2027

Task 5. Preview: *This version of the task is in nearly finalized, but we are waiting on our subject-matter experts (SMEs) to confirm a few details, most particularly, the chemistry of the PW that will be used for bench-scale testing at the contest. Any changes made in the final version will be noted.*

Valorizing Strontium Recovered from Produced Water

Task proposed and developed by Chevron and NGL Water Solutions

Task Summary

You are tasked with developing a process to recover strontium (Sr) from Permian Basin Produced Water (PW). The objectives are twofold: (1) to further improve water quality and move the water one step closer to recycling PW for beneficial reuse, and (2) to convert the recovered strontium into a commercially valuable product, and 3) reduce the volume of PW constituents requiring disposal. Competitive solutions will demonstrate technical feasibility, economic viability, and the potential to increase beneficial reuse of produced water while reducing waste streams associated with oil and gas operations.

Proposed concepts may focus on the production of existing strontium compounds, the development of novel strontium-based materials, or the identification of emerging applications that support future market growth.

Problem Statement

Design an innovative process to recover strontium (Sr) from a 25,000 bbl/day stream of Permian Basin pre-treated brine concentrate and convert it into a useful, marketable product. The process must effectively separate Sr from competing constituents, particularly calcium (Ca), which is present at approximately four times the concentration of Sr and has similar ionic characteristics. Although Sr recovery is the primary objective, teams may also recover Ca and convert it into a secondary marketable product.

Your solution should be optimized to obtain the greatest market value from the recovered Sr while reducing the volume of reject brine and associated disposal costs. Teams shall consider Sr recovery, selectivity, product purity and market value, as well as the capital, energy, chemical, operating, and maintenance costs required to produce the final product.

The innovative solution shall go beyond conventional approaches to constituent recovery and may include novel applications for the recovered products and/or development of new markets. Solutions shall be logistically and economically feasible at full scale, provide a long-term offset to PW treatment and disposal costs, and include a plan for post-treatment and/or disposal of the remaining concentrate after Sr recovery.

Background

Strontium and Produced Water

Produced water (PW) from the Permian Basin contains dissolved strontium (Sr), providing a potential source of a commercially valuable material. Strontium is used primarily in compounds such as strontium carbonate and strontium nitrate for ceramic ferrite magnets, pyrotechnics and signal flares, medical products, ceramics, and other specialty applications. The United States currently has no domestic strontium-mineral production, leaving the country dependent on imported material [1].

Market analyses anticipate continued growth in Sr demand [2, 3]. Therefore, recovering Sr from Permian Basin PW could provide a domestic source of a valuable material while generating revenue to help offset the cost of treating PW for beneficial reuse.

Produced Water in the Permian Basin: An Untapped Water Source

The water itself represents another valuable resource. The western and southwestern United States are facing severe drought, while groundwater levels throughout the region have fallen to historic lows. With more than 60 million people depending on these limited water resources, identifying supplemental water sources is critical [4]. One abundant and largely underutilized source in this region is PW generated in the Permian Basin (Fig. 1).

Fig. 1. Permian basin (shaded in light grey). Within the Permian, lies the Delaware and Midland basins (both darker grey and outlined in brown. (*Photo reproduced from IEEFA* [5])

Produced water, a byproduct of oil and gas (O/G) production, is generated in large volumes throughout the Permian Basin. As oil and gas are pumped from deep underground, they are accompanied by *formation water*, which is naturally occurring saline water that has been trapped in rock formations for millions of years. After reaching the earth's surface, the oil, gas, and water are separated, and the hydrocarbons are sent for processing and sale. The remaining brine is called PW.

PW is approximately four times more saline than seawater and contains some residual oil. Depending on its basin of origin, it has its own signature of additional contaminants, including dissolved minerals, metals, naturally occurring radioactive materials (NORM), and other constituents that are drawn from the rock formations. Because of these contaminants, it has historically been treated as an industrial waste stream requiring disposal. However, that perspective has changed as the O/G industry explores opportunities for water reuse and resource recovery.

