Anticipating and Taming Complexity for New Mexico's Strategic Water Supply Plan

Introduction and Summary

Taylor Dotson, PhD*
Associate Professor of Social Science
New Mexico Tech
Taylor.Dotson@nmt.edu

Michael Bouchey, PhD
Lecturer of Social Science
New Mexico Tech
Michael.Bouchey@nmt.edu

*primary contact

Drs Dotson and Bouchey are experts in the politics of technological risk and sociotechnical change. Their research has encompassed issues ranging from community life in a digital age, the privatization of space, urban planning, nuclear power, biodiversity, and environmental politics. Dr. Dotson (2019) has published on the governance challenges surrounding the recycling produced waters in The Journal of Responsible Innovation, and has been involved in the New Mexico Tech Climate & Water Consortium since beginning his professorship at Tech in 2015.

Our proposal for the state's Strategic Water Supply (SWS) project is a set of strategic considerations for the management of complexity. The SWS faces considerable uncertainties in the technological, economic, and political realms: Which technology or technologies are not just feasible but optimal? How can a homegrown green industry supplied with recycled produced waters be stewarded into existence? How can public trust in recycled produced waters be assured?

Our core recommendations include a "staged-gate" R&D process, streamlining state support of SWS projects to encourage starting small and scaling gradually, setting up and incentivizing industry-wide information sharing, and ensuring a transparent process that organizes productive disagreement and provides insights to help SWS stakeholders avoid the most contentious uses for produced waters and demonstrate their trustworthiness. In short, the most important strategic consideration for the SWS is to put ongoing learning at its center.

The Problem

A Primer on Averting (Political) Catastrophe

Creating a strategic water supply based on produced and brackish waters in New Mexico is bound to be a complex and large scale endeavor. Such projects have unique technological, economic, and also political risks. Achieving a future where produced waters are not only technically and economically viable but also politically acceptable will require the careful management of uncertainty. Our contribution to Governor Luhan-Grisham's request for information is to help the state government to understand this facet of the Strategic Water Supply project.

A long literature in policy studies, business, and technologies studies finds that large scale projects have failed because decision-makers have plunged blindly forward. Although they may have comprehensive technical and economic analyses in hand, they lack an adequate appreciation of the likelihood that reality will surprise them. Technologies can underdeliver or bring unintended consequences. Industries can fail to arrive or sustain themselves. And public opinion can quickly sour in response to mistakes. Even worse, these surprises can arrive after expensive infrastructure has been built, after financial investment sunk into one technology or region at the expense of alternatives, or after public officials have claimed programs to have been a success.

In this regard, the state's request for expert information this early on is admirable. The Governor's office is demonstrating a degree of anticipation and foresight that is tragically rare in the political world.

That said, there remains a high risk that the effort to commercialize produced and brackish waters will end up being a technological, economic, or political dead end. These three facets are interrelated, but in the following responses, we address each one individually. Nevertheless the overall problem is the need to efficiently scan and select for water recycling technologies that satisfy certain technical and economic benchmarks, directing them to feasible economic uses, all the while assuring the New Mexico public that such waters are being responsibly utilized toward meeting larger environmental goals.

Technical Uncertainties and Risks

At the core of New Mexico's produced water program is the problem of technological choice. Simply put, it is simultaneously in the state's interest to converge quickly on one or more produced/brackish water recycling technologies, but also to avoid settling on a suboptimal technology. However, there is a paradox at the center of this problem. Technologies can seem promising at the laboratory or pilot scale, but suffer from unanticipated problems upon scaling. Learning their actual performance requires putting skin in the game. Even worse, sunk cost thinking can lead to throwing good money after bad.

The United States' nuclear industry suffered dearly from this paradox. It settled on a light-water reactor (LWR) design, because early military research and development made it a more certain bet. However, that design ended up unable to satisfy public safety worries. Only now is the industry finally experimenting with more inherently safe designs, but still has a very skeptical public (and Nuclear Regulatory Commission) to deal with (Dotson and Bouchey 2020).

