Task 5. Request for Proposals: 2024

Treatment of Water Recovered from Salt Water Disposal Wells for Hydrogen Production

Task proposed and sponsored by NGL Water Solutions

Task developed by NGL Water Solutions, NM Produced Water Research Consortium, and AWC Engineering, LLC

Task Summary

Teams are asked to explore an opportunity to treat water for hydrogen production. An innovative element of the task is to take advantage of the stored energy in deep salt water disposal wells (elevated temperatures and pressures) to reduce treatment costs. Salt water disposal wells have been used historically to dispose of by-products from oil and gas production operations.

Background

Energy storage has become an important issue as the world moves toward net-zero carbon emissions. Hydrogen is attractive for energy storage because it provides high energy density without releasing greenhouse gasses [1]. The Western Interstate Hydrogen Hub Coalition (WISHH) was established to support hydrogen production in the United States, and New Mexico joined WISHH in March 2022 when the governor of New Mexico signed an executive order directing state agencies to support the Coalition [2]. New Mexico's academic institutions and national laboratories are working toward this goal through the Northern Rio Grande Corridor Collaborative [3].

The greatest challenge for hydrogen production in the arid western US is sourcing water. However, one source of water is plentiful–produced water from oil and gas operations–with approximately 15 million barrels (bbl) of water being processed per day in the Permian Basin [4]. Though a potential source of water, the primary challenge is that it is a brine that is expensive to treat. This task proposes a way to overcome this obstacle.

Hydrogen as Energy Storage

Although it is the most abundant element on Earth, hydrogen is not found in nature as an isolated element; it is always bound to other compounds such as water and hydrocarbons. To be utilized for energy storage, hydrogen needs to be isolated. Once isolated, it can be stored long-term in a variety of forms until the energy is needed. To retrieve the stored energy, hydrogen is placed in contact with oxygen, causing a chemical reaction that releases energy and water but no greenhouse gases. The released energy can be used to power large transport vehicles, power plants, etc. (Figure 1).

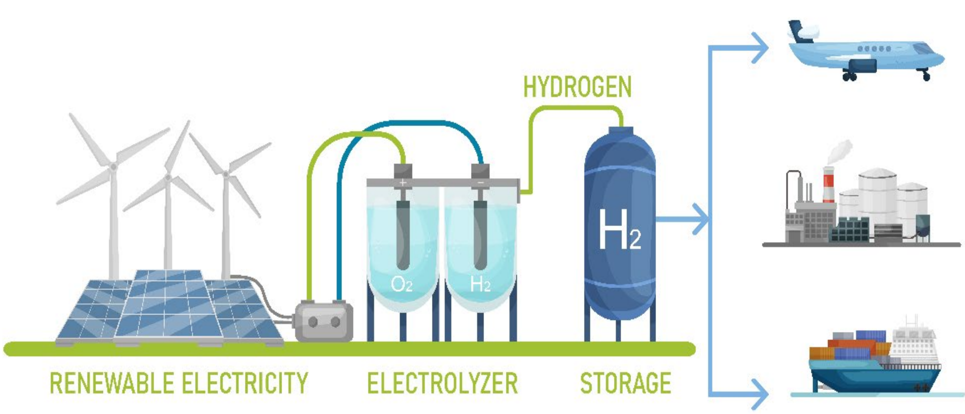

Figure 1. Green hydrogen production: solar or wind power provides the energy needed to isolate hydrogen (H_2) through electrolysis. The H_2 can be stored and later used to power transportation or industrial facilities.

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Hydrogen's ability to be stored and used later without releasing greenhouse gases makes it attractive as a clean energy source. The current primary source of hydrogen for this purpose is hydrocarbons, mostly from natural gas, but water is being widely proposed as an alternate source of hydrogen to store renewable energy from alternative sources such as wind and solar.