PW in the Permian Basin

The Permian Basin is the largest oil-producing region in the United States. In this region, for every barrel (bbl) of oil pumped from the ground, an average of 3 to 5 bbl of water is also brought to the surface. This is expressed as the water-to-oil (WOR) ratio. The WOR in the Permian basin reaches up to 10:1 in the Delaware Basin. In terms of water volumes produced, the Permian is producing between 22-24 million bbl per day (MMbbl/d) of PW (or 1.01 billion gallons per day (BGD); 1 bbl = 42 gallons), and volumes continue to rise [6].

These large WOR ratios are not found in all O/G basins. For reference, another prolific basin in Appalachia yields PW at only 0.33 MMbbl/d. To get a feel for the volumes of supplemental water needed in the arid southwest, the city of Albuquerque, NM, with a population of about 687,000, uses approximately 87.5 million gallons of water per day (MGD). The amount of PW retrieved from the Permian could support the water needs of 11.5 comparably sized cities every day. Hence, in an arid region that is greatly in need of water, there is PW in abundance, providing opportunities for enhancing regional water supplies and mitigating drought issues.

Saltwater Disposal Wells

Historically, the most cost-effective means of disposing of these large volumes of PW has been through injection into geologic formations via EPA Class II Saltwater Disposal Wells (SWDs). The prevailing philosophy in the early days was that this ancient water, once deeply buried, was being returned to the subsurface where it originated. In addition, the cost of injection is relatively small ($0.60 - $1.25/bbl), compared with other options that can climb up to $7/bbl.

Initially, SWD capacity appeared limitless. However, this deep saltwater injection has created widespread underground pressure problems. Although PW continues to be injected into SWDs, regulators have placed strict capacity limits on the wells. Once SWDs reach permitted capacity, they are decommissioned, and no further injection is allowed. These constraints create growing challenges for oil and gas operators tasked with safely managing increasing volumes of produced water.

The imbalance between the amount of PW produced every day and the limits on disposal is creating the beginning of an economic crisis in the O/G industry. It is estimated that PW disposal costs could increase by $6/bbl - a steep rise compared with current pricing. This increase could result in profitable wells becoming uneconomical, especially in the Delaware basin that has the highest WOR and also the strictest limits on SWD disposal of all basins in the Permian [7].

With a need to manage these large volumes of water, combined with the strict limits on SWD disposal and an interest in conserving fresh water, PW operators have begun recycling a portion of their PW for use in fracking operations, when formerly they used fresh water. Although this recycling effort adds up to $0.25 per barrel compared to using fresh water, it has significantly advanced water conservation in the industry. However, demand for fracturing water does not keep pace with the high volumes of PW generated in the Permian Basin.

Beneficial Reuse of PW

To fully utilize this precious source of water, the O/G industry is strongly supporting research in treating PW for beneficial reuse. Research groups, such as the New Mexico Produced Water Research Consortium (NMPWRC), are taking the lead in this research, but progress is slow. Environmental regulators, such as the New Mexico Environment Department (NMED), remain cautious about permitting PW reuse that might be harmful to humans or the environment. Similar organizations are working in tandem in their own U.S. states.

Initially, recycled PW will be used for non-edible agriculture, industry, habitats, or recreation. The degree of treatment will be determined by the intended purpose of the water. This is referred to as fit-for-purpose reuse. These recycling efforts will decrease the amount of PW slated for SWD disposal and preserve existing fresh water for drinking water and other higher-standard uses. Future plans that extend PW treatment for edible agricultural use and drinking water, will require more stringent treatment protocols and testing.

After environmental approval, the limiting factor for treating PW for reuse will be cost. Removing salts, organics, and other constituents requires a complex, energy-intensive treatment train. Although recent technological developments are bringing down costs, PW treatment has been ranging from $2.00-$4.00/bbl to treat PW for unrestricted beneficial use. This range is up to eight times the cost of treating surface waters for potable use (about $0.48/bbl) [6].

Table 1 compares the primary PW management approaches, including their costs, current share of PW management, and potential adverse consequences [8]. Although not always included among PW management options, enhanced evaporation is included in the table because it is being used as a temporary measure while operators await permits for treatment and beneficial reuse [9].

Table 1. Primary means of PW Management, their costs, Percentage of market, and adverse effects [8, 9].