The scale of the potential consequences of recycled produced waters are not so catastrophic, but the underlying challenge remains the same. Settling too early on a technology that proves to be infeasible or produces unintended consequences at scale could be such an embarrassing failure that it sinks the program.

A local example comes from Albuquerque Rapid Transit (ART). ART initially appeared to be a simple incremental alteration to the existing Rapid Ride along Central Ave (Bouchey 2023b). The city had already made the conservative decision to implement bus rapid transit (BRT) rather than the more expensive and infrastructure intensive light rail. But instead, ART turned out to be a parallel implementation of several technological changes all at once: new stations, right of way, new buses, and pedestrian improvements. ART, which was already controversial, turned out to have bit off more than it could chew, leading to several highly visible mistakes.

In order to qualify for federal funding, Albuquerque purchased electric buses from BYD. This was the first time the city had worked with BYD, and the first time BYD had put that model of bus into commercial production. The buses were defective and the city eventually defaulted to standard articulated diesel buses from the experienced company New Flyer. Furthermore, the construction contractors built some of the stations too close to intersections, in no small part because of the uncertainty surrounding the buses. The city was able to solve both of these problems without increasing the budget for the project. In fact, the total cost was only 11.7% above initial estimates (Bouchey 2023a). But combined they delayed the project by over two years, damaging local businesses and goodwill alike. The city's political capacity for future transit was so harmed that they had to cancel a follow-on BRT route along University Ave to the Sunport (Chavez 2019).

For the SWS, there is a strong incentive and rationale to focus on pilot projects where infrastructure already exists (i.e., wells, produced water distribution pipelines) and end users can be found (e.g., agriculture, oil and gas firms). From the standpoint of intelligent technical scaling, that is appropriate. However, the state will want to avoid most agricultural uses, apart from fiber crops, and ensure that uses within the oil and gas industry can be persuasively framed as transitory, as a "bridge" to the new green economy. But that raises still more uncertainties.

Economic Uncertainties and Risks

If New Mexico manages to navigate the uncertainties of technological selection, it is still possible that green industries may not move to (or develop themselves within) New Mexico. As a result, the state faces a considerable risk of discovering after a considerably long lead time, and significant capital investment, that a produced water-fueled green industry economy isn't readily forthcoming.

The best known instance of industry agglomeration is Silicon Valley (Arthur 1990). The region formed around Stanford University. But there are exceptional universities all over the country. Why Stanford? A few key players in the electronics industry (i.e., Hewlett and Packard, Varian Bros, and Shockley) decided to take advantage of the benefits Stanford provided and set up shop there. Once those firms were established, the relative advantage for additional firms also locating in the same area increased. Those initial players could have located their firms near any number of prestigious universities, so their decision to locate near Stanford can be said to be somewhat random. But once they decided to locate there, increasing returns led other firms there as well, creating an agglomeration effect that eventually formed Silicon Valley.

But emulating this effect intentionally is more difficult than this case would indicate. In Kalunborg Eco-Industrial Park (EIP) in Denmark, an agglomeration of firms became a world-famous prototype for Industrial Ecology (Frosch and Gallopoulos 1989). Firms, such as a coal power plant, a fish farm, and a fertilizer plant, were co-located because the waste byproducts of some firms were important inputs to others. The firms together form a closed-loop system that dramatically cut industrial wastes and realized higher levels of efficiency.

However, attempts to replicate the successes of Kalunbord have been mostly failures (Perrucci et al. 2022). Of the 16 attempts in the United States to create EIPs, only four of them succeeded. The inter-firm relationships necessary for the success of these sorts of industries are extremely complex. No amount of careful planning seems to be sufficient to construct these relations, and successful construction of these sorts of industries either requires industrial actors to self-sort into these relationships or very large government subsidies (ex. The Fairfield EIP in Maryland required federal support on the order of $100M) to keep businesses afloat while managers dealt with initial inefficiencies.

The difficulties of intentionally creating EIP agglomerations is especially salient to making use of or disposing of other product and waste streams related to the treatment of produced waters. Even if the state finds technical uses for these streams, there is no guarantee that these technologies will translate to economic activity. The state will need to be prepared to either build up such industries slowly and incrementally or to risk extremely high capital intensity to deal with initial inefficiencies.