Hydrogen is isolated through "hydrogen production." Currently, 95% of all hydrogen production is from steam reforming of natural gas. This process emits a small amount of CO_2. When coupled with CO_2 capture and storage, steam reforming is termed "blue hydrogen production" to emphasize the containment of greenhouse gas emissions. "Green hydrogen" uses electrolysis to isolate hydrogen from water. It is called green hydrogen because the energy needed to break down water molecules would come from renewable "green" energy sources. Several breakthroughs are required before electrolysis can be a viable source of hydrogen, but it is attractive as a way to store energy from renewable sources that are inherently intermittent and unpredictable. [5, 6].

Treating Water for Hydrogen Production

To produce either blue or green hydrogen, two essential things are needed: large amounts of pure water and energy to break the strong hydrogen bonds. This task focuses on the first requirement–providing large volumes of pure water. The standard of purity chosen herein is that of deionized (DI) water (Table 1) to address strictest standards of green hydrogen production.

Stoichiometrically, green hydrogen production requires 9 liters (L) of water for every kilogram (kg) of hydrogen (H_2) produced, but in practice, most commercial electrolyzing units report requiring 10-11 L water per kg of H_2 produced. Steam methane reforming stoichiometrically requires 4.5 L of water per kg of H_2 produced, but companies report needing 5.85 L water/kg H_2 produced, and some additionally require up to 7.35 L of water for "excess steam production," resulting in a potential need of up to 13.2 L of water per kg of H_2 produced. [7]

For context, based on the assumptions that one kg of hydrogen provides about 33 kWh of usable energy, and that the stoichiometric amount of water is needed for electrolysis, 20,000 bbl of deionized (DI) water is required (and in practice, up to 25,500 bbl) to provide enough hydrogen to produce power at the same rate as a 500 MW power plant. Similarly, steam reforming theoretically requires 10,000 bbl of water (and in practice up to 29,300 bbl) to produce power at that rate.

Such large volumes of water must be treated before they can meet DI quality. This task asks teams to treat produced water from oil and gas operations to DI-quality water with the goal of treating the highest volume of water at the lowest price.

Using Produced Water in New Mexico for Hydrogen Production

One water supply that New Mexico has in abundance is produced water (PW) from oil and gas operations. Over 15 million bbl per day of PW were produced across the Permian Basin in the first half of 2022, and this trend continues. [4]

PW is a byproduct of oil and gas production. When oil is pumped from the ground, every barrel comes to the surface mixed with several barrels of saline water that was trapped millions of years ago in the rock formations. The oil and water are separated, the oil then goes to market, and the remaining water (a brine) is termed "produced water." The PW is considered wastewater, having a salinity approximately four times that of ocean water. It also contains small amounts of residual oil and may contain various additional components that could potentially be recovered for beneficial use.

Because treatment of PW water for beneficial use is currently too expensive to be economically feasible, it is either pumped into geologic formations via EPA Class II saltwater disposal wells (SWDs), or it is recycled for fracking activities. To distinguish between the two sources of water related to oil and gas operations discussed in this task, this document will use "PW" as described above (primary saline water after oil/water separation) and will use "brine" to describe the saline water after it has been injected into SWDs.

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An innovative alternative to considering PW as waste would be to extract the brine from SWDs and treat it for beneficial use. Because extraction would be more costly than simply using PW directly, this requires that the selected SWDs provide advantages over treating primary PW. Across the Permian Basin, SWDs vary in depth from 1000 to 18,000+ feet. The deepest SWDs, due to their higher water temperatures and pressures, may provide a source of energy for water treatment that can increase the economic viability of treating PW for beneficial use.

Well Siting and Unique Conditions in Deep SWDs

The area of interest is at the northern edge of the Delaware Basin, within the Permian Basin, in the southeast corner of New Mexico (see Figure 2) where injection activity in some SWDs has been shut down due to regulatory requirements [8]. These shut wells are currently inactive, and due to their existing infrastructure, they are good candidates for saltwater extraction.

