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Small Modular Reactors for Nuclear Desalination and Cogeneration in the Permian Basin

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"We need a Manhattan Project to deal with the produced water."

— Kirk Edwards, former chairman of the Permian Basin Petroleum Association, April 2025[2]

Executive Summary

Nuclear energy can potentially supply baseload, carbon-free electricity and process heat to repurpose and utilize some of the Permian Basin's roughly 25 million barrels per day of oilfield produced water.[3] Doing so would free up local natural gas supplies for other uses, create a new water resource, and potentially, help address increasingly significant challenges with induced seismicity related to injection disposal of produced water.

Furthermore, nuclear reactors' substantial heat output is well-suited for thermal distillation — the most robust process for oilfield waters whose variable quality, including contamination with hydrocarbons and high salinity, can severely challenge reverse osmosis-based treatment systems.[4] If a modern Manhattan Project is needed to handle produced water, the core tools of the original Manhattan Project — nuclear reactors — could potentially be very well suited for the task.

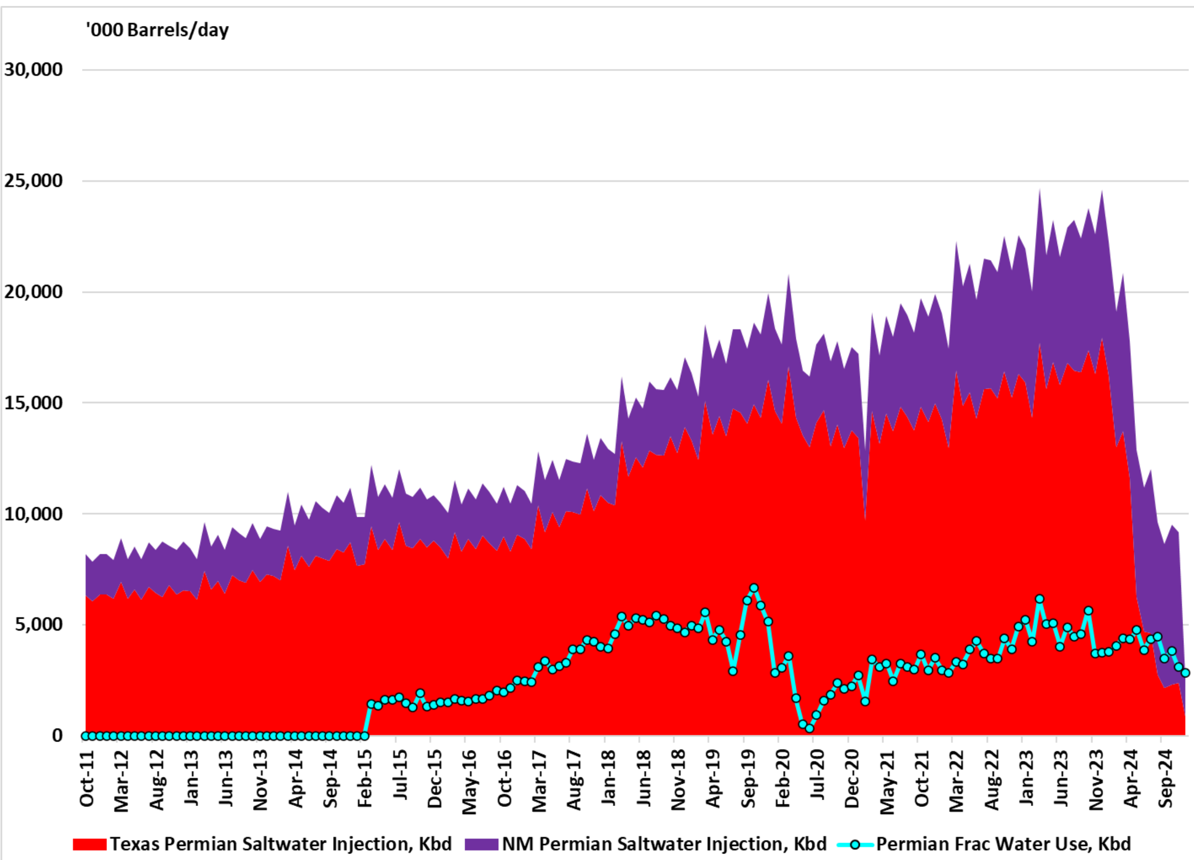
This simple analysis aims to sketch out first cut techno-economic parameters of how nuclear-powered water treatment might look. Oilfield applications of distributed nuclear power would align well with new Texas policy that explicitly recommends using nuclear power to treat oilfield produced water.[5] Many small modular reactor designs could also likely physically fit onto pad sizes similar to what the water midstream industry already uses for recycling and treatment operations.

