Optimizing West Texas

Wind & Solar Energy Generation

Using

Closed-Loop Pumped Storage Hydropower

SwRI Southwest Research Institute

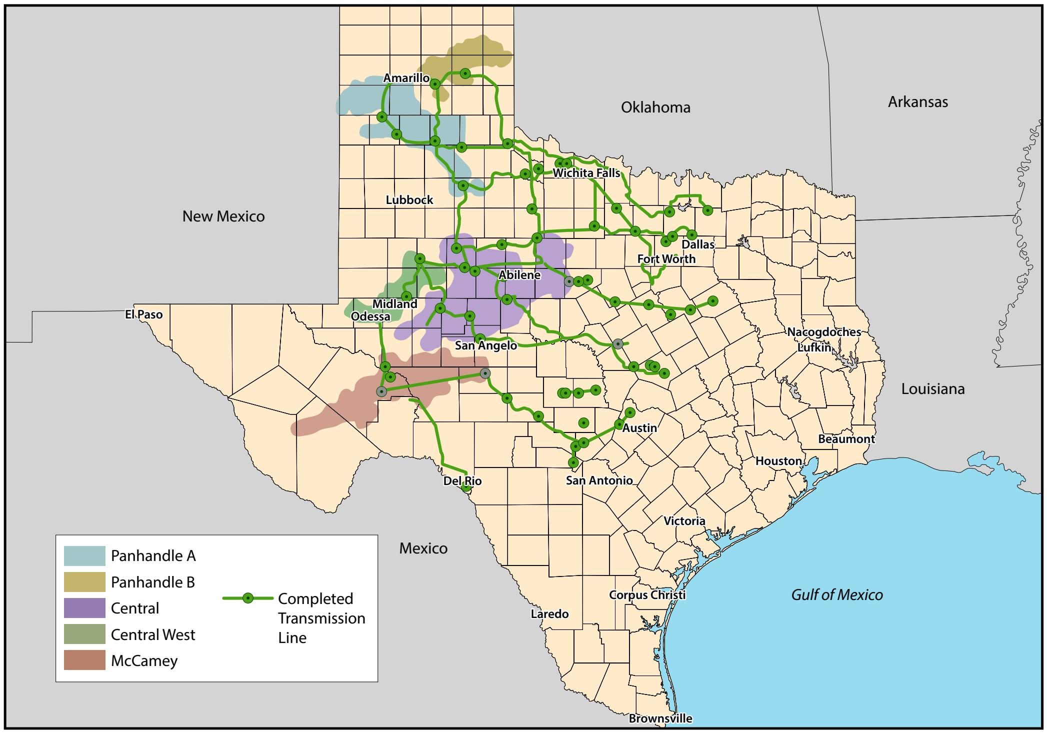


Figure 1. Map of Competitive Renewable Energy Zones (CREZ) in Texas and transmission lines

