Overview

As a finalist for the Solar Desalination Prize (SDP), the BrineZero team led by AIL Research (AILR) will demonstrate the commercial potential of two innovative technologies: (1) a non-tracking solar collector that directly produces low pressure steam, and (2) a steam-driven, non-membrane, thermal distillation process with an exceptionally high Gain Output Ratio (GOR). The two technologies will be proven in a one-week demonstration that validates performance metrics for treating cooling-tower blowdown. Key aspects of the demonstration are:

- the simulation of a 30X reduction in tower blowdown volume by converting over 97% of 4,000 ppm TDS brackish water from Well No. 3 at the Brackish Groundwater National Desalination Research Facility (BGNDRF) to mineral-free water,
- operation in a batch mode sized to duplicate the blowdown disposal needs of a 100-ton cooling tower (i.e., 9,000 gallons of brackish water treated in a seven-day cycle),
- operation at a product-averaged Gain Output Ratio of 10.1, and
- operation on thermal energy provided by a 100 m^2 steam-generating solar array.

Brief Review of Technical Operating Principles

As shown in the one-plate illustration in Figure 1, the key components of a brine concentrator that uses Diffusion-Gap Distillation (DGD) are (i) the condenser—a plastic-plate heat exchanger within which the feed brine flows upward, (ii) the evaporator—a porous hydrophilic wick positioned opposed to the condenser plate on which the hot brine flows downward, and (iii) the brine heater—an external source of thermal energy that further heats the preheated brine exiting the condenser plate before delivery to the wick. During operation, water vapor diffuses across the small gap (2 to 4 mm) between the wick and the condensing plate, condenses and forms a falling film on plate's surface. The latent heat released by the condensing vapor preheats the brine flowing upward within the plate. With most of the brine's temperature rise provided by condensing vapor, DGD achieves exceptionally high GORs.

The second demonstrated innovation is a low-cost, highly efficient solar thermal collector that converts radiation to low pressure steam. The basic operation of this collector is shown in Figures 2 and 3. The active element is a dewar-type solar tube (i.e., double-walled cylinder with a vacuum between the walls). During predawn hours each tube is partially filled with water. As the tubes become illuminated, solar radiation is absorbed by the selective surface on the vacuum-side of the inner glass cylinder. As the temperature of this surface increases, it radiates to the water. When the water temperature exceeds 100^{o}C, its vapor pressure exceeds ambient pressure and steam is pushed out of the tube and into the collection manifold. Steam aggregated from multiple manifolds is delivered to the heat load.

