PRODUCED WATER FROM OIL AND GAS DEVELOPMENT AND CRITICAL MINERALS

The U.S. Department of Energy's (DOE's) Office of Fossil Energy and Carbon Management (FECM) is investing in research and development projects to advance water treatment and management technologies while also recovering critical minerals from produced water. These efforts are integral to helping the United States achieve a clean energy and industrial future. Produced water1 is a term used in the oil and gas industry to refer to the water that comes out of a well during the oil and gas production process. Like oil and gas, this non-potable water exists naturally underground. Depending on the chemistry of the rocks, it may contain many different chemical constituents, including mineral salts, organic compounds, heavy metals, naturally occurring radioactive materials, critical minerals, and other minerals.

The majority of U.S. produced water volume from oil and gas development is produced in seven main shale plays: Permian, Eagle Ford, Appalachia, Bakken, Anadarko, Niobrara, and Haynesville. These areas collectively account for over 70% of U.S. oil and gas production. Refer to Figure 1.

The volume of water produced per well during oil and gas development and production can vary greatly depending on geological factors. However, as the number of wells and production increases, so does the volume of produced water. The Permian Basin, which spans western Texas and New Mexico, represents about half of U.S. oil production and an oversize share of produced water production. Refer to Figure 2.

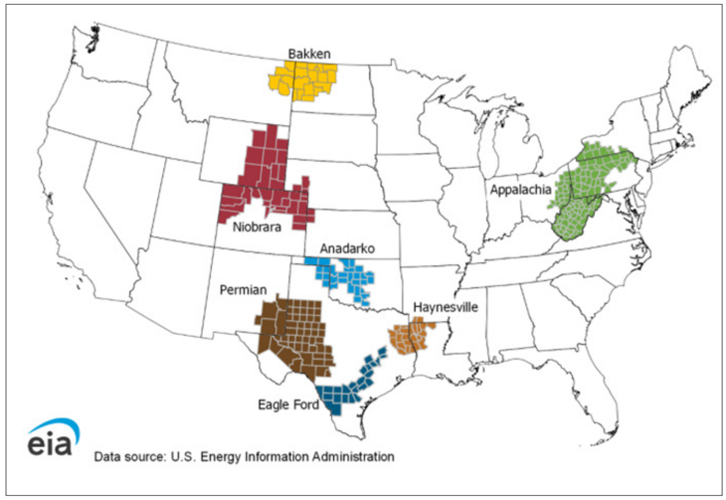


Figure 1: Shale Oil and Gas Regions

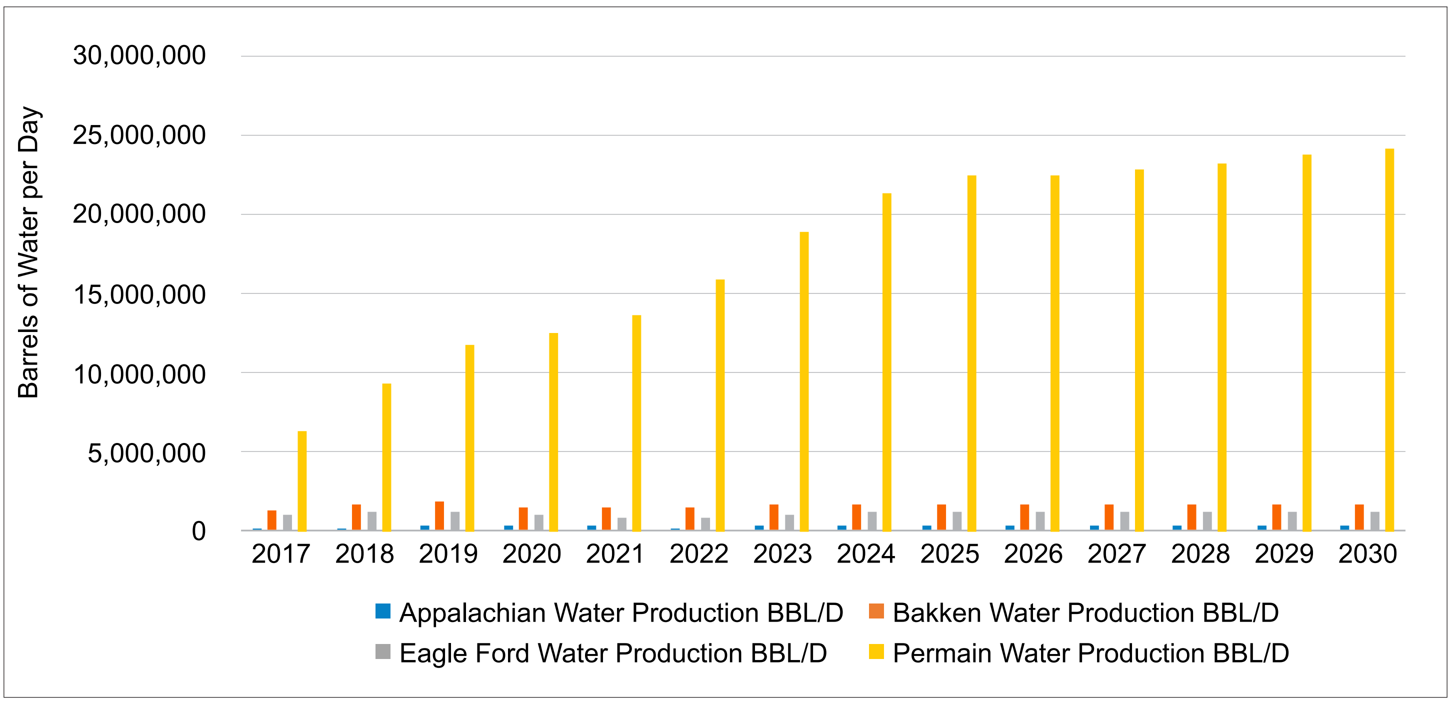


Figure 2: Produced Water Volumes in Oil and Gas Development Regions[2]

[1] Produced water also includes brines from geological carbon dioxide storage, discharges from coal mining, electric-generating power plant effluents, and releases from coal byproduct impoundments such as ash ponds. This information is not in the scope of this fact sheet.

[2] Groundwater Protection Council: *May 2023 Produce Water Report: Regulations & Practices Updates*