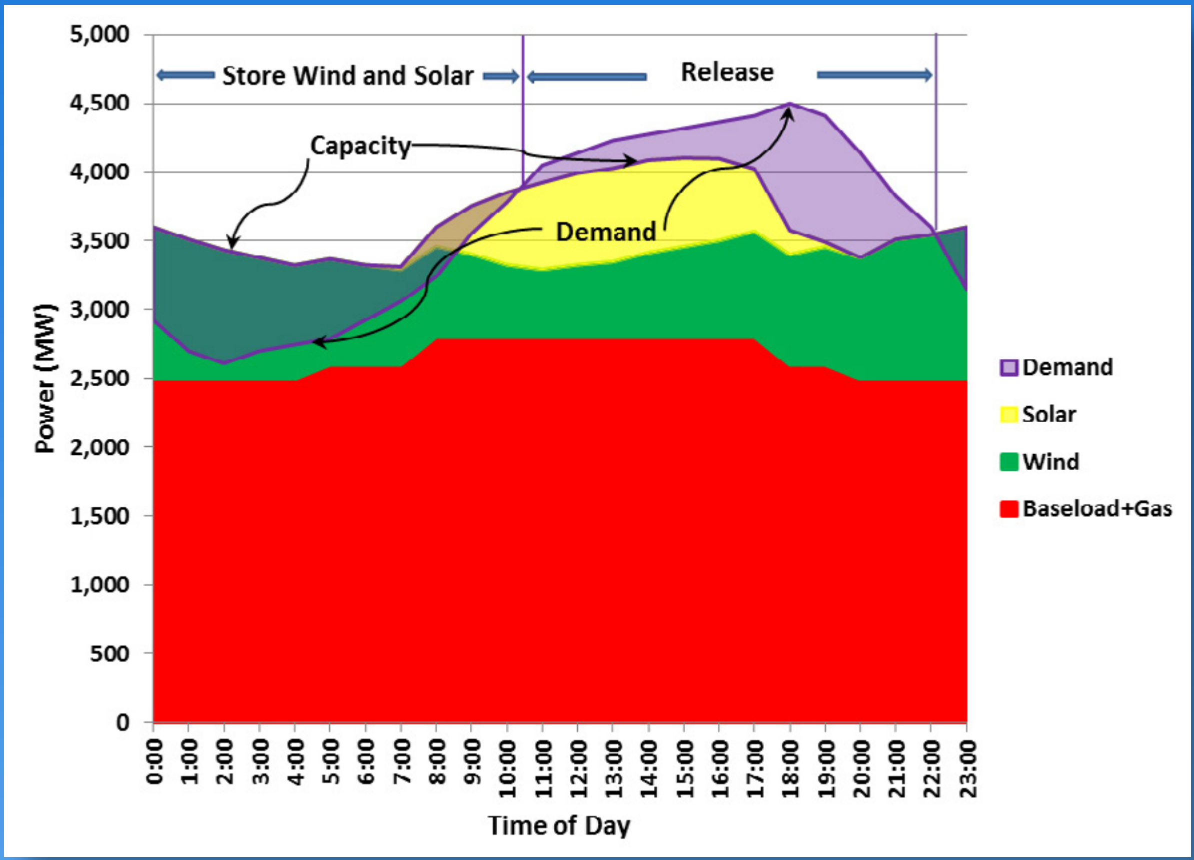
Introduction

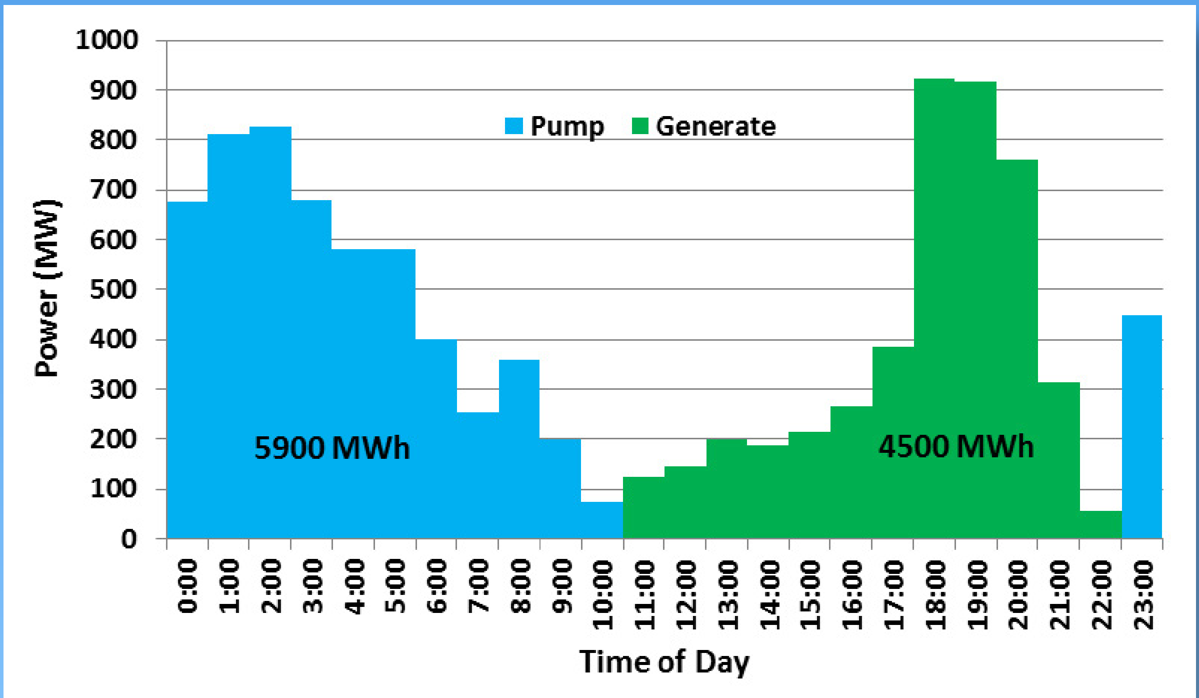
Southwest Research Institute® (SwRI®) has assessed the feasibility of developing closed-loop pumped storage hydropower (PSH) units in West Texas. SwRI (i) evaluated local topography for siting reservoirs with hydraulic head differences adequate for PSH; (ii) examined infrastructure, including transmission capacity and intermittent renewable energy (RE) sources that would benefit from PSH; (iii) identified a new permitting process that should accelerate closed-loop PSH licensing; and (iv) located water supplies to fill and maintain the off-stream reservoirs. In addition, SwRI has identified some of the benefits that may be realized by power generators, transmission and distribution service providers, retail electricity providers, and vertically integrated electrical utilities that deploy PSH. Revenue, initial capital cost, and level cost of energy storage will be evaluated in a subsequent phase of evaluation.

Background

Topographic relief in the Pecos River valley between the Edwards and Stockton Plateaus is sufficient to support development of multiple 10 to 1,000 MW capacity PSH units. Reservoirs on the flat tops of mesas and in the canyons on their steep sides can store 30 to 30,000 GWh per year of RE from wind farms and solar photovoltaic (SPV) farms in Pecos, Crockett, and Upton counties. At present, wind generation capacity is 1,055 MW and SPV capacity is 732 MW in the study area.

For power generation companies, PSH units collocated and operated in conjunction with intermittent RE generation units can firm power generation, generate peaking power, and provide ancillary services, such as frequency and voltage regulation. Transmission and distribution service providers (TDSPs) with PSH can improve grid reliability, decrease congestion, and defer investment in new transmission lines. For retail electricity providers (REPs), the benefits of PSH are less clear; however, PSH should increase service reliability. Existing 345-kV transmission lines from RE generators in the McCamey, Central, and Central West Competitive Renewable Energy Zones (CREZ) (Figure 1) to REPs and utilities in major metropolitan areas, could allow PSH units to be located hundreds of miles from RE generation units in West Texas.


