use/Fixture (z)	Baseline Flow Rate [1]					Reduced Flow Rate [2]	Units
	Arizona	Colorado	New Mexico	Oregon	Washington		
Toilet	1.6	1.28	1.6	1.28 1.6 (remote areas)	1.28	1.28	gal/flush
Showerhead	2.0	2.0	2.5	1.8	1.8	2.0	gal/min @ 80 psi
Bathroom Faucet	2.2	1.5	2.2	1.5	1.2	1.5	gal/min @ 60 psi
Kitchen Faucet	2.2	2.2	2.2	1.8	1.8	—	gal/min @ 60 psi
Dishwashers							
Standard			5.0			3.2	gal/cycle
Compact			3.5			2.0	gal/cycle
Clothes Washers							
Top-loading, Compact			12.0			4.2	gal/cycle/ft^3
Top-loading, Standard			6.5			4.3	gal/cycle/ft^3
Front-loading, Compact			8.3			4.2	gal/cycle/ft^3
Front-loading, Standard			4.7			3.2	gal/cycle/ft^3

Sources: See footnote (1) for state codes.

EnergyStar. 2021. *Clothes Washers Key Product Criteria*. Accessed February 3, 2025. https://www.energystar.gov/products/clothes_washers/key_product_criteria.

EnergyStar. 2023. *Dishwashers Key Product Criteria*. Accessed February 3, 2025. https://www.energystar.gov/products/dishwashers/key_product_criteria.

U.S. Environmental Protection Agency (EPA). 2024. *WaterSense Products*. Last revised November 13, 2024. Accessed February 13, 2025. https://www.epa.gov/watersense/watersense-products.

[1] Flow rates established per the following codes and regulations. Where no state requirement, the minimum federal efficiency standard is shown.

- Arizona = 2024 International Plumbing Code
- Colorado = Senate Bill 14-103 (compliance with EPA WaterSense plumbing fixture)
- New Mexico = 2021 International Plumbing Code
- Oregon = 2023 Oregon Plumbing Specialty Code (OPSC)
- Washington = Chapter 51-56-0400 WAC
- Federal standards for dishwashers and clothes washers (all states) = DOE 10 CFR Part 430

[2] EPA WaterSense for toilet, showerhead, and bathroom faucet. Energy Star for all other fixtures.

Table W-4.4. Non-Residential Baseline and Reduced Flow Rates by Fixture Type

End-Use/Fixture (z)	Baseline Flow Rate [1]					Reduced Flow Rate [2]	Units
	Arizona	Colorado	New Mexico	Oregon	Washington		
Toilet	1.6	1.28	1.6	1.28 1.6 (remote areas)	1.28	1.28	gal/flush
Urinals							
Wall-Mounted	1.0	0.5	1.0	0.5	0.125	0.5	gal/flush
Floor-Mounted	1.0	0.5	1.0	0.5	0.5	0.5	gal/flush
Showerhead	2.0	2.0	2.5	1.8	1.8	2.0	gal/min. @ 80 psi
Bathroom Faucet	0.5	0.5	0.5	0.5	0.5	—	gal/min. @ 60 psi
Kitchen Faucet	2.2	2.2	2.2	2.2	1.8	—	gal/min. @ 60 psi
Dishwashers - High Temperature							
Under Counter			1.1			0.86	gal/rack
Single Tank Door			1.3			0.89	gal/rack
Single Tank Conveyor			0.9			0.7	gal/rack
Multi-Tank Conveyor			1.0			0.54	gal/rack
Dishwashers - Low Temperature							
Under Counter			1.7			1.19	gal/rack
Single Tank Door			2.1			1.18	gal/rack
Single Tank Conveyor			1.3			0.79	gal/rack
Multi-Tank Conveyor			1.0			0.54	gal/rack
Clothes Washer							
Top-loading			8.8			—	gal/cycle/ft^3
Front-loading			4.1			4.00	gal/cycle/ft^3

Sources: See footnote (1) for state codes.

EnergyStar. 2021a. *Commercial Dishwashers Key Product Criteria*. Accessed February 3, 2025. https://www.energystar.gov/products/commercial_food_service_equipment/commercial_dishwashers/key_product_criteria.

EnergyStar. 2021b. *Clothes Washers Key Product Criteria*. Accessed February 3, 2025. https://www.energystar.gov/products/clothes_washers/key_product_criteria.

U.S. Environmental Protection Agency (EPA). 2024. *WaterSense Products*. Last revised November 13, 2024. Accessed February 13, 2025. https://www.epa.gov/watersense/watersense-products.

[1] Flow rates established per the following codes and regulations. Where no state requirement, the minimum federal efficiency standard is shown.

- Arizona = 2024 International Plumbing Code
- Colorado = Senate Bill 14-103 (compliance with EPA WaterSense plumbing fixture)
- New Mexico = 2021 International Plumbing Code
- Oregon = 2023 Oregon Plumbing Specialty Code (OPSC)
- Washington = Chapter 51-56-0400 WAC
- Federal standards for dishwashers (all states) = U.S. EPA and U.S. DOE. Savings Calculator for ENERGY STAR Certified Commercial Kitchen Equipment.
- Federal standards for clothes washers (all states) = DOE 10 CFR Part 431

[2] EPA WaterSense for toilet, urinals, and showerhead. Energy Star for all other fixtures.

Table W-5.1. Annual Average Evapotranspiration (inches per year)

Station[1]	State	Period	Rate (B)	Station[1]	State	Period	Rate (B)
BARTLETT DAM	AZ	1939-2005	117.54	ELEPHANT BUTTE DAM	NM	1917-2005	112.41
BLACK RIVER PUMPS	AZ	1948-2005	50.53	ESTANCIA	NM	1914-2005	55.63
DAVIS DAM # 2	AZ	1958-1977	154.32	FARMINGTON AG SCIENCE C	NM	1978-2005	66.81
DAVIS DAM	AZ	1948-1961	101.53	FLORIDA	NM	1939-1992	99.93
DOUGLAS	AZ	1948-2005	73.63	GALLUP RANGER STN	NM	1966-1975	62.46
FORT VALLEY	AZ	1909-2005	27.52	JEMEZ DAM	NM	1953-2005	82.04
GRAND CANYON NATL PARK	AZ	1957-1977	46.04	JORNADA EXP RANGE	NM	1925-2005	88.82
GRAND CANYON N P 2	AZ	1976-2005	44.04	LAGUNA	NM	1914-2005	63.23
HAWLEY LAKE	AZ	1967-1988	33.17	LAKE AVALON	NM	1914-1979	112.93
MANY FARMS SCHOOL	AZ	1951-1975	90.77	LAKE MC MILLAN	NM	1941-1949	79.51
MC NARY 2 N	AZ	1933-2005	37.56	LOS LUNAS 3 SSW	NM	1923-2005	73.1
MESA	AZ	1896-2005	94.38	NARROWS	NM	1948-1964	104.88
NOGALES 6 N	AZ	1952-2005	91.2	NAVAJO DAM	NM	1963-2005	59.61
PAGE	AZ	1957-2005	80.57	PORTALES 7 WNW	NM	1934-1960	89.13
ROOSEVELT 1 WNW	AZ	1905-2005	96.49	HOOD RANGER STN	NM	1954-2005	56.7
SACATON	AZ	1908-2005	107.42	ROSWELL WSO AIRPORT	NM	1893-1972	75.96
SAFFORD AGRICULTURAL CTR	AZ	1948-2005	97.57	SANTA FE	NM	1867-1972	62.9