Focusing on the deeper (~18,000 ft) shut SWDs affords potential advantages: 1) wells at this depth have high bottom-hole water temperatures (280°F) and could provide a source of heat for water treatment, 2) elevated water pressures in these wells could facilitate economically feasible water treatment volumes and processes, and 3) existing wells and infrastructure provide low-cost access to these deep brines.

The elevated temperatures mentioned above are due to Earth's geothermal gradient, and elevated fluid pressures are due to the wells' depth, injection siting within confining rock layers, and historical injection volumes. The ability to sustain these elevated temperatures and pressures over long-term extraction of brines from the SWDs should be taken into account, but that is beyond the scope of this task. Teams may assume that the stated temperatures and pressures can be sustained indefinitely through PW injection in adjacent wells.

Your team is challenged to design economical treatment processes that can harness the energy provided by these deep SWDs to improve the feasibility of treating PW for beneficial use—in this case, hydrogen production. Teams may consider all possibilities for utilizing the brines from deep SWDs. These may include: 1) treating the extracted brines directly while making use of the energy they carry (elevated T and P) and/or 2) harnessing the energy carried by the brines and applying this to treating primary PW, or some combination of 1) and 2). All approaches should take into account the fate of any remaining brine or waste products.

Although your team may explore OCD data to select a suitable SWD disposal well, you may assume that the well of interest is 18,000 feet deep and that the wellbore and wellhead are in place and ready to provide water at 280°F, an initial pressure of 2,000 psi, and a throughput of 1000 gal/minute when the wellhead is first opened.

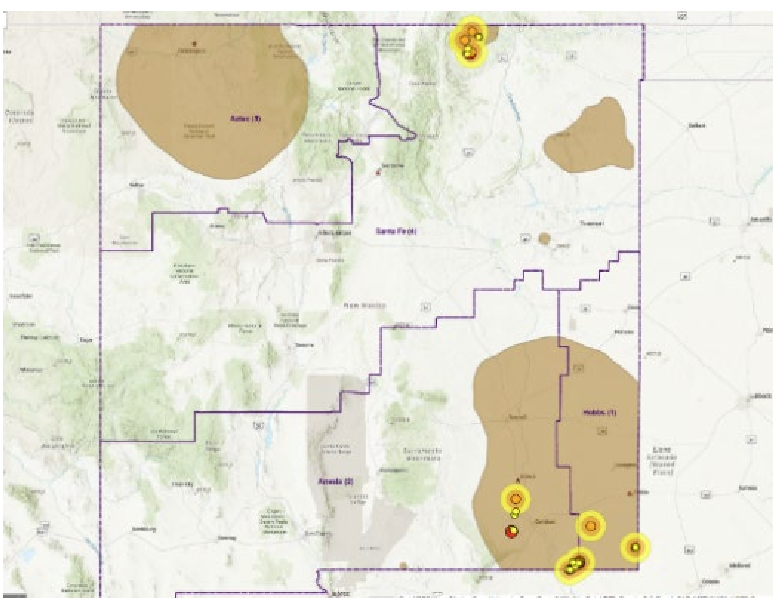

Figure 2. Map of NM Class II disposal wells. The large tan area in the SE (bottom right) corner outlines the northern edge of the Delaware basin. Wells indicated by yellow, orange, and red circles in the SE of the map are likely candidates for this project. (From the interactive New Mexico OCD Oil and Gas Map. [9])

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Enhanced PW Treatment for Hydrogen Production

Teams are asked to treat PW/brine to DI quality. This requires desalination and removing other constituents such as suspended and dissolved solids and organic carbon. Desalination is an expensive part of PW treatment because the process requires adding heat and/or pressure, which increases the cost of energy, capital equipment, and operating inputs. Additional treatment, such as removing oils, will add to these costs. However, tapping into existing hot, pressurized water could result in significant savings and may bring the cost of treating PW down sufficiently so as to be competitive with the cost of treating other water sources that have lower salinities, such as groundwater or surface waters.

