RECLAMATION
Managing Water in the West

Paradox Valley Unit Brine Crystallization Technology Assessment

Western Colorado Area Office

Paradox Valley Unit, Colorado

Upper Colorado Region

U.S. Department of the Interior
Bureau of Reclamation

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Paradox Valley Unit Brine Crystallization Technology Assessment

Paradox Valley Unit, Colorado
Western Colorado Area Office

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For:
Western Colorado Area Office
Upper Colorado Region

Acronyms

°C	Celsius degrees
$	dollar
%	percent
$M	million of dollars
$M/yr	million of dollars per year
/ton solids	per ton of solids
AC	alternating current
BBT	Brine Bulb Technology
brine	saline water
CDS	concentrated draw solution
CO2/yr	carbon dioxide per year
DC	direct current
DDS	diluted draw solution
d/w	days per week
EDI	Electrodeionization
EDR	Electrodialysis Reversal
EIS	Environmental Impact Statement
EVRAS™	Evaporative Reduction and Solidification
ft	foot/feet
ft2	square foot
FTE®	Freeze Thaw/Evaporation
Gal	gallon
gpd	gallons per day
gpm	gallons per minute
HDH	humidification-dehumidification
hr/d	hours per day
kg	kilogram
kWh	kilowatt hour
lbs	pounds
MBC	Membrane Brine Concentrator
MD	Membrane Distillation

MED	Multi-Effect Distillation
MGD	million gallons per day
mg/L	milligrams pre litre
MOhm-cm	mega ohm-centimeter
MSFD	Multi-Stage Flash Distillation
MVC	Mechanical Vapor Compression
MVR	mechanical vapor recompression
MW	megawatts
MWh/yr	megawatts hours per year
NREL	National Renewable Energy Laboratory
O&M	operations & maintenance
PV	present value
PVU	Paradox Valley Unit
Reclamation	Bureau of Reclamation
RFI	request for information
RO	reverse osmosis
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TVC	Thermal Vapor Compression
WAIV	Wind-Aided Intensified Evaporation
WCAO	Western Colorado Area Office (Reclamation)
ZLD	zero liquid discharge

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Project Scope and Objectives

The Paradox Valley Unit (PVU) is a Bureau of Reclamation (Reclamation) facility that collects hypersaline groundwater, or brine, from wells near the Dolores River in the Paradox Valley in Montrose County, Colorado, and injects the brine into deep geologic formations. The location of the PVU is shown in figure 1. Under the Colorado River Basin Salinity Control Act of 1974, the Western Colorado Area Office (WCAO) implements the PVU Project for salinity control. Currently the PVU is one of the most effective salinity control projects and provides about ten percent of the total salinity control in the Colorado River.

The PVU consists of a shallow collection well field, surface treatment facility, injection facility, and a 16,000-foot deep injection well.

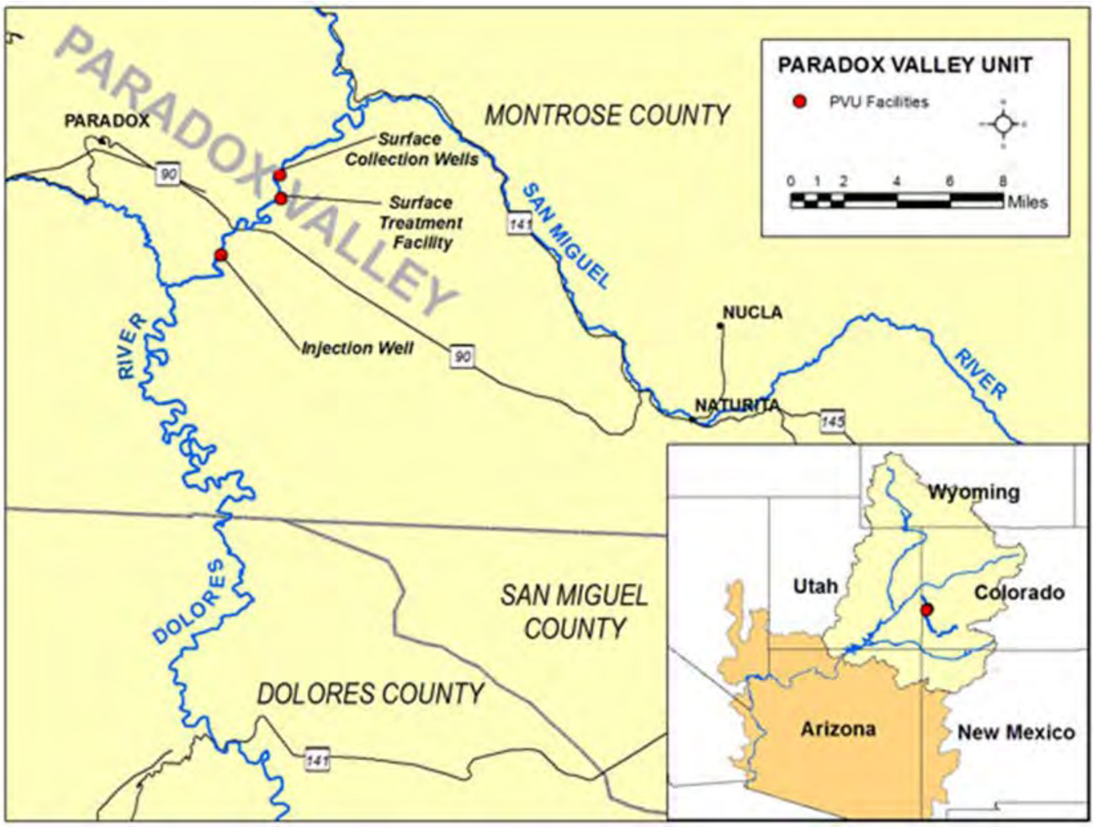

Figure 1— PVU location (source: http://www.usbr.gov/uc/wcao/progact/paradox/).

The shallow collection wells intercept brine with approximately 260,000 mg/L of total dissolved solids (TDS) at 200 gallons per minute (gpm) as it travels through the ground toward the Dolores River. Water from each well is combined in the surface treatment facility and pumped to the injection facility. At the injection well, brine is pumped into the ground for long-term disposal. This prevents approximately 100,000 tons of salt per year from entering the Dolores River, a tributary of the Colorado River.

The collection wells are capable of collecting 400 gpm. However salinity control benefits may decrease at collection rates greater than 300 gpm. Therefore, for the purposes of this study the goal is to manage 300 gpm of brine; this collection rate would reduce the salt loading to the Dolores River by 170,000 tons per year.

As the existing injection well reaches the end of its useful life, there is a need for evaluating alternatives other than deep well injection for the management of the brine and salinity control in the Colorado River. The purpose of this technical memorandum is to support the WCAO efforts for the on-going Environmental Impact Statement (EIS) for future PVU alternatives to the current injection well.

This technical memorandum provides a summary of the treatment technologies that were investigated as alternatives to deep well injection including brine minimization and zero liquid discharge (ZLD) technologies. The scope of this assessment was limited to technologies that have the capability of producing a solid for disposal or would be an integral part of a ZLD process.

The objectives of this technical memorandum are to:

- Identify technologies with the capability to reduce the brine to a solid waste product
- Investigate the potential to incorporate alternative energy sources to offset process energy requirements
- Summarize and evaluate commercially available technology alternatives relevant to the PVU
- Provide recommendations for future on-site testing

Implementation of a brine crystallization technology would likely produce a solid waste product that would require permanent disposal in a solid waste landfill. Prior to disposal solids would have to be screened for hazardous constituents using the Paint Filter Liquids Test (SW-846 Test Method 9095B) and Toxicity Characteristic Leaching Procedure (TCLP, SW-846 Test Method 1311). Consideration of solid waste handling and characterization was outside the scope of this effort.

Brine Water Quality

Technology screening depended heavily on the water quality of the PVU brine, which is presented in table 1. Complete analytical water quality results from the SGS Accutest Mountain States lab in Wheat Ridge, Colorado, were provided by WCAO. The data in table 1 are from sample ID D26319-2 in 2011, which was chosen because it was a composite sample from several wells.

PVU brine water quality is unique, because it has a high TDS) concentration of approximately 260,000 mg/L. By comparison, seawater typically has a TDS of 35,000 mg/L, and reverse osmosis (RO) concentrate from a seawater desalination facility may have a TDS concentration around 70,000 to 100,000 mg/L. Therefore, the technologies considered and evaluation criteria were tailored to the high source water TDS, which is an uncommon initial salinity level for many desalination or brine management processes. PVU brine also contains hydrogen sulfide (H_2S) which is dangerous to human and wildlife health when inhaled, and is also corrosive to process equipment. Although the dissolved concentration in table 1 is only 6 mg/L, project staff report typical H_2S concentrations near 80 mg/L.

Table 1— PVU Brine Water Quality for Constituents Measured above the Method Reporting Limit (lab sample ID D26319-2)

Constituent	Units	Value
Alkalinity	mg/L as $CaCO_3$	210
Ammonia	mg N/L	0.5
Bicarbonate	mg/L as $CaCO_3$	210
Boron	mg/L	8.2
Calcium	mg/L	1,320
Carbon Dioxide	mg/L	90
Chloride	mg/L	151,000
Hardness	mg/L as $CaCO_3$	9,470
Hydrogen Sulfide	mg/L	6.2
Magnesium	mg/L	1,500
Manganese	mg/L	0.3
pH	Standard Units	6.7
Potassium	mg/L	4,080
Sodium[1]	mg/L	94,800
Specific Conductance	mS/cm	210
Strontium	mg/L	25
Sulfate	mg/L	5,980
Sulfide	mg/L	50
Total Dissolved Solids	mg/L	259,000
Turbidity	NTU	40

[1]Sodium was not in the analytical reports but as determined by a mass/charge balance.

Preliminary Technology Screening

Preliminary Screening Approach and Summary

High level screening was conducted to identify potential technologies for further investigation at the PVU. Technologies were considered to have potential if they met the following screening criteria:

- Can the technology process brine concentrations of 260,000 mg/L?
- Can the technology produce a solid product (i.e., ZLD) or pretreat water in anticipation of a ZLD process?
- Has the technology been previously demonstrated?
- Is the technology commercially available?

Preliminary screening included technologies that either reduce brine volume or produce a solid product. Some of the technologies that were considered are stand-alone systems capable of reducing the brine to a solid product. However, some technologies that cannot produce a solid product can be used as part of a treatment train to further concentrate the brine prior to a ZLD process. Brine concentration prior to a ZLD process can improve energy efficiency of downstream unit operations. For example, crystallizers often follow brine concentrators, which reduce the volume to be processed by the crystallizer.

Due to the high TDS, pressure driven membrane technologies, such as RO, were not considered because of the high pressure requirements that would result in high energy requirements, operational challenges, and potential safety concerns. Recovery of fresh water from the brine was also not a priority of the WCAO. Other efforts by Reclamation are evaluating conventional evaporation ponds and were therefore not considered herein. Natural treatment systems (e.g., wetlands, halophyte farming) were not considered due to the large footprint that would be required to meet the PVU brine flow rates.

Through alternative development efforts for the on-going PVU EIS, it is anticipated that the solid waste produced from any alternative would be permanently stored in a solid waste landfill. Based on conversations with a landfill operator in the Paradox Valley, a material must pass the paint dry test in order to be considered a solid waste. Prior to disposal solids would have to be screened for hazardous constituents using the Paint Filter Liquids Test (SW-846 Test Method 9095B) and TCLP (SW-846 Test Method 1311). Where possible, information was obtained for anticipated solid waste characteristics.

Table 2 and table 3 provide a summary of potential technologies, descriptions, and commercial vendors for ZLD and non-ZLD processes, respectively. The final column in table 2 and table 3 indicates whether the technology met the initial screening criteria. In general, a generous approach was taken in determining whether a technology met the screening criteria. Only technologies that were poorly suited to the application were eliminated from further evaluation. In the section titled Technology Descriptions, more detailed explanations are provided for all technologies included in preliminary screening. Information presented below was gathered from publicly available sources.