PW Management Method	Cost/bbl	Costs include	% of available PW	Effects
Inject into geologic formations via EPA Class II Saltwater Disposal Wells (SWDs)	$0.60 - $1.25/bbl	Transport & injection.	40-50%, and declining	1) SWDs have limited capacity. 2) PW becomes unavailable for any other use.
Recycling for Fracking Operations	$0.75 - $1.50	Treatment & Delivery	50-60%, and increasing	2) Cannot keep pace with PW production.
Enhanced Evaporation [9]	$0.22 - $1.50	Transport, maintenance, & regulatory compliance.	2%	1) PW becomes unavailable for any other use. 2) Cannot keep pace with PW production.
Treating for reuse	$2 - $4/bbl (agricultural)$4 - $7/bbl (drinking)	Transport, treatment, & regulatory compliance.	<1%, emerging	PW is available for reuse. Not currently approved by NMED
Compare with treating surface waters for drinking water	$0.48			

Valorizing PW Constituents

One attractive option for offsetting PW treatment costs is to recover, process, and sell valuable materials from the water. Sometimes called *brine mining* or *valorization*, this active area of research may involve recovering elements directly or using them as feedstocks to produce marketable compounds [10].

Valorization can contribute to a circular economy by recovering useful resources rather than disposing of them through SWD injection. Recovery may also reduce reliance on conventional mining and its associated environmental impacts.

Task 3: Recovering Strontium from PW

Strontium commonly occurs in nature, averaging 0.034% of all igneous rock; only two minerals, celestite (strontium sulfate) and strontianite (strontium carbonate) are important strontium-bearing minerals, but it is also found in Permian Basin PW.

Table 2 reflects the typical constituents found in Permian Basin clean brine concentrate. The concentrate, often used for research purposes, is the effluent (often termed "reject") from a PW desalination treatment train. The resulting brine has low total suspended solids (TSS), low organic content, and high total dissolved solids (TDS; >200,000 ppm).

Table 2. Typical constituents in Permian Basin Clean Brine Concentrate.

Constituent	Feed (ppm)
TDS	252,000
TPH*	<5
Cl	144,600
Na	76,324
Ca	9,108
Sr	2,696
Mg	1,502
K	1,294
NH_3	TBD
SO_4	540

Constituent	Feed (ppm)
HCO_3	240
Li	64
Si	34
Ba	13.2
PO_4	7.4
Fe	2
Mn	0.72
Al	0.28
Zn	0.08
Pb	1

*TPH: Total Petroleum Hydrocarbons

Successful solutions to this design challenge will help offset PW treatment costs by producing a marketable strontium-based product. Recovering strontium will also reduce the quantity of dissolved material requiring disposal in SWDs—both important goals for the O/G industry.

The key constituents that will play the largest role in your team's solution are strontium (Sr) and calcium (Ca). Separating these elements presents a particular challenge because both occur in the brine primarily as divalent cations (Sr^{2+} and Ca^{2+}) and have similar ionic characteristics. Their identical charge and similar ionic size cause them to behave similarly in many separation processes, making it difficult for a treatment method to selectively capture Sr^{2+} while leaving Ca^{2+} in solution.

This challenge is compounded by the brine chemistry: Ca in the Permian is approximately four times the concentration of Sr, creating substantial competition for processes intended to selectively recover Sr. As such, your team may also consider recovering Ca in a saleable form, but this is secondary to Sr recovery.

Other key considerations and challenges are listed below.

Competing ions and ionic strength. At >200,000 ppm TDS, the brine is extremely saline, and coexisting ions can interfere with Sr recovery or alter equilibrium behavior. High concentrations of Ca^{2+} are especially problematic, but Mg^{2+}, Ba^{2+}, Na^{+}, and other ions may also compete depending on the separation mechanism.

Selectivity versus recovery. Teams should distinguish between recovering a high percentage of Sr and producing a high-purity Sr product. A process may remove substantial Sr but still co-recover too much

Ca or other material to create a marketable product. Recent Sr-recovery studies explicitly use sequential impurity removal to improve product purity.

Scaling and unintended precipitation. Sulfate- and carbonate-based chemistries can precipitate Sr, but they may also precipitate Ca, Ba, or mixed solids. That creates challenges related to selectivity, fouling, solids handling, and downstream processing.

pH and reagent dosage. Precipitation and adsorption behavior can be highly sensitive to pH, alkalinity, and reagent concentration. Teams should consider not only whether a process works, but the operating window needed to make it selective.

