

Title: Produced Water: A Potential Solution to Achieve America Energy Dominance**Authors/Affiliations:** Prashant Sharan (Staff Scientist 3, Los Alamos National Laboratory),

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Focal Area(s):

Treating produced water from oil and gas extraction is highly energy-intensive, leading many operators to prefer deep well injection over treatment. Integrating produced water treatment with critical mineral extraction and energy production offers a promising approach to make produced water treatment economically viable for reuse in mining operations, cooling towers, and as deionized water in process industries.

Existing Challenge:

Produced water, a byproduct of oil and gas extraction, represents a significant yet underutilized water resource that could help address rising water demands¹. The amount of produced water generated can be up to 6 times the volume of oil and gas extracted for a well². In 2017, 3.9 billion m³ of produced water was generated globally, of which 92% was disposed as waste³. The dominant disposal method—deep well injection—has been linked to contamination of potable aquifers and increased seismic activity⁴. The technical challenges, high energy demand, high treatment cost, and social and regulatory hurdles have complicated produced water treatment. For example, membrane desalination technologies, despite being energy efficient, are prone to fouling and membranes degrade in the presence of the organics typically found in produced water.^{5,6} Traditional thermal desalination methods, such as distillation, struggle with high salinity solutions that contain scale-forming compounds such as calcium carbonate.⁷ In addition, organic compounds in produced water can evaporate and contaminate the distillate.⁸ These desalination techniques must employ pretreatment steps including settling tanks, hydro-cyclones, and coagulation and flocculation tanks to remove detrimental compounds.⁹⁻¹⁰ While these additional steps increase life expectancy of the entire process, they also increase the treatment cost. For produced water to become a viable clean water source, alternative technologies that can better handle both organics and high salt concentrations must be developed. Additionally, if the organic present in the produced water can be effectively utilized as an energy source, the net energy consumption for produced water treatment can be brought down to zero, and the water treatment cost can be brought down effectively.

Near-Term Opportunity:

Oil and gas extraction sites are often located in semiarid regions facing severe water scarcity, such as the western United States (U.S.).¹¹ Treatment and purification of produced water could supplement the current sources for domestic, agricultural, and municipal use, industrial cooling, and oil & gas extraction. To enable the sustainable reuse of produced water, new treatment

approaches are needed that can efficiently and simultaneously handle both organic and saline contaminants. Currently we have programs to successfully treat the produced water, via supercritical water desalination¹²⁻¹³, membrane distillation¹⁴ and evaporator with catalytic oxidation¹⁵.

Supercritical water desalination and oxidation (SCWDO) is a promising technology for effective treatment of produced water¹²⁻¹³, with potential of net-zero energy consumption. In the supercritical phase (temperature >373 °C and pressure >221 bar), high thermal energy disrupts hydrogen bonding and randomizes water dipoles, while the sharply reduced dielectric constant—similar to steam—greatly lowers salt solubility¹⁶⁻¹⁷. As a result, saline feed solutions separate into two phases: a concentrated brine and a supercritical water distillate with low salt content. Under these conditions, the vapor phase has a lower density than the brine phase and can be readily separated in the reactor chamber by controlling the operating temperature and pressure. The low density and non-polar nature of supercritical water enhance mass transfer and increase the solubility of organics and oxygen, making it an excellent medium for oxidation reactions that convert >99% of organics to carbon dioxide¹⁸⁻¹⁹. Because these reactions release substantial heat, the overall SCWDO process can achieve near net-zero energy consumption¹²⁻¹³. We successfully treated different produced water samples across different basins in USA, with TDS ranging from 10,000-280,000 mg/L to generate a drinking water quality distillate. Similarly, we demonstrated that the evaporator with catalytic oxidation (ECO) process is a feasible approach for treating produced water, enabling the utilization of organic content as an internal energy source. We are currently building a pilot-scale demonstration for both the SCWDO and ECO processes. In addition, we have developed a high-temperature membrane distillation process using a highly selective and dense polybenzimidazole (PBI) thin-film membrane for treating actual produced water samples. The membrane exhibited excellent stability in brine solutions at temperatures approaching 200 °C, achieving 99.9% salt and organic rejection and producing high-purity distillate.