Because of the presence of mineral salts, organic compounds, heavy metals, naturally occurring radioactive materials, and other minerals, produced water is often disposed of in deep underground injection wells, commonly referred to as saltwater disposal wells. This activity increases the fluid pressure within the disposal formation, and in some cases, it can induce seismicity (cause earthquakes). Instead of being disposed of underground, produced water can be characterized and treated to be beneficially reused in many industrial and non-industrial applications, including fire control, power generation, vehicle and equipment washing, and non-edible crop irrigation. This could reduce the need for freshwater resources, which is important in water-scarce regions of the nation. Additionally, produced water can contain valuable critical minerals and rare earth elements, such as lithium, that are important for the development of clean energy technologies, including solar panels, wind turbines, and hydrogen fuel cells.

Concentration of Critical Minerals in Produced Water from Shale Plays

In 2022, the U.S. Geological Survey (USGS) released the list of critical minerals, 50 mineral commodities critical to the U.S. economy. The USGS Produced Water Database, an online tool for characterizing the geochemical composition of produced water samples, allows users to determine if any of those critical minerals are present in produced water samples. To date, the database has identified 40 of the USGS's 50 critical minerals in produced water samples, although fewer of these critical elements are found in the Appalachia, Bakken, and Permian shale plays.

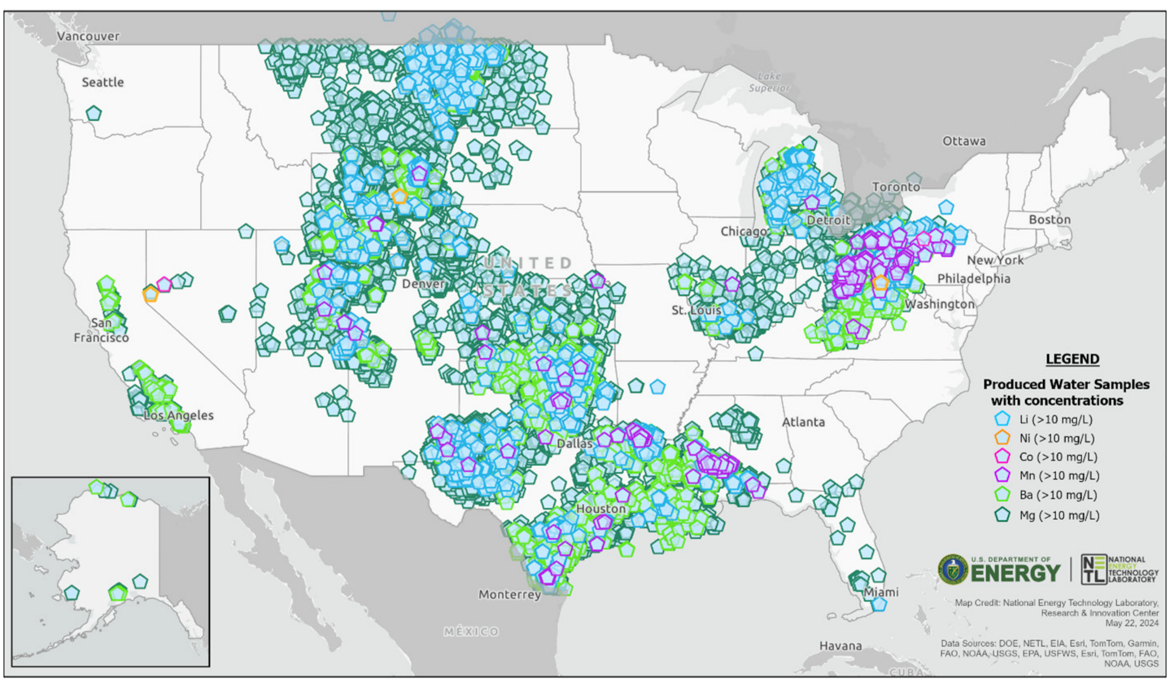
The samples in the Produced Water Database illustrate the potential opportunity for recovery of critical minerals from produced water. For example, over 15,500 metric tons of lithium per year could be recovered from the large Permian shale play, which is five times more than the U.S. annual consumption of 3,000 metric tons per year.[3] Even in smaller shale plays, like Appalachia and Bakken, higher concentrations of lithium in the sample sizes still indicate recovery potential. Figure 3 shows the location of produced water samples with concentrations of lithium, manganese, cobalt, and nickel. These locations overlap significantly with the largest shale oil and gas regions referenced in Figure 1.