Product form and marketability. Require teams to identify the intended Sr-containing product—elemental Sr, $SrCO_3$, $SrSO_4$, another compound, etc.—and establish purity specifications or a plausible end use. Valorization only helps the economics if the recovered material can actually be sold or reused.

Residuals and secondary waste. A process that recovers Sr but generates large quantities of Ca-rich sludge, spent adsorbent, or chemical waste may simply shift the disposal problem elsewhere.

Water recovery and compatibility with the larger treatment train. Because this is a desalination reject stream, students should consider whether Sr recovery improves or interferes with subsequent brine management or beneficial-reuse treatment.

Regeneration and reagent reuse. If applicable, media regeneration, loss of capacity over repeated cycles, and management of the regenerant should be evaluated.

Energy and chemical intensity. A technically successful separation may not be economically feasible if it requires excessive heating, pressure, reagents, or multiple treatment stages.

Scalability and throughput. Bench-scale selectivity is not enough. Teams should estimate residence time, flow rate, media quantity, reactor size, and solids-handling requirements at full scale.

Maximizing Value of the Treated PW Concentrate Stream

Consider the full economics of the problem by determining the best balance between three issues:

1) recovering high-purity Sr from the brine to make a useful product;

2) identifying an existing market or proposing a new market for the product that will generate reliable revenue;

3) considering transportation costs from the oilfield to the processing facility, to distribution of the final product;

4) reducing the volume of liquids and solids to be disposed of after you have recovered valuable constituents.

Teams should also factor into their analysis the possibility that their process may be more cost effective when scaled to higher production volumes than specified in this task. If this is the case, cost-recovery calculations for processing up to 150K bbl/day of concentrate may be included in the technical report.

Treating and Disposing of Produced Water
For PW, "treatment" usually refers to desalination. Pre-treatment and post-treatment refer to removing oils, VOCs, suspended solids, etc. Every PW application has its own unique treatment train (pretreatment, treatment, and post-treatment) requirements.

To gauge the success of your product in reducing waste streams, consider that, based on the salinities in the Permian Basin, current treatments require approximately 50,000 bbl of PW to produce 25,000 bbl of desalinated water, leaving 25,000 bbl of concentrated brine as the residual effluent stream. Your team will be removing constituents from this residual stream, but will not be expected to treat produced water for reuse.

After removing the constituents needed to produce your product, your team will be left with your own residual stream that, in your full-scale operation, you should plan to inject into an SWD. These residuals should be in liquid form because the disposal of solid waste from PW is difficult and expensive. Further, to minimize down-hole pressures, regulations limit TDS to 250,000 ppm for SWD injection. Teams are cautioned to ensure that any chemicals they may add while producing their valuable product will not elevate the TDS levels of their residual effluent.

Consider the cost of SWD injection to be $1.00/bbl (conversely, reducing disposal volumes will save $1.00/bbl). Assume that the processing facility will be sufficiently close to an SWD site that there will be no transportation costs related to delivering remaining brine to an SWD.

See the Appendix for additional PW-related terms (p. 6).

Design Considerations

Your proposed design should provide specific details and outcomes as follows.

- Base your analysis on a 50,000 bbl/day treatment facility having a 25,000 bbl/day reject concentrate stream.
- Produce a usable and marketable product from Sr recovered from the provided concentrated brine. Prioritize a product that will optimize a long-term, stable income from the sale of the product while minimizing the costs associated with disposal of the remaining concentrate.
- Include a Process Flow Diagram (PFD) for the selected treatment process. The PFD must include mass and energy balances (input and output streams, reactants, reaction rates, etc.). Take extra care to ensure that all processes and waste streams are included. This is a major element of judging (see Team Manual for PFD examples).
- Propose a plan for waste-stream management after product generation. If post-treatment prior to injection into an SWD is needed to ensure safety and/or regulatory compliance, include this in your PFD and process analyses as theoretical considerations. A bench-scale demonstration of waste stream post-treatment is not required.
- Ensure that the TDS of your residual (waste) stream will be no higher than 250,000 ppm to comply with SWD injection regulations.
- Assume that constituent recovery and disposal of any remaining brine will be accomplished within the PW treatment facility, thus eliminating the need for considering transportation logistics or costs on either end of your process.
- Present a Techno-Economic Assessment and Analysis (TEA) to construct a full-scale process to produce a usable product that will scale with an influent rate of 25,000 bbl/day of brine concentrate. This will include your estimate of costs for a full-scale solution. Include appropriate graphical representation of your cost data.
  - All costs must be demonstrated, including the cost of managing and disposing of the residual streams, staffing, and any post-treatment needed after product generation.
  - CAPEX (Capital costs) typically include, but are not limited to, equipment, pipes, pumps, etc. Do not include costs of buildings and appurtenances to the treatment process.