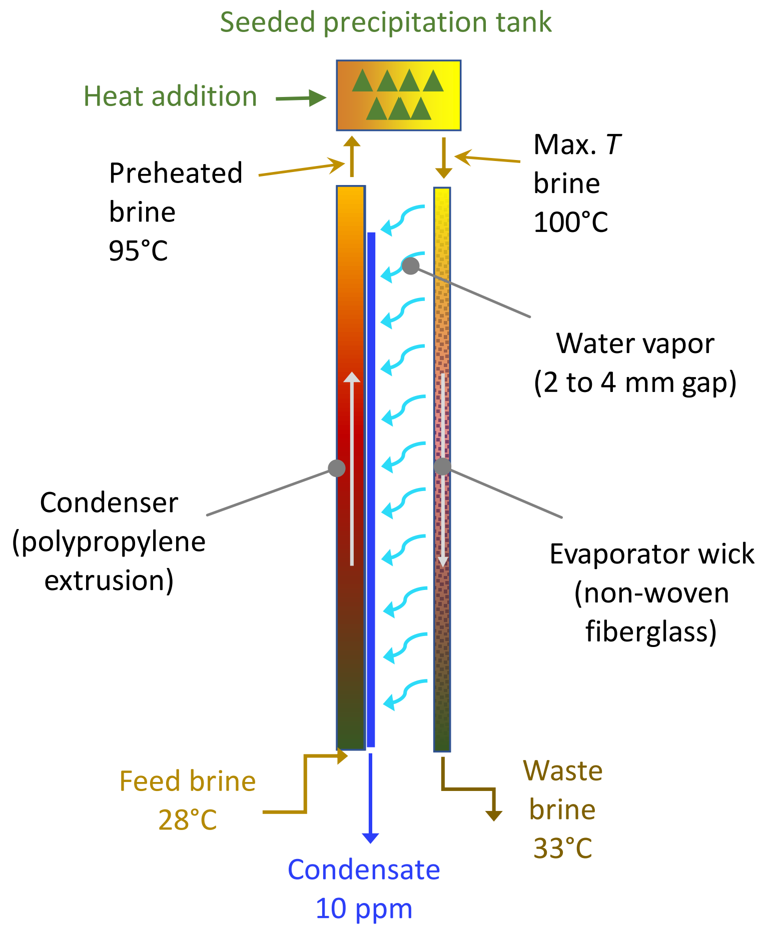

Figure 1 – Functional Operation of the Diffusion-Gap Distillation Process

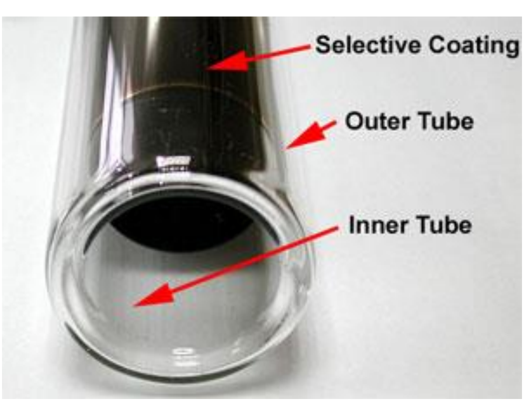

Figure 2 – Dewar-Type Solar Evacuated Tube

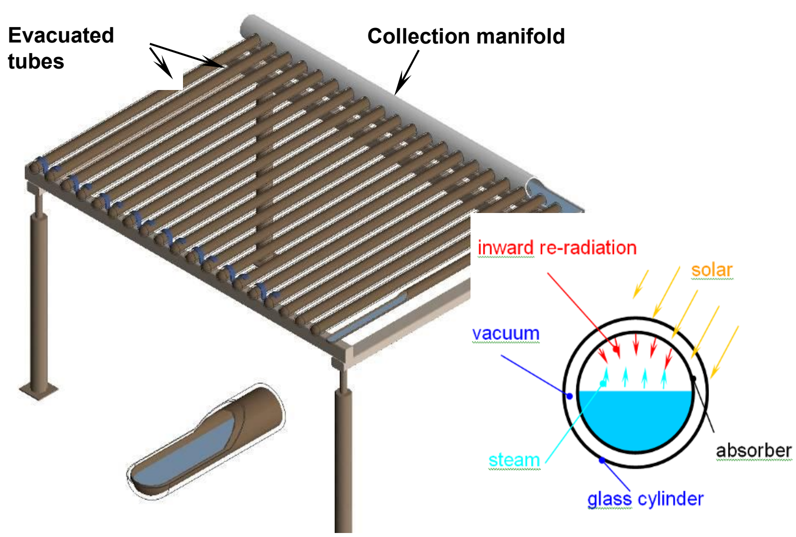

Figure 3 – A Steam-Generation Solar Collector

For the SDP competition steam is directly injected into a tank of preheated brine where it condenses releasing energy that drives the DGD process. (Although direct steam injection reduces the process' GOR by one—the condensing steam dilutes the brine—the elimination of an expensive, scale-prone brine-to-steam heat exchanger more than compensates for the loss.)

Project Readiness – Technology

Both the DGD processor and the steam-generating solar collector have been field operated at capacities that require no more than a 3X scale-up for the SDP competition.

<u>BrineZero DGD processor</u>

A 1-gpm DGD brine concentrator operated for the week of June 21, 2022 at the Yuma Desalting Plant as a finalist in the More Water, Less Concentrate (MWLC) competition sponsored by the Bureau of Reclamation. The Yuma concentrator, which is shown in Figure 4, was driven by steam supplied by a 17-kW electric boiler.

The Yuma DGD processor consisted of three, 70-plate stacks referenced as Red, Green and Yellow. Operational data for product purity and GOR is shown in Figure 5. As shown, product purity during the first day was mostly between 300 and 1,500 µS/cm for the Yellow stack—well below the competition's 3,000 µS/cm acceptance threshold—and mostly below 3,000 µS/cm for the Green stack.

Unfortunately, all stacks experienced a buckling instability that seriously degraded performance. Figure 6 shows the buckled plates of the Green stack at the end of the test. This severe buckling collapsed the gaps between the wicks and the condensing plates leading to the observed contamination of the condensate.

Despite the buckling, operation of the Yellow and Green stacks from Hour 42 through Hour 77 demonstrated a GOR that mostly equaled or exceeded the GOR predicted by AILR's DGD computer model.

Figure 4 – Three 70-plate Modules for Yuma Competition Prior to Adding Insulation

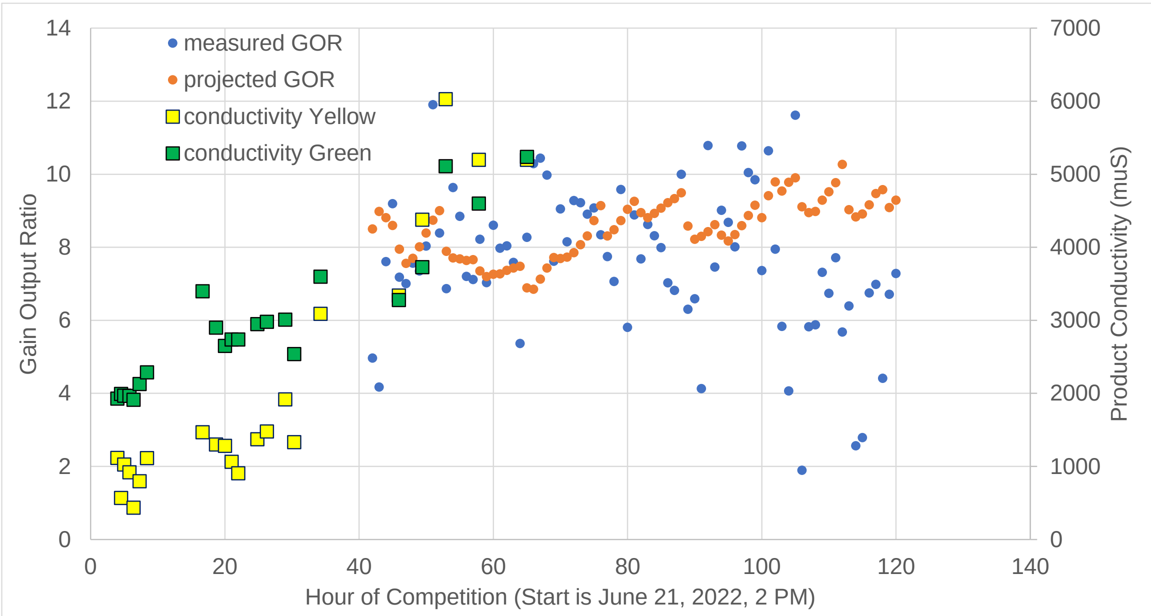

Figure 5 – First 140 Hours of Operation for the Yellow and Green Stacks

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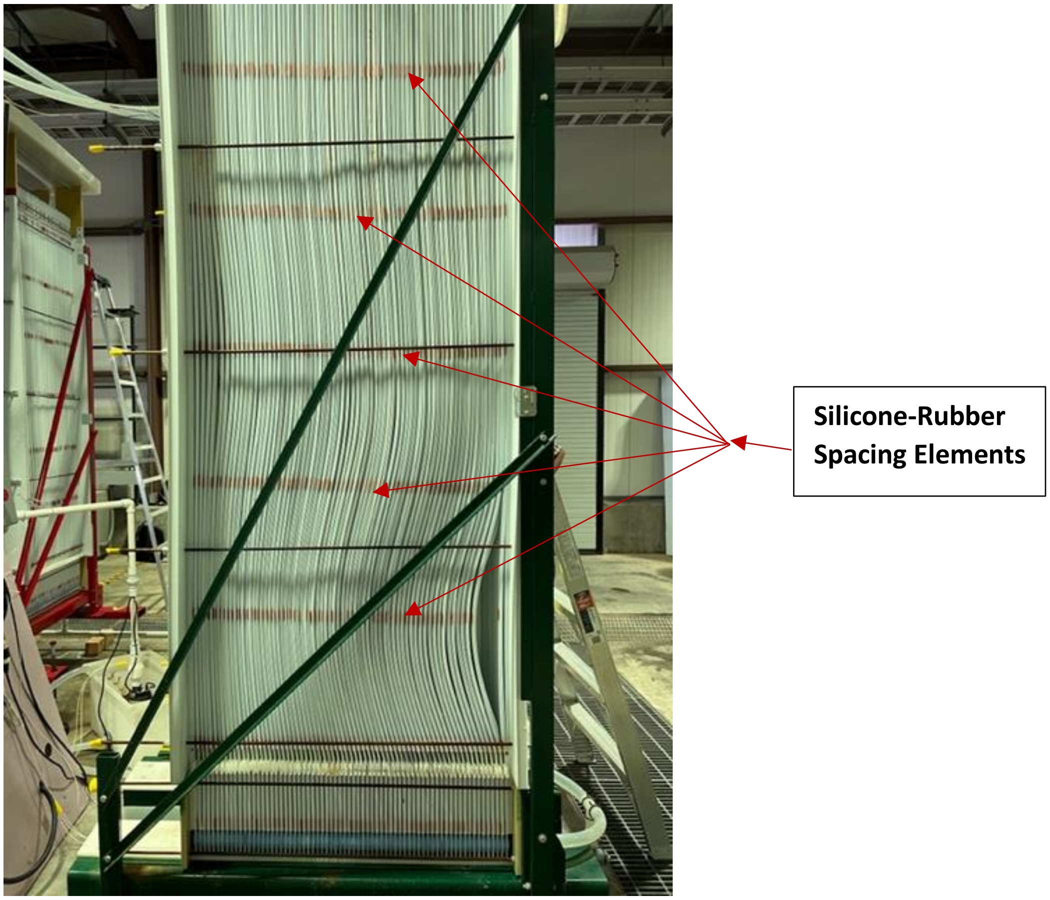