Although the task parameters specify the condition of the brine to be 280ºF and 2000 psi, at the bench-scale demonstration, due to safety restrictions (see "Bench Scale Demonstration" below), teams must limit their bench-scale apparatus to operating at atmospheric pressures and the boiling point of the brine in Las Cruces, New Mexico (3900 feet elevation). Therefore, in the technical report, teams shall report a theoretical energy budget that addresses how energy is captured at the wellhead and utilized to treat the PW/brine; this shall be supported with a process flow diagram and pertinent calculations and may also be supported by credible references and/or analogies from a model based on the team's assumptions.

Although your team's treatment technology may improve upon this efficiency rate, based on the salinities in the Permian Basin, current treatments require approximately 40,000 bbl of PW to produce 20,000 bbl of DI-quality water. The remaining water is injected into SWDs as a concentrate. Address your team's predicted treatment efficiency in your technical report.

Produced Water as a Resource

In arid climates where water is scarce, it is important to evaluate how each water source can best support the environment. In particular, is PW better used for hydrogen production, or should it be reserved for other applications such as drinking water or agriculture? Four issues that indicate that PW may be better applied to hydrogen production are: 1) other water sources have lower risk profiles than PW for drinking or agriculture, 2) other water sources are easier and more economical to treat for drinking or agriculture, 3) PW is plentiful and its use will decrease the need for disposal, and 4) the demand for high-quality water in the hydrogen production industry may overcome the extra costs required for PW treatment.

General Notes on Treating Produced Water and answering the RFP

When treating PW, "treatment" usually refers to desalination. Pretreatment and posttreatment refer to removing oils, VOCs, suspended solids, etc. Every PW application has its own unique treatment train (pretreatment, treatment, and posttreatment) requirements. When designing the treatment train for this task, consider the need to capture energy for desalination. Consider, also, the order of treatments that would best capture the energy. Note that 1) ultra-hot water cannot be used in RO systems, 2) thermal processes tend to have lower pretreatment requirements, and 3) even after boiling, there may be carry over of salts or oils in the steam.

When answering this and any RFP, consider opportunities to add value to the client. In this case, what potential benefits and/or additional resources are possible as a result of extracting brines from shut SWDs, and how can these bring new revenue streams and/or reduce costs of disposal, transport, treatment, etc., for the PW industry?

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Problem statement

Design a treatment train to accept water from a Class II SWD in the Permian Basin that can, as inexpensively as possible, treat this brine to meet hydrogen production influent standards of DI-quality water.

Assume that, when it reaches ground level, the surface the water will be 280° F and 2000 psi, based on a well that is 18,000 ft deep. Assume the throughput at the well head at full scale is 1000 gal/minute.

Design requirements

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

- Develop a treatment process that is designed to operate at starting temperatures and pressures of 280° F and 2000 psi, respectively. Support your assumptions as appropriate.
- Tailor the bench-scale demonstration to safely work at atmospheric pressure and boiling temperature of brine at the elevation of Las Cruces, New Mexico.
- Include a Process Flow Diagram (PFD) for the selected treatment process(es). The PFD must include mass and energy balances (input and output rates, waste streams, reactants, reaction rates, etc.).
- Base your analysis on a treatment facility that will yield a minimum of 20,000 bbl/day water that meets the standards shown in Table 1. Report the predicted treatment efficiency.
- Include an analysis of the energy savings and cost savings from capturing the energy from the elevated temperatures and pressures from the deep disposal wells as compared with costs of conventional PW treatments for DI-quality water.
- Address benefits and/or potential new revenue streams that may result from extracting brines from deep SWDs.
- Present a Techno-Economic Analysis (a.k.a. Techno-Economic Assessment) to construct a full-scale water treatment process to produce 20,000 bbl/day of DI-quality water. This will include your estimate of capital costs (CAPEX) and operational costs (OPEX) for a full-scale solution and appropriate graphical representation of your cost data.
    - Demonstrate all costs including all waste stream disposal. Although only one step in the treatment, consider that the current cost for traditional desalination is approximately $1.00/bbl.
    - Operating expenses (OPEX) should be calculated as cost/bbl of DI water produced on an annual basis. This include, but is not limited to, materials needed, including consumables (chemicals, sacrificial components, etc.). In addition to other operating costs that your team identifies, include these operating costs, as applicable: staff labor rate of $70/hour; solids disposal costs ($50/ton); energy requirements (cost/bbl and Kwh/bbl): research an industrial natural gas rate and state in $/MM BTU; use an electricity rate of $0.09/kWh.
    - Visualization tools: Sensitivity analyses, etc.
- Identify and address the fate of any waste products generated by the treatment technology.
- Include a public involvement plan that addresses public perception and contribution in utilizing PW and/or SWD brines for hydrogen production (see Team Manual).
- Document success in improving energy efficiency, pollution prevention, and/or waste minimization, as it applies to your project, to qualify for the P2 Award. Place this in a separate section of the report.
- Address any intangible benefits of the selected treatment process.
- Address safety aspects of handling the raw produced water, volatiles, and any final products. Safety issues for both the full-scale design and the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP)