Glass recycling in Albuquerque demonstrates that having the necessary technological infrastructure doesn't necessarily lead to industrial success. Glass is one of the easiest materials to recycle, it can often be cheaper to make glass products from recycled glass than from raw materials. Albuquerque's glass recycling system is also municipal, which reduces the costs to any buyers. Even with these advantages the city has had a difficult time sustaining in-state markets for recycled glass, with no buyers once a local firm, Growstone, went out of business (Van Note 2019). So Albuquerque's glass now accumulates in a dedicated landfill, since transportation costs are prohibitive for a low cost product. Fortunately, the case of glass recycling is low stakes: the ground glass can sit inert and harmless for as long as it takes another in-state buyer to appear. But the consequences will be much higher for more capital intensive projects.

Another local example is the Mesa del Sol development south of Albuquerque. The master plan for this development was first approved in 2008, but it remains a shadow of what was projected. Post-2008 economic malaise, difficulties in attracting people to a far off, new development with relatively few amenities (and jobs) combined with other factors to result in, well, relatively little. While there are positive signs, including the stadium for New Mexico United and a planned hydrogen facility, the case nonetheless demonstrates how difficult establishing new economic agglomerations can be. It may take Mesa del Sol stakeholders twenty years to achieve what arguably should have been done in five.

With regard to produced waters, the state is stuck in a Catch-22, much of the state's sociotechnical systems are set up to supply water to currently dominant users in the Permian Basin region: oil and gas operators and agriculture, but these are exactly the water users that the state's effort (for political reasons, see below) will want to deemphasize. The challenge of attracting out-of-state green industry or fostering home-grown firms is probably bigger than the technical hurdles of achieving relatively low-cost water recycling.

Of course, to be considered economically feasible, produced water recycling doesn't just need to offer realistic chances for economic transition, they must also satisfy public concerns about pollution and the effectiveness of the water treatment process. These concerns are neither static nor totally definable ahead of time, for they depend upon the eventual uses of the water. Such political concerns can sink the viability of this project as surely as the failure to attract industry.

Political Uncertainties and Risks

Even if the Strategic Water Supply program succeeds in converging on one or more technically and economically feasible treatment technologies and in fostering a healthy base of users, the endeavor could nonetheless end up being a disaster. We have already mentioned nuclear energy, but there are still other examples where promising technologies have struggled to make inroads in the face of popular opposition, genetically engineered crops for example. But we need only look to Kern County, California to get a taste of what could happen in New Mexico.

During the peak of the 2010s California drought, Chevron supplied the Cawelo Water District with much needed water (Dotson 2019). The move, however, was contentious. The district paid to bring in outside consultants to demonstrate that irrigation water sourced from Chevron met drinking water standards, but that did little to quell the controversy. <u>And that's because these kinds of public disputes cannot be easily settled by data collection and statistical studies</u>, for they are deeply rooted, value-based disputes hinging on *trust*. Citizens disputed the adequacy of the study, of applying drinking water standards for waters containing potentially unknown and unmeasurable contaminants, some of which were industry secrets. Most of all, they suspected that public officials were in bed with the oil and gas industry and making important decisions with too little transparency, oversight, and public input. Or, they felt that recycled waters were inherently a contamination of food products or in conflict with broader environmental values.

Part of the problem is that food and agriculture is a particularly contentious use for recycled produced waters. Risk scholars would note the high “dread factor,” for situations involving invisible, often novel substances that could be present in food stuffs, and might be feared to influence the development of still more dreadful outcomes like cancer or birth defects. The other difficulty stems from the regulatory novelness and uncertainty of these waters. Either a trusted institutional regulator is absent, or there has not been enough time and experience for the public to believe that existing institutions can be trusted to responsibly steward the new resource.

