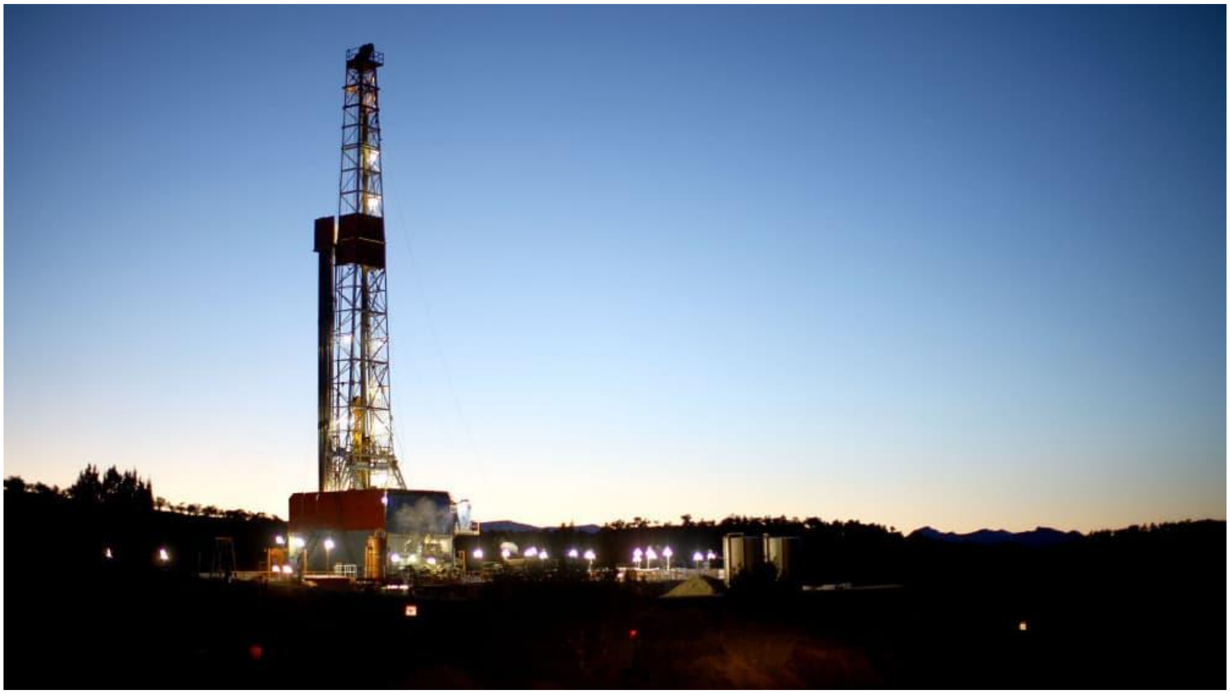
Frac & Shale Produced Water Management, Treatment Costs & Options

Summary:



- There are four types of shale waters, each with unique properties, uses, and treatment approaches.
- Economic shale water management strategies require you to explore: treatment options, treatment costs compared to disposal costs, and methods to manage risk.
- Open-to-atmosphere evaporators offer the best economics for shale volume reduction, although it is important to ensure that: your emissions of volatile organic compounds (VOCs) are managed, a low cost heat source is available, your permit will allow it, and sufficient water volume removal can be achieved (i.e. produce solids).
- Membrane systems may be economic for producing freshwater if the shale water being treated is lower than 40,000 mg/L total dissolved solids (TDS), which is approximately 4% salt and 96% water. Ensure that your membrane

technology option can tolerate organics if you are treating produced water. Using pre-treatment to achieve this can make costs unfeasible.

- Water hauling and logistics can get expensive; evaluate options for treatment to reduce disposal volume hauled, and consider combining treatment with hauling for optimal costs.
- If your produced water contains NORMs (naturally occurring radioactive material), plan to manage them by keeping them in solution, precipitation and safe handling, or dilution followed by water disposal.
- Total dissolved solids in produced water cannot be destroyed, so consider the end-of-life for any reject waste, including innovative options to industrially re-use the reject salts. Secondary revenue streams for these salts are unlikely due to their low commercial value.
- Consider the impact of water chemistry on disposal well lifespan and explore innovative options to reduce disposal well scale risk (BrineRefine) and achieve lower cost volume reduction through evaporation (AirBreather).