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Bench Scale Demonstration

Bench-scale demonstrations will serve to illustrate the design considerations listed above.

The bench-scale unit should demonstrate a process that can be scaled up to produce 20,000 bbl/day of DI water assuming a 1000 gal/minute throughput of produced water at the wellhead. It will include a synthetic solution of produced water of chemistry given in Table A (See Appendix). The constituents of the synthetic solution are typical for a sample of produced water from the Delaware Shale play.

For safety at the contest, teams will operate their bench-scale apparatus at approximately atmospheric pressure and the boiling point of the synthetic solution (see Table A). When preparing to run the bench-scale demonstration in Las Cruces, New Mexico, consider the elevation of 3900 feet, and adjust your predicted boiling point as needed. To reflect the energy captured at the wellhead, teams will report the calculated energy budget available for treatment, including processes that will result in lowering the temperature and pressure from 280ºF and 2000 psi to surface pressure and boiling temperature.

After treatment, your team shall submit four 100-mL samples for water-quality analysis, based on Table 1.

Teams will bring to the contest

Teams will be expected to provide their own apparatus that can maintain boiling temperatures with a capacity of no more than 4 liters. Teams wanting to use a larger apparatus should submit this request in their ESP. All exposed piping will be protected from incidental contact and secured or tethered to prevent hot fluid burns if disconnection occurs. 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 four 100-mL sample bottles for effluent collection and a minimum of 5 liters of synthetic solution to work with during the bench-scale demonstration. Teams needing more than 5 liters of synthetic solution should submit this request in their ESP. A kiddie wading pool and tarps will be provided as secondary containment in case of spills.

Contest Analytical Testing Techniques

At the contest, water quality will be analyzed as indicated below according to the standards listed in Table 1.

- ***Conductivity*** — Electroconductivity meter
- ***Turbidity***—Light transmittance probe measuring NTU (nephelometric turbidity units).
- ***Total Organic Carbon–*** Shimadzu TOC-VCPH instrument

Table 1. Final goal for DI-quality water that will be ready for hydrogen production.
The bench-scale effluent will be tested for these parameters.

Conductivity	**Turbidity**	**TOC**
< 0.1 micro siemens/cm	< 5ppm	< 10 ppb (0.01 mg/L)

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

- Today: Email us to let us know you are interested in this task to get on our Task 5 emailing list. We will contact you with any breaking news, FAQs posted, etc.
- October 15, 2023 - December 31, 2023: Early Bird Registration (discount applies).
- October 15, 2023 – February 1, 2024: After team registers, submit requests for synthetic solution components, if needed.
- December 1, 2023 – March 31, 2024: Optional On-demand Course: WERC Safety and Environmental Topics. See Team Manual for more information.
- December 1, 2023 - February 20, 2024: Mandatory On-demand Course: Preparing the Experimental Safety Plan (ESP). Attend at least one week prior to submitting the ESP. See website and Team Manual for ESP information.
- February 15-March 1, 2024: Submit requests for water and/or ancillary equipment to werc@nmsu.edu
- February 15 - 24, 2024: ESP due.
- March 1, 2024: 30% Project Review due.
- March 8, 2024: Final date to register a team.
- March 31, 2024: Technical Report due
- Weekly: Check FAQs weekly for updates:
  - Task-specific FAQs: 2024 Tasks/Task FAQs
  - General FAQs: 2024 General FAQs
- All dates or task requirements are subject to change. Check FAQs for updates online.