Station[1]	State	Period	Rate (B)	Station[1]	State	Period	Rate (B)
SAN CARLOS RESERVOIR	AZ	1948-2005	91.3	SANTA FE 2	NM	1972-2005	60.22
SIERRA ANCHA	AZ	1913-1979	75.39	SHIPROCK	NM	1926-2005	73.16
SNOWFLAKE 15 W	AZ	1965-1998	63.63	SOCORRO	NM	1914-2005	56.44
STEWART MOUNTAIN	AZ	1948-2005	106.23	STATE UNIVERSITY	NM	1959-2005	92.91
TEMPE ASU	AZ	1953-2005	74.29	SUMNER LAKE	NM	1921-2005	92.04
TUCSON UNIV OF ARIZONA	AZ	1894-2005	103.51	TUCUMCARI 4 NE	NM	1904-2005	74.3
TUCSON U OF ARIZ # 1	AZ	1982-2005	111.07	UTE DAM	NM	1965-2005	89.44
WAHWEAP	AZ	1961-2005	100.18	ASTOR EXPERIMENT STN	OR	1948-1973	27.82
WHITERIVER 1 SW	AZ	1900-2005	77.65	BEND 7 NE	OR	1991-2005	39.07
WINKELMAN 6 S	AZ	1942-1980	95.78	CORVALLIS STATE UNIV	OR	1889-2005	38.32
YUMA CITRUS STATION	AZ	1920-2005	99.21	COTTAGE GROVE DAM	OR	1943-2005	38.46
AKRON 4 E	CO	1918-2005	67.69	DETROIT DAM	OR	1954-2005	37.78
ALAMOSA WSO AP	CO	1948-2005	53.91	DORENA DAM	OR	1948-2005	39.00
ARBOLES	CO	1957-1963	47.83	FERN RIDGE DAM	OR	1943-2005	40.7
BONNY LAKE	CO	1949-2005	68.01	HERMISTON 2 S	OR	1928-1997	57.72
CLIMAX	CO	1949-2005	18.53	HOOD RIVER EXP STN	OR	1928-2005	35.51
CONEJOS 3 NNW	CO	1948-1960	48.32	KLAMATH FALLS AGR STN	OR	1949-2004	56.54
ESTES PARK	CO	1948-1994	40.49	LOOKOUT POINT DAM	OR	1955-2005	39.59
FORT COLLINS	CO	1900-2005	41.04	MADRAS 1 NNW	OR	1952-2005	50.97
GRAND JUNCTION WALKER	CO	1900-2005	92.34	MALHEUR BRANCH EXP STN	OR	1943-2005	52.99
GRAND JUNCTION 6 ESE	CO	1962-2005	64.13	VOLTAGE 2 NW	OR	1959-2005	45.41
GRAND LAKE 6 SSW	CO	1948-2005	35.51	MEDFORD EXP STN	OR	1937-2003	41.28
GREEN MOUNTAIN DAM	CO	1948-2005	31.9	MORO	OR	1928-2005	59.64
JOHN MARTIN DAM	CO	1941-2005	74.21	N WILLAMETTE EXP STN	OR	1963-2005	41.44
LAKE GEORGE 8 SW	CO	1948-2005	32.54	ODELL LAKE LAND PAN	OR	1948-1980	19.22
MEREDITH	CO	1963-2005	39.71	ODELL LAKE WATER PAN	OR	1945-1959	18.02
MONTROSE 1	CO	1948-1982	57.45	PELTON DAM	OR	1958-2005	45.32
PLATORO	CO	1949-1991	34.62	PENDLETON BR EXP STN	OR	1956-2005	57.69
PUEBLO WSO AP	CO	1954-2005	66.58	SUMMER LAKE 1 S	OR	1957-2005	53.71
PUEBLO CITY RESERVOIR	CO	1948-1971	74.62	UNION EXP STN	OR	1928-2005	35.34

Station[1]	State	Period	Rate (B)	Station[1]	State	Period	Rate (B)
PUEBLO RESERVOIR	CO	1975-2005	62.67	WARM SPRINGS RESERVOIR	OR	1931-1974	52.9
PUEBLO 6 SSW	CO	1971-1985	64.87	WICKIUP DAM	OR	1941-2005	36.56
SAN LUIS LAKES 3W	CO	1948-1955	56.32	WINCHESTER	OR	1950-2005	30.7
SPRINGFIELD 7 WSW	CO	1956-2002	72.38	WINCHESTER 3 W F STN	OR	1981-1989	45.32
SUGARLOAF RESERVOIR	CO	1948-2005	25.23	BELLINGHAM 2 N	WA	1948-1985	29.09
TRINIDAD LAKE	CO	1989-2005	64.44	BELLINGHAM 3 SSW	WA	1985-2005	22.31
TWIN LAKES RESERVOIR	CO	1949-2005	39.58	BUMPING LAKE	WA	1931-1967	23.88
VALLECITO DAM	CO	1948-2005	37.67	CONNELL 1 W	WA	1960-2003	56.22
WAGON WHEEL GAP 3 N	CO	1948-1972	35.46	ELTOPIA 6 W	WA	1954-1973	48.16
WALSH 1 W	CO	1951-2005	63.82	ELTOPIA 8 WSW	WA	1974-2005	39.82
WIGGINS 7 SW	CO	1960-1971	54.12	LAKE KACHESS	WA	1931-1977	25.41
ABIQUIU DAM	NM	1957-2005	72.13	LIND 3 NE EXP STN	WA	1931-2005	54.69
AGRICULTURAL COLLEGE	NM	1892-1959	93.06	MOSES LAKE 3 E	WA	1943-1979	48.5
ALAMOGORDO DAM	NM	1939-1975	104.86	OROVILLE 1 S	WA	1960-1970	36.58
ANIMAS	NM	1923-2005	100.68	OTHELLO 6 ESE	WA	1941-2002	50.95
ARTESIA 6 S	NM	1914-2005	87.68	PROSSER 4 NE	WA	1931-2005	45.82
BITTER LAKES WL REFUGE	NM	1950-2005	88.89	PUYALLUP 2 W EXP STN	WA	1931-1995	28.74
BOSQUE DEL APACHE	NM	1914-2005	92.51	QUINCY 1 S	WA	1941-2005	49.65
BRANTLEY DAM	NM	1987-2005	109.48	RIMROCK TIETON DAM	WA	1947-1977	39.88
CABALLO DAM	NM	1938-2005	107.06	SEATTLE MAPLE LEAF R	WA	1941-1960	34.52
CAPULIN NATL MONUMENT	NM	1966-1979	46.19	SPOKANE WSO AIRPORT	WA	1889-2005	48.41
CLOVIS 13 N	NM	1929-2005	86.68	WALLA WALLA 3 W ENT LA	WA	1931-1962	43.69
COCHITI DAM	NM	1975-2005	88.01	WENATCHEE EXP STN	WA	1950-1997	40.88
CONCHAS DAM	NM	1938-2005	80.89	WHITMAN MISSION	WA	1962-2005	47.11
EAGLE NEST	NM	1937-2005	42.96	WIND RIVER	WA	1901-1977	27.79
EL VADO DAM	NM	1923-2005	51.99	YAKIMA WSO AP	WA	1946-2005	47.21

Source: Western Region Climate Center (WRCC). 2025. *Evaporation Stations*. Accessed March 3, 2025. https://wrcc.dri.edu/Climate/comp_table_show.php?stype=pan_evap_avg>.

[1] For information on the city, county, and station latitude and longitude coordinates, visit the WRCC's Station Data Inventory Listing webpage.

Table W-5.2. Irrigation Efficiency Based on Assumed Distribution Uniformity

Irrigation Type	Efficiency (E)[1]
Drip - Standard	70%
Drip - Press Comp	90%
Fixed Spray	65%
Microspray	70%
Rotor (or rotating nozzles)	70%

Source: U.S. Environmental Protection Agency (EPA). 2020. *WaterSense Water Budget Tool Version 1.04*. Released June 2020. Accessed March 3, 2025. https://www.epa.gov/watersense/water-budget-tool.

[1] Factor represents the lower-quarter distribution uniformity (DU_{LQ}), which is the ratio of the lowest 25 percent water measurements compared to the overall average water measurement for the irrigation system.

Table W-5.3. Plant Factors (F_s) by Vegetation Type and General Water Requirement Category

	Water Requirement		
Vegetation Type	Low	Medium	High
Trees	0.2	0.5	0.9
Shrubs	0.2	0.5	0.7
Ornamental groundcover	0.2	0.5	0.7
Turfgrass	0.6	0.7	0.8

Source: U.S. Environmental Protection Agency (EPA). 2020. *WaterSense Water Budget Tool Version 1.04*. Released June 2020. Accessed March 3, 2025. https://www.epa.gov/watersense/water-budget-tool.