This analysis ultimately aims to drive additional conversations with parties including the Texas Produced Water Consortium, Abilene Christian University, Natura Resources, Oklo, NuScale, Blue Energy and many others who are focused on — or who could help address — various challenges invoked by oilfield water management, power, and nuclear energy issues.

The Market Opportunity

The Permian Basin oilfield now faces a situation in which several water-related challenge factors coincide. First, the amount of produced water that must be handled now approaches 25 million barrels per day — nearly 5 times the amount of oil produced (**Figure 1**). Second, even with 100% recycling of produced water for subsequent fracs, the total volume of produced water would still exceed frac water demand by approximately 5:1.

Figure 1 — Permian Basin Produced Water Volumes Versus Frac Water Demand, Kbd (Monthly Average Basis)



Source: FracFocus, NM OCD, Texas RRC, and author's analysis.
Note: For perspective, the City of Midland used about 600 thousand bpd of water in Fiscal 2023.[6]

Third, injection disposal now regularly triggers significant seismic events, including some that have impacted Midland/Odessa, the region's largest urban center. As such, finding ways to reduce injection volumes is a policy imperative. Fourth, shallower injection disposal of produced water has also created subsurface overpressure in areas such as the San Andres formation in Midland and Martin counties that forces drillers to use extra casing strings and adds to well costs. Nuclear-powered water treatment could offer a way to extract some of this water and render it usable for other purposes, thus helping to address local water scarcity while also depressurizing the subsurface.

Nuclear-powered treatment could also offer a way to process water from currently uncontrolled releases such as those that have created Lake Boemer and which have occurred in the Antina Ranch area, reduce subsurface pressure, and help reduce the risk of contamination currently looming over local groundwater resources.[7] Finally, in an arid region chronically short of water, nuclear-powered desalination and purification could potentially create additional water usable for industrial purposes, data centers, non-food crops, and other uses.

Thermal distillation processes are the most robust when processing feedwater of variable /lower quality, a likely challenge in the oilfield. Data from Scanlon et. al. suggest a purified water yield rate of 10%-to-20% for multistage flash distillation (MSF) and 20%-to-35% for multiple effect distillation.[8] MSF's robustness in the face of variable water quality makes it especially attractive for harsh oilfield applications.

Assuming a 20% yield rate would suggest a simple mass balance equation for which every 10 barrels of produced water fed into the nuclear-powered distillation system would yield 2 barrels of purified water and 8 barrels of reject brine that would likely ultimately need to be injected into a saltwater disposal well. Water streams with lower total dissolved solids content could be looped back through the facility until saturated brine is left.

Water could potentially be further distilled and in the most extreme case, approached from a zero liquid discharge perspective that aimed to leave only solids behind. I do not do this for the purposes of the instant analysis because an inbound stream of water with 100,000 parts per million of total dissolved solids ("TDS") water contains about 13 kg of sodium chloride ("salt") per barrel if we assume 80% of the TDS is NaCl.[9] As such, every 8,000 bbl of inbound water contain enough dissolved salt to fill a rail hopper car.[10] If a facility processing 100,000 bpd of 100k TDS produced water did so with zero liquid discharge, it would have to find a place for roughly a unit train worth of salt every 10 days. Reject brines are also likely to have other metals and compounds in them, some of which are potentially toxic.

Accordingly, this analysis assumes that water treatment operators would rather "shrink" the injectable fluid volume by extracting some water and then disposing of the concentrated reject brine. While not perfect, this approach could help reduce subsurface fault burdens and lower seismicity risks while also creating a purified water stream that, pending additional scientific work and regulatory changes, could eventually become usable at scale outside the oilfield.

Nuclear Desalination Historical Case Example: Kazakhstan

Nuclear desalination is a new concept in the Permian Basin but is not new globally. From 1973 through 1999, the Soviet Union and the successor state of Kazakhstan operated a desalination facility powered by a BN-350 sodium-cooled fast breeder reactor near the city of Aktau on the Caspian Sea. By 1980, the facility was yielding 125 MW of nuclear-generated electricity and 85,000 cubic meters per day of desalinated water (approximately 534 thousand barrels per day).[11] It's worth noting that at roughly 12,800 mg/l TDS Caspian Sea water is only about 1/3 the salinity of seawater and much less saline than most Permian produced waters.[12]

Figure 2 — Shevchenko Heat, Power, and Desalination Complex Where BN-350 Reactor Was Located

Source: Rosatom.[13]

Russian state nuclear firm Rosneft claims that the BN-350 reactor "*never had a single nuclear or radiation incident.*"[14] Nevertheless, by Rosneft's account the Kazakh government chose in 1997 to shut the reactor down amidst strong anti-nuclear sentiments in the country, amplified by the reactor's potential to produce weapons grade plutonium.[15] The city of Aktau now obtains its water from a smaller (24,000 M^3 per day) desalination complex on the same site that is powered by natural gas.[16]