Produced water often contains valuable critical minerals (CM) such as lithium, magnesium, strontium, and other rare earth elements. However, extracting CMs from produced water presents significant challenges due to their low concentrations and the chemical similarity among dissolved salts. The SCWDO process offers a promising opportunity by producing a high concentrated liquid brine, thereby reducing the energy consumption of the subsequent CM extraction steps. We have successfully demonstrated the partial extraction of CM from the mixed salt solutions²⁰. We are currently developing a membrane made from natural materials that is both inexpensive and environmentally benign. We will also look for integration of this membrane-based mineral extraction with SCWDO produced water treatment process that could transform waste streams into sources of economic and strategic materials while offsetting treatment costs - making the oil and gas sector more sustainable, reducing environmental impacts, and strengthening national supply chain resilience for CMs.

To summarize, for produced water to be a viable solution in the energy-water nexus, focus should be on use of dissolved organic as an energy source, CM extraction potential and reducing the treatment cost.

Success Measure:

There can be various **quantitative** and **qualitative** assessment which could be deployed for accessing the success for produced water treatment.

Quantitative Assessment

- Ability to bring the treated water quality within EPA drinking water standards
- The system efficiency and ability to treat the produced water at $< 5\text{kWh}_e/\text{m}^3$
- The treatment cost should be lower than current produced water disposal cost of 5-6 $\$/\text{m}^3$ to be economically feasible

Qualitative Assessment

- The technology should be compatible in handling different water quality.
- Potential of scale up to deploy the produced water treatment technology from pilot scale to industrial scale to treat somewhere around 1000-5000 m^3/day .
- Critical mineral recovery technology development within 5 years: successful demonstrated a low-cost, eco-friendly membrane for extracting CMs from concentrated brine at the laboratory scale.
- Integrated process development within 10 years.: Established a viable pathway to integrate membrane-based CMs extraction with SCWDO, paving the way for pilot scale implementation of this integrated approach.
- Potential for reuse of treatment produced water
- The technology should be socially acceptable, and meet the standard compliance for discharge and reuse.

A tool should be developed to account for all these parameters and come up with a cumulative score on qualitative and quantitative assessments. This will help the industry and policy makers to identify the optimal technology across different basin in USA.