Shale water management starts with understanding the distinct types of water, their uses, and their volumes. This will enable better management of the site's water balance to ensure there is the right amount of water available when needed and excess water does not exceed your storage capacity. Practitioners also need to consider the chemistry, which may include scalants, total dissolved solids (TDS), and NORMS (naturally occurring radioactive material). The water chemistry significantly impacts shale produced water treatment strategy, as well as informing end-of-life options for the waste byproducts that are left behind once clean water is removed. These byproducts are often referred to as reject or residuals.

The Different Types of Waters Used in Shale Gas Operations

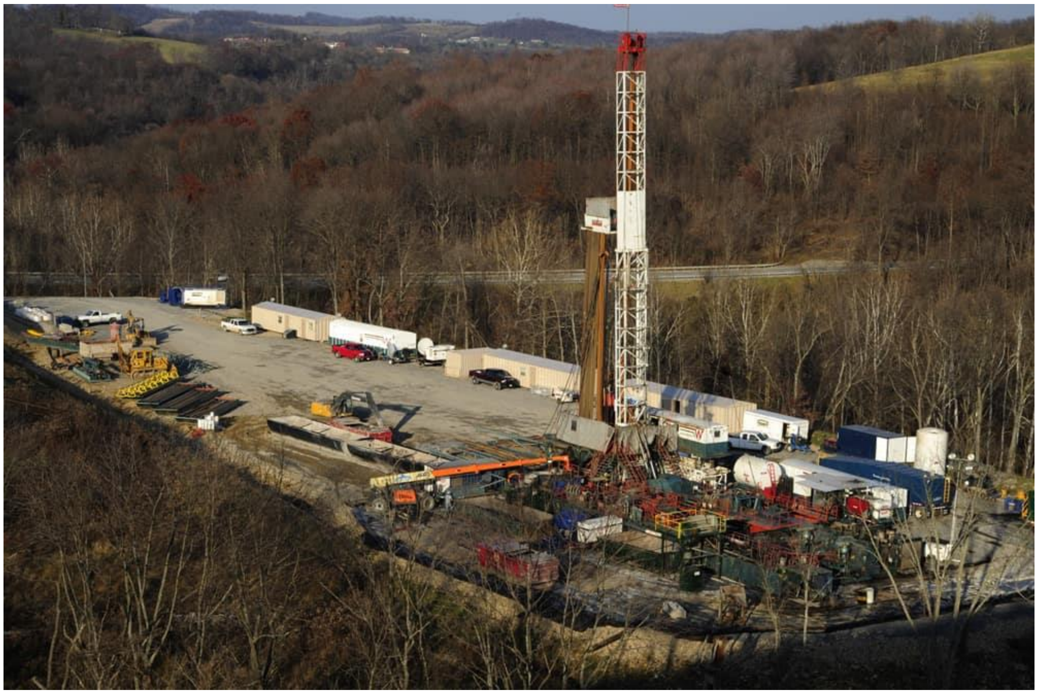
There are four primary types of water used in shale gas operations.

Source water is drawn from nearby water sources, such as surface waters or groundwater, and is typically used for hydraulic fracturing (also known as 'fracking').

Saline Re-Use Water is the water that returns after the fracking process, with increased salinity, but can sometimes be re-used as source water. It may require mild treatment before being used for another fracking process.

Frac Flowback is the water that returns from the ground, following a fracking process. Most of it returns rapidly after the fracking process and will include chemicals employed in fracking that can change the treatment equation. The flowback flow rate slows over the first week(s), while TDS increases. Some of this flowback may become saline re-used water, if needed for future fracking applications.

Produced Water also returns to the surface, like flowback, but produced water largely originates in the formation. It will tend to flow more steadily over longer periods of time and will have a higher TDS.



Water Type	Utilization	Characteristics	Treatment	Volume (m3/day)
Source Water	Fracking	Staged evaporation to atmosphere, concentrating and producing lithium. Locally-sourced at lowest cost.	Chemicals and sand enhancements may be added.	High during fracking process, then tapers to zero.
Saline Re-Used Water	Fracking (Re-Used)	TDS: 10,000 to 200,000 mg/L. Scaling ions can be present.	If re-used in a fracking process, it is often filtered and occasionally softened (remove Barium & Calcium).	Best maximized to reduce future management volumes.
Frac Flowback	Re-used if source water needed, otherwise disposed or treated.	TDS increases over the first week of flowback.	Treatment options below.	High immediately post fracking (~70% of injected water returns), flow rate tapers down over the first week.
Produced Water	Re-used if source water needed, otherwise disposed or treated.	TDS varies but often as high as 100,000 to 200,000 mg/L.	Treatment options below.	Ranges from 10-1000 m^3/day (63-6,300 BBL/day) per well.