Store Wind and Solar
Release
Capacity
Demand
Power (MW)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day
Demand
Solar
Wind
Baseload+Gas


Pump
Generate
5900 MWh
4500 MWh
Power (MW)
1000
900
800
700
600
500
400
300
200
100
0
0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time of Day

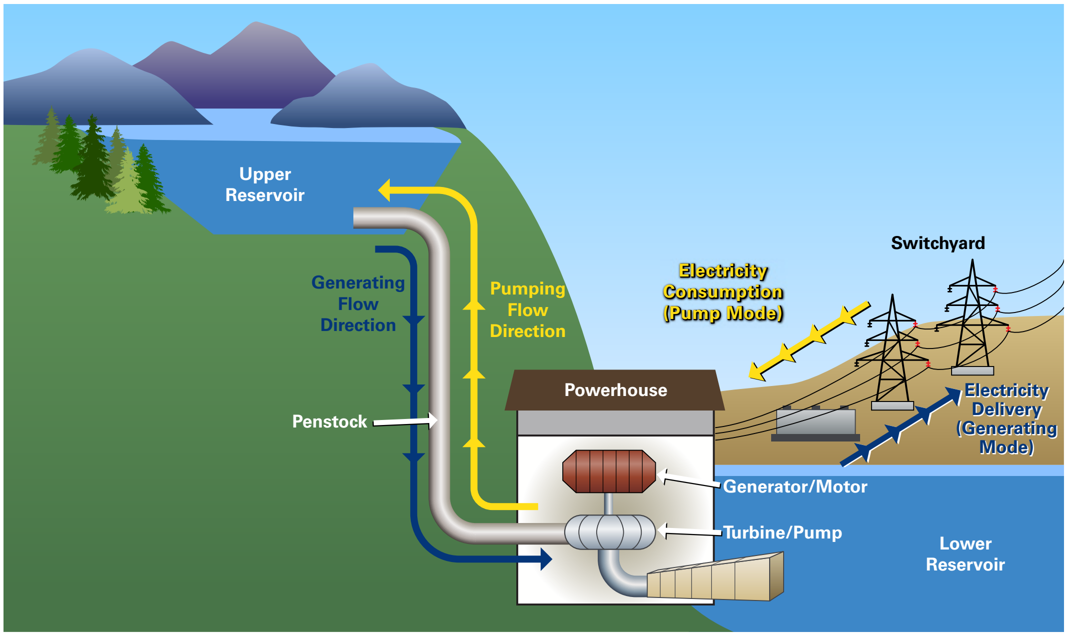


Figure 2. Typical PSH unit

Traditional on-stream PSH units (Figure 2) are subject to a long (5 years or more) permitting process by the Federal Energy Regulatory Commission (FERC). The Hydropower Regulatory Efficiency Act (HREA, H. R. 267) of 2013 directed FERC staff to evaluate the feasibility of licensing new hydropower projects at existing non powered dams and new off-stream closed-loop PSH projects in a 2 year period. For a closed loop PSH unit, neither the upper reservoir nor the lower reservoir is located on a dammed stream. In 2017, FERC staff finished a pilot study that showed the permitting process for off stream closed-loop PSH units could be completed in 2 years. FERC staff will provide recommendations to the Commission on issuing regulations for implementing the 2 year process for PSH projects that meet the siting criteria. By reducing the time needed to obtain construction permits for closed-loop PSH units, FERC is hoping to increase grid storage and improve grid stability.

Study Area

The land along the Pecos River valley between Girvin and Iraan is cut by numerous small, ephemeral streams that have eroded softer limestone and marl strata, leaving steep sided mesas 300 to 500 feet (ft) above broad flat valleys. These mesas include Big Mesa east of Fort Stockton in Pecos County, King Mountain north of McCamey in Upton County, Sherbino Mesa south of Bakersfield in Pecos County, Indian Mesa west of Iraan in Pecos County, and Southwest Mesa southeast of McCamey in Upton and Crockett Counties. By siting upper reservoirs on the mesas' flat caprocks, lower reservoirs within the canyons that incise the mesas' side slopes, and powerhouses underground to minimize penstock lengths, highly-efficient, compact, closed-loop PSH units can be constructed. Because the reservoirs are not sited on environmentally-sensitive perennial streams, closed-loop PSH units in this area can be licensed under the proposed 2 year FERC permitting process.

Site Identification and Concept Evaluation

SwRI has examined three potential sites where local topographic relief is sufficient for constructing closed-loop PSH units. Because SwRI only evaluated the feasibility of PSH, land owners, lease holders, and local governments have not been contacted and consulted. The reservoirs for the hypothetical PSH units directly overlie existing roads, buildings, utility corridors, and pipeline easements.