Table 2— Preliminary Screening of ZLD Treatment Technologies

Technology/ Process	Description	Product(s)	Vendor(s)	Meets Initial Screening Criteria
Brine Bulb Technology (BBT)	Electro-coagulation precipitates solids and heats brine for vacuum distillation	Distilled water, wet solids	Eric Dole with Hazen and Sawyer	No, technology is still in the early phases of development
Crystallization	Heat vaporizes water in the concentrated brine, precipitating salt crystals	Distilled water, wet solids	GE Water, Aquatech, Saltworks, Degremont, Veolia, GEA, WaterFX, Swenson, Ecoplanning, Suez	Yes
Evaporative Reduction and Solidification (EVRAS™)	Heat evaporates water from preheated brine in a high surface area cooling tower coupled with a crystallizer	Wet solids	Layne	Yes
Forward Osmosis (ClearFlo Complete™)	A thermolytic draw solution concentrates brine using forward osmosis coupled with a crystallizer	Wet solids	Oasys Water	Yes
SAL-PROC™	System couples a series of chemical reaction steps, evaporation, and cooling	Specific wet solids (e.g., gypsum)	Geo-Processors, Inc.	No, technology appears to be cost effective only when salable by-products are produced

Table 3— Preliminary Screening of Non-ZLD Treatment Technologies

Technology	Description	Product(s)	Vendor(s)	Meets Initial Screening Criteria
Dewvaporation (AltelaRain®)	Thermal process operating below the boiling point of water (humidification-dehumidification) to evaporate water	Distilled water, concentrated brine	Altela	Yes
Electrodeionization (EDI)	Electrochemical process using electrodes separated by anion and cation ion exchange resins to remove salts	Ultrapure water, concentrated brine	GE Water, Veolia, Dow Water, Cal Water, SnowPure Water Technologies, Evoqua	No, not intended for high salinity brines
Electrodialysis Reversal (EDR)	Electrochemical process using electrodes separated by anion and cation selective membranes to remove salts	Ultrapure water, concentrated brine	GE Water, Evoqua	No, not intended for high salinity brines
Freeze Thaw/Evaporation (FTE®)	In cold weather climates, fresh water is separated from brine through freezing	Fresh water, concentrated brine	Polar Bear Water Treatment	No, because of requirement for consistent below freezing temperatures
Membrane Distillation (MD)	Hydrophobic membranes separate water from heated brine stream to form condensed water vapor	Fresh water, concentrated brine	Solar Spring, Aquaver, Memsys	No, technology is still developing and requires a large footprint
Multi-Effect Distillation (MED)	Steam heat and reduced pressure evaporate water in several stages followed by condensation	Distilled water, concentrated brine	Sidem, Wabag, AquaSwiss AG, IDE Technologies, Alfa Laval	Yes
Multi-Effect Distillation Mechanical Vapor Compression (MED-MVC)	Steam produced by water evaporation is compressed using a thermocompressor and recycled as heat source for brine distillation	Distilled water, concentrated brine	Sidem, Aqua Swiss, IDE Technologies, Alfa Laval, Wabag	Yes
Multi-Effect Distillation – Thermal Vapor Compression (MED-TVC)	Steam produced by water evaporation is compressed with mechanical compressor and recycled as heat source for brine distillation	Distilled water, concentrated brine	Sidem, Wabag	Yes
Multi-Stage Flash Distillation (MSFD)	Steam heat and reduced pressure flashes (boils) water in several stages	Distilled water, concentrated brine	Sidem, Wabag	Yes

Technology	Description	Product(s)	Vendor(s)	Meets Initial Screening Criteria
Pellet Softening	pH adjustment and use of ballast, such as sand, precipitates dissolved solids to form settleable and disposable pellets.	Wet solids, disposable pellets, less concentrated brine	Veolia, Rwb	No, technology only precipitates minerals such as calcium carbonate and does not reduce brine volume
Wind-Aided Intensified Evaporation (WAIV)	High surface area materials enhance wind-driven evaporation	Wet solids, concentrated brine	Lesico CleanTech	Yes

Technology Descriptions

This section provides more detail for each brine management technology that was identified in table 2 and table 3. Each technology section provides a brief description, process schematic, advantages and disadvantages, list of vendors, and known applications. At the end of each technology section, the potential for direct coupling of renewable energy (solar thermal or geothermal) to offset heat requirements is addressed. Renewable energy is discussed further in the section titled Preliminary Renewable Energy Assessment.

For the technologies deemed potentially feasible for the PVU, information request sheets (Appendix A), were sent to vendors to allow for a more comprehensive alternatives assessment (see section titled Technology Assessment).

Brine Bulb Technology

Brine Bulb Technology (BBT) is a relatively new combination of technologies developed by Eric Dole with the engineering consulting firm Hazen and Sawyer. The process uses electrocoagulation to:

- Form floc seeds for solids precipitation and settling
- Warm the brine through the breaking of surface tension bonds between water molecules
- Reduce brine specific heat capacity
- Reduce brine latent heat of vaporization

Therefore electrocoagulation reduces the energy requirements for distillation, which is enhanced in the process using a vacuum. Although promising, BBT is still in the bench scale development phase.

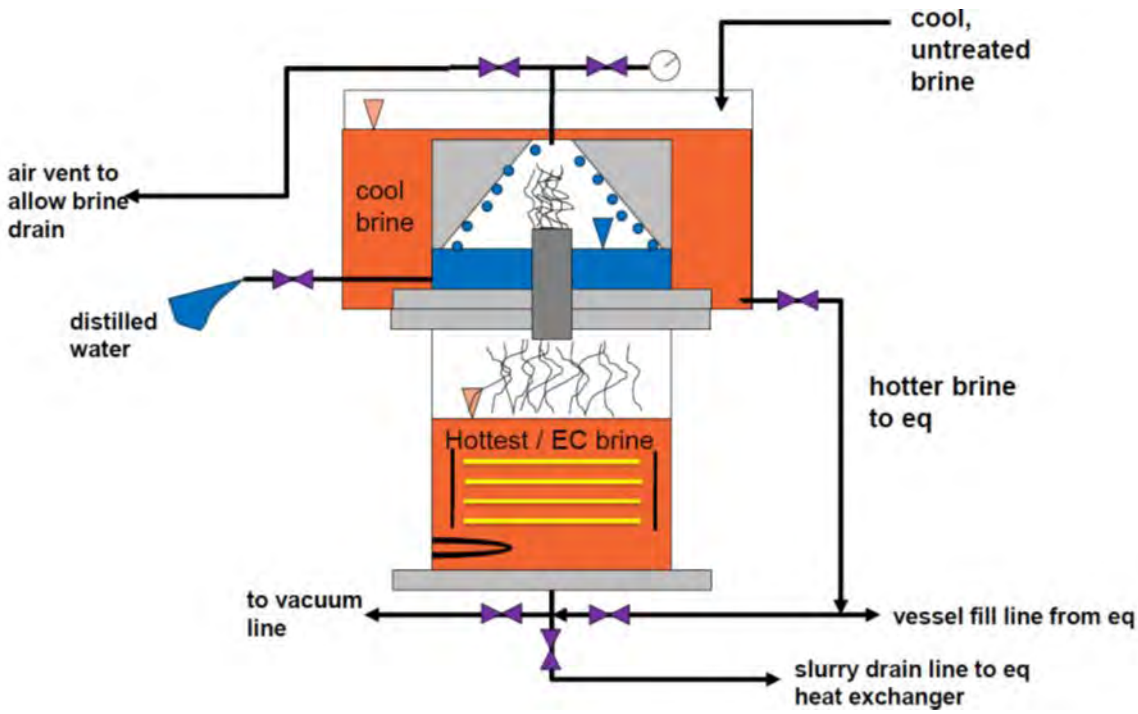

Figure 2— Schematic of the BBT process (from http://www.desaltech2015.com/assets/presenters/Dole_Eric.pdf) "eq" refers to an equalization chamber, not shown in the figure.

Advantages	Disadvantages
Produces a slurry that can be dewatered	Very early development stages
Low energy	

Vendors

None identified

Installations

None identified

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

This technology is still in the early phases of development and has not been sold as a commercial product. Therefore, Hazen and Sawyer was not contacted.

Crystallization

Crystallizers are used to precipitate solids that can be dewatered from pre-concentrated brine streams. The brine is typically concentrated using brine concentrators, which are very similar in principle to crystallizers. In a crystallizer, concentrated brine is recirculated between a heat exchanger and a main vessel where water vapor exits the top and salt crystals precipitate in the concentrated brine. Concentrated brine slurry from the bottom of the main vessel is discharged to a dewatering process such as a centrifuge. Crystallizers are commonly used when other disposal methods, such as deep well injection or ocean discharge, are not feasible. The Aqua4™ by WaterFX is similar to conventional crystallization processes, except it uses concentrated solar thermal arrays to heat the concentrated brine.

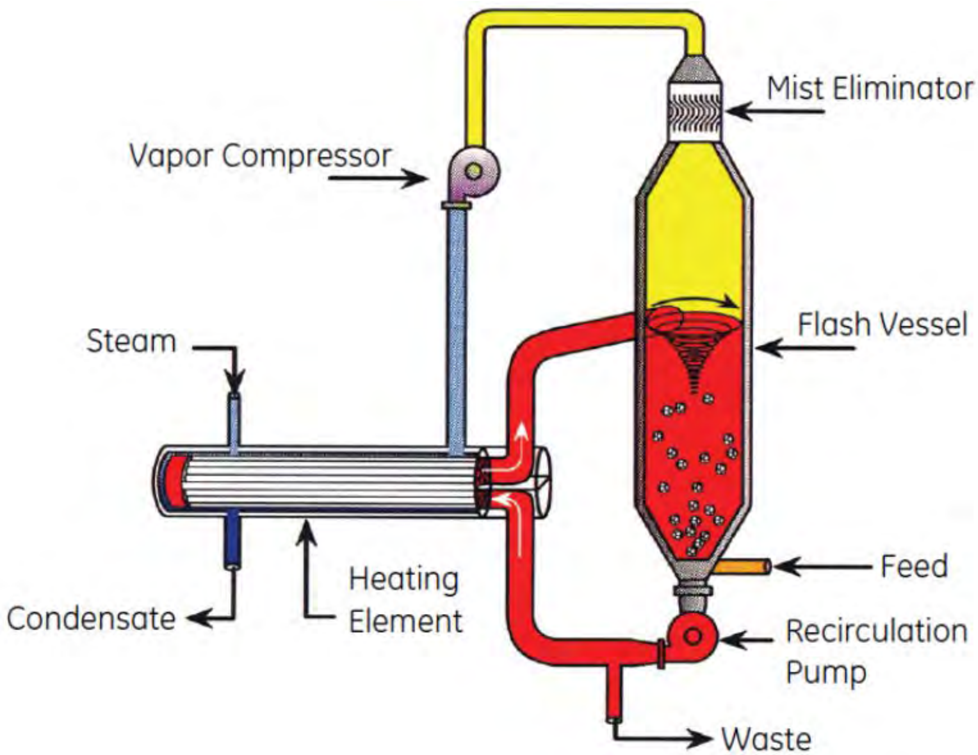

Figure 3— Schematic of a crystallization process (from http://www.gewater.com/zero-liquid-discharge-zld.html#featuredproductssection).

Advantages	Disadvantages
Produces a solid that can be dewatered	Requires a readily available supply of steam and/or vapor compressor
Centrate from dewatered solids can be recycled	Scaling and corrosion from inorganics
Many vendors with varying designs	Energy intensive

Vendors

GE Water	Saltworks Technologies, Inc.	WaterFX
Aquatech	GEA	Swenson
Degremont Technologies	Veolia	Ecoplanning

Installations

Shenhua Coal Liquefaction Project, Inner Mongolia, 590 gpm, 2009
Huntington Power Station, Huntington, Utah, 200 gpm, 1974
Indiantown Generating Plant, Indiantown, Florida, 580 gpm, 1995
Gila River Power Station, Gila Bend, Arizona, 2400 gpm, 2003
PEMEX Cadereyta Refinery, Monterrey, Mexico, 116 gpm, 1998
Lithium chloride production, Argentina
Pure Salt Baytown, salt crystallization system, Baytown, Texas
IC Potash Corp., potassium sulfate crystallization, New Mexico

Potential for Integration with Renewable Energy

This technology is energy intensive because of the steam and power requirements. Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

Crystallizers have been used extensively at the full-scale for similar applications, and there are numerous technology vendors. Therefore vendors that manufacture crystallizers were contacted for additional information.

Evaporative Reduction and Solidification System (EVRAS™)

The EVRAS™ by Layne is an integrated heating and evaporative process similar to cooling towers. Brine is first preheated in a direct contact floating bed heat exchanger, which eliminates problems associated with fouling and scaling. The heated brine is then sprayed over a flexible plastic film that provides high surface area for contact with ambient air flow. Humid air is then carried out of the unit by a fan as with cooling towers. Concentrated brine is collected at the bottom of the unit and either recycled to be heated again or discharged to solids handling after crystallization.

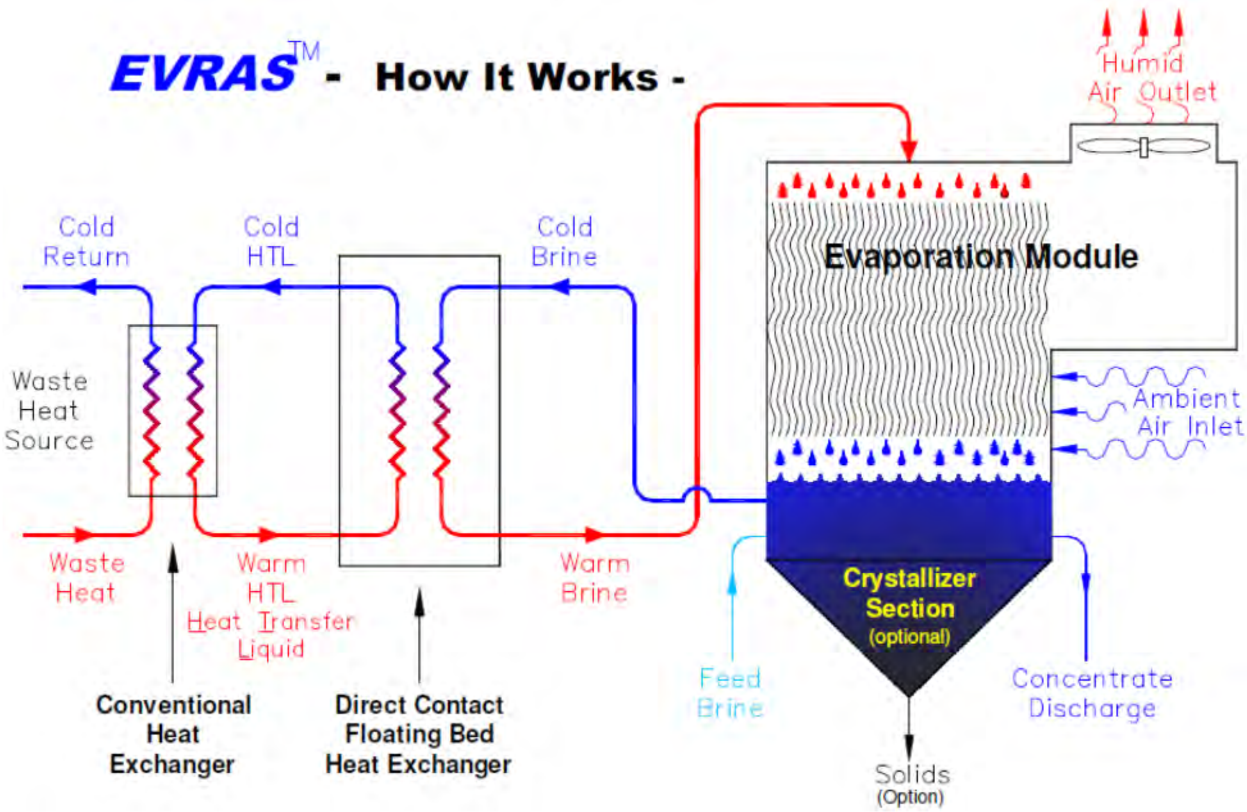

Figure 4— Schematic of EVRAS™ process (from http://ipec.utulsa.edu/Conf2011/Full%20Manuscripts%20&%20PP%20presentations/Stone_56.pdf).