Source Water and Disposal Costs in Shale

Although there are many water management options available for shale operators, there is no one-size-fits-all solution. It is important to understand the costs, alternatives, and technical limitations of each option and develop a blended water management strategy to balance costs and risks. Start with identifying the costs of nearby disposal and source water costs – these options should be viewed as the competition to any treatment solution.
For example:

Disposal: \$6 to \$60/m^3 (\$1 to \$10/BBL)

Freshwater: \$0.5 to \$6/m^3 (\$0.1 to \$1/BBL)

Re-use: many operators reuse flow back and produced water, and the cost is largely linked to storage, transport, and any treatment to reduce particulate load (microfiltration) and scalants (chemical softening).

In some cases, logistics or water hauling can dominate the cost equation, therefore treatment at the source to reduce volume may make sense.

Shale Water Treatment Options

In general, there are three categories for treatment:

Particulate & Hardness Removal: (\$)

Technology:

- Water hardness is removed by chemical softening and particulates are removed by bag filters. New developments in chemical softening system design remove pains of the past, such as over or under dosing, poor control, large physical footprint and lack of modularity.

Considerations:

- **Dosing:** Conventional chemical softening systems use set dosing rates, which result in poor precision on constantly changing shale waters. This can lead to underdosing, which may cause scale, or overdosing, which results in wasted chemicals and increased operating costs. Modern chemical softening systems that use sensor-driven precision dosing avoid these problems by reducing waste and maintaining treatment system performance.
- **Filter Quality:** Some bag filter systems are treated as disposable, resulting in higher waste, higher manual handling, and greater disposal costs. Opting for re-usable, highly robust filters with a semi-automated solids handling system can reduce these costs, and improve both the operability and environmental footprint of your particulate removal program.

- **Intervention:** Whether dealing with bag filters or chemical softening, conventional systems can require high operator intervention. New technologies, such as our BrineRefine platform, come as a packaged, automated system that reduces intervention and improves the economics of this water treatment process.

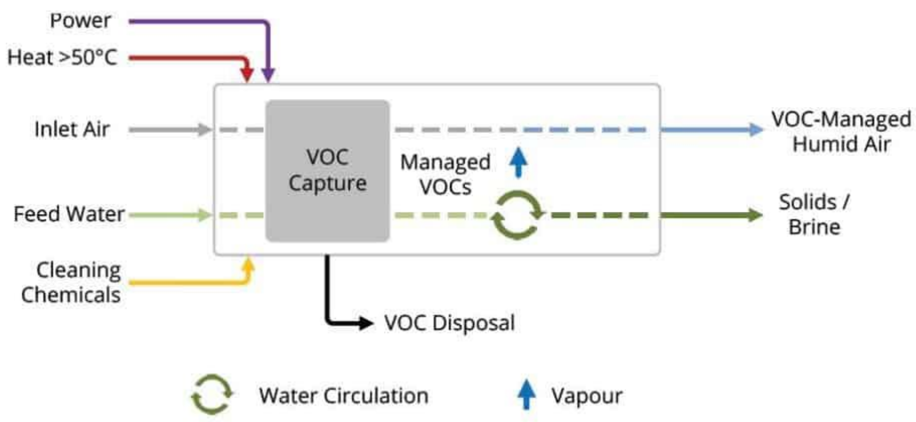
Volume Reduction: ($$)

Technology:

- **Open to Atmosphere Evaporators:** Evaporation to atmosphere will reduce produced water volumes at a lower cost than closed evaporators (discussed later in this article). However, their fit with respect to thermal needs, air emissions, reject concentration, and permitting must be confirmed. Total cost of ownership (capital cost + operating costs) may range from \$12-\$24/m^3 (\$2-\$4/BBL).

Considerations:

- **Air Emissions:** Although water vapour is harmless to the environment, produced water may include volatile organic compounds (VOC) that evaporate with the water. Benzene is the most common VOC in produced waters, and is a regulated carcinogen. There are also volatile forms of arsenic and radium that exist as a part of organic complexes. Make sure you plan ahead for VOC management, since regulators and stakeholders will expect it. Open to Atmosphere Evaporators have been procured and then rapidly shut down due to stakeholder concerns. Invest in risk management and possibly a pilot project prior to making a large capital purchase. Saltworks' open-to-atmosphere evaporator, AirBreather, includes a novel VOC management system that removes VOCs from the exhausted water vapour. Pilot plants are available to prove this and can be complemented with air dispersion modeling to support permitting discussions.