Figure 6 – Buckling Failure Mode for Large Plate Assemblies

The spacing elements that maintained the gaps between the condensing plates were the "weak link" that led to the buckling instability. As shown in Figure 6, five discrete silicone-rubber spacers were located along the two vertical edges of each condensing plate—a design that had worked well in assemblies of up to 15 plates.

The lesson learned in Yuma is that discrete spacers do not work for large plate assemblies. Although the spacers are solid silicone rubber, the underlying condensing plates are hollow, twin-wall extrusions. The compressibility of the condensing plates can lead to a slight perturbation in the registration of the plates. This perturbation, while not significant for small assemblies, can accumulate in larger assemblies, eventually leading to the gross buckling of plates shown in Figure 6.

Figure 7 – Retrofit of Red Stack with Continuous Edge Spacers Inserted between the Silicone-Rubber Spacers

Our design modification that stabilizes a large plate assembly is to reinforce the edge spacers so that they are continuous along almost the entire two vertical edges of the condensing plates. As shown in Figure 7, the Red stack was rebuilt with this design change to the edge spacers. Following the rebuild, the Red stack operated hot with brine circulation for 160 hours and cold with brine circulation for more than 400 hours. Following operation with circulating brine, the stack remained filled with brine for 4 months, which kept the plates under the same compressive loads as under operation. No plate buckling was observed throughout this test, confirming that continuous edge spacers prevent plate buckling (at least for operation of thousands of hours).

Three additional positive observations from the Yuma test were:

- the DGD process was driven for seven days by the direct injection of steam into a tank of preheated brine—thereby demonstrating a thermal separation process that does not require an expensive, scale-prone, brine/steam heat exchanger,
- a post-test inspection of the wicks did not detect any scaling or solids accumulation—a necessary condition to confirm that the DGD process can operate long-term without wicks fouling, and
- the polypropylene precipitation tank with steam injectors performed as expected throughout the test with no sign of deformation from high temperature operation.

Steam-Generating Solar Array

The thermal energy to drive the DGD process will be provided by an innovative, patented solar array that generates 4 psi steam within dewar-type solar tubes. In locales with abundant solar resources, such as the Alamogordo test site, the steam-generating solar array is projected to deliver thermal energy at $0.015 per kWh (levelized over a 30-year service life).

Our solar collector is a low-cost, high efficiency alternative to conventional non-concentrating thermal collectors. Advantages over current technology include:

- passive tracking of the sun provided by cylindrical absorbers that intercept direct and scattered radiation over large incidence angles,
- a simplified thermal transport in which slightly pressurized steam moves from its source within the evacuated tubes to its end-use without pumps, heat pipes or intermediary heat exchangers, and
- the delivery of thermal energy at 100ºC (high for non-concentrating arrays).

In preparation for the SDP competition, an 8-panel, 480-tube array was installed in August 2021 on a farm in Freestone, CA. The array is shown in Figure 8, with storage tanks and fan/coil steam condenser in the background.

A critical requirement for array installation is to maintain all panels that have a common water/steam circuit within a common horizontal plane. This requirement was met by the mounting system shown in Figure 9 in which earth anchors are first driven in the ground at six points on the perimeter of each panel. A laser level is then used to position locating nuts on the threaded rods extending from the heads of the earth anchors. With the locating nuts all in a common plane, the panels are loaded in position and locked in place on the locating nuts. The 8-panel Freestone array was level to within 3 mm.

The Freestone array began operation on September 17, 2021. During the first week, adjustments were made to the initial charge of water within the tubes. (An array's thermal output will be highest when the initial charge of water is close to the minimum that avoids dry-out before the end of the day.)

Figure 8 – Eight-Panel Steam-Generating Solar Array, Freestone, CA Installation

Figure 9 – Array Mounting System Based on Earth Anchors

The Freestone array operated continuously with no problems until October 23, 2021 when a violent storm damaged the control panel. However, although the storm was described as "historic" in news reports, the array was not damaged and stayed in plane.

Repairs to the control panel were completed in late summer 2022, and the array resumed normal operation on September 2, 2022.

The monitored operation of the Freestone array confirmed the high solar conversion efficiency for the steam-generating collector. The data in Figure 10 compares the thermal energy delivered by the steam-generating collector and by a conventional collector that uses evacuated tubes with internal heat pipes manufactured by Apricus. Except for days when the tubes were undercharged (which led to dry-out before the end of the day), the steam-generating collector supplied more thermal energy at a higher end-use temperature (i.e., 212ºF vs 204ºF) than the conventional Apricus collector.

Figure 10A shows detailed data for the array performance on 9/22/2021 (the circled data point in Figure 10). As shown in this figure steam production started 3.4 hours after sunrise and continued for 7.1 hours. The panel was illuminated for 10.7 hours. (The green data points track the cumulative supplied steam energy; the blue/orange points track the cumulative solar energy incident on the panels.)