Advantages	Disadvantages
Produces a solid that can be dewatered	Requires a heat source
Modular design	Limited installations
No freshwater handling or discharge	Only one vendor
Minimizes fouling and scaling associated with traditional heat exchangers	

Vendors

Layne

Installations

Deicing glycol regeneration plant, Newell, West Virginia

Food processing plant, Nevada

Gas field brine concentrator, California

Barnett shale site

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

EVRAS™ produces a solid product and has several installations. Therefore Layne was contacted for additional information.

Forward Osmosis with Crystallization

ClearFlo Membrane Brine Concentrator (MBC)™ by Oasys Water is a forward osmosis and crystallizer system for the recovery of water from concentrated brine. Forward osmosis uses a semipermeable membrane to concentrate a brine solution based on an osmotic dilution process. Forward osmosis acts as a pre-concentration step prior to crystallization to reduce the energy requirements of evaporation in the crystallizer. Osmotic dilution occurs when a semipermeable membrane separates two fluids of different osmotic pressure. Water will permeate from the solution with the lower osmotic pressure (feed solution) to the solution with higher osmotic solution (draw solution). In this application, the brine acts as the feed solution. The concentrated draw solution (CDS) consists of a thermolytic salt that can exert a higher osmotic pressure than the feed solution. The end product from the forward osmosis process is concentrated brine and a diluted draw solution (DDS). The DDS is fed to a recovery system that can recover the thermolytic salt using low grade heat that is recycled for further separation. The concentrated feed solution (brine) passes to a crystallizer for to produce a solid product.

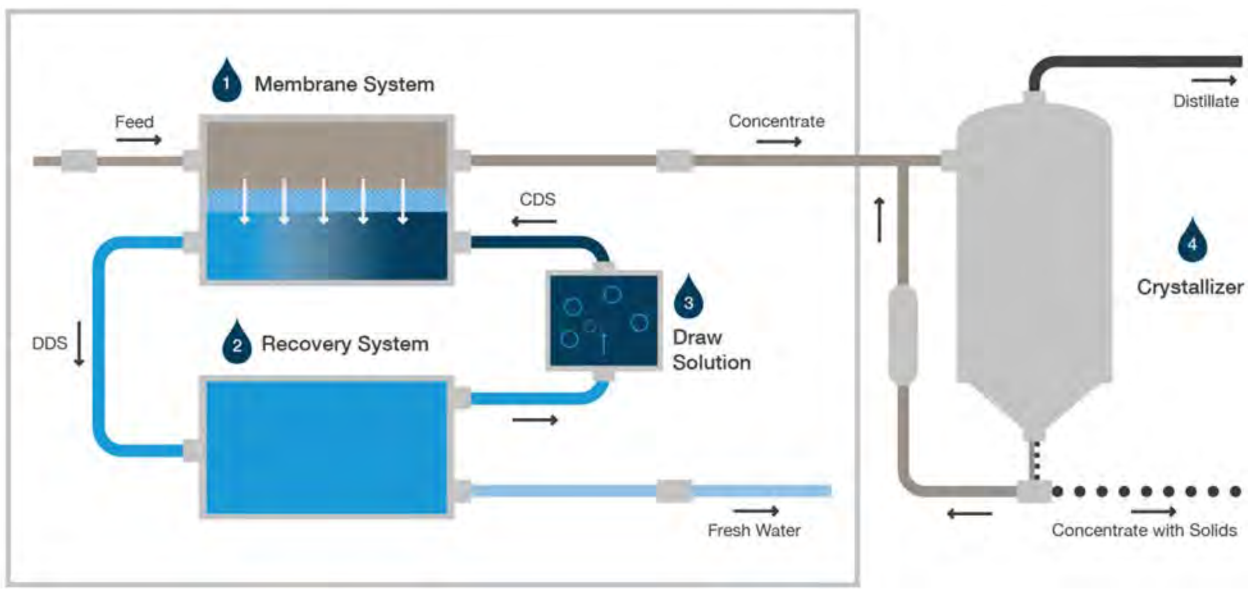

Figure 5— Schematic of ClearFlo MBC™ process
(from http://oasyswater.com/solutions/clearflo-complete/).

Advantages	Disadvantages
Combined forward osmosis and crystallization reduces crystallization energy requirements	Additional unit operations required for thermolytic draw solute recovery and recycling
No thermal scaling during concentration as forward osmosis is conducted at ambient temperatures	Only one vendor
More energy efficient than evaporative technologies	Limited full-scale installations

Vendors

Oasys Water

Installations

Power Plant Wastewater: Changxing, China (630 m3/day)

Produced Water: Permian Basin, Midland, Texas

Produced Water: Marcellus Shale (4-month study treating 60,000 gallons)

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

ClearFlo Complete™ system produces a solid product by using less energy than conventional systems. Therefore Oasys Water was contacted for additional information.

SAL-PROC™

SAL-PROC™ is a proprietary process developed by Geo-Processors, Inc. Through a series of reactions including conventional mineral and chemical processing steps, evaporation, and cooling, solids minerals, such as calcium chloride, are recovered from concentrated brine streams.

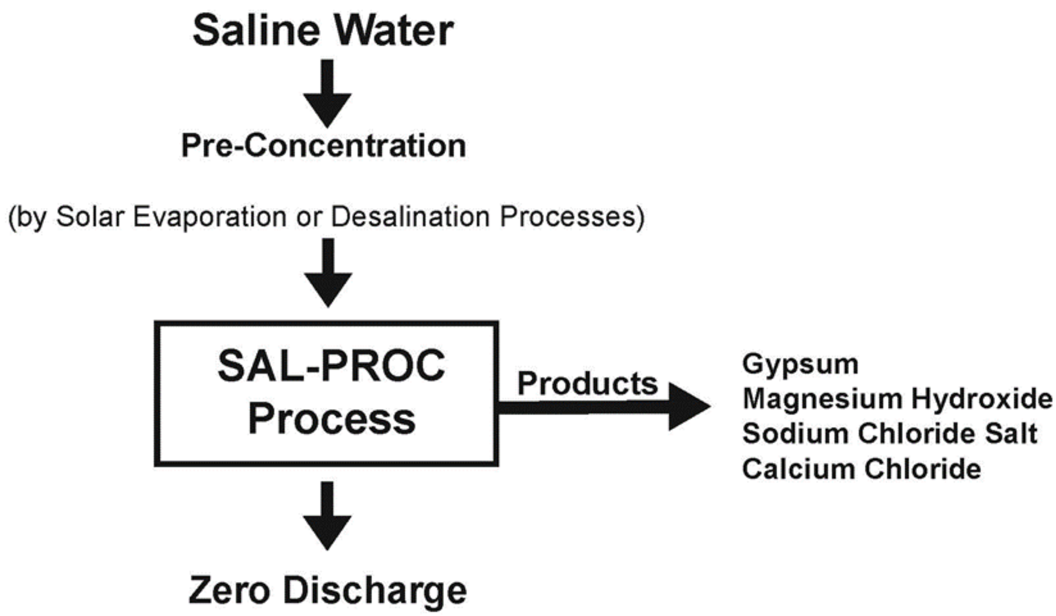

Figure 6— Schematic of SAL-PROC™ process (from http://www.geoprocessors.com/salproc.html).

Advantages	Disadvantages
Produces a solid that can be dewatered	Requires a heat source
Produces salable products	Requires evaporation ponds
	Limited installations, mostly field trials and pilot studies
	Only one vendor

Vendors

Geo-Processors, Inc.

Installations

It is unclear from initial research if any full-scale, permanent installations exist.

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

No full-scale installations were identified and salable products are not desired at the PVU. Therefore, Geo Processors, Inc. was not contacted.

Dewvaporation

Dewvaporation, or AltelaRain® by Altela, Inc., belongs to a class of technologies called humidification-dehumidification (HDH), which refers to thermal processes that operate below the boiling point of water. HDH processes operate based on the fact that hot air can carry more water vapor than cold air. Hot air in contact with salt water evaporates water, which results in cooling and a loss of sensible heat. Distilled water is recovered by contacting the humid air with a condensing surface. The condensation process produces heat that can be conveyed through a heat exchange surface back to the brine for continued evaporation. Dewvaporation differs from traditional HDH processes in that both water extraction and water condensation occur in the same heat exchanger tower.

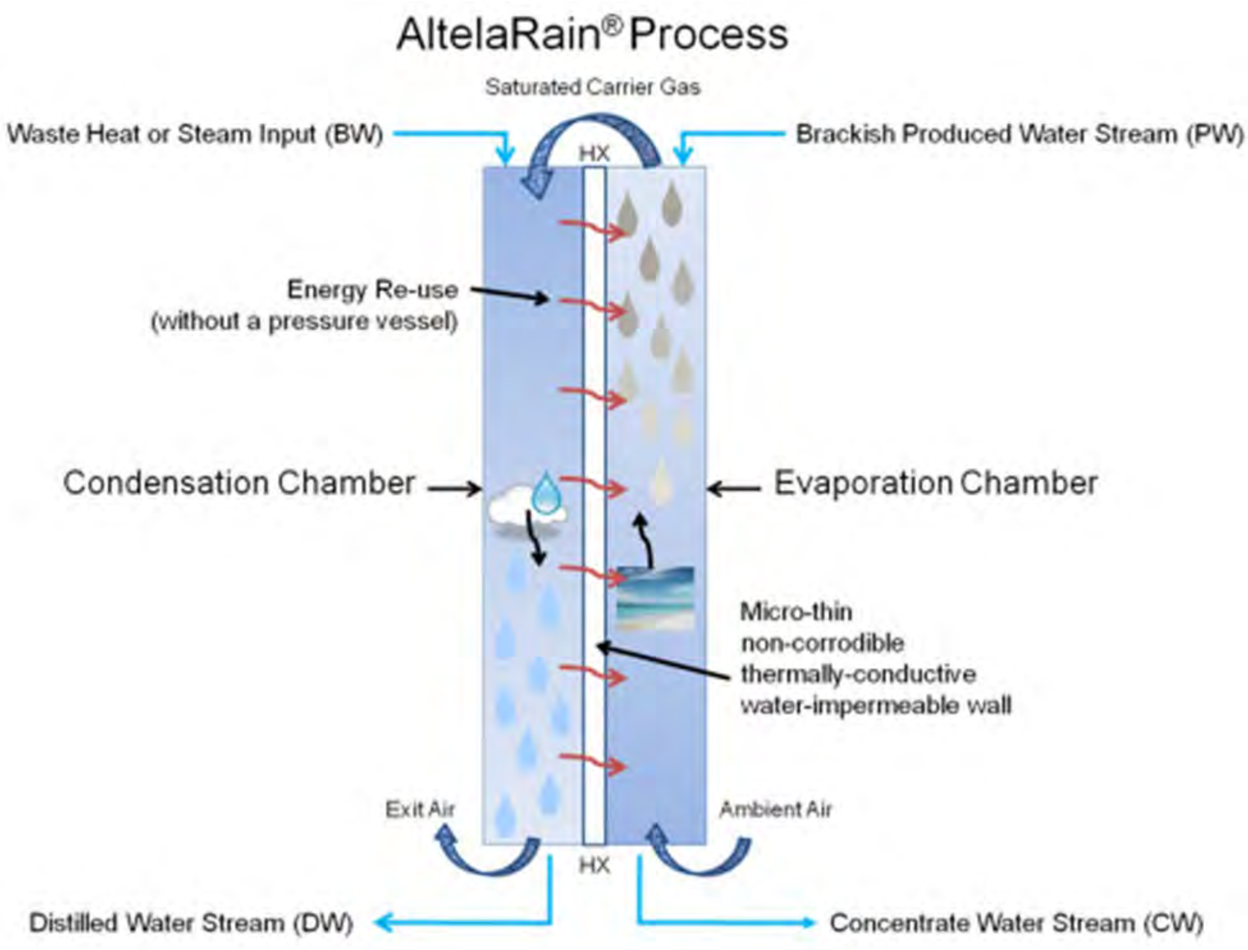

Figure 7— Schematic of AltelaRain® process (from http://altelainc.com/).