  - OPEX (Operating costs) should be calculated as cost to produce your product on an annual basis, based on a rate of 25,000 bbl/day of influent brine concentrate. Include these costs:
    - Materials needed, including consumables (chemicals, sacrificial components, etc.)
    - Professional labor rate ($150/hr); Staff labor rate ($70/hour); solids disposal costs ($50/ton); energy requirements (cost/bbl and Kwh/bbl): use an electricity rate of $0.10/kWh and research an industrial natural gas rate and state in $/MM BTU.
    - Additional operating costs that your team identifies.
    - If higher production rates (up to 150,000 bbl/day) would improve earnings from constituent recovery, include this analysis in your TEA, along with 25,000 bbl/day estimates).
  - Address the cost offset for treating PW that will result from the sale of your recovered constituent. Compare this with the current cost of $1-3/bbl for treating PW and the disposal rate of $1.00/bbl for SWD injection.
  - Visualization tools: Sensitivity analyses, etc.
  - Teams are advised to create a multi-disciplinary team by inviting a business major to help draw up economic plans for full-scale implementation of your designs.
- Include a public involvement plan that addresses public perception and potential public contributions in utilizing PW in your chosen product and its application (see Team Manual).
- Address any intangible or indirect benefits of the selected treatment process, such as improving the environmental impact of mining and/or producing your selected product.
- Address safety aspects of handling the raw clean brine concentrate, residual streams, and final products. Safety issues for the full-scale design should be addressed in the written report. Safety issues for the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).

Bench Scale Demonstration

The bench-scale unit should demonstrate a process that will produce a useful, marketable Sr-based product *from pre-treated brine concentrate* obtained from the Permian Basin. The bench-scale design should be scalable to a plant that produces 25,000 bbl/day of concentrated brine.

Note: WERC is currently seeking a source for the clean brine concentrate from a PW Operator. If this is not possible, we will provide a recipe for a synthetic solution that mimics the clean brine concentrate.

The chemistry of the brine will be similar to that shown in Table 2. In January 2027, the NMPWRC will report constituent values for the brine to be used at the contest. Teams should consider the corrosive nature of the clean brine concentrate and ensure that materials used in the bench-scale apparatus will maintain their integrity when exposed to fluids of chemistry shown in Table 2.

At the contest, each team will be provided with up to 18 liters (5-gallon container) of clean brine concentrate to work with during the bench-scale demonstration. You are not required to use the entire amount of the solution during the demonstration. Teams requiring less PW concentrate should indicate this in their ESP by March 1, 2027.

After treatment, your team shall submit 125-mL samples for analysis: one sample of influent (brine concentrate), two samples of your waste stream, and additional samples of your final product, as warranted by your ESP. Collection of samples will be witnessed by a WERC staff member.

PW EHS Protocols
Untreated PW is considered a hazardous material, but it is not a hazardous waste. It can be toxic and/or corrosive. Teams should consult their institution's Environmental Health and Safety (EHS) protocols for handling and disposing of the brine concentrate. At the contest, teams will follow all handling and disposal protocols outlined by the NMPWRC and the New Mexico Environment Department (NMED).

Teams will bring to the contest
Teams will bring a functioning apparatus that will fulfill the requirements of the task, with all piping properly tethered. All experimental conditions and equipment must be documented in the ESP for review.

WERC will provide at the contest
At the contest, each team will be provided with:

1) a kiddie wading pool and/or tarps as secondary containment in case of spills,
2) Up to 18 liters of concentrated brine to work with during the bench-scale demonstration, and
3) 125-mL sample bottles for influent, waste stream, and product collection.