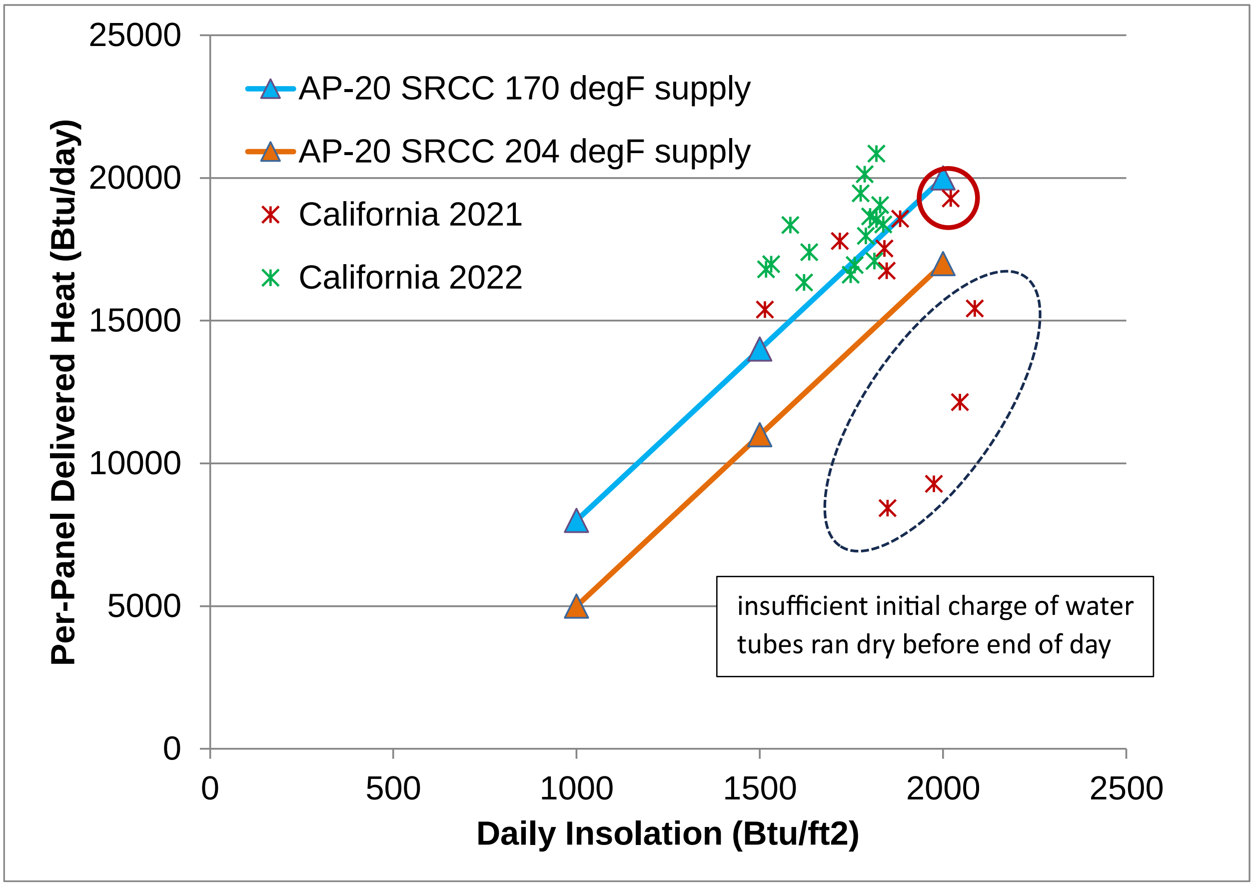


Figure 10 - Comparative performance – Conventional 20-Tube Panel Manufactured by Apricus and Measured Performance of Freestone Array of Steam-Generating Panels (scaled to 20 tubes)