Advantages	Disadvantages
Many commercial installations for difficult-to-treat water types	Requires a heat source
Technology model for waste management (rather than "treatment")	May require large footprint relative to volume of brine managed
Reasonably low capital and operating costs	Does not directly produce a solid that can be dewatered
	Only one vendor

Vendors

Altela, Inc.

Installations

Leachate treatment facility, Pennsylvania

Clarion Altela Environmental Services Treatment Facility, Pennsylvania

South Platte River Basin Reverse Osmosis Brine, Colorado

Navajo Nation Waste-to-asset conversion, Navajo Nation, northwestern New Mexico

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

AltelaRain® has been used at the full-scale for similar applications. Therefore Altela, Inc. was contacted for additional information.

Electrodeionization (EDI)

EDI is an electrochemical treatment method that is designed to produce ultrapure water (conductivity 5-17 MOhm-cm). Electrodes (i.e., anode and cathode) are used to induce ion transport towards the appropriate electrode. Between the electrodes lies both anion and cation ion exchange resins. Dissolved ions exchange sites on the resin releasing either protons (H+) or hydroxide ions (OH-) in their place. The system produces an ultrapure product and a concentrate stream. Regeneration of the ion exchange resin depends on the specific model. Some units regenerate continuously while others require periodic regeneration.

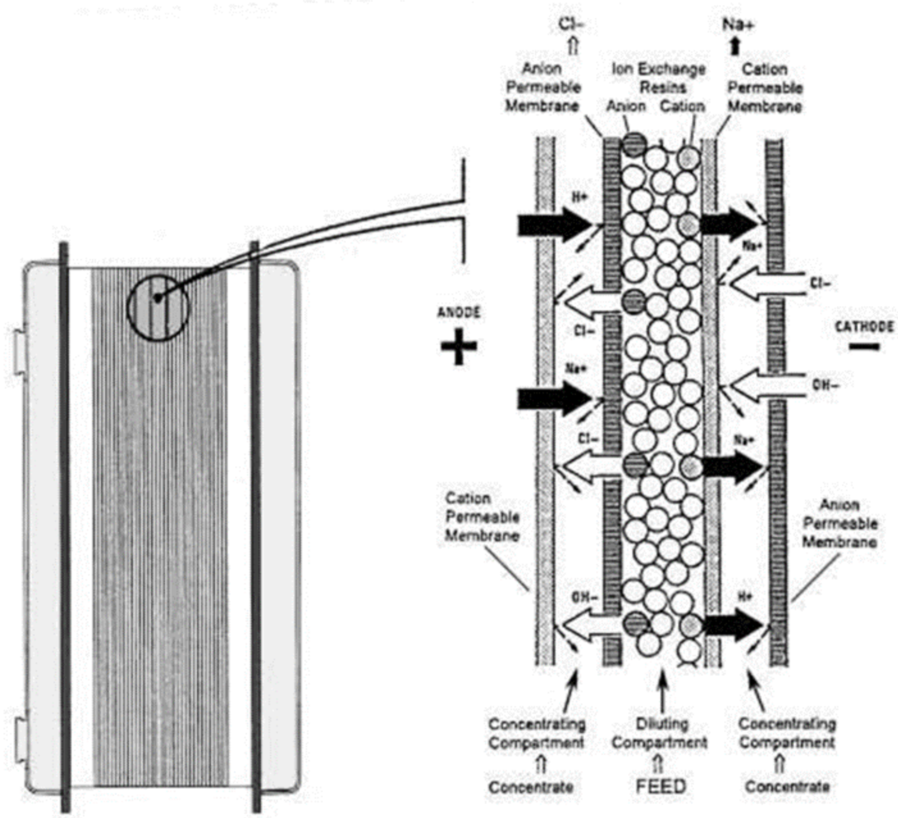

Figure 8— Schematic of EDI process (from http://www.reverseosmosis.com.au/webcontent6.htm).

Advantages	Disadvantages
Produces ultrapure product (5-17 MOhm-cm) with low organic carbon (<20 ppb)	Most models not designed for high salinity feed waters
No chemical regeneration	Evoqua model can only handle influents with a TDS up to 750 mg/L
No resin or chemical disposal	Does not directly produce a solid that can be dewatered

Vendors

GE Water	Dow Water	SnowPure Water Technologies
Veolia	Cal Water	Evoqua

Installations

No installations relevant to application of interest

Potential for Integration with Renewable Energy

There are no heat requirements and therefore there is minimal potential for renewable energy to provide a direct energy offset for this technology.

Technology Disposition

This technology is not intended for high salinity water. Therefore EDI vendors were not contacted.

Electrodialysis Reversal (EDR)

EDR is an electrochemical-driven separation process. An electrical potential difference is applied across an anode and cathode, which drives dissolved ions to migrate through solution to the appropriate electrode (i.e., cations migrate towards the cathode). In between the electrodes, ion exchange membranes are layered alternating cation-selective and anion-selective membranes. Ions migrating in opposite directions can pass through one selective membrane but will be rejected by the next membrane of opposite selectivity. This process leads to an accumulation of ions in alternating layers and desalinated water between the remaining layers. This process produces a desalinated product stream and concentrated brine. The polarity of the electrodes may be periodically reversed to prevent fouling or scaling.

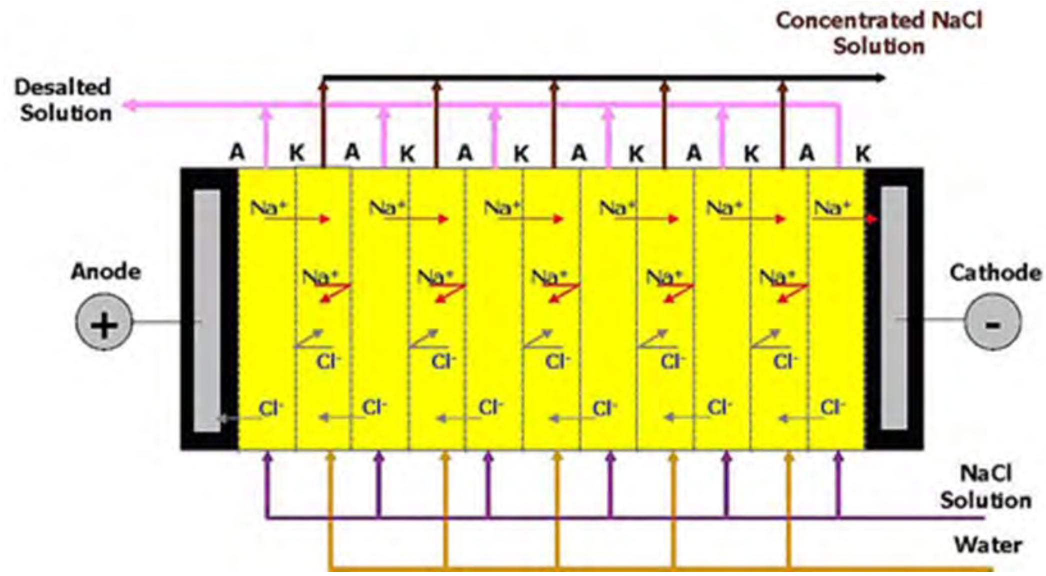

Figure 9—Schematic of EDR process (from http://www.netl.doe.gov/research/coal/crosscutting/pwmis/tech-desc/membrane).

Advantages	Disadvantages
Electrical energy input rather than thermal	Most economical for low TDS feed solutions
Ideal for feeds with high scaling potential	Evoqua Ionpure® VNX-Si unit has a nominal recovery of 68% and maximum feed TDS of 750 mg/L as NaCl
	GE 2020 system designed for feed TDS up to 12,000 mg/L
	Does not directly produce a solid that can be dewatered

Vendors

GE

Evoqua

Installations

Evoqua Ionpure® VNX-Si module treats up to 5 gpm of RO concentrate. Can be installed in parallel

GE 2020 EDR System produces 280 or 520 gpm depending on model

Potential for Integration with Renewable Energy

There are no heat requirements and therefore there is minimal potential for renewable energy to provide a direct energy offset for this technology.

Technology Disposition

This technology is not intended for high salinity water. Therefore EDR vendors were not contacted.

Freeze Thaw/Evaporation

Freeze-thaw/evaporation, or FTE® by Polar Bear Water Treatment, LLC, allows for both salt removal from brine and disposal of water. When the ambient temperature drops below 0°C, brine is sprayed onto a freezing pad. As the spray freezes, an ice pile forms. Brine, with elevated salt concentrations and lower freezing point, drains naturally from the ice piles. The high-salinity brine, identified by its high electrical conductivity, is separated and pumped to a pond where it is later evaporated or stored for beneficial use. When the ice on the freezing pond melts, the purified water is pumped from the freezing pond and discharged or stored for later beneficial use. During the warmer months, the FTE® facility operates as a conventional evaporation facility. No new wastes are generated by the FTE® process and no chemical addition is required. Coupling the natural processes of freezing and evaporation makes the FTE® process more economical and effective for the treatment and disposal of brine and allows for year-round operation of the FTE® facility.

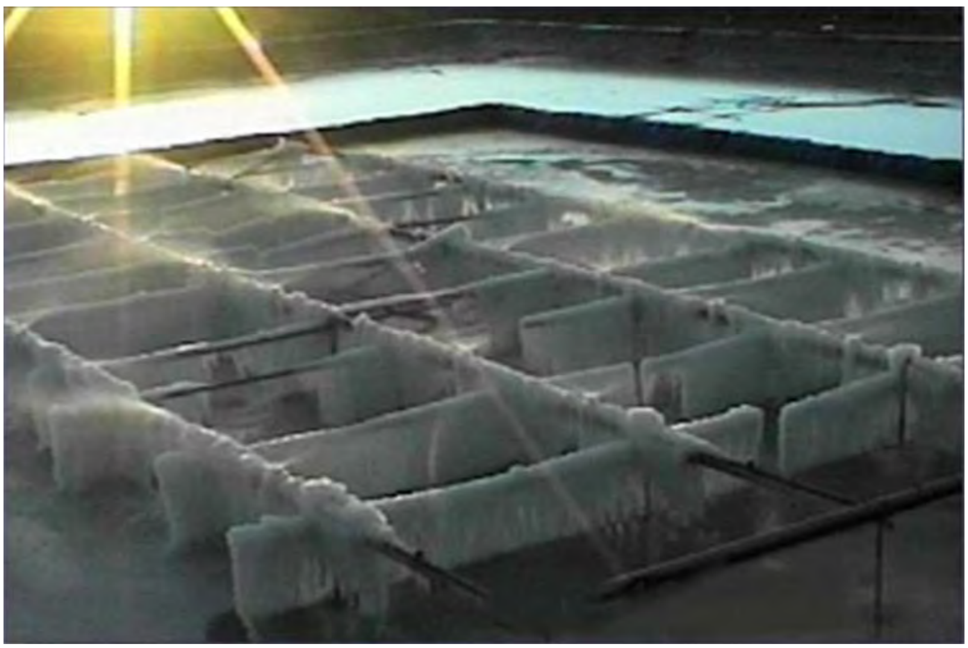

Figure 10—Photo of FTE® field demonstration (from http://polarbearwater.net/).

Advantages	Disadvantages
Minimal external energy requirement	Potentially large land area required
Low operational cost	Water processing capability is seasonally dependent
	Only one vendor
	Significant residual brine produced
	Does not directly produce a solid that can be dewatered

Vendors

Polar Bear Water Treatment, LLC

Installations

Treatment of produced water, Sweetwater county, Wyoming

Potential for Integration with Renewable Energy

This process relies primarily on environmental conditions for freezing, thawing, and evaporation. Therefore, there is little need for the incorporation of additional renewable energy to reduce the energy consumption of this process.

Technology Disposition

This technology would require significant land area, require additional fluid processing, and is seasonally dependent. Therefore, Polar Bear Water Treatment, LLC was not contacted.

Membrane Distillation (MD)

MD)uses hydrophobic membranes to allow the passage of water vapor but not liquid water or brine through the membrane. On the feed side of the membrane, water vapor generated from preheated brine (50 to 60°C) passes through the hydrophobic membrane and condenses on the permeate side. Condensation of the water vapor permeate is enhanced by heat exchange with a chilled concentrate stream or coolant. The condensate is collected as a combined distillate for fresh water use. Final brine concentrations will depend on the influent water quality and difference in temperature between the feed and chilled concentrate stream.

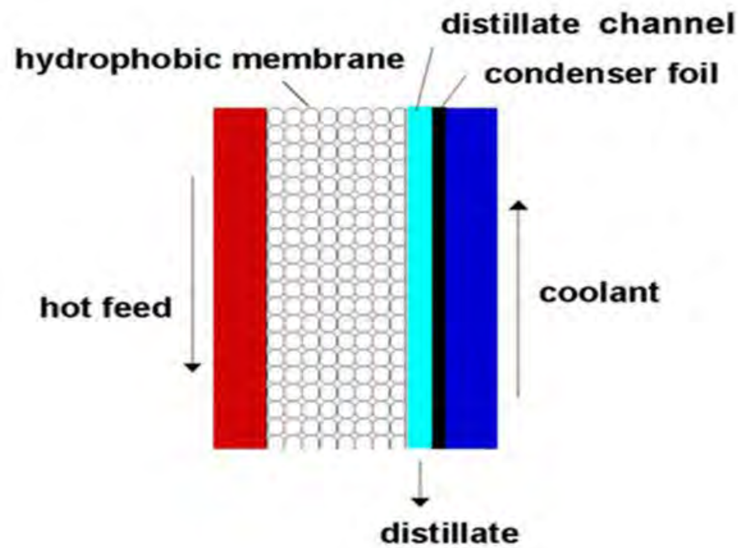

Figure 11—Schematic of MD process (from http://www.solarspring.de/index.php?id=7).