Table W-5.4. Annual Average Rainfall (inches per year)

Station[1]	Period	State	Rate (G)
Flagstaff WSO AP	1950-2006	AZ	21.32
Phoenix WSFO AP	1949-2006	AZ	7.53
Tucson WSO AP	1949-2006	AZ	11.42
Yuma WSO AP	1949-2006	AZ	2.95
Colorado Springs WSO AP	1949-2006	CO	16.08
Denver WSFO AP	1949-2006	CO	15.5
Grand Junction Walker	1949-2006	CO	8.69
Pueblo WSO AP	1954-2006	CO	11.86
Albuquerque WSFO AIRPORT	1949-2006	NM	8.71
State University	1959-2006	NM	9.35
Eugene WSO AIRPORT	1949-2006	OR	46.76
Medford WSO AP	1949-2006	OR	19.31
Portland WSFO	1949-2006	OR	37.58
Seattle Tacoma WSCMO AP	1949-2006	WA	38.17
Spokane WSO AIRPORT	1949-2006	WA	16.72
Yakima WSO AP	1949-2006	WA	8.15

Source: Western Region Climate Center (WRCC). 2025. *Mean Monthly and Annual Precipitation*. Accessed March 3, 2025. https://wrcc.dri.edu/Climate/comp_table_show.php?stype=ppt_means.

AP = airport; WSO = weather service office; WFO = weather forecast office

[1] For information on the city, county, and station latitude and longitude coordinates, visit the WRCC's Station Data Inventory Listing webpage.

Table LL-1.1. Average Landscape Equipment Horsepower

Equipment	Tech Type	Average HP
Chain Saws < 6 HP (commercial)	G2	2.8
Chain Saws < 6 HP (commercial)	G4	1.4
Chain Saws < 6 HP (residential)	G2	1.4
Chain Saws < 6 HP (residential)	G4	1.4
Chain Saws > 6 HP	G2	5.9
Chippers/Stump Grinders (commercial)	G4	22.7
Turf Equipment (commercial)	G2	1.2
Turf Equipment (commercial)	G4	7.7
Front Mowers (commercial)	G4	9.4
Lawn Mowers (commercial)	G4	1.5
Lawn Mowers (residential)	G2	2.8
Lawn Mowers (residential)	G4	1.5
Leaf Blowers/Vacuums (commercial)	G2	2.6
Leaf Blowers /Vacuums (commercial)	G4	8.7
Leaf Blowers /Vacuums (residential)	G2	1.7
Leaf Blowers /Vacuums (residential)	G4	2.4
Other Lawn & Garden Equipment (commercial)	G2	11.9
Other Lawn & Garden Equipment (commercial)	G4	3.0
Other Lawn & Garden Equipment (residential)	G2	11.9
Other Lawn & Garden Equipment (residential)	G4	3.0
Rear Engine Riding Mowers (commercial)	G4	4.1
Rear Engine Riding Mowers (residential)	G4	4.1
Rotary Tillers < 6 HP (commercial)	G2	0.7
Rotary Tillers < 6 HP (commercial)	G4	1.8
Rotary Tillers < 6 HP (residential)	G2	0.7
Rotary Tillers < 6 HP (residential)	G4	1.8
Shredders < 6 HP (commercial)	G4	2.9
Shredders > 6 HP	G2	16.4
Shredders > 6 HP	G4	7.3
Trimmers/Edgers/Brush Cutter (commercial)	G2	2.0
Trimmers/Edgers/Brush Cutter (commercial)	G4	2.1
Trimmers/Edgers/Brush Cutter (residential)	G2	1.4
Trimmers/Edgers/Brush Cutter (residential)	G4	2.1

Source: U.S. Environmental Protection Agency (EPA). 2024. Latest Version of Motor Vehicle Emissions Simulator (MOVES). Released November 2024. Accessed December 2024. https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#guidance.

HP = horsepower; G2 = two-stroke gasoline; G4= four-stroke gasoline

Note: Operating hours used to define an activity-based average of horsepower for each equipment category. The activity distribution is the same across states and years analyzed (2025 through 2050). Horsepower values are inclusive of equipment load.

Table S-1.1. Washington State Annual Waste Disposal Rates by County (2021) (tons landfilled per person)

County	Tons per Person	County	Tons per Person
Adams	1.06	Lewis	0.37
Asotin	0.85	Lincoln	0.42
Benton	1.22	Mason	1.10
Chelan	1.27	Okanogan	0.93
Clallam	0.17	Pacific	1.00
Clark	0.77	Pend Oreille	0.59
Columbia	2.74	Pierce	1.52
Cowlitz	3.71	San Juan	0.78
Douglas	0.88	Skagit	1.07
Ferry	0.46	Skamania	0.58
Franklin	1.32	Snohomish	1.00
Garfield	0.78	Spokane	2.25
Grant	1.29	Stevens	1.42
Grays Harbor	1.03	Thurston	0.79
Island	0.68	Wahkiakum	0.09
Jefferson	1.79	Walla Walla	1.54
King	1.16	Whatcom	0.95
Kitsap	0.83	Whitman	0.67
Kittitas	1.95	Yakima	1.90
Klickitat	1.13	Statewide	1.25

Sources: Washington State Department of Ecology. 2025. Excel file provided to ICF with waste disposal rates and waste stream data. January.

Washington State Office of Financial Management. 2022. Projections of the Total Resident Population for Growth Management: 2022 GMA Projections–Middle Series. Last Revised December 2022. Accessed February 6, 2025. https://ofm.wa.gov/tags/population.

Note: Total waste disposal by county provided by Washington State. County values exclude waste sent to the Spokane Regional Waste to Energy Facility. County population statistics obtained from Washington State Office of Financial Management.

Table S-1.2. Oregon State Annual Waste Disposal Rates by Wasteshed (2022) (tons landfilled per person)

Wasteshed	Tons per Person	Wasteshed	Tons per Person
Baker	0.82	Lane	0.74
Benton	0.83	Lincoln	0.89
Clatsop	0.99	Linn	0.77
Columbia	0.62	Malheur	0.77
Coos	0.91	Marion	0.96
Crook	1.06	Metro	0.79
Curry	0.92	Milton Freewater	0.67
Deschutes	1.09	Morrow	1.88
Douglas	0.93	Polk	0.62
Gilliam	1.41	Sherman	0.67
Grant	0.64	Tillamook	1.17
Harney	0.64	Umatilla	1.33
Hood River	1.09	Union	0.79
Jackson	1.02	Wallowa	0.68
Jefferson	0.82	Wasco	0.84
Josephine	0.96	Wheeler	0.32
Klamath	1.07	Yamhill	1.09
Lake	0.70	Statewide	0.86

Source: Oregon Department of Environmental Quality. 2025. Excel file provided to ICF with waste disposal rates and waste stream data. February 2025.

Note: Wastesheds defined per OAR 340-090-0050 (see https://oregon.public.law/rules/oar_340-090-0050).

Table S-1.3. Arizona, Colorado, and New Mexico Statewide Annual Waste Disposal Rates (2022) (tons landfilled per person)

State	Tons per Person
Arizona	0.61
Colorado	0.91
New Mexico	0.66

Source: U.S. Environmental Protection Agency (EPA). 2025. State Inventory Tool–Municipal Solid Waste. Version 2025.1.

Table S-1.4. Washington State Waste Profile (2021) (% of total waste by material type)

Material	Percent of Waste Stream
Paper	18.8%
Newspaper	0.4%
Cardboard & Mixed Recyclable Paper	10.3%
Compostable Food-Soiled Paper Products	6.1%
Other Paper	1.9%
Plastic	14.8%
Plastic Containers & Other Non-film Recyclable Plastic	4.6%
Film Plastic	6.2%
Other Plastic	4.1%
Glass	2.3%
Glass Containers	1.6%
Other Glass	0.7%
Metal	4.3%
Metal	4.3%
Organics	16.9%
Food Waste	13.1%
Yard Waste	3.8%
Construction Materials	18.5%
Construction and Demolition Debris	18.5%
Consumer Products	5.5%
E-Waste	1.0%
Textiles and Shoes	4.5%
Other Materials	18.8%
Diapers	3.5%
Vehicle Batteries	0.0%
Other Hazardous / Special Waste	2.3%
Other Material	13.0%

Source: Washington State Department of Ecology. 2025. Excel file provided to ICF with waste disposal rates and waste stream data. January 2025.