To skeptical observers, the state’s interests with the SWS are obvious. As Permian Basin operators are evermore awash in produced waters, as these waters disposal is increasingly complicated by induced seismicity concerns, and as surface waters decline in the face of climate change, recycling these waters for productive use seems like a win-win. But that puts the SWS program’s stated environmental reputation and practical concerns in tension. Environmental groups have already and will continue to rhetorically exploit this apparent discord. The New Energy Economy (2024) lobby group, for instance, calls the SWS a handout to the oil and gas industry and claims the effort will “bleed New Mexico dry.”

The culture of contemporary environmental politics is increasingly saturated with mistrust of compromises. Even if that attitude is politically unrealistic, it nevertheless characterizes the sociocultural terrain. The political success of SWS depends on, at least, achieving three things 1) Maintaining distance from probable dread-inducing beneficial uses for produced waters 2) Instilling trust in regulatory apparatus, namely a transparent, fair, and responsive institution for ensuring the safety of these waters (and post-treatment condensates) 3) persuasively demonstrating that certainty of an eventual transition from recycling produced waters to non-oil and gas brackish waters, and convincingly showing that the dominant users of these waters will in fact be environmental firms, not fossil-fuel related industries.

Solutions

Organizing for Flexibility

Mega-projects like the SWS are especially risky due to potentially high levels of inflexibility (Collingridge and James 1991; Collingridge et al. 1994). It is very easy to invest too much into one technological alternative and find oneself unable to course correct. It would be a tragedy if the SWS program converged too early on a water recycling technology that proved either to be infeasible or resulted in unintended consequences.

While the nuclear power industry converged too quickly on light water reactors, officials involved in the Manhattan Project kept their search for the optimal uranium enrichment technology open as long as possible (Pool 1997). Parallel innovation pursued at Oak Ridge National Laboratory, eventually uncovering that three different processes (gaseous diffusion, electromagnetic separation, and thermal diffusion) needed to be combined for the process to work.

Oak Ridge scientists successfully managed uranium enrichment while nuclear power got stuck on LWRs because they kept open the possibility of alternative technologies for longer. In contrast, nuclear power was privatized too early on, which forced convergence before gaining sufficient experience with alternatives. The lesson we can draw from these two case studies is that it will likely take considerable government support to keep a diversity of water treatment/recycling technologies alive for what may otherwise seem like an inordinate amount of time.

The technological choice problem is considerable, because the options are myriad: nano-filtration, forward and reverse osmosis, electrodialysis, membrane and thermal distillation, evaporation, adsorption, etc. (Groundwater Protection Council 2023) Not only can each of these technologies differ in terms of technical sweetness. Each varies in terms of energy requirements, the networks of infrastructure and expertise needed to support them, modularity, public familiarity, and other features.

NASA faced a similar conundrum when confronted with the question regarding which space launch vehicle would replace the soon-to-be decommissioned space shuttle.

After the failure to get their post-shuttle program off the ground in 2006, NASA successfully implemented a drastic shift in direction through their commercial crew and cargo program. Officials implemented several safeguards against schedule delays and cost overruns caused by inflexibility. First, NASA officials separated the program into no fewer than four parts: a development program and an implementation program for cargo and then crew respectively. Each of these parts was further divided into milestones. Funding was contingent upon meeting milestones. Thus, NASA had ample opportunity to reevaluate their contracts, and if a contractor failed, it saved money for the program to apply to another contractor. This proved important when Rocketplane Kistler (RPK) failed to raise enough private capital to meet their milestone obligations (Pasztor 2007). Because funding was milestone contingent, NASA saved $175M which they were able to use to fund Orbital Science Corporation instead (INSIGHT Staff 2022).

New Mexico should consider implementing similar measures. Especially when considering contract terms with private sector investors. Breaking contracts up into the smallest feasible increments and having funding contingent milestones that are both technical and financial were important aspects of NASA's Space Act Agreement contracts, which were crucial in the commercial program's success.

New Mexico will need to keep options open as long as feasible. Some water recycling technologies may look suboptimal, but it may just be that a breakthrough is just around the corner. At the same time, big failures would be both expensive and delegitimize the SWS program. The scale of technological alternatives should grow only slowly. Requiring pilot facilities often isn't sufficient, such as the example of nuclear energy illustrated above.