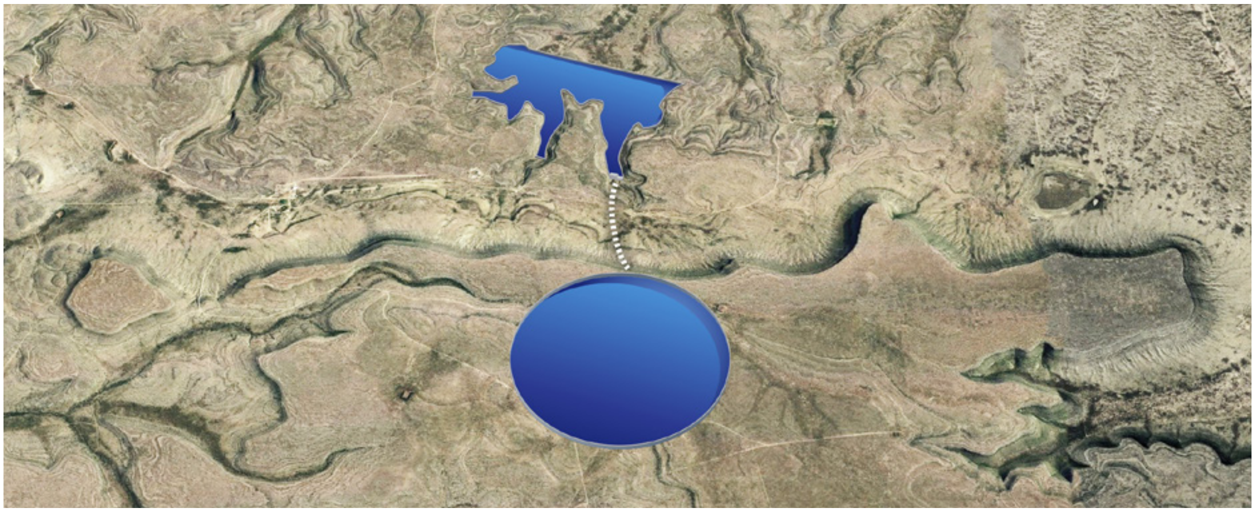


Figure 3. Upper and lower reservoirs for the 100 MW Big Mesa Site

Big Mesa Site

Big Mesa lies on the north side of Interstate Highway (IH) 10 between its intersection with U.S. Route 385 and the town of Bakersfield. NextEra owns the 160 MW Woodward Mountain Wind Farm located in the eastern section of Big Mesa.

SwRI staff evaluated the PSH potential of the north central section Big Mesa located about four miles north northeast of the Tunis Creek Stage Coach Stop rest area on IH-10. The elevation of this section of Big Mesa is about 3,100 ft above mean sea level (msl), while the bottom elevations of the canyons dammed for the lower reservoir range from 2,700 to 2,800 ft msl. The rated head for the PSH unit is 300 ft and the area of the upper circular-shaped reservoir shown in Figure 3 is 300 acres (ac). The turbine-pumps have a capacity of 100 MW with a round trip efficiency of 80 percent, so the rated discharge of the unit is 5,000 ft^3/s. If the PSH unit stores intermittent RE generated during off peak hours and releases the energy over 8 hours during the period of peak demand, the upper reservoir must store 3,300 ac-ft of water. The lower reservoir, shown in Figure 3, has a volume of 4,300 ac-ft at a water surface elevation of 2,800 ft msl.

King Mountain Site

King Mountain lies on the western edge of the Edwards Plateau five miles north of McCamey, Texas. NextEra owns the 278 MW King Mountain Wind Farm that generates more than 750 GWh per year (average of 2,000 MWh per day).