- **Energy:** One cubic meter (6.3 BBLs) of water requires 3.3 GJ (2.2 million BTUs) of energy to evaporate. However, the value of energy, known as 'exergy', depends on its temperature. It may only make sense to spend this energy if a waste heat source or a low temperature heat source is available, such as waste heat from reciprocating engine jacket cooling, exhaust, or waste gas that is flared. Water boils at 100 °C (212 °F), and most engine waste heat sources are 85-95 °C, which is not sufficient to evaporate water. However, the Saltworks' AirBreather does not involve boiling water, instead it humidifies air. This enables the use of a much lower temperature heat source, whereas other open-to-atmosphere evaporators use submerged combustion with direct-fired gas sources, such as natural gas. There is a trade-off in that humidifying air requires larger chambers, but they operate at a lower temperature and can be constructed from engineered plastics to withstand corrosion and scaling issues.
- **Pre-treatment:** Some evaporators cannot tolerate scale-causing compounds, so be sure to complete a water analysis and check with the technology vendor. The AirBreather was developed to accept any fluid without pre-treatment, and remove scale by self-cleaning before it becomes irreversible.

- **Concentration limits:** Most open evaporators are limited to an upper TDS concentration of 150,000 to 250,000 mg/L, where they may start plugging with accumulated low solubility solids. It is worth determining these concentration limits before investing, since they directly impact the plant capacity. If you start with a TDS of 200,000 mg/L and can only concentrate to 250,000 mg/L this means a volume reduction of 20% will be achieved – contact us for help with making these calculations for your project. The AirBreather has no TDS limit, and can make solids due to its built-in self-cleaning and corrosion-proof construction. This means you can squeeze almost all the produced water, reducing your volume to any desired level. However, recall that rejected residual TDS waste must be managed.
- **Corrosion:** After scale, corrosion is the second greatest killer of evaporators. Stainless steel will rapidly corrode when exposed to high chloride produced waters. Super duplex stainless steel variants offer increased resistance, but can cost more than exotic metals, such as titanium and Hastelloy, which do not corrode. The AirBreather's wetted parts are 95% gel-coated fiberglass and engineered plastic to entirely remove the corrosion risk. Heat exchangers are constructed with titanium, but no boiling occurs on any metal surfaces, limiting scale potential. Air Breather's intelligent controls monitor heat

exchanger performance and clean them in an automated manner before any irreversible performance degradation occurs.

Fresh Water Production: ($$ to $$$)

Technology:

- **Membranes ($):** Reverse osmosis (RO) and electrodialysis reversal (EDR) are the most widely used membrane desalination technologies. However, these methods offer limited economic fit to water with mid-range TDS concentrations (less than 40,000 mg/L). Moreover, membrane swelling may occur in both EDR and RO due to the presence of hydrocarbons and solvents. Modern membrane systems, such as Flex EDR Organix, can tolerate solvents due to a next-generation, highly cross-linked ion exchange membrane polymer that does not swell in the presence of solvents. Electrodialysis reversal (EDR) systems also offer the advantage of concentrating to higher levels than reverse osmosis (150,000 mg/L vs. 80-120,000 mg/L) and can selectively remove certain ions that can cause scaling in thermal treatment systems or in disposal wells. Membrane system total cost of ownership (capital cost + operating costs) may range from $3-$9/m^3 ($0.5-$1.5/BBL), however, pre-treatment for reverse osmosis could substantially change this cost equation.

- **Closed Evaporative Crystallizers ($):** Closed evaporative crystallizers can offer applicability across a wide range of TDS concentrations, but they are also the most expensive treatment option due their size and complexity. Closed systems condense water vapour and employ different methods to recycle a portion of the thermal energy, or heat of condensation. This lowers their energy consumption relative to open to atmosphere evaporators, however, increases their relative size requirements and cost. In the case of the SaltMaker open vs. closed models, the open model (SaltMaker AirBreather) offers six times the capacity per unit footprint, but with four times the thermal energy requirement. It is worth noting that both models can employ low-grade waste heat energy sources.