Challenges to Recovering Critical Minerals from Produced Water

Although produced water represents a substantial opportunity for critical mineral recovery, variability in the content of produced water, data gaps and inconsistencies, and high costs present challenges to the sector.

Produced water is a complex mixture of dissolved and particulate organic and inorganic chemicals and highly variable by region and within any given region by formation, formation depth, and time in production. The total dissolved solids (TDS) refer to the combined content of all inorganic and organic substances present in the produced water and is also used to measure salinity as the produced water can range from almost fresh water to brine. Therefore, the TDS levels can significantly impact the characterization of produced water and cause challenges in analytical methods.

Figure 3: Location of Produced Water Samples with Concentrations of Selected Critical Minerals



[3] U.S. annual lithium consumption | Statista

Additionally, current available data on produced water characteristics is fragmented and inconsistent. It reflects the critical elements tracked in the past for their impact on reuse or disposal rather than addressing current needs, such as extracting critical minerals used in technologies. There is no readily available access to comprehensive produced water volumes and compositions given the variable reporting requirements between regions.

Currently, the economics to recover critical minerals from produced water is challenging, given the small concentrations, high cost of separations, and large volumes. Further research and development of extraction technologies is needed to accommodate varying produced water qualities (e.g., very high salinity and TDS) and compositions. The extraction process will depend on the produced water composition, and there are many technology options[4] that need to be tested and evaluated for their effectiveness, economics, and environmental impacts. Some examples include electrocoagulation, chemical precipitation, thermal distillation, adsorption, advanced oxidation, membrane filtration, flotation, solvent extraction, and biological technologies. Additionally, innovative business models leveraging shared water treatment infrastructure at the basin-level could be required.

Resource Sustainability Research and Development

FECM's Office of Resource Sustainability is addressing the challenges to recover critical minerals from produced water through a number of funded research projects:

- $1.9 million to the New Mexico Institute of Mining and Technology to comprehensively characterize produced water from the Permian and San Juan Basins in New Mexico and develop a scalable and highly efficient membrane distillation-crystallization and adsorption process for simultaneous water and critical elements recovery from produced water.
- $2.2 million to Texas Tech University to develop a system engineering approach for produced water resource extraction and management involving vacuum membrane distillation integrated with vapor compression to extract water, selectively recovering elements of interest using staged precipitation, and developing an optimization framework for managing produced water and identifying infrastructure needs.
- $2 million to the University of Oklahoma to sample produced waters; determine their chemistry; determine their concentrations in terms of rare earth elements, critical minerals, and/or elements of interest; and engineer their extraction technologies.
- $1.9 million to the Virginia Polytechnic Institute and State University to support three beneficial uses of produced water, including valuable mineral recovery, carbon fixation, and irrigation water production. The process consists of five major steps: (1) produced water treatment; (2) rare earth elements and critical metals recovery; (3) direct lithium recovery; (4) carbon mineralization; and (5) phyto-microbial treatment.

In addition, FECM and DOE's National Energy Technology Laboratory (NETL) are leveraging artificial intelligence to expedite the identification of extraction processes as water is produced, transported, and stored. To address the potential role for artificial intelligence, NETL is developing a number of decision support tools, including the Constituent Data Replacement Tool (CoDaRT). CoDaRT completes composition data profiles for produced water and other wastewater feedstocks that can be used to develop treatment and recovery process models. The tool applies machine learning algorithms to replace missing data based on user preferences associated with algorithm type, number of features, and classification variables. Training water composition data for CoDART can be downloaded from the NETL National Energy Water Treatment and Speciation Database (NEWTS) Group on EDX.

NETL is also developing the Produced Water Optimization Initiative (PARETO), an open-source, optimization-based produced water decision-support application that can be run by upstream operators, midstream companies, technology providers, water end users, research organizations and regulators. NETL is working with universities through the Water Management Program's Produced Water Research Partnership to develop new capabilities for these tools, including machine learning models with built-in produced water chemistry constraints for the NEWTS Database and modules for critical mineral recovery for PARETO.

Learn More

To learn more about DOE's Office of Fossil Energy and Carbon Management, sign up to receive email updates and follow us on Twitter, Facebook, and LinkedIn.

[4] Standard Water Treatment Techniques and their Applicability to Oil & Gas Produced Brines of Varied Compositions (Book) | OSTI.GOV