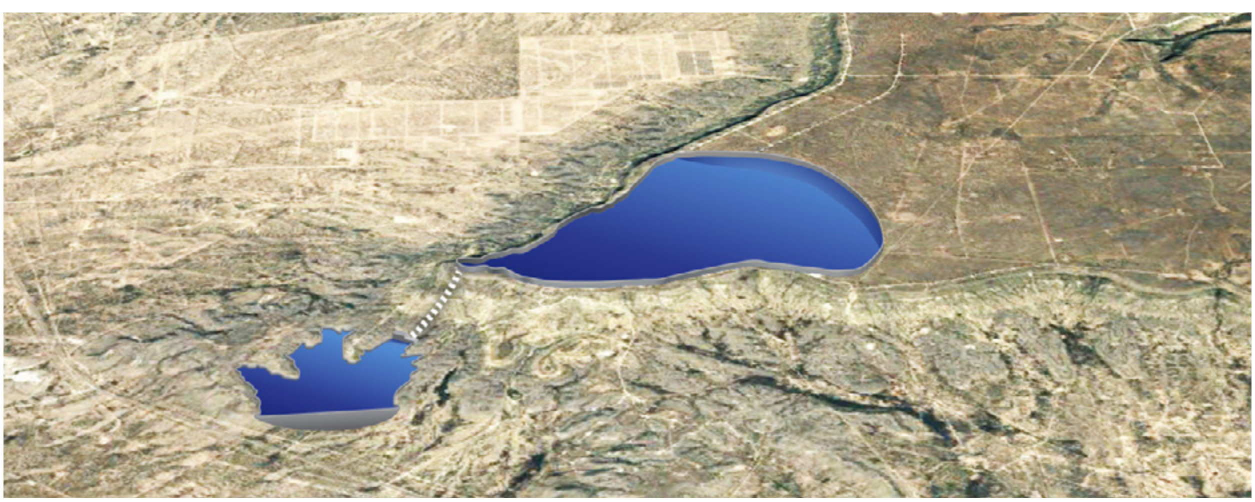


Figure 4. Upper and lower reservoirs for the 1,000 MW King Mountain Site

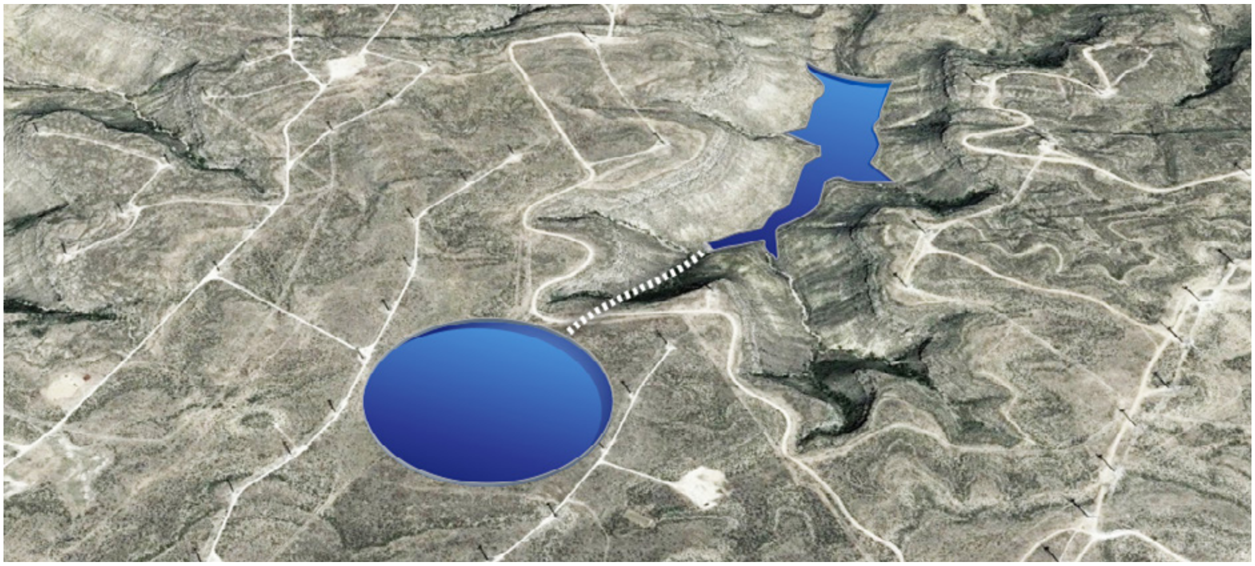


Figure 5. Upper and lower reservoirs for the 50 MW Indian Mesa Site

The elevation of the caprock is approximately 3,100 ft msl, while the small canyons to the southwest where the lower reservoir is located, have elevations that range from 2,550 to 2,700 ft msl. The rated head for the PSH unit is 400 ft and the area of the upper reservoir shown in the upper-right portion of Figure 4 is approximately 1,700 acres. The turbine-pumps have a capacity of 1,000 MW with a round-trip efficiency of 80 percent, so the rated discharge of the unit is 37,000 ft^3/s. If the PSH unit is operated to store RE electricity generated during off peak hours and release energy over 8 hours during the period of peak demand, the upper reservoir must store approximately 24,500 ac-ft of water. The lower reservoir has a surface area of 385 acres and a volume of 32,000 ac-ft at a water surface elevation of 2,700 ft msl.