- When considering a closed evaporative crystallizer, you should also factor in: pre-treatment for scaling, concentration limits of conventional evaporators, and corrosion risk. In addition, if freshwater is produced, it must either be stored, re-used, or released to the environment. One advantage of freshwater storage and transportation over produced water storage is that it requires less containment. Although you should check your local regulations, in many cases, freshwater may be stored in ponds, industrial water bags, or tanks and transported via a lower cost lay flat hose. Freshwater may be used by a neighboring agriculture facility, or can also be discharged to the environment in some jurisdictions, however, environmental discharge permitting in the US may take up to a year and the permit is typically only valid for a single site. These added dimensions speak to why open-to-atmosphere evaporators can be a better option if air emissions are managed and thermal energy is available.

- Closed evaporative crystallizer total cost of ownership (capital cost + operating cost) may range from \$24-\$48/m^3 (\$4-\$8/BBL), making them the most expensive treatment option.

Safety Considerations

- **NORMs:** NORMs are naturally occurring radioactive materials, with radium and its many forms being the most common. Not all produced water contains NORMS, but they are occasionally encountered in North American shale. It is important to understand the major risks associated with handling water that contains NORMs since these risks can be managed. First, ingestion of radioactive material either through inhalation or swallowing is the primary hazard. Always wear gloves and wash your hands and clothes whenever working around potentially radioactive material. Never eat food near NORMs and do not bring gloves used to handle NORMs into a food zone. Gamma rays given off by NORMs are the second way they can be harmful – however, water is an effective insulator. Putting this into context, humans are exposed to more radiation on a 2-hour flight, than standing next to NORM containing produced water for an extended period.

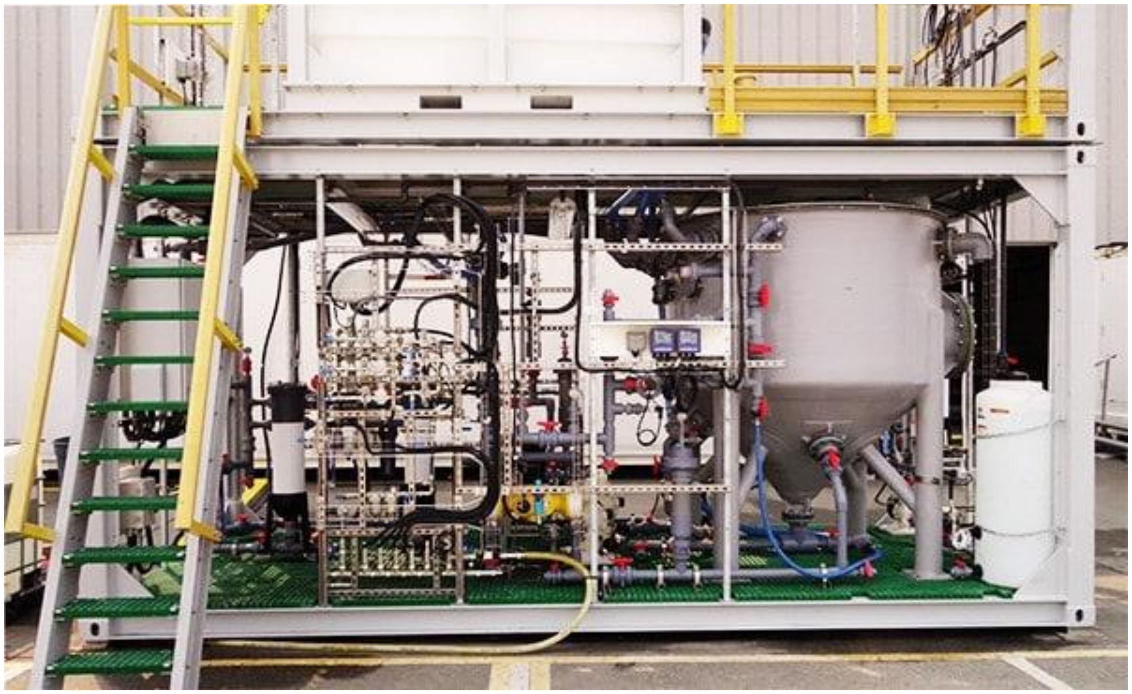
- There can be some risk if NORMs precipitate and become dried out, removing the insulating properties of water. NORMs can be precipitated alongside barium, which can be achieved by adding sulfates (sodium sulfate) or carbonates (sodium carbonate) at an elevated pH (pH > 9-10). NORMs may also precipitate as a sludge on the bottom of tanks and filter bags, and they should be checked with a radioactive test before handling, and safely disposed by a certified party. Diluting NORM sludge with water can improve safety for the reasons mentioned above, however, this will create more liquid waste. The best strategy is to measure the presence of NORMs in your water and develop a plan to manage them – either through precipitation removal and safe handling, or water disposal.