Table S-1.5. Oregon State Waste Profile (2022) (% of total waste by material type)

Material	Percent of Waste Stream
Paper	12.2%
Aseptic Containers	0.0%
Cardboard	3.0%
Gable Top Cartons	0.0%
Newsprint	0.4%
Paper Fiber	7.6%
Printing Writing Paper	1.0%

Material	Percent of Waste Stream
Plastic	10.3%
Plastic Film	3.4%
Plastic Other	5.4%
Rigid Plastic	1.5%
Glass	2.6%
Metal	2.8%
Aluminum	0.3%
Scrap Metal	2.0%
Tinned Can	0.5%
Organics	21.6%
Food Waste	17.0%
Yard Debris	4.7%
Construction Materials	10.0%
Asphalt Roofing	4.0%
Carpeting	2.4%
Gypsum Wallboard	3.6%
Consumer Products	3.9%
Electronics	0.5%
Textiles	3.4%
Other Materials	36.6%
Other	21.0%
Wood	15.7%

Source: Oregon Department of Environmental Quality. 2025. Excel file provided to ICF with waste disposal rates and waste stream data. February 2025.

Table S-1.6. Colorado State Waste Profile (2018) (% of total waste by material type)

Material	Rural	Urban	Statewide
Paper	19.3%	19.1%	19.2%
Cardboard/Kraft	6.6%	6.2%	6.5%
Newspaper	1.2%	2.2%	1.4%
Office Paper	1.6%	1.4%	1.6%
Chip/Paperboard	2.8%	1.6%	2.5%
Junk Mail/Aseptics	1.5%	1.6%	1.5%
Magazines	1.6%	1.2%	1.6%
Other Paper	3.9%	5.7%	4.3%
Plastic	13.8%	11.4%	13.2%
#1 Bottles	1.9%	1.2%	1.7%
#2 Bottles	1.5%	1.1%	1.4%
Rigid #3-#7	1.3%	0.8%	1.1%
Film, Bags & Wrap	3.4%	4.2%	3.5%
Other Plastic	5.8%	4.1%	5.4%

Material	Rural	Urban	Statewide
Glass	4.5%	3.0%	4.2%
Glass Containers	3.7%	2.9%	3.5%
Other Glass	0.8%	0.1%	0.7%
Metal	4.8%	4.3%	4.7%
Aluminum	1.0%	1.0%	1.0%
Steel/Tin	1.3%	1.0%	1.2%
Other Metal	2.5%	2.4%	2.5%
Organics	38.1%	33.8%	37.1%
Food Waste	19.9%	12.5%	18.2%
Yard Waste	10.1%	11.8%	10.5%
Clean Wood	0.7%	1.6%	0.9%
Other Organics	7.5%	7.9%	7.6%
Other	18.1%	15.6%	17.5%
Textiles	5.8%	4.2%	5.4%
Electronics	1.0%	2.2%	1.3%
Batteries	0.3%	0.1%	0.2%
Paint	0.0%	0.0%	0.0%
Motor Vehicle Waste	1.0%	0.4%	0.8%
C&D (non-industrial)	8.6%	8.4%	8.6%
Other HHW/Special	2.1%	0.4%	1.7%
Waste/Residue	1.5%	13.3%	4.2%

Source: Colorado Department of Public Health and Environment. 2018. Waste Composition of Municipal Solid Waste Disposal. Accessed February 4, 2025. https://oitco.hylandcloud.com/cdphermpop/docpop/docpop.aspx.

Table S-1.7. Arizona State Waste Profile (% of total waste by material type)

Material	% Landfilled
Construction & Demolition (C&D), excluding Wood	**9.3%**
Asphalt Roofing	1.1%
Carpet (including Padding)	1.7%
Drywall	1.2%
Fines/Dirt	1.9%
Inerts (Concrete/Brick/Rock/Asphalt)	1.4%
Other C&D	1.9%
Food	**17.3%**
Glass	**2.7%**
Amber Glass (Containers)	0.6%
Clear Glass (Containers)	1.1%
Green Glass (Containers)	0.4%
Other Glass	0.6%
Household Hazardous Waste (HHW)	**1.4%**
Lightbulbs	0.2%
Other HHW (Paint/Asbestos/Household Cleaner)	0.3%

Material	% Landfilled
Pharmaceutical/Medical	0.5%
Vehicle Fluids (including Motor Oil)	0.3%
Metal	**5.6%**
Aluminum Cans	0.7%
Appliances/White Goods	0.6%
Other Ferrous	2.1%
Other Non-Ferrous	1.3%
Steel Cans	0.9%
Other	**5.9%**
Batteries	0.2%
Bulky Items/ Furniture (including Mattresses)	2.6%
Electronics	1.0%
Other Inorganics	1.6%
Tires	0.5%
Other Organics	**6.2%**
Paper	**20.4%**
Corrugated Cardboard	6.3%
Magazine/Glossy	0.9%
Mixed Paper (Other Recyclable)	6.8%
Newspaper	1.3%
Office	1.7%
Other Paper (Non-recyclable)	2.2%
Paperboard	1.2%
Plastic	**14.0%**
#1 PET Bottles	1.4%
#2 HDPE Bottles	0.9%
#3 through #7 Bottles	0.9%
Expanded Polystyrene	1.3%
Film Plastic	5.8%
Other Rigid Plastic	3.7%
Textiles	**4.7%**
Wood (including Painted/Treated/etc.)	**5.3%**
Yard Waste	**7.1%**
Wood (non-C&D)	2.4%
Yard Waste	4.7%

Source: Arizona Circular Recycling Solutions. *Arizona County Waste*. https://azcres.org/arizona-waste/.

Table S-1.8. National Waste Profile (2018) (% of total waste by material type)

Material	% Landfilled
Paper	11.8%
Plastic	18.5%

Material	% Landfilled
Glass	5.2%
Metal	9.5%
Ferrous	7.2%
Aluminum	1.8%
Other Nonferrous	0.5%
Rubber and Leather	3.4%
Textiles	7.7%
Wood	8.3%
Other	2.0%
Food	24.1%
Yard Trimmings	7.2%
Miscellaneous Inorganics	2.3%

Source: U.S. Environmental Protection Agency (EPA). 2020. Advancing Sustainable Materials Management: 2018 Tables and Figures. December 2020.

Table S-3.1. Available Defaults for Analysis of Edible Food Recovery Programs

Food Waste Prevention[1]		
Refrigeration & Freezer Equipment - Energy Consumption	**Factor**	**Unit**
Residential Refrigerator/Freezer Combination	8.46	kWh/year per ft^3 of volume
	335.7	kWh/year
Residential Freezer Only	7.85	kWh/year by ft^3 of volume
	172.3	kWh/year
Residential Refrigerator Only	7.28	kWh/year by ft^3 of volume
	206.7	kWh/year
Commercial Refrigerator with Solid Doors or Walk-in Commercial Refrigerator with Solid Doors	36.5	kWh/year per ft^3 of volume
	744.6	kWh/year
Commercial Refrigerator with Transparent Doors or Walk-in Commercial Refrigerator with Transparent Doors	43.8	kWh/year by ft^3 of volume
	1,219.1	kWh/year
Commercial Freezer with Solid Doors or Walk-in Commercial Freezer with Solid Doors	146.0	kWh/year by ft^3 of volume
	503.7	kWh/year
Commercial Freezer with Transparent Doors or Walk-in Commercial Freezer with Transparent Doors	273.8	kWh/year by ft^3 of volume
	1,496.5	kWh/year
Commercial Refrigerator/Freezer with Solid Doors or Walk-in Commercial Refrigerator/Freezer with Solid Doors	98.6	kWh/year by ft^3 of volume
	-259.2	kWh/year
	255.5	minimum value kWh/year

Refrigerant Average Annual Leak Rate	Source	
	CARB[2]	U.S. EPA (Table R-1.3)[3]
Residential Refrigerator/Freezer Combination	1.0%	0.60%
Residential Freezer Only	1.0%	0.60%
Residential Refrigerator Only	1.0%	0.60%
Commercial Refrigeration Systems with Charge < 50 lbs	15.0%	1.0% to 7.5%
Commercial Refrigeration Systems with Charge 50 lbs to < 200 lbs	15.0%	1.0% to 7.5%
Commercial Refrigeration Systems with Charge 200 lbs to < 2,000 lbs	18.0%	1.0% to 7.5%
Commercial Refrigeration Systems with Charge ≥ 2,000 lbs	17.0%	—
Transportation Vehicle	24.0%	—

Refrigerant Charge Assumptions (pounds)	Source	
	CARB[2]	U.S. EPA (Table R-1.3)[3]
Residential Refrigerators/Freezers and Chest Freezers	0.34 lbs	0.2 lbs
Commercial Refrigerator/Freezers	7.10 lbs	0.4 lbs
Small Walk-in Refrigerator/Freezer	31.40 lbs	10.0 lbs
Large Walk-in Refrigerator/Freezer	122.00 lbs	565.0 lbs
Refrigerated Van	4.00 lbs	—
Refrigerated Box Truck	12.00 lbs	—
Refrigerated Heavy Duty Truck	22.00 lbs	—

Sources: See footnotes.