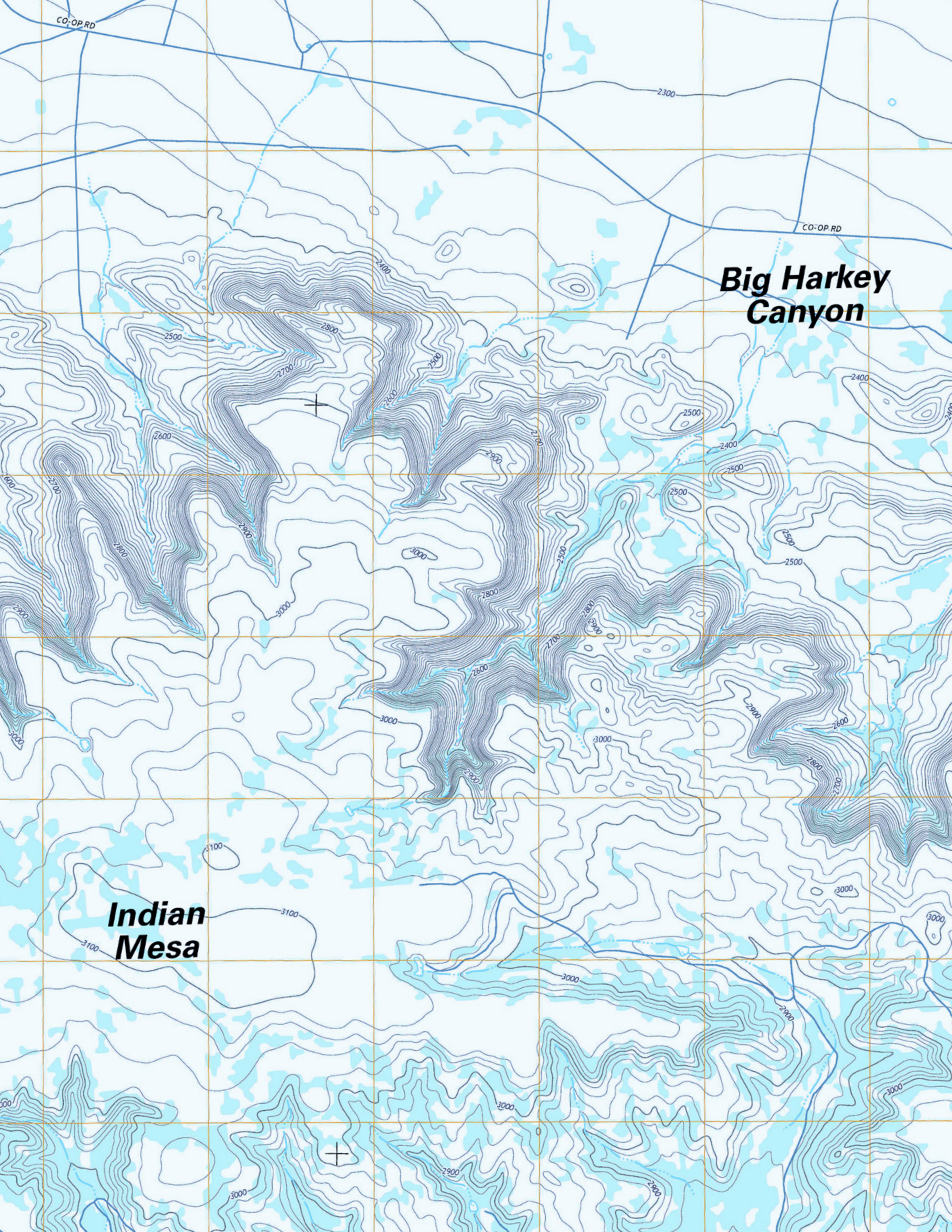
Indian Mesa Site

Indian Mesa is on the eastern edge of the Stockton Plateau 15 miles west of Iraan, Texas (Figure 5, facing page). NextEra owns the 82.5 MW Indian Mesa Wind Farm located on the western half of the mesa. The Lower Colorado River Authority has a Power Purchase Agreement (PPA) for 51 MW and TXU has a PPA for 31.5 MW with the Indian Mesa Wind Farm. American Electric Power (AEP) owns the 160.5 MW Desert Sky Wind Farm located on the eastern half of the mesa (bottom figure on cover). City Public Service (CPS) of San Antonio has a PPA with AEP for all energy produced by the Desert Sky Wind Farm.

The elevation of the Indian Mesa caprock is approximately 3,000 ft msl, while Big Harkey Canyon, where the lower reservoir is located, ranges in elevation from 2,400 to 2,600 ft msl. The rated head is 400 ft and the area of the circular-shaped upper reservoir shown in Figure 5 is 60 acres. The turbine-pumps have a capacity of 50 MW with a round-trip efficiency of 80 percent, so the rated discharge of the PSH unit is 1,850 ft^3/s. If the PSH unit is operated to store RE electricity generated during off-peak hours and to release energy over 4 hours during the period of peak demand, the upper reservoir must store approximately 610 ac-ft of water. The lower reservoir has a surface area of 32 acres and a volume of 1,120 ac-ft at a water surface elevation of 2,600 ft msl.

Water Supply

Initial filling of the Big Mesa, King Mountain, and Indian Mesa reservoirs requires 5,200; 37,100; and 1,800 ac-ft, respectively. Mean annual lake evaporation ranges from 63 to 71 in. Therefore, the mean annual volume of make-up water required for the Big Mesa Site is 1,800 ac-ft; for the King


CO-OP RD
CO-OP RD
Big Harkey Canyon
Indian Mesa

Mountain Site, 9,200 ac-ft ; and for the Indian Mesa Site, 360 ac-ft. Evaporative losses from the upper reservoirs at Big Mesa and King Mountain can be decreased by building higher dams that enclose smaller reservoir surface areas.

The climate in this part of West Texas is semiarid (mean annual precipitation is 13 in) and aside from the Pecos River, there are few perennial streams. Primary tributaries to the Pecos River in the Stockton-Edwards Plateau region are Independence and Live Oak creeks, which join the Pecos 40 to 60 miles southeast of the study area. There are no reservoirs located on the Pecos Rivers below Red Bluff dam near the Texas-New Mexico border. Existing water rights on the lower Pecos River fully appropriate the mean annual flow and all land is privately owned, thus constructing a dam and headworks to store and divert Pecos River water to fill and maintain water levels in an off-stream, closed-loop PSH is probably not feasible.

Water for irrigation, livestock, industry, and municipal supply is pumped from wells in the shallow Pecos Valley or the Edwards-Trinity (Plateau) aquifer. Smaller volumes of water are pumped from the underlying late-Triassic Dockum aquifer and the Permian Rustler and Capitan Reef aquifers; however, water from these deeper aquifers is generally too saline and too high in total dissolved solids (TDS) for municipal and agricultural use.

Using Saline Water

Given the limited supply of fresh water in the study area, using saline water to fill and maintain a PSH unit may be an option. Fortunately, using saline water in a PSH unit is not unprecedented. From 1999 to 2016, J-Power of Japan operated the 30 MW Yanbaru PSH unit in Okinawa, Japan, which stored electricity by pumping seawater from the Philippine Sea to a reservoir excavated on a flat highland 450 ft above the sea. To mitigate corrosion from seawater [TDS 35,000 parts per million (ppm), chloride concentration 20,000 mg/l], the penstock of the Yanbaru PSH unit was constructed from fiber-reinforced plastic, while the wicket gate, turbine runner, main turbine shaft, and draft tube, which are exposed to high velocity seawater, were constructed from austenitic stainless steel. To prevent seawater seeping from the 460 ac-ft upper reservoir into the local groundwater, the reservoir base was lined with impermeable fabric.

News reports indicate that the Yanbaru PSH unit was closed and dismantled because of the low growth rate of electricity demand in Okinawa , not technical problems. Although detailed information on J Power's corrosion control and abatement procedures has not been obtained, the fact that the Yanbaru PSH unit was operated for 17 years when it was only intended to be a 10-year pilot study suggests that corrosion was manageable.