Advantages	Disadvantages
Produces high quality water	Heat source required
Concentrates brine streams	Scaling and corrosion from inorganics with some module configurations
	Does not directly produce a solid that can be dewatered
	Most systems are low feed flow (~1 to 4 gpm)

Vendors

Solar Spring

Aquaver

Memsys

Installations

Maldivian Island of Gulhi, 1.8 gpm

Mostly bench- and pilot-scale

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

MD has not been implemented for an application of this scale and is still in development. Therefore, MD vendors were not contacted.

Multi-Effect Distillation (MED)

MED uses a series of reduced pressure stages to produce water vapor and subsequently condense it into fresh water. Preheated influent salt water or brine enters the first stage, or effect, where it is evaporated by spraying it over a heat exchanger. The water vapor enters the next stage on the inside of a heat exchanger in which it condenses due to cool influent water contacting the outside of the heat exchanger. Each subsequent stage has a lower pressure than the previous one. Water that does not vaporize is collected as concentrated brine at the bottom of each stage. Concentrated brine travels through each stage until it is discarded after the final stage. Final brine concentrations depend on the influent water quality and the number of stages.

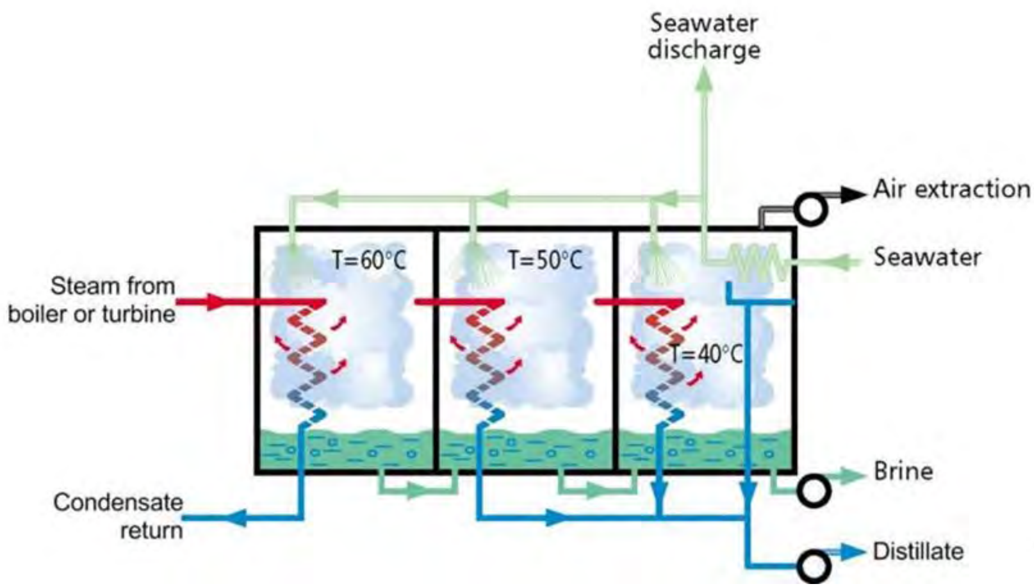

Figure 12— Schematic of MED process (from http://www.sidem-desalination.com/en/Process/MED/Process).

Advantage	**Disadvantages**
Produces high quality water	Energy intensive
Widely used for desalination (mainly in the Middle East)	Readily available supply of steam required
	Scaling and corrosion from inorganics
	Does not directly produce a solid that can be dewatered

Vendors

Sidem (Veolia)

Wabag

AquaSwiss AG

IDE Technologies

Alfa Laval

Installations

Ras Laffan C IWPP, Qatar (7.6 MGD units)

Fujairah II IWPP, United Arab Emirates (10 MGD units)

Marafiq IWPP, Saudi Arabia (7.9 MGD units)

Zawia Derna Sussa, Libya (5.3 MGD units)

Al Hidd IWPP, Bahrain (7.2 MGD units units)

Layyah D12/D13, United Arab Emirates (9.6 MGD units)

Abutaraba, Libya (3.5 MGD units units)

Ras Al Khaimah/Ajman, United Arab Emirates (6.0 MGD units)

Al Taweelah A1, United Arab Emirates (4.5 MGD units)

Layyah D10/D11, United Arab Emirates (6.0 MGD units)

Umm Al Naar West, United Arab Emirates (4.2 MGD units)

Tobruk, Libya (3.5 MGD units)

Al Ghalilah, Oman (0.13 MGD units)

Priolo Gargallo, Italy (1.9 MGD units)

Jebel Dhanna, United Arab Emirates (2.4 MGD units)

Curacao, Netherland Antilles (3.2 MGD unit)

Trapani, Italy (2.4 MGD units)

Pantelleria, Italy (0.42 MGD units)

Hangu, Tianjin, China (52.8 MGD)

Jamnagar, Gujarat, India (42 MGD)

Jamnagar, Gujarat, India (17 MGD)

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

MED is a well-established technology and could be used to reduce the PVU brine volume. Therefore MED vendors were contacted for additional information.

Multi-Effect Distillation Mechanical Vapor Compression (MED-MVC)

MED-MVC is similar to other distillation processes, except that a heat pump configuration is used to generate steam. Feed water enters the system and passes through a heat exchanger where it is preheated by the heated brine and distillate streams exiting the system. The heated feed solution is then sprayed on to heated coils where a fraction of the incoming stream evaporates to form steam. The steam passes through a compressor that increases the temperature before the steam enters the inside of the heat exchanger coils to act as the heat source to evaporate more incoming feed. The steam condenses inside the heat exchanger coils forming a distilled water product. Brine that does not evaporate upon first pass of the heat exchanger can be recycled or used in a multi-effect configuration. The main difference between this system and other distillation processes is that the heat source is compressed vapor formed by the incoming feed solution, and a separate boiler with a closed loop steam cycle is not needed. The end product is concentrated brine that would be sent to a crystallizer for complete water removal.

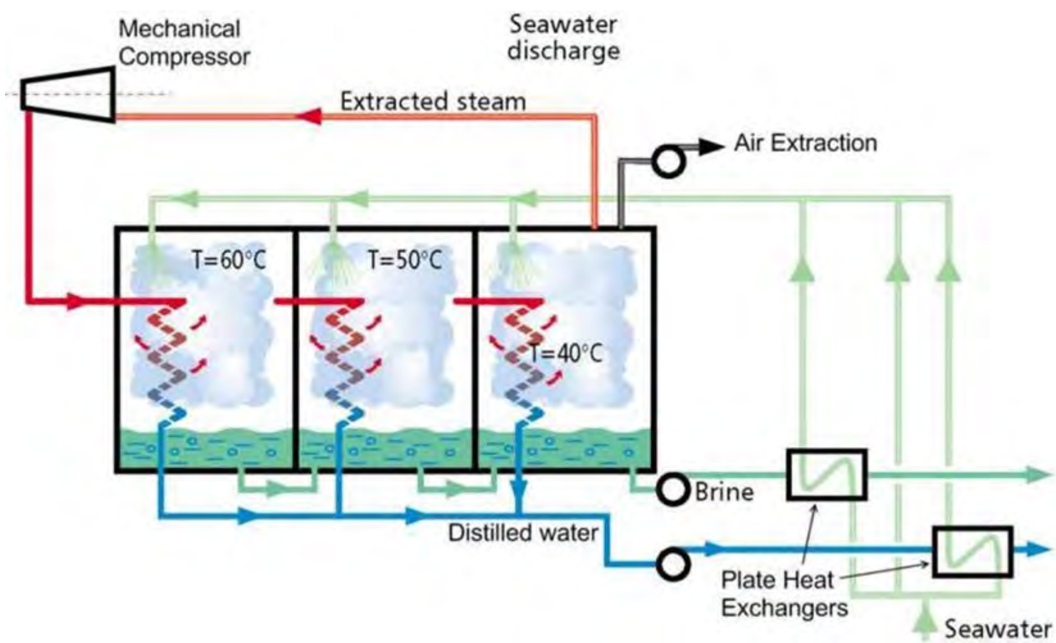

Figure 13— Schematic of MED-MVC process (from http://www.sidem-desalination.com/en/Process/MED/MED-MVC).

Advantages	Disadvantages
Higher thermal efficiency compared to MED	Energy intensive evaporative process
No external boiler needed to provide steam	Does not directly produce a solid that can be dewatered

Vendors

Sidem Veolia

Aqua Swiss

IDE Technologies

Alfa Laval

Wabag

Installations

Al Ghalilah, Sultanate of Oman (2 x 0.13 MGD)

Pantelleria, Italy (2 x 0.42 MGD)

Sardinia, Italy (4.6 MGD)

Turkmenbashi, Turkmenistan (2 x 0.79 MGD)

Puerto Coronel, Chile (0.51 MGD)

Nueva Ventanas, Chile (2 x 0.3 MGD)

Tocopilla, Chile (0.16 and 0.096 MGD units)

Emlichheim Oil Field, North Germany (0.32 MGD)

Tutuka Power Station, South Africa (0.32 MGD)

Burrup, Peninsula, Australia (0.95 MGD)

CHP, Taba, Egypt (0.53 MGD)

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

MED-MVC is a well-established technology and could be used to reduce the PVU brine volume. Therefore MED-MVC vendors were contacted for additional information.

Multi-Effect Distillation Thermal Vapor Compression (MED-TVC)

MED-TVC is similar to MED-MVC desalination with one modification. A thermo-compressor is used rather than a mechanical compressor to generate steam to feed to the evaporator. Medium or low pressure motive steam generated by a boiler is fed to the thermo-compressor via a sonic nozzle. The expansion of this steam sucks in water vapor evaporated from the brine. A shock wave within the compressor increases the pressure of the steam before exiting the compressor. This steam is used as the heat source in the heat exchanger bundles to evaporate more liquid from the brine. The unit produces distilled water and concentrated brine. The concentrated brine would then be fed to a crystallizer to produce a solid salt product.

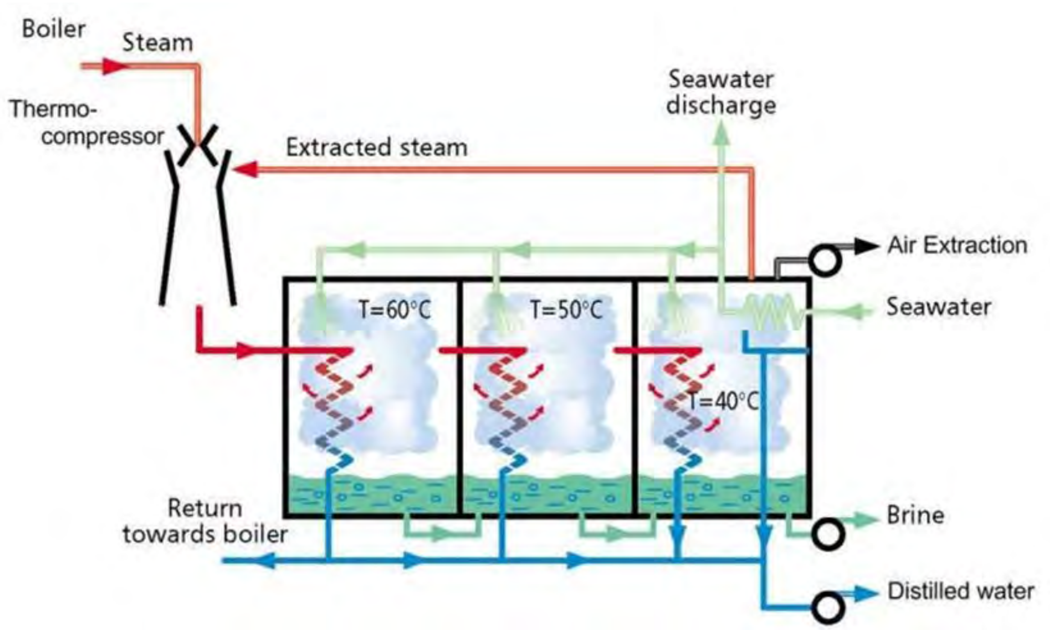

Figure 14— Schematic of MED-TVC process (from http://www.sidem-desalination.com/en/Process/MED/MED-TVC/).

Advantages	Disadvantages
Higher thermal efficiency compared to MED	Energy intensive evaporative process
Reduced inorganic scaling risk	Requires a boiler in addition to the thermo-compressor to produce motive steam
Efficient use of latent heat from evaporated brine with a 'heat pump' design	Does not directly produce a solid that can be dewatered
High gain output ratios (upwards of 17 kg distillate produced per kg of motive steam fed)	

Vendors

Wabag

Sidem/Veolia

Installations

Suralaya, Java, Indonesia (1.59 MGD)

Benghazi, Libya (1.27 MGD)

Pertamina, Indonesia (1.32 MGD)

Tobruk, Libya (3.5 MGD)

Layyah, United Arab Emirates (2 x 6 MGD)

Ras Laffan, Qatar (10 x 6.3MGD)

Fujairah, United Arab Emirates (12 x 8.33 MGD)

Marafig, Saudi Arabia (27 x 6.59 MGD)

Zawia Derna Sussa (8 x 5.3 MGD)

Al Hidd (10 x 6 MGD)

Layyah D12/D13, United Arab Emirates (2 x 8 MGD)

Abutaraba, Libya (3 x 3.4 MGD)

Ras Al Khaimah, United Arab Emirates (3 x 6.0 MGD)

Al Taweelah, United Arab Emirates (14 x 3.77 MGD)

Layyah D10/D11, United Arab Emirates (2 x 6.0 MGD)

Umm Al Naar West (2 x 4.2 MGD)

Tobruk, Libya (3 x 3.5 MGD)

Al Ghalilah (2 x 0.13 MGD)

Jebel Dhanna (2 x 2.4 MGD)

Curacao, Netherland Antilles (1 x 3.17 MGD)

Trapani, Italy (2 x 2.37 MGD)

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

MED-TVC is a well-established technology and could be used to reduce the PVU brine volume. Therefore MED-TVC vendors were contacted for additional information.