Japan, India, and Pakistan have more than 125 reactor years' worth of experience conducting smaller scale nuclear desalination operations to supply reactors' own needs. Data the author was able to locate show these facilities can each variously produce between 1,000 and 6,300 cubic meters/day of water (6,280 bpd to approx. 40,000 bpd).[17]

Nuclear Desalination and Electricity Cogeneration Simple Model for the Permian Oilfield

Multiple SMR types could potentially support thermal desalination operations. This analysis incorporates construction cost data from the Idaho and Argonne National Laboratories that are agnostic to reactor technology type.[18] This is because multiple SMR designs are being developed, including light water, pressurized water, sodium-cooled, gas-cooled, and molten salt reactors. It is not clear which technologies will “win” and the most likely scenario is that multiple reactor technologies each fit for distinct purposes will ultimately be available in the marketplace over a 10-to-15-year timeframe.

This working paper’s rough estimate assumes the following:

1. A 2-reactor pod is deployed, with one unit optimized for thermal output to power multi-stage flash distillation while the other is optimized for generating electricity for sale into the grid or to adjacent consumers through an oilfield microgrid.

2. The reactors are rated to each produce 15 MW of electricity or 30 MW of thermal energy. In this simple model’s configuration, one reactor maximizes electrical output and the other thermal energy to run the desalination process.[19]

3. Entities trying to offload produced water would pay the reactor operator $0.45/barrel to take the produced water (set to price as a disposal option competitive with saltwater injection disposal wells). Assuming MSF yield of 20% means that plant would need to take in as feedstock 5X the volume of clean distilled water it can produce.

4. Entities needing water would pay $0.25/bbl for clean distillate water coming out the backside of the desal plant.

5. The reactor + desal operator would need to pay $0.35/bbl to dispose of reject brine concentrate left over after the MSF distillation process. This assumes a discount based on a full proprietary injection disposal capacity coverage. The 5:1 ratio above means that for every 5 barrels of inbound raw produced water, there are 4 barrels of brine concentrate to dispose of — reaching about 475 kbd at full run rate. Brine at 250,000 TDS would likely have a viscosity about 25% higher than 100,000 TDS feedwater, which would increase energy costs and potentially pose injection disposal challenges.[20]

6. Wholesale electricity is assumed to average $75/MWh over the course of a given year.

7. Customers bring water pipelines and power transmission infrastructure up to the "reactor gate."

8. The nuclear reactor's capital cost of construction ranges from $5,250/kW in the Optimistic Case, to $8,000/kW in the Base Case, and $9,250/kW in the Conservative Case.[21] The data come from a 2024 report from a team of researchers at the Argonne and Idaho National Labs that examined nuclear energy costs.[22] The team produced estimates for a "between a first-and-Nth-of-a-kind" reactor that would correspond to the prospective costs of not the first reactor built, but "near-term follow-on units" constructed next.[23]

9. Capital Costs for a 5 MIGD/120 kbd MSF desalination plant are assumed to be approximately $10/gal/day.[24]

10. MSF desalination is assumed to require 38 kWh of thermal energy per M^3 of water (6.05 kWh/bbl) and 3.5 kWh/M^3 of electricity (0.56 kWh/bbl).[25]

11. The cost of capital is 6.5% and the financing term is 20 years.

12. The following sensitivities apply to this model: each cent per barrel movement changes annual net revenue by the following amount: water processing fee ($2 million), water sales fee ($0.4 million), disposal charges ($1.8 million), each $/MWh power price movement changes annual net revenue by $0.2 million.

The Permian Basin's simultaneous need for produced water treatment and rapid electricity load growth suggest two things. A single 2-reactor module (which might be oilfield customers' preferred option for scale and CAPEX reasons) would likely be optimized toward water treatment. Under the modelled parameters, the reactor complex would likely become cash-positive rapidly in most scenarios. In ERCOT, there would be exceptional electricity price periods that might improve reactor economics for power sales, especially in years with multiple extreme weather events. Likewise, if series production reduced reactor capital costs, that would also improve overall project economics. Project developers might also consider partnering with battery storage operators to optimize electricity sales opportunities by storing energy when wind and solar are operating at high levels and then release it during higher price periods. Developers could also sign firm power purchase agreements with data centers, oil companies needing power to run pipelines and artificial lift, and other customers needing high-reliability, weather-proof generation resources.