Experience at the Yanbaru PSH unit shows that it is technically feasible to operate a PSH unit supplied with moderate- to high-salinity water pumped from the Dockum aquifer. Additional hydrogeologic information would need to be reviewed to determine if the Dockum can provide the required fill and evaporation make up water without impacting other water users. If the Dockum Aquifer cannot be used to fill and maintain the PSH reservoirs, there are others sources of saline water in the study area.


Photo Courtesy of Robert D. Flaherty Photography

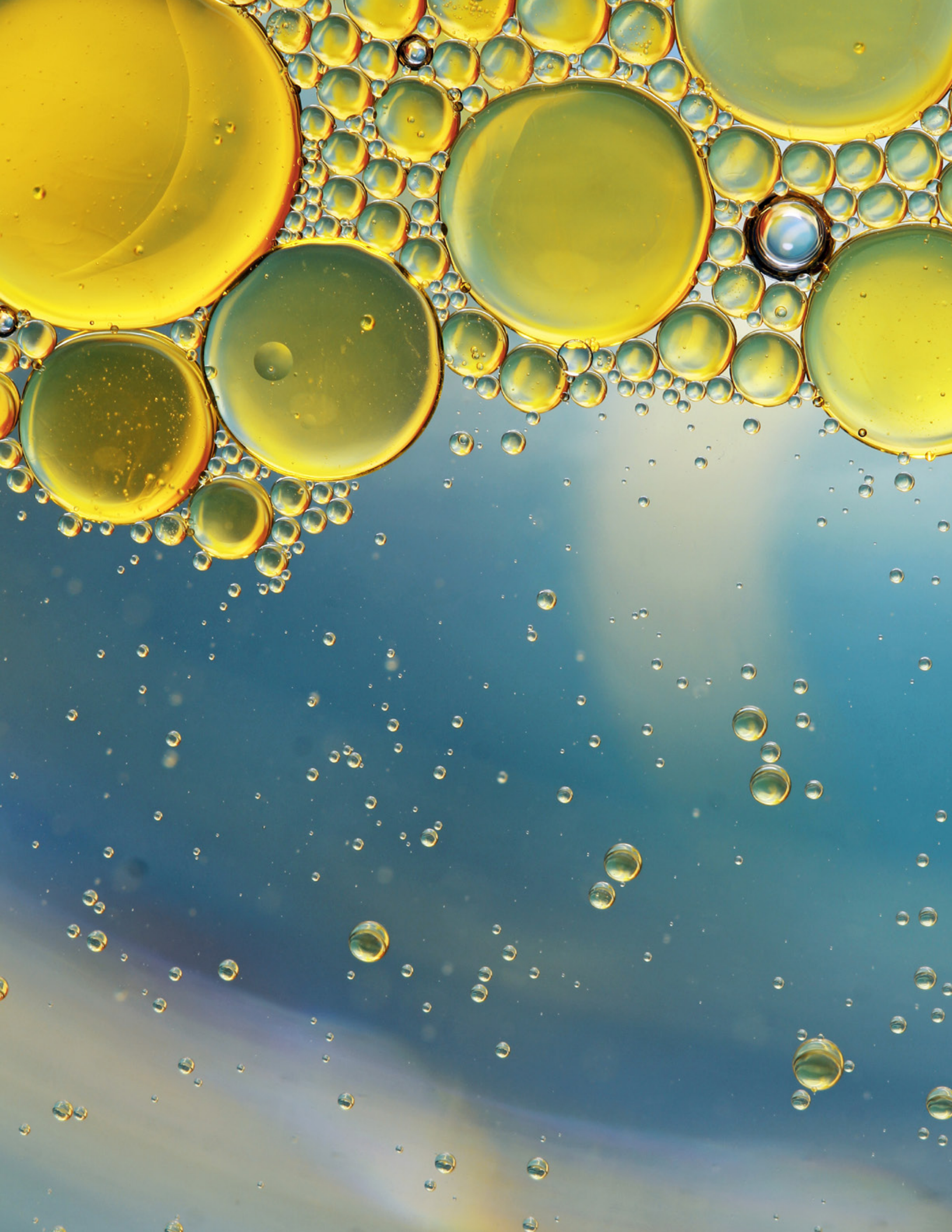
Permian Basin Produced Saline Water

Since 2012, oil production in the Permian Basin, located just north of the study area, has increased from 1.25 million barrels per day (MMBD) to 2.6 MMBD from increased well yields obtained by drilling longer laterals and using more proppant and fluid during the hydraulic fracturing process (a "frac job"). Many frac jobs now use highly saline produced water instead of fresh water; however, even a large frac job injecting 250 thousand barrels (MBBL) to 1 million barrels (MMBBL) of frac water, would use only a small fraction of the total produced water from the Permian Basin. In the Permian Basin for each 1 barrel (B) of oil pumped, 7 B of high salinity formation water are produced that must be separated and recycled or disposed. Based on the 2017 oil production rate of 2.6 MMBD, the total produced water in 2017 was 6.6 billion barrels (BBL) (860,000 ac-ft). A very large frac job using 1 MMBBL, uses less than 0.1 percent of the annual produced water of the Permian Basin. Even if one thousand very large produced water frac jobs were completed in 2017, 720,000 ac-ft would still require disposal.