MJ = megajoules; mpg = miles per gallon; mpgde = miles per gallon of diesel equivalent; gal = gallon; kWh = kilowatt-hours; CO2e = carbon dioxide equivalent; g = grams

[1] 10 Code of Federal Regulations 431.66 and Venkat, K. 2012. *The Climate Change and Economic Impacts of Food Waste in the United States*. April 2012. Accessed January 2025. https://www.cleanmetrics.com/pages/ClimateChangeImpactofUSFoodWaste.pdf.

[2] California Air Resources Board (CARB). 2020. Benefits Calculator Tool for the Food Waste Prevention and Rescue Program. June 2020. Accessed January 2025. https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/calrecycle_finalfoodcalc_19-20.xlsx.

[3] U.S. Environmental Protection Agency (U.S. EPA). 2016. *Accounting Tool to Support Federal Reporting of Hydrofluorocarbon Emissions: Supporting Documentation*. October 2016. Accessed May 2021. https://www.epa.gov/sites/production/files/2015-09/documents/hfc_emissions_accounting_tool_supporting_documentation.pdf.

Table S-3.2. Solid Waste Emission Factors for Analysis of Edible Food Recovery Programs

	Grid Zone	
Grid Electricity Emission Factors (lbs/kWh)[1]	**WECC**	**SPP**
ROG	0.000010	0.000027
NOx	0.000384	0.000505
$PM_{2.5}$	0.000036	0.000048
Avoided Landfill Flare Combustion Emission Factors (lbs/wet short ton of food waste)[2]		
ROG		0.092
NOx		0.033
$PM_{2.5}$		0.014
Avoided Transportation Emission Factors (lbs/short ton of food waste)[3]		
ROG		0.016
NOx		0.299
$PM_{2.5}$		0.009
Diesel		0.001

Sources: See footnotes.

ROG = reactive organic gases; NO_X = nitrous oxides; $PM_{2.5}$ = fine particulate matter; PM = particulate.

[1] U.S. Department of Energy (U.S. DOE). 2024. "The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model." 2024 Release. Accessed January 28, 2025. https://greet.anl.gov/

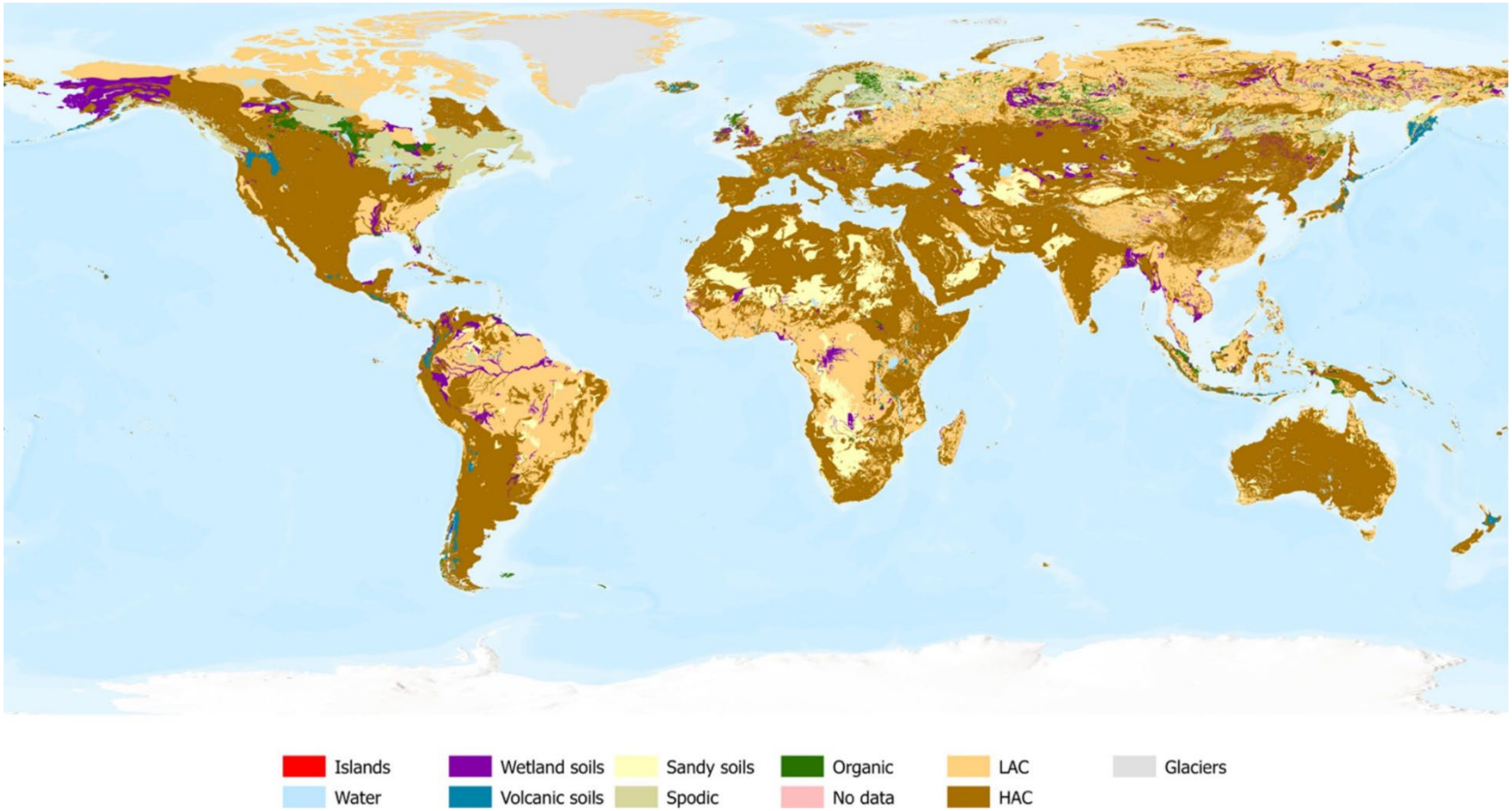
Grid electricity emission factors are defined for 2025 and available for two geographies as defined in the U.S. DOE's GREET model—the Western Electricity Coordinating Council (WECC) and Southwest Power Pool (SPP). Arizona, Colorado, Oregon, and Washington are wholly within WECC. New Mexico is split between WECC and SPP. Refer to Figure E-26.1 in Appendix A.

[2] California Air Resources Board. 2020. Benefits Calculator Tool for the Food Waste Prevention and Rescue Program. Accessed August 2023. https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/calrecycle_finalfoodcalc_19-20.xlsx.

Avoided landfill flare emission factors were calculated by CARB for their Food Waste Prevention and Rescue Program using typical flare emissions rates from U.S. EPA's AP-42, Chapter 2.4, Municipal Solid Waste Landfills, and CARB's *Methods for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities*. The AP-42 emissions rates are based on source test data. CARB's quantification method uses studies representing a variety of landfill conditions, locations (national and within California), years of operation, and degrees of controls. Thus, the emission factors are generally applicable.

[3] Venkat, K. 2012. *The Climate Change and Economic Impacts of Food Waste in the United States*. April 2012. Accessed January 2025. https://www.cleanmetrics.com/pages/ClimateChangeImpactofUSFoodWaste.pdf.

Figure N-1.1. IPCC Soil Classifications



Source: Sinitambirivoutin, M., E. Milne, L. Schiettecatte, I. Tzamtzis, D. Dionisio, M. Henry, I. Brierley, M. Salvatore, and M. Bernoux. 2024. An updated IPCC major soil types map derived from the harmonized world soil database v2.0. Catena, 244(108258).