References

1. M.S. Mauter, P.S. Fiske, Desalination for a circular water economy, *Energy Environ Sci* 13 (2020) 3180–3184. <https://doi.org/10.1039/d0ee01653e>.
2. Fakhru'l-Razi, A. et al. Review of technologies for oil and gas produced water treatment. 170, 530-551 (2009). <https://doi.org/10.1016/j.jhazmat.2009.05.044>
3. C.M. Cooper, J. McCall, S.C. Stokes, C. McKay, M.J. Bentley, J.S. Rosenblum, T.A. Blewett, Z. Huang, A. Miara, M. Talmadge, A. Evans, K.A. Sitterley, P. Kurup, J.R. Stokes-Draut, J. Macknick, T. Borch, T.Y. Cath, L.E. Katz, Oil and Gas Produced Water Reuse: Opportunities, Treatment Needs, and Challenges, *ACS ES and T Engineering* 2 (2022) 347–366. <https://doi.org/10.1021/acsestengg.1c00248>.
4. J. Veil, Produced Water Volumes and Management Practices for 2017, 2020. www.veilenvironmental.com.
5. Jiménez, S. et al. State of the art of produced water treatment. 192, 186-208 (2018). <https://doi.org/10.1016/j.chemosphere.2017.10.139>
6. Igundu, E. T., , Chen, G. Z. & Produced water treatment technologies. 9, 157-177 (2014). <https://doi.org/10.1093/ijlct/cts049>
7. Qiblawey, H. M., , Banat, F. & Solar thermal desalination technologies. 220, 633-644 (2008). <https://doi.org/10.1016/j.desal.2007.01.059>
8. Chen, R. et al. Interfacial Solar Distillation for Freshwater Production: Fate of Volatile and Semivolatile Organic Contaminants. 55, 6248-6256 (2021). <https://doi.org/10.1021/acs.est.0c07191>
9. Zhao, S. et al. Hardness, COD and turbidity removals from produced water by electrocoagulation pretreatment prior to reverse osmosis membranes. 344, 454-462 (2014). <https://doi.org/10.1016/j.desal.2014.04.014>
10. Chang, H. et al. Evaluating the performance of gravity-driven membrane filtration as desalination pretreatment of shale gas flowback and produced water. 587, 117187 (2019). <https://doi.org/10.1016/j.memsci.2019.117187>
11. Scanlon, B. R. et al. Can we beneficially reuse produced water from oil and gas extraction in the U.S.? 717, 137085 (2020). <https://doi.org/10.1016/j.scitotenv.2020.137085>
12. P. Sharan, S.K. Thengane, T.J. Yoon, J.C. Lewis, R. Singh, R.P. Currier, A.T. Findikoglu, A novel approach for produced water treatment: Supercritical water oxidation and desalination, *Desalination* 532 (2022) 115716–115727. <https://doi.org/10.1016/j.desal.2022.115716>.
13. Sharan, P., Dugas, M., Ravichandran, S., Castro, R., Biswas, A., Warsinger, D. M., ... & Findikoglu, A. T. (2025). Supercritical water desalination and oxidation (SCWDO): Effectiveness on complex solutions, technoeconomic, and CO2 impact for produced water treatment. *Desalination*, 118963. <https://doi.org/10.1016/j.desal.2025.118963>
14. Ruba, A. J., Sharan, P., Dugas, M. P., Thakkar, H. V., Berchtold, K. A., & Singh, R. P. (2024). Experimental and Techno-Economic Analysis of Polybenzimidazole Thin-Film Membranes for Efficient Pervaporation Desalination of Produced Water. *ACS Applied Polymer Materials*, 6(23), 14421-14435. <https://doi.org/10.1021/acsapm.4c02441>
15. Sharan, P., Singh, R., Dugas, M., & Findikoglu, A. T. (2025) SYSTEMS AND METHODS FOR HYDROGEN PRODUCTION USING IMPURE WATER SOURCES. S167666.001. Non-provisional patent filed on April 2025.
16. M. Boero, K. Terakura, T. Ikeshoji, C.C. Liew, M. Parrinello, Hydrogen Bonding and Dipole Moment of Water at Supercritical Conditions: A First-Principles Molecular Dynamics Study, *Phys Rev Lett* 85 (2000) 3245.
17. Y. Zhang, S. Wang, Y. Li, J. Zhang, D. Xu, C. Yang, J. Yang, J. Li, T. Xu, Inorganic salts in sub-/supercritical water— Part A: Behavior characteristics and mechanisms, *Desalination* 496 (2020) 114674–114694. <https://doi.org/10.1016/j.desal.2020.114674>.
18. Marrone, P. A. & Supercritical water oxidation - Current status of full-scale commercial activity for waste destruction. 79, 283-288 (2013). <https://doi.org/10.1016/j.supflu.2012.12.020>
19. Bermejo, M. D., , Cocero, M. J. & Supercritical water oxidation: A technical review. 52, 3933-3951 (2006). <https://doi.org/10.1002/aic.10993>
20. T.J. Yoon, P. Sharan, E.P. Craddock, J.C. Lewis, J.A. Matteson, J.G. Seong, R.P. Singh, K.A. Maerzke, R.P. Currier, A.T. Findikoglu, Selective recovery of critical materials in zero-liquid discharge supercritical water desalination, *Desalination* 537 (2022). <https://doi.org/10.1016/j.desal.2022.115849>.