To reduce water tanker traffic and decrease the cost of produced water reuse and disposal, several midstream operators have begun to construct water gathering lines, central water treatment facilities, detention ponds, and transmission lines to supply wellpads in the Permian Basin. Over the past two years information from Rockwater Energy Solutions, H2O Midstream, Solaris Midstream, Noble Midstream, Pioneer Natural Resources, and others suggest that 300 to 400 mi of pipelines and 500 mi of gathering and distribution lines have been constructed in the Permian.

Produced water chemistry data reported for individual oil wells in the study area show TDS values from 7,500 ppm to 175,000 ppm and chloride concentrations from 2,400 mg/l to 110,000 mg/l. The more concentrated oil-field brines are more saline than seawater (110,000 vs 20,000 mg/l); however, depending on development of Permian Basin produced-water infrastructure, produced water for the three PSH sites could come from other plays. Produced water chemistry data from Rockwater Energy Solutions shows average TDS values in the Permian Basin range from 20,000 to 45,000 mg/l, while average chloride concentrations are between 13,400 and 30,100 mg/l. These data reflect the quality of produced water received by Rockwater Energy Solutions before it is treated and supplied to wellpads for slickwater frac jobs.

TDS and chloride concentration data reported by Rockwater bound the average values for seawater. Therefore, it should be possible to fill and top off the reservoirs for the three proposed PSH units with produced water if the materials used to construct units are similar to those at Yanbaru. If available produced water is too saline, or if the water in the reservoir becomes too saline from evaporation, low- to moderate-salinity groundwater from the Dockum aquifer can be used for make-up water. Because of the high evaporation rates, the salinity of reservoirs would need to be monitored and managed. This may require injecting moderate volumes of highly saline reservoir bleed water into existing deep disposal wells.



Proposal for Pre-Feasibility Study

Developing a medium to large PSH project is complex. The process may take between 2 to 7 years before construction begins and 5 to 12 years before operations commence. Development follows the general steps shown in the graphic at right, which is based on the guide prepared by International Finance Corporation. This briefing document presents results from completing items (a) and (b) under Step 1: Site Identification and Concept Development.

SwRI seeks funding from an interested organization to conduct a pre-feasibility study. Once SwRI has signed a contract to conduct the pre-feasibility study, item (c) of Step 1 "Secure funding for project development" will be complete.

SwRI will develop a proposal for conducting a pre-feasibility study to determine (i) if constructing and operating closed-loop PSH units in the study area is economically feasible; and (ii) identify sites and types of PSH pump-turbine and motor-generator combinations (e.g., reversible centrifugal pump turbine, separate pumps and turbines; fixed-speed motor-generator, variable speed motor-generator, ternary system with hydraulic short circuit for simultaneous storage and generation) that would maximize net benefits. If the proposal is accepted, SwRI, with support from an energy storage consultant, will prepare a report that presents (i) an evaluation of several potential PSH projects (installed capacities, energy storage quantities, site locations, PSH design); (ii) the required permitting processes for these projects; (iii) estimates of the level cost of stored electrical energy based on rough costs of construction, equipment, and operations; and (iv) the estimated revenues generated by the project over its anticipated 50 year life.

If the pre-feasibility study identifies at least one site and project concept that appears technically and economically feasible, SwRI will submit a proposal to conduct a feasibility study. SwRI typically does not serve as the lead designer or prime contractor for major civil construction projects, but regularly provides technical assistance and independent evaluations of such projects. Steps 4 through 7 should be led by companies that have extensive experience in final hydroelectric design (particularly PSH) and large civil construction.

SwRI will promote PSH for improving grid reliability in other areas where intermittent RE is abundant, but the availability of water is limited and topographic relief is modest. Areas similar to the West Texas study area currently under consideration by SwRI include the Mescalero Escarpment in New Mexico, the Canadian River Breaks in New Mexico and Texas, and the Caprock Escarpment in the Texas Panhandle.

Summary

SwRI has determined (i) the topography in the study area is suitable for constructing PSH units whose upper and lower reservoirs produce rated hydraulic heads between 300 and 400 ft; (ii) the installed capacity of intermittent RE in the study area is 1,800 MW and there is a 345 kV transmission line that connects the McCamey CREZ to the Electric Reliability Council of Texas (ERCOT) operated grid; (iii) the streamlined permitting process proposed by FERC staff will eliminate much of the uncertainty associated with licensing off-stream, closed-loop PSH; and (iv) saline water is available in this semiarid region that can be used for filling and maintaining the reservoirs and operating the turbines and pumps. Finally, SwRI has identified the next steps in the development process and will prepare and submit a proposal to conduct a formal pre-feasibility study when requested.


1
Site Identification & Concept Development
a. Identification of potential sites
b. Development of rough technical specifications
c. Secure funding for project development
2
Pre-Feasibility Study
a. Assessment of technical options
b. Identification of permitting needs
c. Development of rough estimates of costs and benefits of options
3
Feasibility Study
a. Detailed technical and financial analysis of the preferred option
b. Initiation of permitting process
c. Assess financing options for project
4
Financing & Contracts
a. Supplier selection and contract negotiation
b. Permitting process well underway
c. Major civil construction selection and contract negotiation
d. Complete short-term and long-term finance plan
5
Detailed Design
a. Prepare and check detailed design for elements of project
b. Prepare project construction and implementation schedule
c. Complete permitting process
6
Construction
a. Budget, schedule, quality management
7
Commissioning
a. As built inspection
b. Performance testing

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