Contest Analytical Testing Techniques
At the contest, each team's bench-scale demonstration will be analyzed by:

- Composition and/or functionality of the product produced, as determined by the team's ESP.
- Waste stream reduction (volume)
- TDS of the team's reject brine (to be less than 250,000 ppm)
- Additional analyses may be warranted by the team's ESP and may include pH, turbidity, TSS, etc.

Deliverables (See *Team Manual*)
Each team must submit (*see Dates and Deadlines, next page*):

- 30% Project Review
- ESP and required short course
- Technical Report—System design, data analysis, bench-scale results, full-scale plans, and 3 independent audits.
- Equipment Transport Form (if shipping equipment to Las Cruces)
- Flash Pitch—The audience for the Task 2 Pitch is El Paso Electric Company as potential investors. (Other Tasks may be assigned to pitch to community leaders or funding agencies.)
- Oral Presentation—Slides and presentation summarizing the design and key findings
- Poster Presentation—Visual summary of the design and results; presentation at the poster.
- Bench-Scale Demonstration—Working model, tested onsite; presentation benchside.

Evaluation Criteria
Each year, the WERC Environmental Design Contest and its sponsors award more than $35,000 in cash prizes. Awards include task-specific prizes and overall contest awards.

Read the *2027 Team Manual*, as a team, for a comprehensive understanding of the contest evaluation criteria: https://werc.nmsu.edu/team-info/guidelines.html

Judges' evaluation of your entry will include consideration of the following points specific to this task.

- Quality and completeness of the process flow diagram.
- Quantitative confirmation of strontium recovery, including recovery efficiency, selectivity, and purity of the recovered product.

- Quality, marketability, and demonstrated value of the strontium-based product and, if applicable, a secondary calcium-based product.
- Bench-scale demonstration that effectively demonstrates the proposed recovery and separation technology.
- Potential for full-scale implementation, including process effectiveness, reliability, scalability, operational complexity, and integration with PW treatment.
- Efficient use of energy, chemicals, water, and other consumable materials.
- Effective management of the remaining brine, residuals, and other waste streams.
- Cost effectiveness of the proposed solution, including its potential to offset PW treatment and disposal costs through product recovery and reduced waste volume.

Dates, Deadlines, FAQs (*dates subject to change—watch website FAQs*)

Today	Email us to reserve a spot for your team and join the email list for this task. Registration is limited to the first 34 teams.
Weekly	Check FAQs weekly for updates: Task-specific FAQs: [2027 Tasks/Task FAQs] General FAQs: [WERC General FAQs]
Nov. 1 – Dec. 31, 2026	Early Bird Registration (discount applies)
Dec. 31, 2026	30% Project Review Due
Dec. 1, 2026 – March 1, 2027	Mandatory on-demand Course: *Preparing the Experimental Safety Plan*. See WERC's website and Team Manual for information.
February 15, 2027	Final date to register a team.
March 1 – 5, 2027	Email ESP to Juanita Miller (miljgh@nmsu.edu). Include requests for chemicals, materials, etc.
March 22, 2027	Submit Equipment Transport form (if shipping items to Las Cruces)
March 26, 2027	Technical Report due
March 29, 2027	Submit Flash Pitch Slides and Summary
April 4 – 7, 2027	Contest in Las Cruces

Contacts:

ESP and Safety Officer: Juanita Miller, miljgh@nmsu.edu

Program Manager: Ginger Scarbrough, gscarbro@nmsu.edu (for non-ESP questions)

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Appendix: Produced Water Terms

Brine used at the contest - Pretreated produced water concentrate resulting from a desalination treatment process. It will have low TSS, low organics, and high TDS (>200,000 ppm).

Brine – any solution with a concentration of over 35,000 ppm TDS (USGS definition).
PW and PW concentrates are usually brines.

Clean Brine – A clean brine is a high-salt concentration PW with oils, greases, suspended solids, iron, and bacteria removed. It has been pH adjusted. It has NOT been desalinated. The term "clean brine" must be associated with produced water. (Produced Water Society definition)

Distillate - desalinated water or desalinated brine, using a thermal process.

Permeate - desalinated water from an RO process

Desalination concentrate - the highly saline reject concentrate that comes out of a desalination (RO or distillation) process.