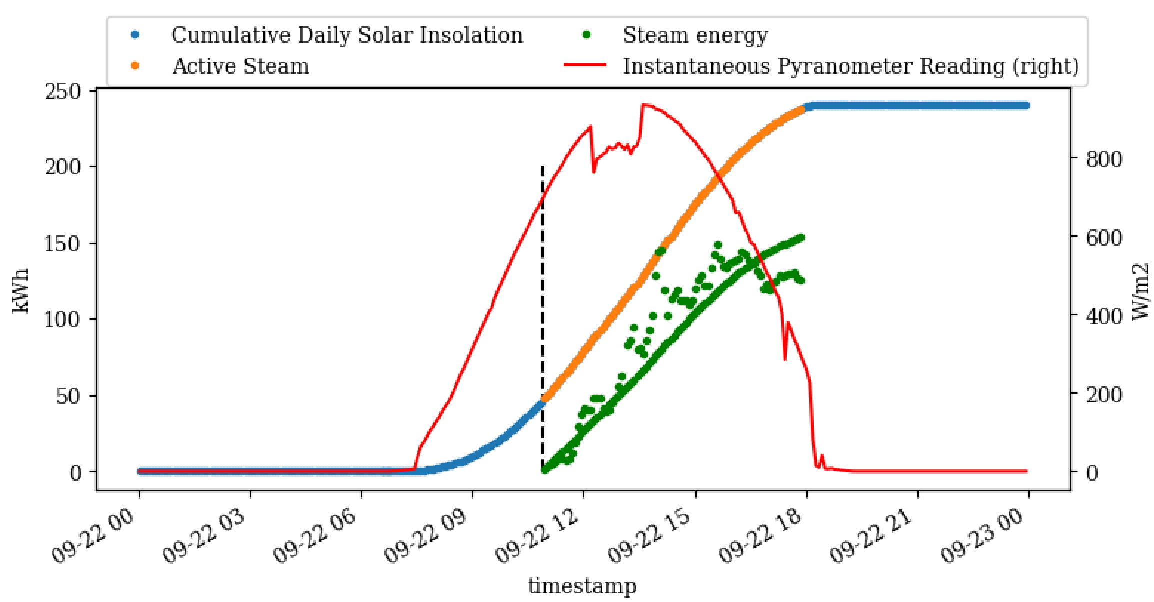


Figure 10A—Array performance on September 22, 2022

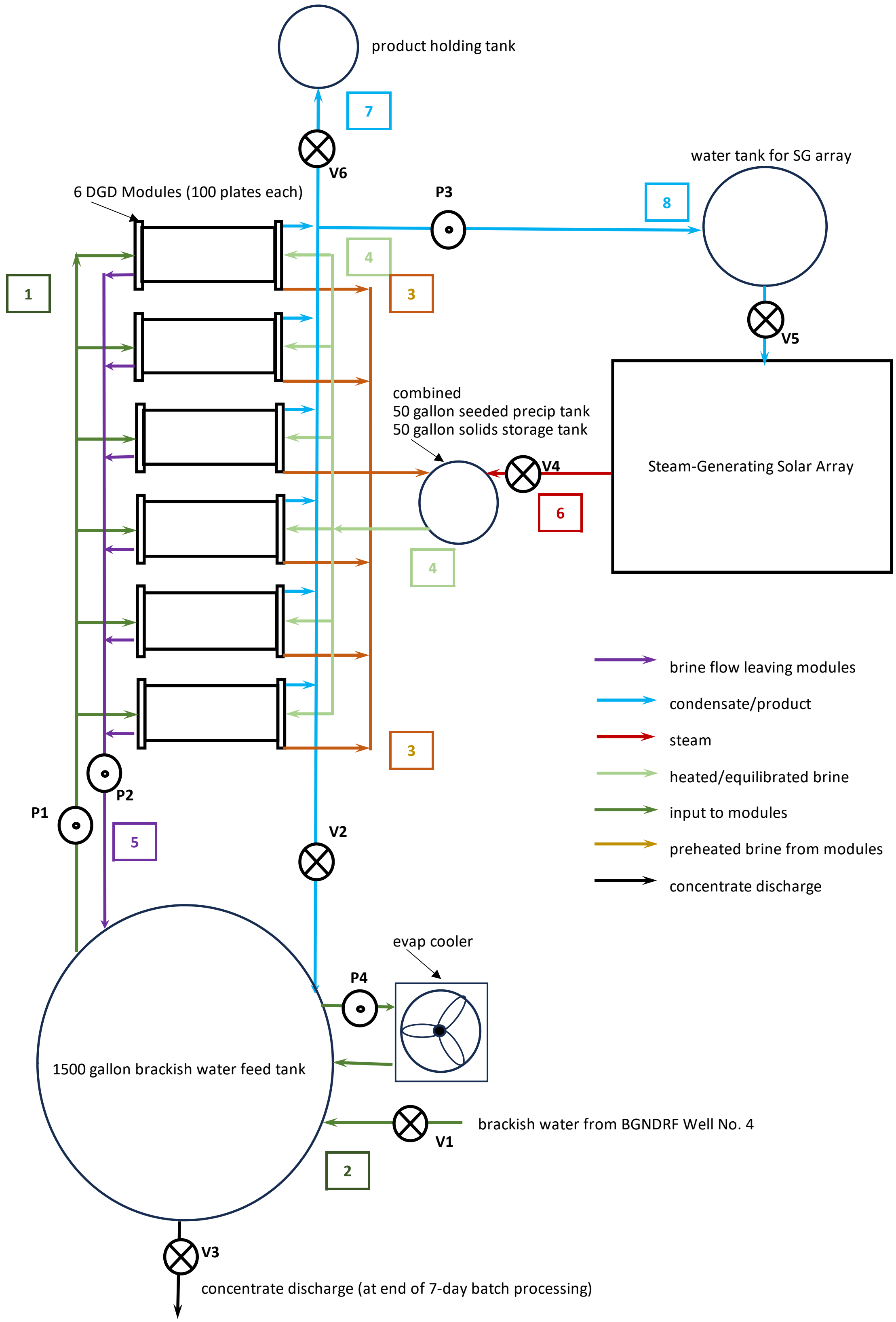


Figure 11—Process Flow Schematic for SDP Testing at BGNDRF

Project Readiness – System Design and Operation

A schematic flow diagram of the BrineZero system to be installed at the Bureau of Reclamation's Brackish Groundwater National Desalination Research Facility (BGNDRF, Alamogordo, NM) is shown in Figure 11. As shown in this diagram, the key system components are: (1) a six-module DGD processor, (2) a 1,500-gallon brackish-water/brine storage tank, (3) a seeded precipitation tank (50 gal) integrated with a solids holding tank (50 gal), (4) a 1,500-gallon holding tank for product, (5) a 300-gallon tank that stores water for the steam-generating solar array, (6) the solar array composed of fourteen 60-tube panels, and (7) an evaporative cooler that controls the temperature of the water stored in the feed tank.

Six-Module BrineZero DGD Processor and Containerized System

As shown in Figure 12, the BrineZero processor is composed of six identical modules, each with 100 pairs of plates and wicks, housed within a standard 20-foot shipping container. (Appendix B includes an engineering drawing showing the steam and brine pipe runs within the container.)

The basic design of the plate/wick pairs duplicates the Yuma design with the following three modifications:

- Continuous edge spacers maintain the gaps between plates and wicks, providing a more rigid plate stack,
- The height of the plates is reduced from 8 feet to 6 feet to accommodate installation within shipping container, and
- The wicks are single sheets of 35-mil non-woven fiberglass[1]

Figures 13 and 14 are engineering drawings for the brine wick with collection gutter and condensing plate, respectively. Figure 15 is an engineering drawing of a 100-plate module. Table 1 is the Bill of Material for a single 100-plate module, and Table 2 is the Bill of Material for all ancillary components mounted within the 20-foot shipping container. (Tables 1 and 2 are for designs and material purchases that apply to the proposed demonstration. Tables in Appendix A apply a 165,000 gpd BrineZero facility for concentration the brine discharged from an inland RO desalting plant for brackish water with 320-plate modules produced at volumes of at least 1,000 per year.)

[1] The wicks for the Yuma DGD processor were two sheets of non-woven fiberglass that were sewn together. For the SDP operating conditions, single-sheet wicks will carry the required brine flow.