Multi-Stage Flash Distillation (MSFD)

MSFD uses a series of reduced pressure stages to flash, or generate water vapor, from preheated influent salt water or brine. Generated water vapor condenses on the outside of condenser tubes that also act as influent water piping. Condensed water vapor is collected in trays as a combined distillate for fresh water use. Increasingly concentrated brine then travels to subsequent stages where flashing is enhanced using decreasing pressures until it is discarded after the final stage. Final brine concentrations depend on the influent water quality and the number of stages.

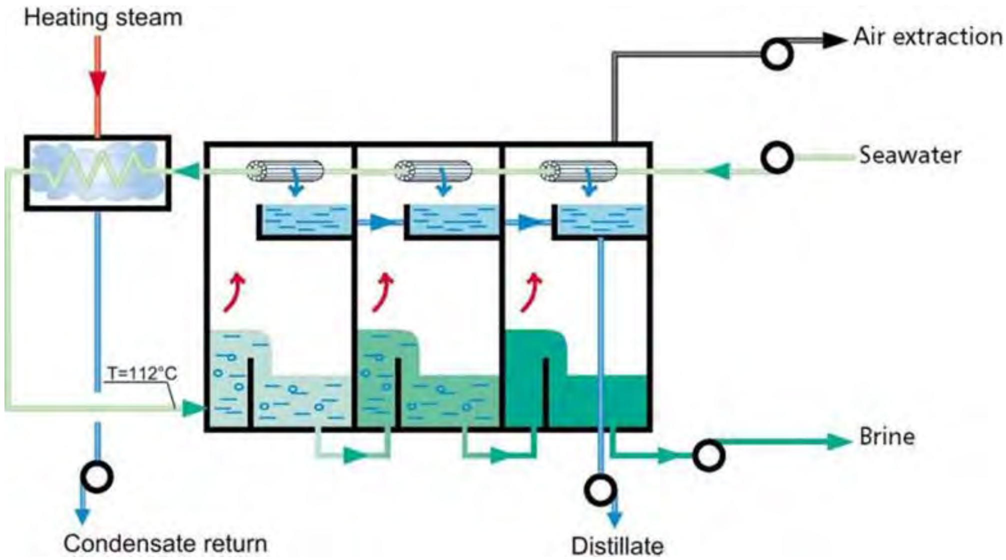

Figure 15— Schematic of MSFD process (from http://www.sidem-desalination.com/en/Process/MSF/).

Advantages	Disadvantages
Produces high quality water	Energy intensive
Widely used for desalination, many installations in the Middle East	Readily available supply of steam required
	Scaling and corrosion from inorganics
	Does not directly produce a solid that can be dewatered
	Most existing installations for flows larger than 0.43 MGD

Vendors

Sidem (Veolia)

Wabag

Installations

Al Taweelah A, United Arab Emirates (8.8 MGD units)

Umm Al Naar East & West, United Arab Emirates (7.3 MGD units)

Al Khobar 2, Saudi Arabia (7.0 MGD units)

Abu Dhabi 1, United Arab Emirates (4.0 MGD units)

Zliten, Libya (2.6 MGD units)

Potential for Integration with Renewable Energy

Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

MSFD is a well-established technology and could be used to reduce the PVU brine volume. Therefore MSFD vendors were contacted for additional information.

Pellet Softening

Pellet softening uses seeding nuclei or ballast, typically fine sand, to initiate precipitation and settling of minerals such as calcium carbonate. The technology is widely used for softening but may also have application for concentrated brines. After raising the pH using lime or caustic soda, dissolved solids will precipitate onto the sand ballast until the combined specific gravity is high enough to cause the newly formed pellet to settle. Pellets are then removed from the fluidized bed system and dried prior to disposal. As pellets are removed, new sand is periodically added to the system.

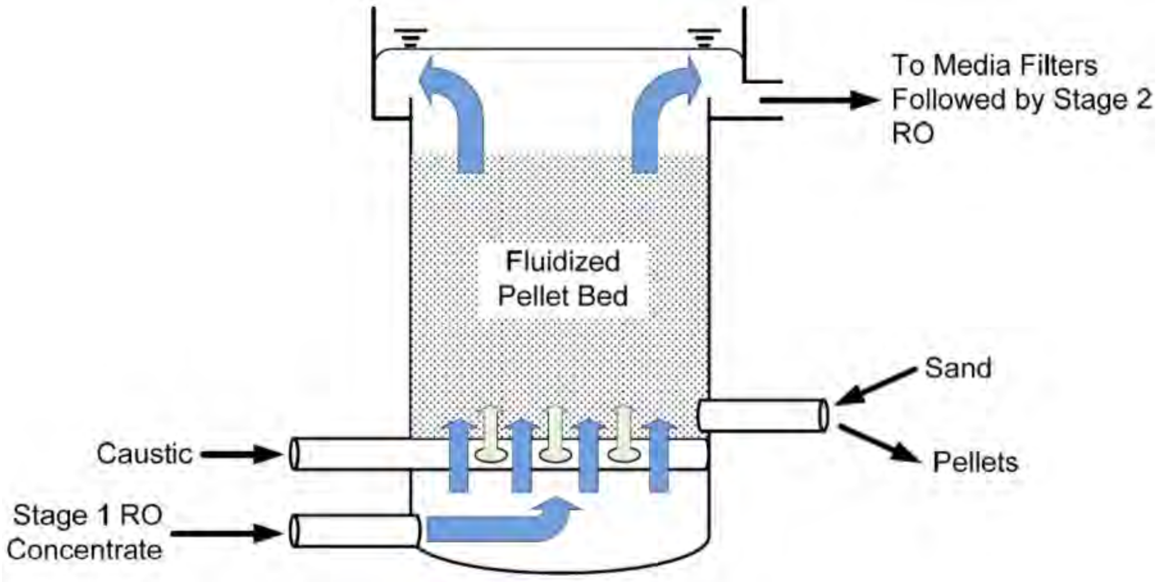

Figure 16— Schematic of a pellet softening process (from http://www.chinodesalter.org/DocumentCenter/View/23).

Advantages	Disadvantages
Produces high quality water	Energy intensive
Widely used for desalination, many installations in the Middle East	Readily available supply of steam required
	Scaling and corrosion from inorganics
	Does not directly produce a solid that can be dewatered
	Most existing installations for flows larger than 0.43 MGD

Vendors

Rwb

Veolia

Installations

Rouessé-Fontaine, France, (2015), 880 gpm

Mandelieu-La Napoule, France, (2014), 6605 gpm

Montsoult, France, (2014), 1233 gpm

Bruz, France, (2013), 1211 gpm

Montry, Marne et Morin, France, (2012), 1277 gpm

Puchay, France, (2011), 572 gpm

Bouil de Chambon, France, (2011), 2202 gpm

Courcelles-la-Forêt, France, (2010), 705 gpm

Cluses, France, (2009), 1101 gpm

Sète, France, (2008), 5280 gpm

Emmerin-Arbrisseau, France, (2007), 5504 gpm

Torcy, France, (2003), 1651 gpm

Beaune, France, (2003), 2202 gpm

Ijzeren Kuilen, Netherlands, (2000), 10,040 gpm

Malmö, Sweden, (1999), 24,400 gpm

Val-de-Reuil, France, (1994), 3960 gpm

Leiduin, Netherlands, (1987), 55,042 gpm

Potential for Integration with Renewable Energy

The potential for renewable energy to offset power requirements for this process is low.

Technology Disposition

Pellet softening would remove some dissolved salts from the PVU brine but mostly divalent ions such as calcium, leaving sodium chloride still dissolved. Pellet softening also does not reduce brine volume. Therefore pellet softening vendors were not contacted.

Wind Aided Intensified Evaporation (WAIV)

WAIV uses high surface area materials that are wetted with concentrated brine to increase evaporation volumes. At the surface of evaporation ponds, wind velocities are slower and the evaporation efficiency decreases with increasing pond area. Volcanic rock, geotextiles, and nettings have been used to provide the higher surface area while still allowing wind to pass through WAIV units or arrays. Although the evaporation rates per unit area are less than pan evaporation due to tight array arrangements, cumulative evaporation volumes can be much greater than pan evaporation. Therefore, WAIV units can have a much smaller footprint than evaporation ponds.

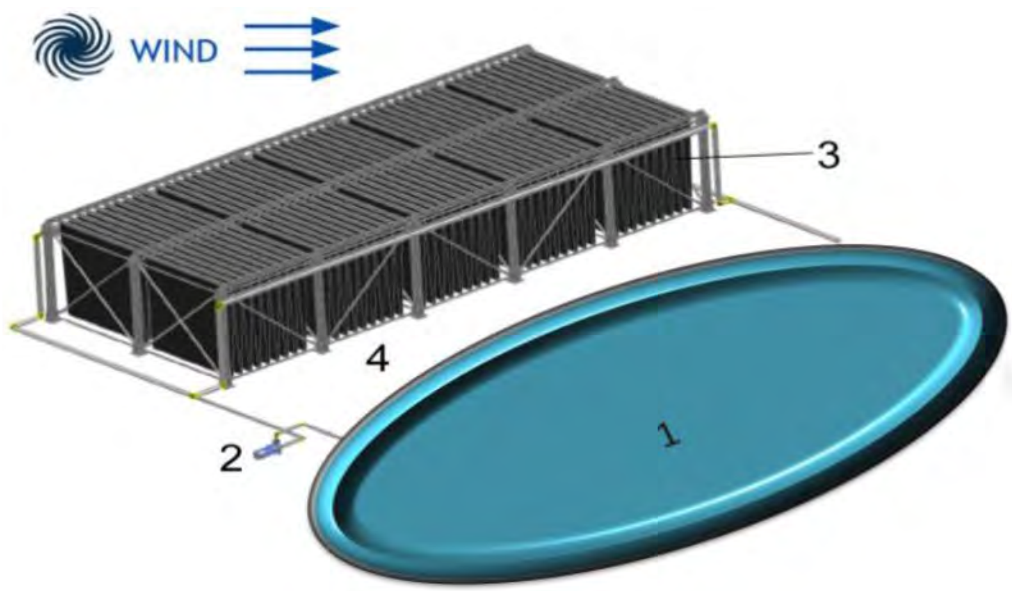

Figure 17— Schematic of the WAIV process (from http://www.lesico-cleantech.com/wp-content/uploads/Lesico-CleanTech-Report.pdf). 1 holding pond, 2 – feed pump, 3 – wetted evaporation surfaces, 4 – impervious surface to allow brine to flow back to holding pond.

Advantages	Disadvantages
Low energy requirements	Does not directly produce a solid that can be dewatered
Smaller footprint than conventional evaporation ponds	Still requires larger areas
	Still requires small (evaporation) holding pond, from which solids will have to be removed
	Limited full-scale applications

Vendors

Lesico CleanTech

Installations

Desalination plant at General Motors in Ramos Arispe, Mexico (pilot-scale)

Mineral brines, Dead Sea Works, Israel (pilot-scale)

Produced water management for Santos, Australia (pilot-scale)

Pettavel winery brackish water reverse osmosis plant, Melbourne (pilot-scale)

Copping landfill, Tasmania (pilot-scale)

Mekorot (Israel's national water company) brackish water reverse osmosis plant (pilot-scale)

Mineral processing, Chile (pilot-scale)

Potential for Integration with Renewable Energy
Solar thermal or geothermal heat could be used to offset heat requirements.

Technology Disposition

Although evaporation ponds are already being considered under another project, the footprint of WAIV is smaller than conventional evaporation ponds. Therefore Lesico CleanTech was contacted.

Technology Assessment

Information request sheets (Appendix A) were sent to vendors of the technologies deemed relevant and potentially viable for the PVU. Rather than requesting vendors to provide additional information about specific technologies identified in the section titled Preliminary Technology Screening, vendors were requested to identify a technology appropriate for the PVU based on their company’s technology portfolio, knowledge, and field experience. It was stated in the information request that Reclamation is seeking additional information regarding potential solutions for the treatment/volume reduction of concentrated brine and/or byproducts for the existing PVU.

Background information including water quality was provided, but mainly the requests focused on acquiring the following information from the vendors:

Process/Technology description

Land requirements

Power requirements

Chemical requirements

Labor requirements

Capital cost

Solids water content

Fresh water production

Byproducts

Fate of H_2S

Solar thermal or geothermal potential

Demonstrated applications

Pilot testing potential

Environmental impacts

It was also stated that the information they provided would be used for planning purposes or preliminary level cost estimates of ±50 percent. Based on the preliminary screening in the section titled Preliminary Technology Screening, 18 technology vendors were contacted, of which 6 provided substantial responses. Vendor responses are not included in this version of the report, as these responses contained sensitive and proprietary information.