Table N-1.1 Crosswalk of Statewide Land Cover Classes to Available Land Cover Types by IPCC Climate Zone for Measure N-1[1]

			Crosswalk for Measure N-1	
State	2019 IPCC Climate Zone[2]	Land Cover Class[3]	2006 IPCC Climate Zone	Land Cover Type
AZ	Cool Temperate Moist	Temperate or Subpolar Needleleaf Forest	Temperate Continental	Conifer Forest
AZ	Cool Temperate Moist	Temperate or Subpolar Shrubland	Temperate Continental	Shrubland
AZ	Cool Temperate Moist	Temperate or Subpolar Grassland	Temperate Continental (Cool Temperate Moist)	Grassland
CO	Cool Temperate Moist	Temperate or Subpolar Needleleaf Forest	Temperate Continental	Conifer Forest
CO	Cool Temperate Moist	Temperate or Subpolar Shrubland	Temperate Continental	Shrubland
CO	Cool Temperate Moist	Temperate or Subpolar Broadleaf Deciduous Forest	Temperate Continental	Broadleaf Forest
CO	Boreal Moist	Temperate or Subpolar Needleleaf Forest	Temperate Continental	Conifer Forest
CO	Cool Temperate Moist	Temperate or Subpolar Grassland	Temperate Continental (Cool Temperate Moist)	Grassland
CO	Boreal Moist	Temperate or Subpolar Shrubland	Temperate Continental	Shrubland
CO	Polar Moist	Temperate or Subpolar Needleleaf Forest	Temperate Continental	Conifer Forest
CO	Polar Moist	Temperate or Subpolar Grassland	Temperate Continental (Cool Temperate Moist)	Grassland
CO	Polar Moist	Temperate or Subpolar Shrubland	Temperate Continental	Shrubland
CO	Boreal Moist	Temperate or Subpolar Grassland	Temperate Continental (Cool Temperate Moist)	Grassland
CO	Cool Temperate Moist	Mixed Forest	Temperate Continental	Mixed Forest (Conifer Broadleaf)
CO	Boreal Moist	Temperate or Subpolar Broadleaf Deciduous Forest	Temperate Continental	Broadleaf Forest
CO	Boreal Moist	Mixed Forest	Temperate Continental	Mixed Forest (Conifer Broadleaf)
CO	Polar Moist	Temperate or Subpolar Broadleaf Deciduous Forest	Temperate Continental	Broadleaf Forest
NM	Cool Temperate Moist	Temperate or Subpolar Shrubland	Temperate Continental	Conifer Forest
NM	Cool Temperate Moist	Temperate or Subpolar Grassland	Temperate Continental	Mixed Forest (Conifer Broadleaf)
NM	Cool Temperate Moist	Mixed Forest	Temperate Continental	Broadleaf Forest
OR	Cool Temperate Moist	Temperate or Subpolar Needleleaf Forest	Temperate Oceanic	Conifer Forest
OR	Warm Temperate Moist	Temperate or Subpolar Needleleaf Forest	Temperate Oceanic	Conifer Forest
OR	Cool Temperate Moist	Temperate or Subpolar Shrubland	Temperate Oceanic	Shrubland

			Crosswalk for Measure N-1	
State	2019 IPCC Climate Zone[2]	Land Cover Class[3]	2006 IPCC Climate Zone	Land Cover Type
OR	Cool Temperate Moist	Temperate or Subpolar Grassland	Temperate Oceanic (Cool Temperate Moist)	Grassland
OR	Warm Temperate Moist	Mixed Forest	Temperate Oceanic	Mixed Forest (Conifer Broadleaf)
OR	Warm Temperate Moist	Temperate or Subpolar Shrubland	Temperate Oceanic	Shrubland
OR	Cool Temperate Moist	Mixed Forest	Temperate Oceanic	Mixed Forest (Conifer Broadleaf)
OR	Warm Temperate Moist	Temperate or Subpolar Grassland	Temperate Oceanic (Warm Temperate Moist)	Grassland
OR	Warm Temperate Moist	Temperate or Subpolar Broadleaf Deciduous Forest	Temperate Oceanic	Broadleaf Forest
OR	Cool Temperate Moist	Temperate or Subpolar Broadleaf Deciduous Forest	Temperate Oceanic	Broadleaf Forest
OR	Boreal Moist	Temperate or Subpolar Needleleaf Forest	Temperate Oceanic	Conifer Forest
OR	Boreal Moist	Temperate or Subpolar Grassland	Temperate Oceanic (Cool Temperate Moist)	Grassland
OR	Boreal Moist	Temperate or Subpolar Shrubland	Temperate Oceanic	Shrubland
WA	Cool Temperate Moist	Temperate or Subpolar Needleleaf Forest	Temperate Oceanic	Conifer Forest
WA	Cool Temperate Moist	Temperate or Subpolar Shrubland	Temperate Oceanic	Shrubland
WA	Cool Temperate Moist	Temperate or Subpolar Grassland	Temperate Oceanic (Cool Temperate Moist)	Grassland
WA	Warm Temperate Moist	Temperate or Subpolar Needleleaf Forest	Temperate Oceanic	Conifer Forest
WA	Cool Temperate Moist	Mixed Forest	Temperate Oceanic	Mixed Forest (Conifer Broadleaf)
WA	Warm Temperate Moist	Mixed Forest	Temperate Oceanic	Mixed Forest (Conifer Broadleaf)
WA	Cool Temperate Moist	Temperate or Subpolar Broadleaf Deciduous Forest	Temperate Oceanic	Broadleaf Forest
WA	Warm Temperate Moist	Temperate or Subpolar Shrubland	Temperate Oceanic	Shrubland
WA	Warm Temperate Moist	Temperate or Subpolar Broadleaf Deciduous Forest	Temperate Oceanic	Broadleaf Forest
WA	Warm Temperate Moist	Temperate or Subpolar Grassland	Temperate Oceanic (Warm Temperate Moist)	Grassland
WA	Boreal Moist	Temperate or Subpolar Shrubland	Temperate Continental	Shrubland
WA	Boreal Moist	Temperate or Subpolar Grassland	Temperate Continental (Cool Temperate Moist)	Grassland

Sources: See footnotes.

[1] Not all land cover classes and/or 2019 IPCC climate zones could be mapped to the available land cover type by 2006 IPCC climate zone combinations addressed in Measure N-1. See the IPCC climate zone map, available online from the IPCC at Publications - IPCC-TFI. The following are excluded from the table: Barren Land, Wetlands, Other, Water, and Urban (all western state climate zones); Cropland (Cool Temperate Moist, Warm Temperate Moist); Snow and Ice (Cool Temperate Moist, Polar Moist); Temperate or Subpolar Broadleaf Deciduous Forest (Cool Temperate Moist); and Temperate or Subpolar Needleleaf Forest (Cool Temperate Moist).

[2] Panagos, P., M. Van Liedekerke, P. Borrelli, J. Köninger, C. Ballabio, A. Orgiazzi, E. Lugato, L. Liakos, J. Hervas, A. Jones, and L. Montanarella. 2022. "European Soil Data Centre 2.0: Soil data and knowledge in support of the EU policies." *European Journal of Soil Science* 73 (6), e13315. DOI: 10.1111/ejss.13315.

[3] Commission for Environmental Cooperation (CEC). 2024. "2020 Land Cover of North America at 30 meters." North American Land Change Monitoring System. Canada Centre for Remote Sensing (CCRS), U.S. Geological Survey (USGS), Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), Comisión Nacional Forestal (CONAFOR), Instituto Nacional de Estadística y Geografía (INEGI). Ed. 2.0, Raster digital data [30-m]. http://www.cec.org/north-american-environmental-atlas/land-cover-30m-2020/.

Table N-1.2. Above- and Belowground Biomass Carbon Accumulation (metric tons) per Hectare by Land Cover Type and IPCC Climate Zone

IPCC Climate Zone[1]	Cover Type[2]	MT C/ha	Source	MT C/ha/yr[3]
Temperate Continental	Broadleaf Forest	185	IPCC 2019	9.3
Temperate Continental	Conifer Forest	155	IPCC 2019	7.8
Temperate Continental (Warm Temperate Dry)	Grassland	6	IPCC 2006	0.3
Temperate Continental (Cool Temperate Dry)	Grassland	7	IPCC 2006	0.4
Temperate Continental	Mixed Forest (Conifer Broadleaf)[4]	170	IPCC 2019	8.5
Temperate Continental	Shrubland	186	Chopping et al. 2007	9.3
Temperate Oceanic	Broadleaf Forest	183	IPCC 2019	9.2
Temperate Oceanic	Conifer Forest	167	IPCC 2019	8.4
Temperate Oceanic (Warm Temperate Moist)	Grassland	14	IPCC 2006	0.7
Temperate Oceanic (Cool Temperate Moist)	Grassland	12	IPCC 2006	0.6
Temperate Oceanic	Mixed Forest (Conifer Broadleaf)[4]	175	IPCC 2019	8.8
Temperate Oceanic	Shrubland	81	Martin et al. 1981	4.1

Sources: IPCC (Intergovernmental Panel on Climate Change). 2019. *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Edited by C. Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, S. Ngarize, A. Osako, Y. Pyrozhenko, P. Shermanau, and S. Federici. Switzerland: IPCC.