Table 1

item	material	no.	per unit	unit	cost	source
Condensing Plate (1)	2 mm Coroplast	100	$0.33	per ft2	$301	Harbor Sales
Segmented Brine Wick (1)	30 mil, treated non-woven fiberglass	100	$0.25	per ft2	$199	Lydall
I/O silicone inserts	silicone or other elasomer; Noryl	600	$0.50	each	$300	Gruendeman
Top Slot Cover Plate; 3 mm Coroplast (2)	3 mm Coroplast	200	$0.31	per ft2	$8	Harbor Sales
Bottom Slot Cover Plate; 4 mm Coroplast (2)	4 mm Coroplast	200	$0.31	per ft2	$35	Harbor Sales
wick spreader; 8/10 mm Coroplast (1)	8/10 mm Coroplast	200	$1.06	per ft2	$6	Harbor Sales
Wick Gutters	ABS or PVC	100	$0.73	per ft	$119	Seagate
Edge Spacer (2)	4 mm Coroplast	400	$0.31	per ft2	$14	Harbor Sales
Central Spacer; 4 mm Coroplast (2)	4 mm Coroplast	200	$0.31	per ft2	$7	Harbor Sales
Top/Bottom Compression Member	6061-T6 Aluminum 4" U-Channel	4	$16.52	each	$66	Coremark
Top/Bottom Compression Member Cap	6061-T6511 Al Round Bar - 2-1/2"	4	$1.69	each	$7	Coremark
Sidewall Segment	1 mm aluminum sheet metal	10	$4.49	each	$45	Indus. Metal Supply
Tie Rod	3/8" aluminum rod	13	$1.66	each	$22	Coremark
Base (one per two DGD modules)	2" x 2" 16 ga. tubular steel	0.5	$97.24	each	$49	Coremark
Upper Brine Feed Tube	35 mil wall, 1/2" cupronickel pipe	2	$24.00	each	$48	Aviva Metals
Adhesive	PMMA		$20.00		$20	
Miscellaneous Hardware		1	$25.00		$25	
Total					$1,269	

Table 2

item	description/model	no.	per unit	unit	cost	source
20' Shipping Container	side door access	1	$4,403	each	$4,403	containerone.net
Solar Panels	320 W, 24 V	4	$347	each	$1,386	Renogy
Charge Controller	60A	1	$280	each	$280	Renogy
Batteries	24 V, 100 Ah LiPo battery	1	$760	each	$760	Renogy
Bluetooth Controller	BT-1 Module	1	$39	each	$39	Renogy
Flow Control Valve	1" motorized	6	$40	each	$240	US Solid
Brine Pump	magnetic drive; ITG-7	4	$120	each	$480	Corsair
Evap Fluid Cooler	2-ton capacity	1	$1,500	each	$1,500	estimate
Main Brine Storage Tank	1500 gallon PE	2	$1,408	each	$2,816	PlasticMart
Hot Seeded Storage Tank	50 gallon, PP	1	$460	each	$460	Tampco
Hot Auxiliary Storage Tank	50 gallon, PP	1	$460	each	$460	Tampco
100-Plate DGD Modules	low volume production w/o labor	6	$1,177	each	$7,060	in-house
Control Panel and wiring		1	$56	each	$56	
High temperature plumbing		60	$5	per foot	$293	US Plastic
low temperture plumbing		60	$1	per foot	$30	US Plastic
High temperature plumbing fittings		15	$5	each	$75	US Plastic
Low temperature plumbing fittings		15	$1	each	$15	US Plastic
Material Total					$20,353	

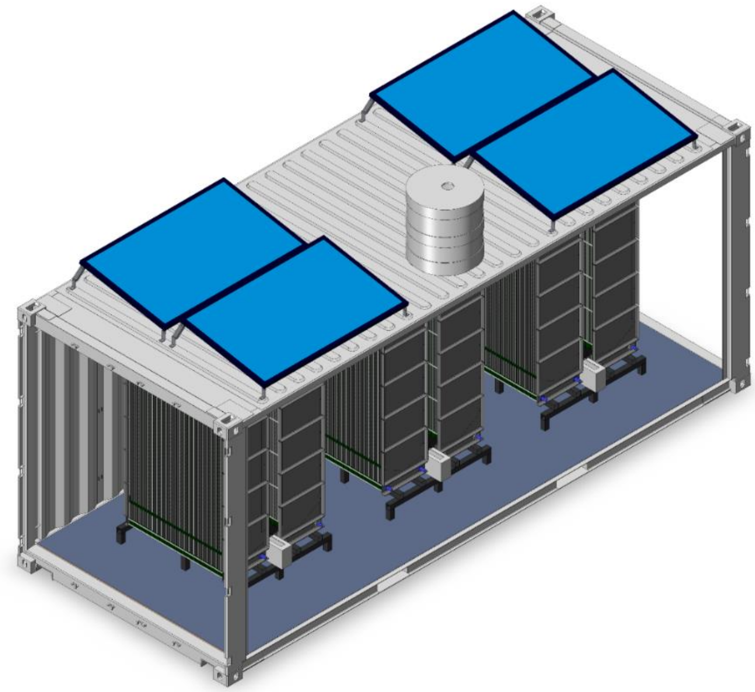
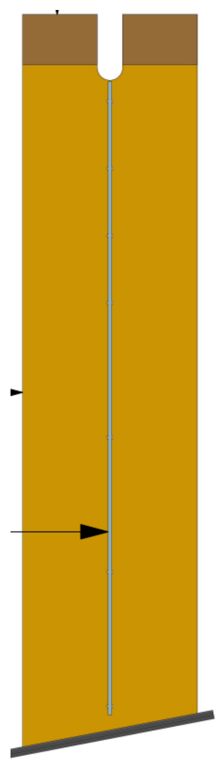