Figure 3 — Simple Model for Permian Basin Nuclear Desalination Facility

Capital Cost ($ millions)	**Nuclear MSF, Optimistic**	**Nuclear MSF, Base**	**Nuclear MSF, Conservative**
2-Reactor Pod, 15 MWe apiece	30	30	30
Capital cost ($ /kW)	$5,250	$8,000	$9,250
Nuclear plant capital cost, $ Million	$158	$240	$278
5 MGD Desalination plant capital cost, $ Million	$71	$71	$71
Reject Disposal Well Capital Cost (35 wells at 15 kbd apiece at $7 million/well)	$245	$245	$245
Desalination plant cost as % of nuke plant capital cost	45%	30%	26%
Annual Operation & Maintenance Cost ($ millions)			
Nuclear O&M per unit of power produced, $/MWh	$29	$34	$45
MWh/yr @90% utilization	236,520	236,520	236,520
Nuclear Plant	$7	$8	$11
Desalination plant	$4	$4	$4
Operational Parameters			
MSF thermal reqmts, kWh/bbl	6.05	6.05	6.05
MSF electricity reqmts, kWh/bbl	0.56	0.56	0.56
Water production potential, Kbd	119	119	119
Water Intake at 20% MSF Yield, Kbd	595	595	595
Reject Disposal at Full Run, Kbd	476	476	476
Net Power sales potential, MWh/d	357	357	357
Cash Flows & Liabilities ($ millions)			
Annual water intake revenue	$98	$98	$98
Annual clean water sales revenue	$11	$11	$11
Annual water disposal costs	-$61	-$61	-$61
Annual net revenue from water	$48	$48	$48
Annual net revenue from electricity sales	$18	$18	$18
Coupled plant net annual revenue	$65.5	$65.5	$65.5
Annual Capital Payback Needs	$43	$50	$54
Implied Gross Margin	34.4%	23.0%	17.8%
Plant simple payback time (years)	3	5	5

Source: Author's analysis based on these sources: Tewari, Pradip K., and Ibrahim Khamis, "Desalination & Water Management: Opportunities & Issues," presentation at the 16th INPRO Dialogue Forum on Opportunities and Issues in Non-Electric Applications of Nuclear Energy, Vienna, Austria, December 12, 2018; Larsen, Levi M., Abdalla Abou-Jaoude, Nahuel Guaita, and Nicolas Stauff, "Nuclear Energy Cost Estimates for Net Zero World Initiative," Idaho National Laboratory, INL/RPT-23-74378, 2024; based on smallest reactor size parameter offered in Oklo Inc. Q4 2024 Quarterly Company Update, Santa Clara, CA: Oklo Inc., March 24, 2025; Phillips, S.L., A. Igbene, J.A. Fair, H. Ozbek, and M. Tavana, "A Technical Databook for Geothermal Energy Utilization," LBL-12810, UC-66a, Berkeley, CA: Lawrence Berkeley Laboratory, University of California, June 1981 (p. 32 of 60), Molal concentration calculated using Calculator.net "Molarity Calculator"; Morin, O.J., “Cost Aspects – MSF,” in “Thermal Desalination Processes” Vol. II, 1–9, Black and Veatch, Florida, USA, accessed April 29, 2025. URLs contained in endnotes.

Conclusion

The small modular reactors currently being developed by NuScale Oklo, Holtec, and other firms are all ultimately fixed assets designed to operate for a licensed lifetime of 40 years in a single location. If mobile reactors came to market, water treatment operators might prefer those given that their mobility would reduce drilling and commodity price risk because they could be moved to follow the action. But those are likely at least 5 years further into the future than the first commercially deployable, American-made fixed location SMRs. Russia has deployed mobile barge-based SMRs but such platform types would not be suitable in the major U.S. oil & gas basins, which are located hundreds of miles inland.

Water movement infrastructure likely offers a better pathway to manage the risk of geographical shifts in drilling activity. For instance, a more integrated “hydrovascular grid” of fixed water movement lines bridged where needed by short distance layflat hoses could help manage locational risks and allow water processors to capitalize on the scale economics of larger fixed reactor projects like the one modelled in this analysis.

There are also additional potential monetization pathways, including: pairing desalination oriented SMR modules with carbon capture and sequestration projects that need electricity and heat, partnering with firms seeking to extract minerals from concentrated reject brines[26], and if additional reactors can be added to the pad and negotiated operational footprint, providing dedicated behind the meter power to bitcoin miners and/or high-performance computing clusters handing AI workloads. A new Manhattan Project for handling the ongoing produced water tsunami by bringing low emissions, high density nuclear energy and heat supplies can open a new era of “the nuclear oilfield.”

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Notes

[1] The author is the Water-Energy Thrust Leader at Rice University's Water Institute and holds a membership interest in Cactus Water Services, LLC. This relationship is covered by a Rice University conflict of interest management and monitoring plan.
[2] Benoit Morenne, "The Oil Patch's 'Manhattan Project': How to Fix Its Gargantuan Water Problem," The Wall Street Journal, 21 April 2025, https://www.wsj.com/business/energy-oil/the-oil-patchs-manhattan-project-how-to-fix-its-gargantuan-water-problem-aebda706.
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