The incentive structure needs to reward incremental growth, providing the state multiple opportunities to reassess the technical, economic, and political promises of different options and to reevaluate their prioritization. This is often referred to as a "stage-gate" process. And this should apply not only to the development of individual recycling technologies as well as their surrounding infrastructure.

Supporting Green Industry Growth

The challenges for the state, however, are not limited to uncovering and implementing technically feasible and economically sound recycling technologies, but also sowing the seeds for a vibrant green industry in the regions where produced and brackish water resources can be developed. The complexities involved in industry agglomeration are an order of magnitude higher than for the problem of technology selection.

Given the difficulty of intentionally stewarding whole new industries into existence, are there any examples of successes that might help guide policy in New Mexico? The Danish success at dominating the global wind turbine industry despite better funded competition from Germany and the United States gives us some insight.

In the 1970s and 1980s, engineers at NASA quickly scaled up highly technically sophisticated wind turbine designs that, in practice, broke down quickly and frequently (Heymann 1998). Believing that turbines were simpler than they actually were, and overestimating their own understanding, NASA engineers scaled up before they had enough practical experience with their designs.

Wind turbines in Denmark, in marked contrast, started with amateur craft peoples who made small prototypes. In part, this industry was supported by Danish government wind energy investment credits. Although the craft industry could not produce fast enough to take advantage, they could sell their patents to agricultural implement manufacturers who could take better advantage of the investment credit program.

Because many of these manufacturers had previously made farming machinery, and had pivoted to wind turbine manufacturing, they lacked relevant expertise. But the Danish government provided a testing facility as part of the licensing process for the investment credits. Thus these small scale manufacturers got access to expertise to build on their trial-and-error based designs.

As Danish wind companies began scaling up their operations, they founded an association of turbine owners and manufacturers. This association's monthly journal provided key connections between firms that enabled them to learn from one another, by sharing advancements, new design elements, and failures.

Denmark started with small and simple 22kW turbines in 1976. They gradually scaled up their turbine designs, with policies explicitly aimed at enhancing learning. By 1989 they had 500kW designs that were more economical and reliable than any other design on the market. By the early 2000s Danish companies were selling turbines in the MW range and controlled 45% of the wind turbine market.

The most promising economic pathways for the SWS will be non-obvious in advance. Several options are worth exploring. Most advantageous are ones that utilize already existing infrastructures and human capital. The people in these areas have seen booms and busts already. They will likely look with worry to the stumbling energy transition in Farmington, where many workers received a paltry severance and locals chased schemes to save the shuttered coal plant, because they had little faith that green energy would deliver the promised quality and number of jobs quickly enough (Bowlin 2023; Marston 2023).

Hydrogen production is a promising possibility. The process itself is water intensive and its sociotechnical system has significant overlaps with oil and gas. Other uses for produced waters include the production of hydroxides and hydrochloric acid and data center cooling (Anthony 2022). But, as we have recommended throughout, the state should discern the smallest feasible increment for outlaying infrastructure, support, and regulation for these different uses, and devising ways for these different economic uses to "prove" themselves.

Uncertainty about where in the state these industries are most likely to operate is just as high as uncertainty about which industries will ultimately be successful (despite what some industry analysts will have you believe). Different areas are likely to be attractive to different industries. Even those areas that are most attractive for some produced water uses may also have too much competition from oil and gas for other resources like infrastructure.

The state may also want to keep in mind *political* objectives associated with location. For example the state may alleviate opposition based on economic anxiety by focusing on improvements in areas skeptical of the energy transition, like the citizens of Farmington were.

The Danish government would not have been able to predict which craft people would make the initial turbine designs, or which farming equipment companies would retool to manufacture them. Similarly, New Mexico won't necessarily be able to predict which areas of the state will be most enthusiastic about developing the infrastructure for industries based on produced waters. The state will certainly have to target promising areas to some degree. However, policies promoting economic development should be flexible enough to support the organic growth and maturation of these industries.