References

[1] Sonal Singh, et al. Hydrogen: A sustainable fuel for future of the transport sector. Renewable and Sustainable Energy Reviews. Vol. 15, pp. 623-633. November 2015.

[2] Memorandum of Understanding. February 2022. Western Interstate Hydrogen Hub Coalition (WISHH).

[3] Northern Rio Grande Corridor Collaborative (website accessed 7/13/2023).

[4] Produced Water Report: Regulations and Practices Updates. Groundwater Protection Council. May 2023. 2023-Produced-Water-Report-Update-FINAL-REPORT.pdf (gwpc.org)

[5] Hydrogen Fuel Basics. US Dept. of Energy, Hydrogen and Fuel Cell Technologies Office. Hydrogen Fuel Basics | Department of Energy.

[6] Hydrogen Production: Electrolysis. US Dept. of Energy, Hydrogen and Fuel Cell Technologies Office. https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis.

[7] Saulnier, R., K. Minnich, and K. Sturgess. Water for the Hydrogen Economy. WaterSmart! Water Management Solutions. November 2020. Water-for-the-Hydrogen-Economy_WaterSMART-Whitepaper_November-2020.pdf (watersmartsolutions.ca)

[8] Immediate Response Plan for Seismic Events Related to Class II Underground Injection Control Wells. State of New Mexico Energy, Minerals, and Natural Resources Department, November 2021. 11-23-21-NOTICE-Induced-Seismicity-Immediate-Response-Plan.pdf (nm.gov)

[9] New Mexico Oil Conservation Division Oil and Gas Map. https://nm-emnrd.maps.arcgis.com/apps/webappviewer/index.html?id=4d017f2306164de29fd2fb9f8f35ca75

Appendix. Preparing the Synthetic Solution

Sample Preparation

To prepare samples for preliminary testing at your campus, follow these steps to make 1 liter of synthetic produced water using the chemistry from Table 2, below.

1. Use a wide-mouth, semi-transparent polyethylene or polypropylene container.
2. Mix together water phase.
3. Mix together oil phase.
4. Add solids to oil phase.
5. Add oil phase to water phase and gently mix.
6. Top off with DI water to make 1.0 L.
7. Just before use, use a homogenizer/mixer* to generate small droplets of the oil phase.

*Use a high-speed drill connected to a paint-mixing paddle; blend on highest speed for 5 minutes.

Note: Although disinfection is usually an essential pre-treatment step, it will be disregarded for the contest.

Table A. The bench-scale apparatus shall treat water of the following chemistry[2]

Water phase	Amount per liter of synthetic solution
DI water	750 mL
Sea Salt*	120 g
Oil phase	**Amount per liter of synthetic solution**
TrueSyn 200 I**, ****	92 mg
Solid phase	**Amount per liter of synthetic solution**
Fine-grade Arizona Test Dust (Medium Grade)***, ****	50 mg
Sodium Bentonite Drilling Clay (AquaGel by Baroid Industrial Drilling)****	50 mg

**At the contest, WERC will source the sea salt from a local store (Sprouts store brand). It dissolves fairly easily.*

***Sourcing Option: RB Products will ship to you and* charge for shipping only. Contact micah@rbproductsinc.com

****Sourcing Option: Powder Technologies Inc. offers 4 kg for $80. Contact: levi@powdertechnologyinc.com*

***** Contact WERC–we will gladly ship these items to you. They ordinarily come in industrial quantities.*