- **Chloride Dioxide Treatment and Removal:** Chloride dioxide is used in shale waters to precipitate iron, and NORMs may co-precipitate. As a benchmark, the cost of removing iron using chloride dioxide varies widely from \$3-\$50/m^3 (\$0.5-\$8/BBL), depending on the volume of water that needs to be treated. Chlorine dioxide will damage membrane treatment systems, so if it is being used upstream of a membrane system be sure to remove it. There are many options for this, including activated carbon (expensive) or sulfites addition (more common).

Logistics, Residual Reject Disposal, and Lithium

- **Logistics:** Logistics and water hauling can dominate shale water management costs if a disposal outlet is not nearby. When assessing treatment and disposal options keep an understanding of logistics cost in mind, including wait times for trucks to load and unload. As a rule of thumb, it may cost $15 per m^3 ($94 per BBL) per hour of transport once loading and unloading times are factored in. Costs also vary depending on the quality of roads in the area. It can make sense to review pre-concentration prior to transport, which lowers the volumes of the water being hauled. In many cases, there will be an economic optimum that combines re-use, storage, treatment, and transport for final reject waste disposal.

For example, if transport and disposal is $30/m^3, and volumes can be halved for $10/m^3, and solids produced afterwards for $45/m^3, then it may make the most sense to pre-concentrate and halve the volumes for $10/m^3 followed by transport and disposal for $30/m^3. The net blended cost will be $20/m^3. Preferably, the reject waste is as concentrated as possible until it reaches a cost that is just below the transport-disposal costs. It is important to note that as produced water is concentrated and its volume reduced, it can become denser with more scaling potential. Higher density waters can be beneficial for disposal wells; however, scaling waters may plug them. Technologies, such as BrineRefine, are available to reduce the scaling potential of highly concentrated brines prior to disposal, and thereby protect the disposal well asset from scaling and plugging while maintaining the beneficially high density.



- **Residual Reject Disposal:** Although relatively pure water can be separated from produced waters, reject residual waste is always left behind. This will include organics (petroleum byproducts) and inorganics (mixed salt). It is important to plan for this in advance. One advantage of disposal wells is that they dispose of all residuals, and as noted above, disposal costs and volume can be limited through treatments that pre-concentrate. However, it is also possible to: (a) produce a mixed solid waste for landfill disposal; and (b) separate out the organic phase and produce refined salts for industrial re-use. This includes a combination of chemical pretreatment and staged crystallization.

- Be sure to study and assess the lifetime of disposal options if solids are going to be produced. Landfill waste must pass landfill paint filter, leaching and radioactivity tests. Saltworks can help assess if your produced water may pass these tests through bench testing. Saltworks can also review your water's potential to produce beneficial industrial salt for re-use – although this is unlikely to offer a secondary revenue stream through salt sales. Most salts are of low value and the costs of producing, handling and transport barely offset any revenue generated. However, industrial re-use offsets costs by avoiding the need to pay for landfill disposal.
- **Lithium:** Some oil field brines contain lithium in the 60-100 mg/L range (0.006-0.01%) and there has been some emerging excitement for the potential of harvesting lithium from oil field brines. Saltworks holds patents on lithium extraction, has built machines for lithium companies, and has technology to selectively extract lithium across ion exchange membranes. Saltworks has experience in this field, combined with an understanding of the costs and revenue potential. Extremely large volumes of water must be processed to harvest a meaningful mass of lithium, often pointing to a centralized system and transportation costs to reach that system. In the authors' view, the best economics for produced water management are achieved through sound water management and treatment, rather than lithium extraction, however this option can be reviewed if rich lithium brines are collocated with centralized high volumes of produced water.

For a visual representation of our Flex EDR Selective Technology, click here.

Summary

Shale gas and oil production presents a leading energy source moving forward, yet its future and production is tightly linked to water management. Every water type, job site, and economic case is different. Contact us to review your specific situation, benefit from our expertise, and assess if your water management costs or risks can be lowered.