It is not guaranteed that New Mexico will achieve that feat. To have the best chance, we recommend: 1) Start with small scale industries that use produced waters without considerable capital investment. This can make it easier to incentivize local participation. 2) Scale up industries slowly, by scaling state support accordingly. This ensures there is time to learn about any mistakes or unintended consequences. 3) Provide seed funding, access to state and university expertise, and other support to help local firms to pivot in response to emerging "green" opportunities. 4) Provide knowledge and expertise sharing opportunities to enhance learning regarding both mistakes and advancements.

Organizing Disagreement

Ensuring that the state and produced water producers and users are not caught unaware by growing public mistrust will be the primary political challenge for the SWS. While it is often assumed that quickly moving to try to silence or counter dissent is good public relations, it usually backfires. For risky science and technology, a healthy level of public disagreement is best, for it helps take the fire out of muckraking and lessen the power of more conspiratorial voices.

The easiest first step is to ensure that the Governor's office plays host to critical voices (see Dotson 2016; 2019). Organizations like New Energy Economy aren't simply opponents to the SWS, they provide reminders of the political risks involved if the oil and gas industry remains too much at the center of the program.

Local citizens are often skeptical of glossy images of green industry futures and other slick forms of public relations. They want clear reassurances that proposals actually deliver good jobs and strengthen their communities. Disagreement can provide "reality checks" regarding the feasibility of differing water recycling technologies and plans for economic development. Diverse stakeholders need to be regularly invited and encouraged to speak their minds, otherwise those leading SWS projects might continue unaware of growing discontent, until it is too late.

Furthermore, the evolving regulation of produced waters needs to be legible to ordinary New Mexicans. Public demonstrations of water filtering technologies, for instance, can be more persuasive than toxicology reports. But getting and keeping the public on one's side involves more than just this. It requires establishing and maintaining trust in the public and private actors involved.

In the 1990s, Brookhaven National Laboratory was rocked by a scandal, a leak of radioactive tritium that threatened to move beyond the campus' fences (Dotson 2023). It's a complex story of how an utterly trivial and non-dangerous leak led to the shuttering of a perfectly fine nuclear research reactor. Public engagement efforts stumbled. Strategies to lessen public concerns, like paying to connect locals to the municipal water supply, horribly backfired.

The crisis was largely driven by mistrust of laboratory officials. One of few effective steps they took was letting critical journalists look "behind the curtain." Lurid exposés can only get written in sparse informational environments, which lend themselves to conspiratorial storytelling and tabloid-style reporting. When journalists actually got a look at how laboratory officials were testing and treating local waters, ensuing articles largely vindicated Brookhaven. But these testaments came far too late to help save the lab's research reactor.

While good public relations can sometimes reestablish public trust, the best approach is to never lose it. Mistakes, errors, and accidents must be rare and as small as feasibly possible. The woes faced by Boeing today are emblematic of how quickly things can turn sour. Decades of work to turn airline travel into the safest mode of transportation was undone by a corporate culture that appeared to outsiders to sweep problems under the rug and put profits before safety. Some travelers now even refuse to board Boeing jets. What would happen to the state's SWS if citizens refused to purchase products that came into contact with produced waters?

But examples like airline travel, post-Three Mile Island nuclear power, and other "high-reliability" industries show that adequate oversight and anticipatory regulation can help sustain businesses that make use of risky technologies. Industry-wide sharing of information, a culture that respects the uncertainties involved, and other strategies can ensure the proper management of complexity.

In short, an industry or technology is "politically safe" not only insofar as it really is safe, but also to the extent that its safety can be persuasively signaled to citizens. Perceived secrecy, unfairness, corruption, and other political failings can lead safe technologies to suddenly be coded as risky. Success of the SWS hinges on the ability of citizens to believe that businesses, regulators, and state politicians have their stuff together.

Conclusion

The above analysis is only a preliminary assessment of the uncertainties and complexities that New Mexico will need to navigate as it explores the viability of recycling produced and brackish waters. There are innumerable more strategic considerations to be made, in light of ongoing data gathering regarding the technical, economic, and political parts of produced waters' sociotechnical system. We encourage the state to include funding for further analytical reports on the anticipatory management of the complexities and uncertainties of food-water-energy transitions in further rounds.

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