IPCC. 2006. *IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme. Edited by H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe. Japan: IGES.

Chopping, M., G. G. Moisen, L. Su, A. Laliberte, A. Rango, J. V. Martonchik, and D. P. C. Peters. 2007. "Large area mapping of southwestern forest crown cover, canopy height, and biomass using the NASA Multiangle Imaging Spectro-Radiometer." *Remote Sensing of Environment* 112 (5): 2051-2063.

Martin, R. E., D. W. Frewing, and J. L. McClanahan. 1981. "Average biomass of four Northwest shrubs by fuel size class and crown cover" (Research Note PNW-374). U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station.

MT = metric tons; C = carbon; ha = hectare; IPCC = Intergovernmental Panel on Climate Change; yr = year

[1] The Climatic zones are defined by the IPCC based on annual mean daily temperature, total annual precipitation, total annual potential evapotranspiration, and elevation.

[2] The land cover types are broad and include one or more land cover classes from the North American Environmental Atlas. Table N-1.1 identifies the IPCC climate zones and land cover classes within each western state and crosswalks those to available land cover types provided in this table.

[3] Assumes a carbon accumulation period of 20 years, per IPCC (2006).

[4] 50% average of broadleaf, conifer

Table N-1.3. Annualized Soil Carbon Accumulation (metric tons) per Hectare by Soil Type

		Soil Carbon Accumulation (MT C/ha/yr[1,2])		
Soil Type[3]	IPCC Soil Classification[4]	Conversion to Cropland	Conversion to Grazing Land	Conversion to Forest
Alfisols	High Activity Clay Soils	1.9	2.4	2.5
Andisols	Volcanic Soils	6.2	8.0	8.5
Aquic	Wetland Soils	2.4	3.1	3.3
Aridisols	High Activity Clay Soils	1.9	2.4	2.5
Entisols	Low Activity Clay Soils	1.3	1.6	1.7
Inceptisols	High Activity Clay Soils	1.9	2.4	2.5
Mollisols	High Activity Clay Soils	1.9	2.4	2.5
Oxisols	Low Activity Clay Soils	1.3	1.6	1.7
>70% Sand	Sandy Soils	0.8	1.0	1.1
Spodosols	Spodic Soils	4.3	5.5	5.9
Ultisols	Low Activity Clay Soils	1.3	1.6	1.7
Vertisols	High Activity Clay Soils	1.9	2.4	2.5
Histosol	N/A	0	0	0

Source: Intergovernmental Panel on Climate Change (IPCC). 2006. *IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme. Edited by H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe. Japan: IGES.

MT = metric tons; C = carbon; ha = hectare; IPCC = Intergovernmental Panel on Climate Change; yr = year

[1] Assumes a carbon accumulation period of 20 years, per IPCC (2006).

[2] Based on a carbon stock change factor of 1 for cropland, 1.28 for grazing land, and 1.37 for forest.

[3] Soil types for the user's project area can be obtained from the United States Department of Agriculture's Soil Survey Map.

[4] Refer to Figure N-1.1.

Table C-1-A.1. Tank-to-Wheels and Well-to-Wheels CO_2e Emission Factors for Diesel and Gasoline Equipment (kilograms CO_2e per horsepower-hour)

		Less than or equal to 100 HP		Greater than 100 HP	
Category	Fuel Type	TTW	WTW	TTW	WTW
Construction	Gasoline (2 stroke)	0.52	0.67	0.47	0.60
	Gasoline (4 stroke)	0.53	0.68	0.48	0.61
	Diesel	0.70	0.84	0.63	0.76
Lawn and Garden	Gasoline (2 stroke)	0.52	0.67	0.47	0.60
	Gasoline (4 stroke)	0.53	0.68	0.48	0.61
	Diesel	0.69	0.83	0.62	0.75
Agricultural	Gasoline (2 stroke)	0.52	0.67	0.47	0.60
	Gasoline (4 stroke)	0.53	0.67	0.47	0.61
	Diesel	0.71	0.85	0.63	0.76
Industrial and Commercial	Gasoline (2 stroke)	0.52	0.67	0.47	0.60
	Gasoline (4 stroke)	0.53	0.68	0.48	0.61
	Diesel	0.70	0.84	0.63	0.75

Source: Association of Petroleum Institute (API). 2021. *Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry*. Released November 2021. Accessed June 2025. https://www.api.org/~/media/files/policy/esg/ghg/2021-api-ghg-compendium-110921.pdf.
U.S. Department of Energy (U.S. DOE). 2024. "The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model." 2024 Release. Accessed January 28, 2025. https://greet.anl.gov/
U.S. EPA (U.S. Environmental Protection Agency). 2018. "Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES2014b." Released July 2018. Accessed June 2025. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100UXEN.pdf.
U.S. EPA. 2025. "General Conformity Training Modules: Appendix A Sample Emissions Calculations." Released February 2025. Accessed June 2025. https://www.epa.gov/general-conformity/general-conformity-training-modules-appendix-sample-emissions-calculations.

HP = horsepower; TWT = tank-to-wheels; WTW = well-to-wheels

Table C-1-B.1. Average Construction Equipment Horsepower

Equipment	Fuel Type	Horsepower
Bore/Drill Rigs	Diesel	76.1
Bore/Drill Rigs	Gasoline	2.7
Cement & Mortar Mixers	Diesel	13.5
Cement & Mortar Mixers	Gasoline	4.3
Concrete/Industrial Saws	Diesel	29.3
Concrete/Industrial Saws	Gasoline	5.2
Cranes	Diesel	101.5
Cranes	Gasoline	22.6
Crawler Tractor/Dozers	Diesel	155.1
Crushing/Processing Equipment	Diesel	68.1
Crushing/Processing Equipment	Gasoline	6.6
Dumpers/Tenders	Diesel	7.0
Dumpers/Tenders	Gasoline	4.0

Equipment	Fuel Type	Horsepower
Excavators	Diesel	103.0
Graders	Diesel	126.0
Off-Highway Tractors	Diesel	431.8
Other Construction Equipment	CNG	66.0
Other Construction Equipment	Diesel	194.2
Other Construction Equipment	Gasoline	64.1
Pavers	Diesel	76.8
Pavers	Gasoline	9.2
Plate Compactors	Diesel	3.1
Plate Compactors	Gasoline	2.9
Rollers	Diesel	56.9
Rollers	Gasoline	9.4
Rough Terrain Forklift	Gasoline	40.6
Rubber Tire Loaders	Diesel	146.9
Rubber Tire Loaders	Gasoline	45.6
Scrapers	Diesel	244.8
Signal Boards/Light Plants	Diesel	10.0
Signal Boards/Light Plants	Gasoline	4.8
Skid Steer Loaders	Diesel	12.0
Skid Steer Loaders	Gasoline	19.2
Surfacing Equipment	Diesel	64.5
Surfacing Equipment	Gasoline	4.4
Tampers/Rammers	Diesel	1.9
Tampers/Rammers	Gasoline	2.5
Tractors/Loaders/Backhoes	Diesel	20.8
Tractors/Loaders/Backhoes	Gasoline	10.0
Trenchers	Diesel	45.2
Trenchers	Gasoline	8.0

Source: U.S. Environmental Protection Agency (EPA). 2024. Latest Version of Motor Vehicle Emissions Simulator (MOVES). Released November 2024. Accessed December 2024. https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#guidance.

CNG = compressed natural gas; HP = horsepower

Note: Operating hours used to define an activity-based average of horsepower for each equipment category. The activity distribution is the same across states and years analyzed (2025 through 2050). Horsepower values are inclusive of equipment load.