Figure 12 – Six-Module BrineZero DGD Processing



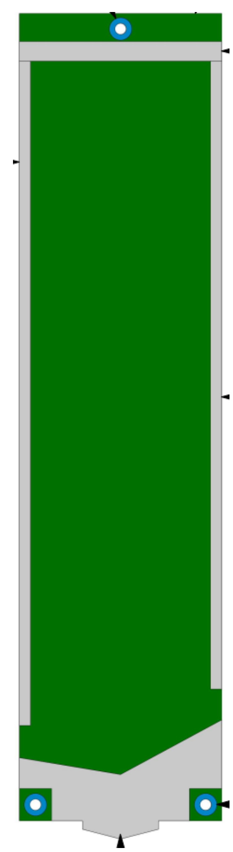


Figure 13 – Brine Wick with Collection Gutter **Figure 14 – Condensing Plate**

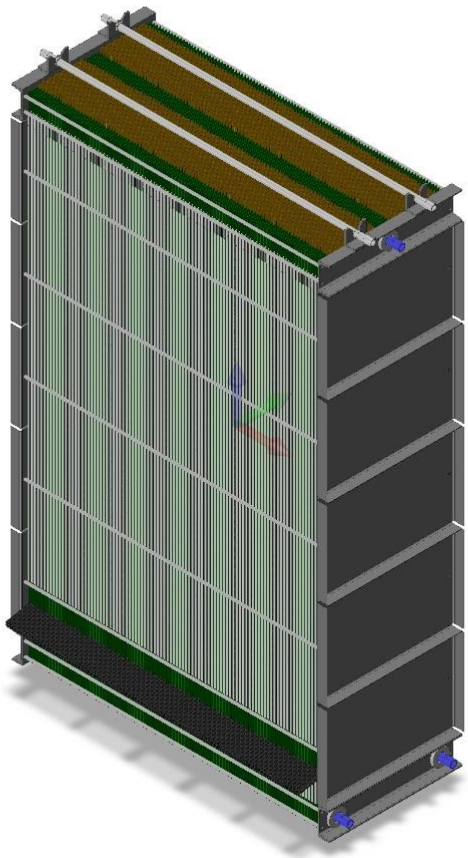


Figure 15 – 100-Plate/Wick DGD Module

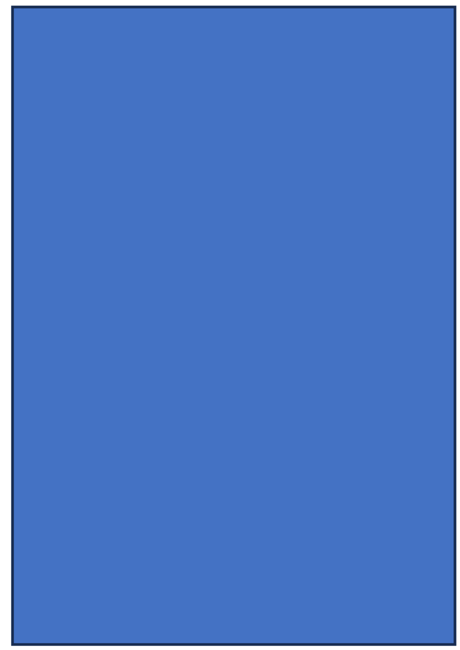


Figure 16 – Intentionally left empty

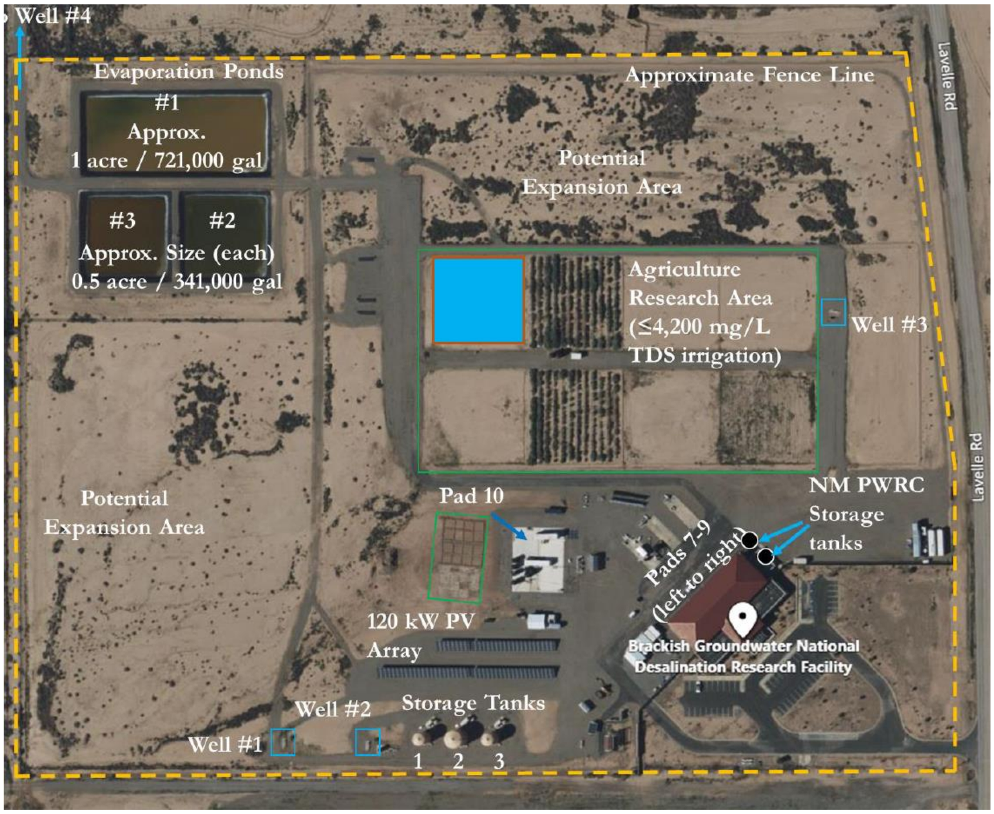


Figure 17 – Proposed Site at BGNDRF for Demonstration (Blue 150' x 150' square in upper picture is the 0.5 acre plot shown in the lower picture available for the Figure 18 layout)