Technical Comparison

All responsive vendors proposed a thermal crystallization process to separate water from salt. The common thread between all proposed technologies is that heat input vaporizes water and crystallization processes occur when the brine becomes saturated with respect to specific solids (e.g., sodium chloride, calcium sulfate, etc.). The slurry is then dewatered prior to disposal. The means by which thermal energy is provided varied between vendors.

No salt recovery process inherently handles H_2S at the same time. Each vendor recommended a separate pretreatment step that would strip or oxidize H_2S. Since H_2S is a dissolved gas in solution, some vendors proposed strippers to transfer H_2S from the liquid phase to the vapor phase by increasing the brine temperature and passing it through a stripping tower that injects steam at the bottom. The gas-liquid separation occurs as the liquid phase travels down the column. Volatilized H_2S is usually passed through a sulfur recovery unit to prevent direct emission to the atmosphere.

Other vendors recommended methods that oxidize the sulfur containing compounds by either chemical (ozone) or thermal processes. These reduction-oxidation reactions would convert the H_2S to either elemental sulfur (S^0) or sulfate (SO_4^{2-}), both of which would be separated as solids in the crystallization process. These responses show that there are multiple approaches to addressing the H_2S content and that further investigation to identify the most effective H_2S control strategy is needed through additional testing.

Economic Comparison

Approach and Assumptions

Based on the responses received from vendors, a preliminary economic analysis was conducted to determine the present value (PV) cost of constructing and operating a treatment process that produces a solid salt product for landfill disposal. If a vendor provided a range of cost estimates, the PV was calculated using the low and high estimates.

All PVs were based on vendor estimates and a number of assumptions, and can only be considered preliminary. First, the assumed project lifetime was 50 years. To calculate the PV of all operating costs, the inflation rate of O&M expenses was assumed to be equal to the discount rate. Landfill disposal costs were not included in the calculations.

The capital and O&M costs provided by the vendors were used under the assumption that they are accurate within ±50 percent. It was assumed that vendors which reported O&M costs included a labor estimate. Some vendors did not provide estimated O&M costs. For these vendors, O&M costs were estimated based on the electricity costs to meet the power requirements at a rate of $0.08/kWh (U.S. Energy Information Administration, 2016) and labor costs of $100,000 per operator per year (including salary and overhead) with three shifts per day. Chemical costs were not included and assumed small compared to energy costs and compared to the uncertainty associated with other operating costs.

Results

A summary of the PV calculation is shown in table 4. The estimated PV costs for the technologies varied considerably, suggesting that further investigation, primarily bench- and pilot-scale testing, is needed to better refine the relative cost effectiveness of each technology. Changing the assumption that the inflation rate of O&M expenses is equal to the discount rate could have a significant impact on the calculations. If the inflation rate of O&M expenses is greater than the discount rate, the technologies with higher capital cost to O&M cost ratios would become relatively less expensive when compared with technologies with lower capital cost to O&M cost ratios. The opposite would be true if the inflation rate of O&M expenses is less than the discount rate. As stated, these process costs were inherently uncertain and should only be used to rationalize further investigations and process testing to refine process economics.

Table 4 — PV comparison of Brine Treatment Processes for the PVU.

Technology Vendor	Vendor Estimate				Present Value (PV)	
	Low Flow		High Flow		Total ($M)	
	Capital ($M)	O&M ($M/yr)	Capital ($M)	O&M ($M/yr)	Low	High
Vendor A	30	3.8	-	-	220	-
Vendor B	22[1]	3.5	-	-	197	-
Vendor C	30	0.64	39	0.86	62	82
Vendor D	14	5.3	-	-	279	-
Vendor E	15	4.3	20	4.3	230	235
Vendor F	24	2.1	-	-	129	-

[1] Because Vendor B only provided equipment and engineering capital costs at $7.4M, it was assumed this represented roughly a third of the total installed capital cost.

Preliminary Renewable Energy Assessment

Because of the large power requirement for the brine minimization technologies described in this report, offsetting the power requirement with renewable energy will be difficult but may offset electrical or thermal energy needs. However, renewable energy would provide some level of protection from escalating energy costs which could become a factor over a 50-year project life. The potential for renewable energy to offset a significant fraction of the process requirements will require more in-depth research and testing specific to the PVU site. The following section summarizes the energy potential from photovoltaic solar, solar thermal, and geothermal for the PVU.

Photovoltaic Solar

Photovoltaic solar cells convert solar irradiance to electricity but require large footprints due to low cell efficiencies. Photovoltaic solar may be used to offset some of the power consumed by the chosen brine treatment technology. The PVU is located in an area with moderate photovoltaic solar resources as shown in figure 18 from the National Renewable Energy Laboratory (NREL). To get an estimate of the land requirements for photovoltaic solar at the PVU, NREL's PVWatts® calculator was used (pvwatts.nrel.gov). Near Bedrock, Colorado, an area of approximately one acre corresponds to a direct current (DC) system size of 600 kW. In PVWatts® the following assumptions were specified:

- Standard module (crystalline silicon, 15% efficient, glass cover)
- Fixed, open rack, ground-mounted panels
- 14% system losses (soiling, shading, snow, etc.)
- DC to alternating current (AC) efficiency of 96%
- 20° panel tilt
- 180° azimuth (south facing)

According to PVWatts® a 1 acre solar array would generate approximately 1,000 MWh/yr (AC) near Bedrock, Colorado. A crystallization system would require approximately 44,000 MWh/yr (estimated from Technology Assessment section). Therefore, for photovoltaic solar panels to offset 50 percent of the energy required, a 22 acre array would be required.

Difficulties in using photovoltaic solar for energy-intensive processes are further illustrated by the recently constructed Carlsbad desalination plant in southern California (Poseidon Engineering, 2008). Preliminary plans had a 50,000 ft2 treatment plant building mounted with photovoltaic solar panels. The photovoltaic solar system was expected to generate approximately 777 MWh/yr of electricity with a net carbon footprint reduction of 275 tons of CO_2 per year. The total power use for the plant was expected to be 274,400 MWh/yr with a carbon footprint of 88,147 tons of CO_2/yr. The portion of the power offset due to solar was expected to be less than 1 percent. The anticipated cost of power generation using the photovoltaic solar system was calculated to be $0.50/kWh, or about five times more expensive than the power supplied from the electric grid. This does not rule out the use of photovoltaic solar at the PVU, but energy savings may not overcome the large footprint and/or capital cost requirements.

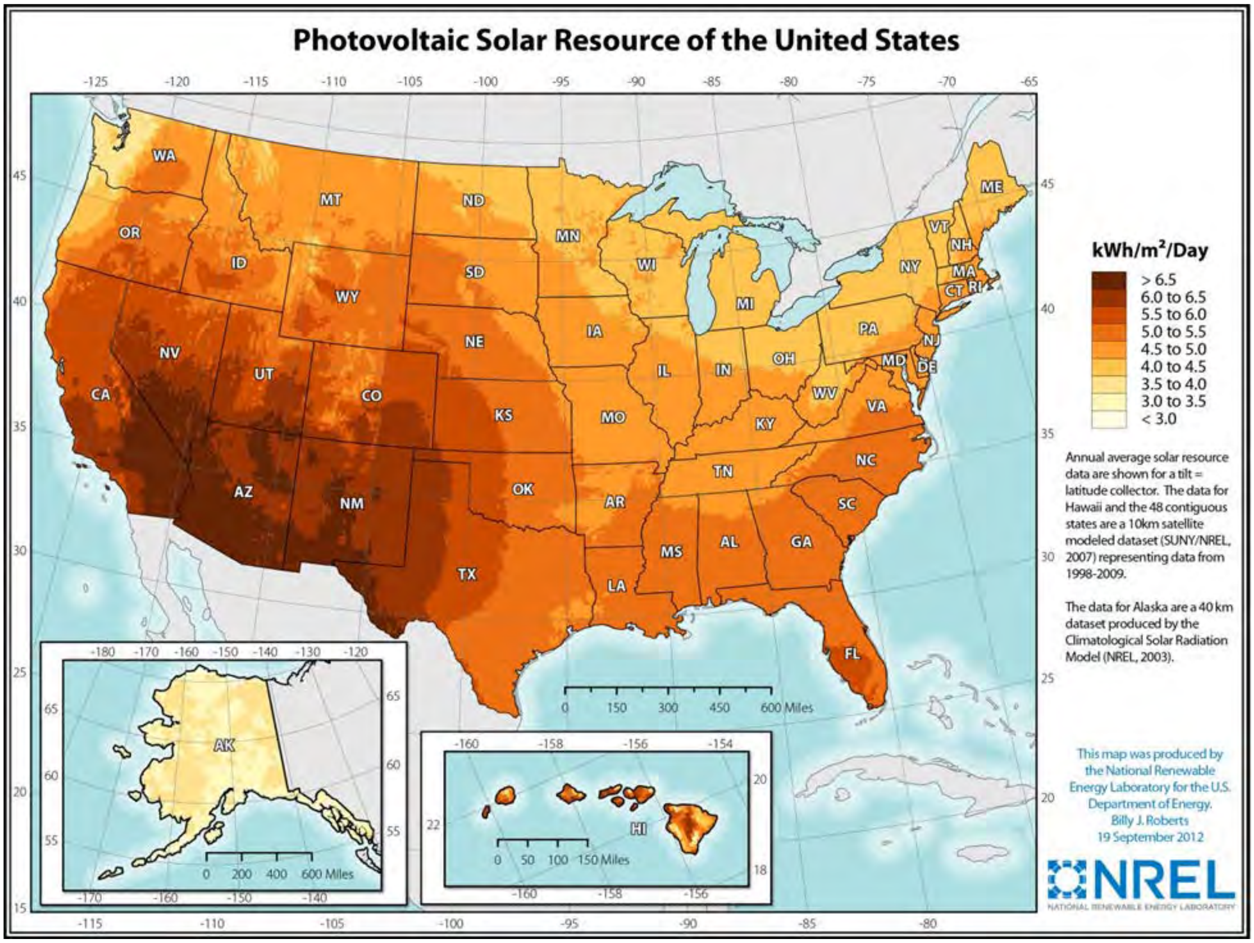

Figure 18— NREL map of photovoltaic solar resource potential (http://www.nrel.gov/gis/images/eere_pv/national_photovoltaic_2012-01.jpg). Approximate project location indicated by yellow circle.

Solar Thermal

Thermal energy from solar collectors can be used to preheat feed streams for thermal processes, which can offset energy requirements from other conventional heat sources (e.g., power plant waste heat and steam generation). Parabolic troughs or mirrors are examples of solar collector technologies. The PVU is located in an area with moderate concentrating solar resource availability as shown in figure 19 from NREL. Because many of the potential technologies use crystallizers to evaporate water from preheated brine, there is a potential for direct use of solar thermal energy as a heat source to reduce conventional energy requirements. One vendor identified solar thermal as a potential opportunity to incorporate renewable energy.

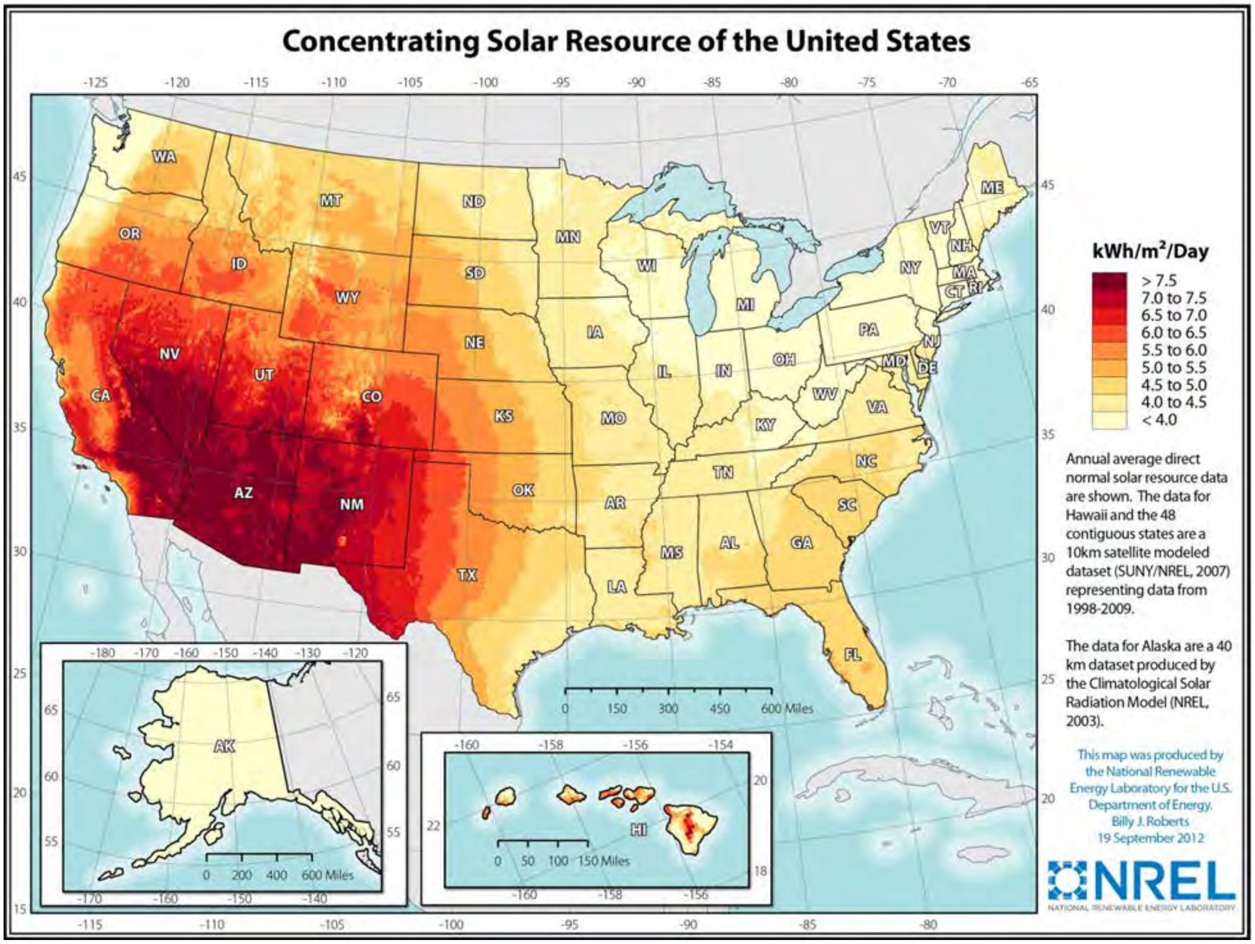

Figure 19— NREL map of concentrating solar resource potential (http://www.nrel.gov/gis/images/eere_csp/national_concentrating_solar_2012-01.jpg). Approximate project location indicated by yellow circle.