Table R-1.1 Global Warming Potentials of Commonly Used Refrigerants

Refrigerant Name	Trade/Common Name (if one exists)	GWP
R-717	Ammonia	0
R-1224yd(Z)	AMOLEA™ 1224yd	1
R-1234ze(E)	Solstice® ze	1
R-744	CO_2	1
R-1234zd(E)	Solstice® zd	1
R-514A	Opteon™ XP30	2
R-600a	Isobutane	3
R-290	Propane	4
R-161	HFC-161	4
R-601	Pentane	5
R-170	Ethane	6
R-123	HCFC-123	79
R-225ca	HCFC-225ca	127
R-152a	HFC-152a	138
R-454B	Opteon™ XL41	467
R-225cb	HCFC-225cb	525
R-124	HCFC-124	527
R-450A	Solstice® N13	547
R-513A	Opteon™ XP10	573
R-452B	Opteon™ XL55	676
R-32	HFC-32	677
R-466A	—	697
R-141b	HCFC-141b	782
R-365mfc	HFC-365mfc	804
R-245fa	HFC-245fa	858
R-401C	Suva® MP-52	876
R-416A	FRIGC FR-12	975
R-401A	MP39	1,130
R-401B	MP66	1,236
R-448A	Solstice® N40	1,273

Refrigerant Name	Trade/Common Name (if one exists)	GWP
R-414B	Hot Shot™	1,274
R-449A	Opteon™ XP40	1,282
R-134a	HFC-134a	1,300
R-426A	RS-24	1,371
R-414A	GHX4	1,375
R-420A	Choice® Refrigerant	1,382
Free Zone	—	1,403
Freeze 12	—	1,436
R-409A	FX-56	1,485
R-407D	—	1,487
R-411A	—	1,555
R-407C	—	1,624
R-453A	RS-70, RS-44b	1,636
R-437A	MO49 Plus	1,639
R-417C	Hot Shot™ 2	1,643
R-4310mee	HFC-43-10mee, HFC-4310mee, R-43-10mee	1,650
R-411B	—	1,659
R-407F	—	1,674
G2018C	—	1,683
GHG-HP	—	1,758
R-22	HCFC-22, Freon	1,760
R-406A	—	1,780
R-442AF	RS-50	1,888
R-407A	KLEA® 60	1,923
R-410A	Puron®, AZ-20	1,924
R-413A	MO49	1,945
R-142b	HCFC-142b	1,980
R-427A	—	2,024
R-410B	AC9100	2,048
R-438A	MO99	2,059
R-417A	MO59, NU22	2,127

Refrigerant Name	Trade/Common Name (if one exists)	GWP
R-452A	Opteon™ XP44	2,140
NARM-502	—	2,211
R-424A	RS-44	2,212
R-402B	HP-81	2,261
R-423A	39TC	2,274
R-422B	NU-22B	2,290
GHG-X5	—	2,359
R-421A	—	2,385
R-422D	MO29	2,473
R-407B	—	2,547
R-402A	HP-80	2,571
R-422C	One Shot™	2,795
R-422A	—	2,847
R-421B	Choice® 421B	2,890
R-434A	RS-45	3,076
R-125	HFC-125	3,170
R-408A	FX-10	3,257
R-227ea	HFC-227ea	3,350
R-428A	RS-52	3,417
Isceon MO89	—	3,527
R-404A	HP-62	3,943
R-507	AZ-50	3,985
R-403B	—	4,457
R-11	CFC-11	4,660
R-502	—	4,786
R-143a	HFC-143a	4,800
R-113	CFC-113	5,820
EP-88	—	6,427
R-14	PFC-14, CF4	6,630
R-13b1	Halon 1301	7,140
R-500	—	7,564

Refrigerant Name	Trade/Common Name (if one exists)	GWP
R-115	CFC-115	7,670
R-236fa	HFC-236fa	8,060
R-114	CFC-114	8,590
R-218	PFC-218	8,900
R-12	CFC-12	10,200
R-116	PFC-116	11,100
R-508B	—	11,698
R-23	HFC-23	12,400
R-503	—	13,300
R-13	CFC-13	13,900

Sources: California Air Resource Board (CARB). 2020. *Refrigerant Management Program: Service Technicians & Contractors*. Accessed January 2021. https://ww2.arb.ca.gov/our-work/programs/refrigerant-management-program/rmp-service-technicians-contractors.

IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/.

World Meteorological Organization (WMO). 2018. *Scientific Assessment of Ozone Depletion: 2018*. Global Ozone Research and Monitoring Project. Report No. 58. Geneva, Switzerland.

— = no common name; R= refrigerant; HCFC = hydrochlorofluorocarbons; HFC = hydrofluorocarbon; PFC = perfluorocarbon; CFC = Chlorofluorocarbons; GHG = greenhouse gas; GWP = global warming potential

Table R-1.2. Charge Size, Service Rate, and Leak Rate for Various Equipment Types by Land Use Type

Land Use Type	Equipment Type	Refrigerant Charge (kg)	Leak Rate	Service Rate	Total Leak Rate[1]
Apartments (any size) (retirement)	Average room A/C & Other residential A/C and heat pumps	2.75	2.50%	2.50%	5.00%
Apartments (any size) (retirement)	Household refrigerators and/or freezers	0.04	0.60%	0.00%	0.60%
Apartments in buildings with 2–4 units	Average room A/C & Other residential A/C and heat pumps	2.75	2.50%	2.50%	5.00%
Apartments in buildings with 2–4 units	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Apartments in buildings with 5 or more units	Average room A/C & Other residential A/C and heat pumps	2.75	2.50%	2.50%	5.00%
Apartments in buildings with 5 or more units	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Education	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Education	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Education	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Education	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Food sales	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Food sales	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Food sales	Supermarket refrigeration and condensing units	1,360.00	16.50%	16.50%	33.00%
Food sales	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Food service	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Food service	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Food service	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Health care - Inpatient	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Health care - Inpatient	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Health care - Inpatient	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Health care - Inpatient	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Health care - Inpatient	Chillers	500.00	2.00%	2.00%	4.00%

Land Use Type	Equipment Type	Refrigerant Charge (kg)	Leak Rate	Service Rate	Total Leak Rate[1]
Health care - Outpatient	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Health care - Outpatient	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Lodging	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Lodging	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Mercantile - Enclosed and strip malls	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Mercantile - Enclosed and strip malls	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Mercantile - Enclosed and strip malls	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Mercantile - Retail (other than mall)	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Mercantile - Retail (other than mall)	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Mercantile - Retail (other than mall)	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Mercantile - Retail (other than mall)	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Mobile homes	Average room A/C & Other residential A/C and heat pumps	2.75	2.50%	2.50%	5.00%
Mobile homes	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Office	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Office	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Other	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Other	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Other	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Public assembly	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Public assembly	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Public assembly	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Public order and safety	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Public order and safety	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Religious worship	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Religious worship	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%

Land Use Type	Equipment Type	Refrigerant Charge (kg)	Leak Rate	Service Rate	Total Leak Rate[1]
Religious worship	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Religious worship	Walk-in refrigerators and freezers	10.00	7.50%	7.50%	15.00%
Service	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Service	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%
Single-family attached	Average room A/C & Other residential A/C and heat pumps	2.75	2.50%	2.50%	5.00%
Single-family attached	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Single-family detached	Average room A/C & Other residential A/C and heat pumps	2.75	2.50%	2.50%	5.00%
Single-family detached	Household refrigerators and/or freezers	0.15	0.60%	0.00%	0.60%
Warehouse and storage	Cold storage	565.00	7.50%	7.50%	15.00%
Warehouse and storage	Other commercial A/C and heat pumps	13.00	4.00%	4.00%	8.00%
Warehouse and storage	Stand-alone retail refrigerators and freezers	0.40	1.00%	0.00%	1.00%

Source: U.S. Environmental Protection Agency (EPA). 2016. *Accounting Tool to Support Federal Reporting of Hydrofluorocarbon Emissions: Supporting Documentation*. October 2016. Accessed January 2021. https://www.epa.gov/sites/production/files/2015-09/documents/hfc_emissions_accounting_tool_supporting_documentation.pdf.

A/C = air conditioning; yr = year

[1] Total leak rate is the sum of the operational leak rate and the service leak rate. This total value would only occur in those years in which servicing is required, which may not be every year of the equipment life.