Geothermal

Geothermal power generation consists of a geothermal resource well, power generation equipment, and an injection well. Hot geothermal fluid is pumped up the production well, processed for energy conversion, and expanded through a turbine to power an electric generator. The used geothermal fluid is then pumped back into the geothermal reservoir. There are four different types of geothermal power plants; dry steam, single-flash, double-flash, and binary. Each geothermal source is unique and suited to a particular process design. Any of the designs can offset electrical or thermal energy requirements for the PVU. The electricity generated can be used to run pumps and other process equipment whereas thermal energy could be used to preheat brine. The PVU is located in an area with minimal geothermal gradient according to the interpretive map shown in figure 20. The map from NREL in figure 21 shows the PVU in an area with moderate geothermal potential. Therefore further testing would be needed to determine the exact capabilities of a geothermal well at the PVU location. Similar to solar thermal incorporation, an economic analysis would be needed to justify if the increased capital costs of geothermal outweigh the reduced operating costs.

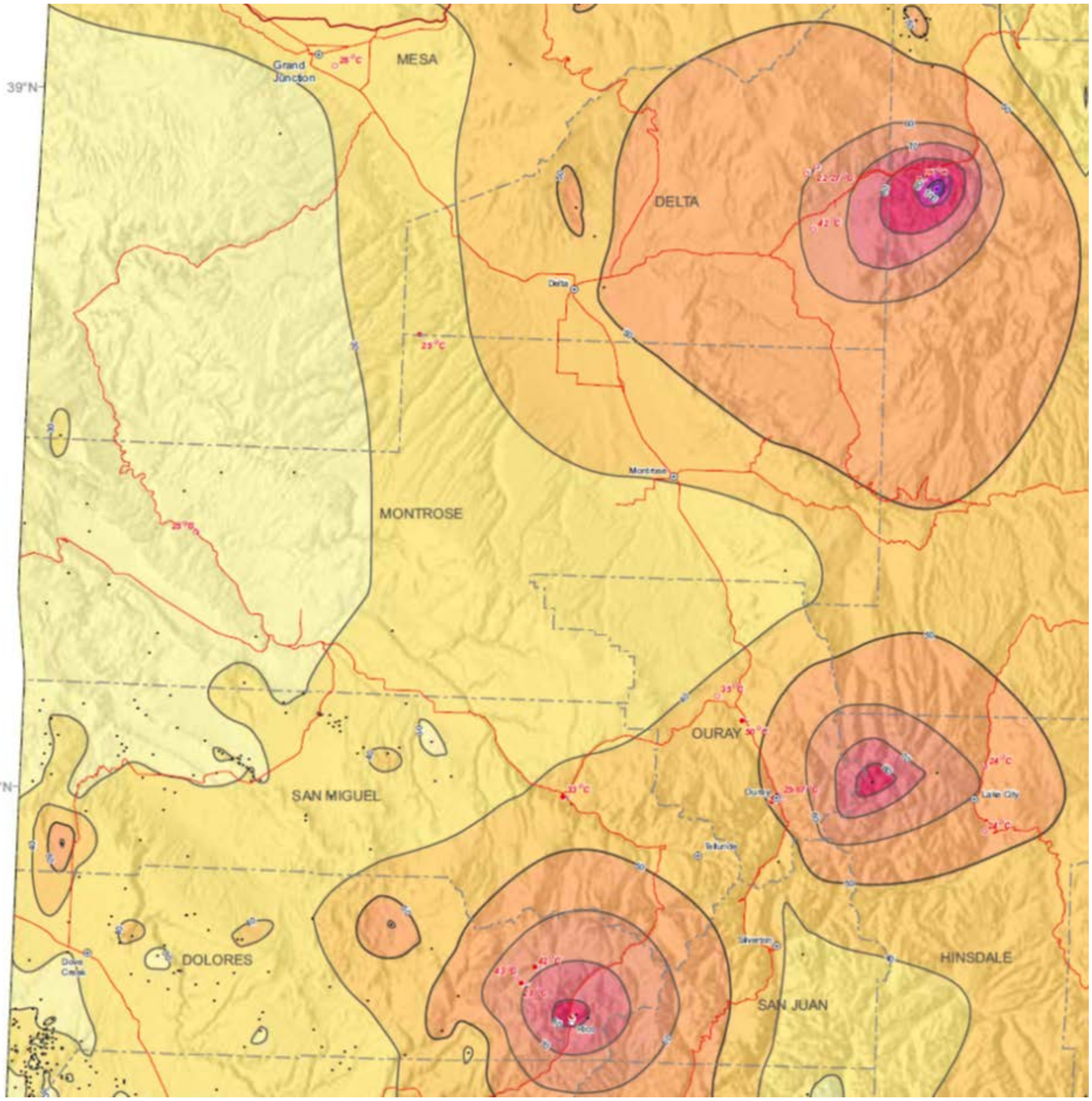

Figure 20— Interpretive geothermal gradient map of southwest Colorado (Berkman and Watterson, 2010). Approximate project location indicated by black circle.

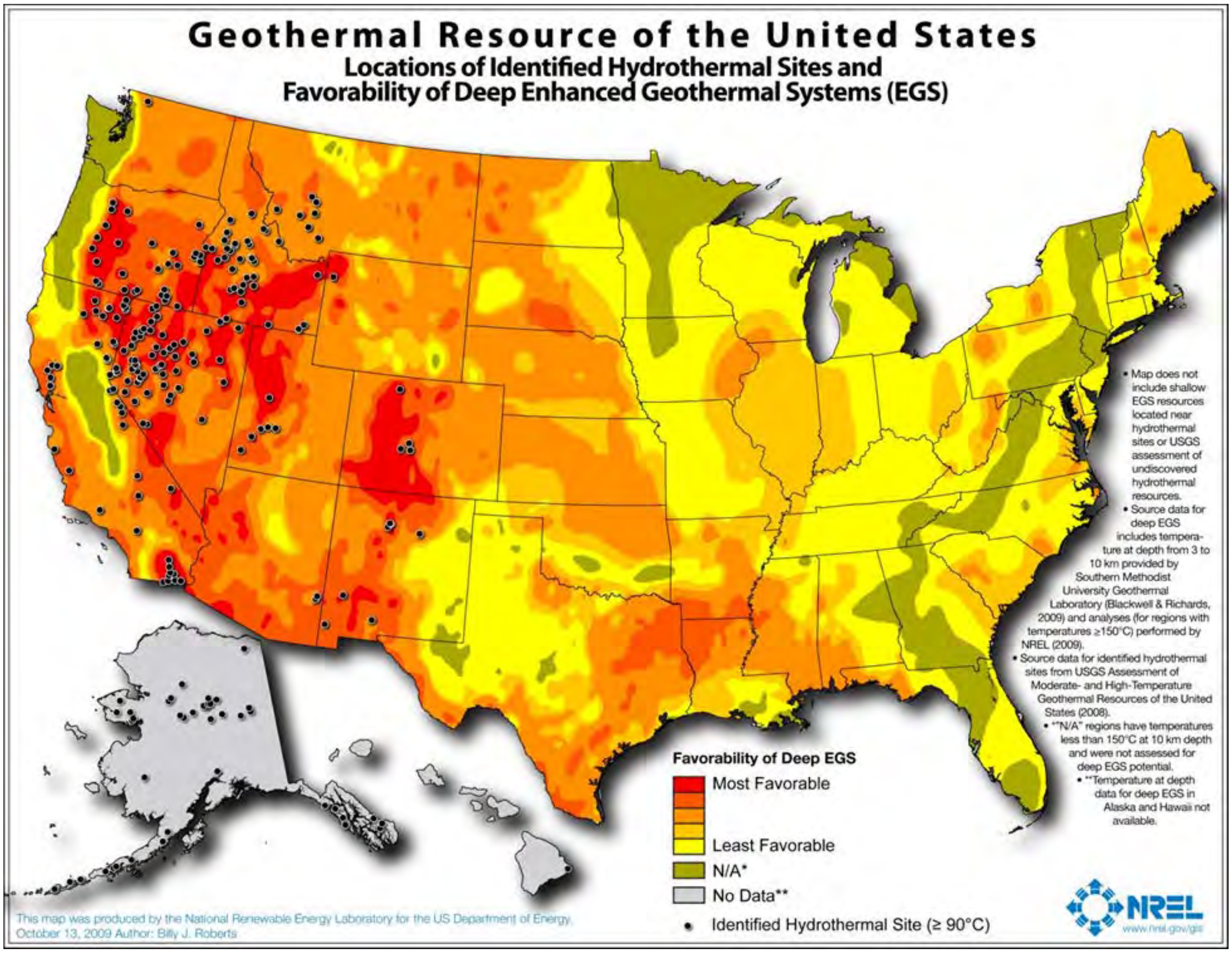

Figure 21— NREL map of geothermal resource potential (http://www.nrel.gov/gis/images/geothermal_resource2009-final.jpg). Approximate project location indicated by yellow circle.

Technology Testing

In the initial vendor request, there was an inquiry about vendor capabilities for pilot testing. After reviewing responses, a follow-up request was sent to inquire about bench-scale testing. A wide range of testing options exists with each requiring different brine quantities and costs and resulting in a varying testing outcomes.

Bench-scale crystallization tests aim to understand the thermodynamic aspects of the crystallization process and mass balance on chemical constituents. Many vendors indicated that they could quantify boiling point rise on the brine, which is an important parameter for sizing a vapor compression unit and determining energy demands. Dissolved salt increases the boiling point of water, and the temperature increase depends on the type and quantity of salt present. Another common outcome of the bench-scale testing, identified in the responses, is characterization of condensate. This step determines the treated water quality, which is important for determining discharge or disposal options for the treated water.

Two vendors stated that physical crystal properties could be investigated, which is important for determining solids bulk density. Two vendors stated that their bench-testing would include an analysis of solids dewatering. The final water content is important for transportation costs to the landfill and potentially volume as well. Only one vendor recommended bench-scale testing of a chemical H_2S oxidation process.

On-Site Demonstration Testing Recommendations

On-site testing at a larger scale is recommended to demonstrate operation of one or more brine management technologies that reduce a portion of the PVU brine to a solid waste product suitable for landfill disposal. Demonstration testing would provide the information necessary to fully evaluate implementation at the full-scale and long-term potential of the process for brine management at the PVU; including, but not limited to the following: process operation requirements, power requirements (including potential for renewable energy), chemical requirements, process consumables, labor requirements, final solid product quantity and composition, and life-cycle costs. Landfill disposal would also have to be part of demonstration testing.

The results of this preliminary assessment did not differentiate the various technologies and equipment manufacturers on the basis of either performance or cost. Therefore, it is recommended that on-site testing services be obtained through an open bidding process. Furthermore, it is recommended that this bidding process be open to all interested parties, including those that were not included in this preliminary assessment. In the proposal, interested parties should provide sufficient supporting documentation such as test plans, quality assurance and quality control plans, and examples of installations currently using the proposed technologies. This approach would allow Reclamation to evaluate each equipment manufacturer and select one or more to perform demonstration testing at the PVU.

The chosen equipment supplier or contractor must demonstrate relevant experience and supply sufficient information concerning their process such that Reclamation can evaluate the potential of the process to meet the needs of the PVU project. Before testing begins, the contractor should provide a test plan to Reclamation for review and comment. The test plan should include equipment operating conditions (flow rates, pressures, chemical composition, etc.) and describe the type and frequency of data to be collected. In addition to process operating conditions, data should also be gathered on chemical, electrical, and thermal energy requirements, as well as other process consumables, such as cartridge filters. Demonstration testing should be conducted for a time period sufficient to meet the objectives described above.

After testing is complete, the testing contractor should provide a report that fully documents all testing conducted in accordance with the approved test plan. At a minimum, the report should include projected process operational requirements, power requirements, chemical requirements, labor requirements, final product composition, and capital and operation, maintenance, and replacement costs. Reclamation should also be provided an electronic copy of all data collected during the testing.

References

Berkman, FE, and Watterson, NA. 2010. Interpretive Geothermal Gradient Map of Colorado. Colorado Geological Survey, Denver, Colorado.

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Appendix A - Vendor Information Request Sheet