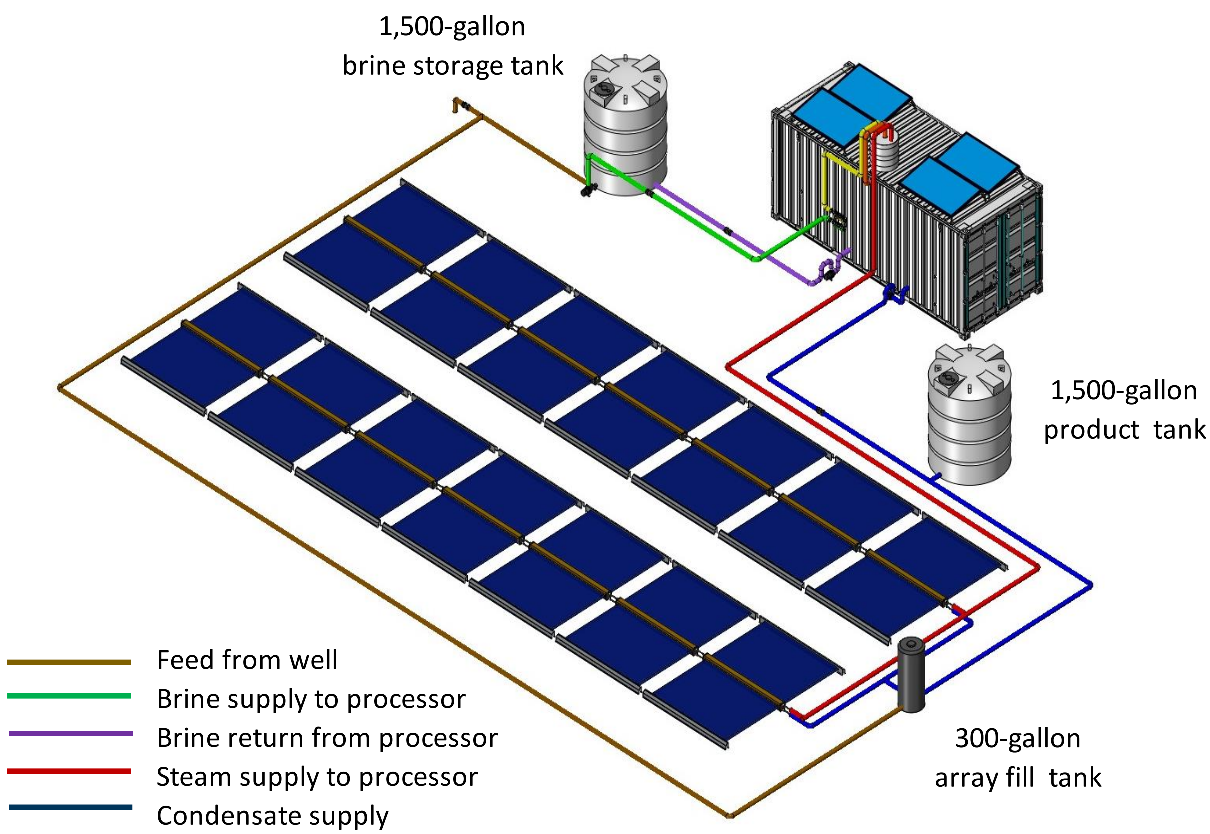


Figure 18 – Proposed Layout and Interconnection of Solar Array and Containerized Processor

<u>Steam-Generating Solar Array and Ancillary Components</u>

Dr. Malynda Cappelle, Facility Manager, BGNDRF, has identified the half-acre site shown as the blue square in Figure 17 for the installation of both the solar array and the containerized processor. The site has no more than 18" change in elevation over its 150' span, which will allow the array to be installed level to within ±3 mm using the adjustable earth anchors previously described.

To provide the required steam, an area of approximately 27 x 60 feet is dedicated to the solar array. As shown in the complete system layout (Figure 18), the array is composed of two parallel circuits of seven panels, each panel containing one central manifold with 60 evacuated tubes.

Daily operation of the steam-generating solar array begins before sunrise when the tubes are partially filled with water using a gravity feed from the condensate storage tank (shown in Figure 18). Each seven-panel circuit of the array is isolated with a solenoid valve that is opened during predawn filling. The volume of water distributed to each circuit is monitored, and when sufficient water is supplied, the valve is closed. (The volume of water is determined based on the forecasted solar insolation so that almost no water remains in the tubes at the end of the day.)

To ensure proper fluid distribution using only a gravity feed, it is critical that the seven panels in each circuit are installed level. The previously described installation procedure for the Freestone array will be replicated at BGNDRF.

Table 3 has the Bill of Materials for the BGNDRF steam-generating solar array.

Test Plan –System Operation for the One Week Demonstration

The six-module containerized processing unit operates sequentially in the following four modes:

1) System Charging – Prior to the start of the one-week monitored test period, the 1,500-gallon feed storage tank is filled with brackish water from Well No. 3. Pumps P1 and P2 recirculate the brackish water through the six-module processing unit, the seeded precipitation tank and the solids storage tank. (The labeling of all pumps and valves appears in Figure 11.) During this initial recirculation of water, approximately 300 gallons of brackish water is added to the feed storage tank as water fills the plates of the modules and the two smaller storage tanks. The 300-gallon water storage tank for the steam-generating solar array is filled with brackish water from Well No. 3[2]. As part of the procedure for system charging, trimming valves (not shown) in the lines feeding brackish water to the six modules are adjusted to balance the flows to the modules.
2) System Preheating – During the early morning with the solar array cold, water is gravity drained from the storage tank to the solar array, filling the horizontal tubes of the array to between 30% and 40% of capacity. Approximate 180 minutes after sunrise when sufficient pressure is measured within the array, valve V4 is opened and steam flows into the seeded precipitation tank. The steam condenses releasing heat that raises the tank's temperature. With heated water flowing onto the wicks of the DGD modules, condensate forms on the water-cooled plates. This condensate is first pumped (P3) to the array storage tank, and then once the array tank is full, the condensate is returned to the feed storage tank (i.e., valve V2 is open and V6 remains closed). The warm concentrate discharged from the modules that is pumped (P2) back to the feed storage tank increases the temperature of the stored brackish water. An evaporative cooler is activated, as needed, to keep the stored water temperature below 28°C. At the end of day, the system is operating at full temperature, steady-state with the feed storage tank fully charged with brackish water.

[2] Prior testing of steam-generating solar arrays has shown an approximately 10% increase in solar conversion efficiency when thin layers of mineral scale are allowed to form on the internal walls of the tubes. Scale formation will be encouraged by initially filling the array with well water. Once a scale layer has formed, the array will be refilled with mineral-free condensate from the processing unit.

Table 3

Bill of Materials One Solar Panel				
Part	Description/Source	ea.	Qty	Cost
Manifold	Global Solar Technology	$20.00	1	$20.00
Solar Evacuated Tube	Global Solar Technology	$4.50	60	$270.00
End rail	Global Solar Technology	$10.00	2	$20.00
Tube End Caps	Global Solar Technology	$0.10	60	$6.00
			Total	$316.00

Bill of Materials 14-Panel Array				
Part	Description/Source	ea.	Qty	Cost
Solar Panel	On site assembly	$316.00	14	$4,424
Earth Anchors	American Earth Anchors	$30.84	84	$2,591
Threaded Support Rods	McMaster-Carr (discounted)	$11.36	84	$954
Silicone Tubing	McMaster-Carr (discounted)	$19.25	14	$270
Level Sensor	Madison	$307.76	1	$308
Solenoid Valve	US Solid	$69.95	3	$210
Water Feed Tank	US Plastics	$348.05	1	$348
			Total	$9,104

Note: the approximately $1,600 cost for shipping a 20’ container from Asia to Long Beach has not been included in the preceding costs

3) Night Operation – As the sun sets and steam pressure within the array falls below a setpoint value, valve V4 is closed (isolating the array from the seeded precipitation tank) and the pumps P1 and P2 are turned off (stopping the recirculation through the modules). Pump P4 for the evaporative cooler remains on through the night to maximize cooling of the feed storage tank. The system remains in this inactive state until the next day when solar insolation again raises steam pressure within the array. (The nightly drop in temperature for the highly insulated processing unit and precipitation tank is predicted to be less than 5ºC during this inactive period.)
4) Active System Processing with and without Brackish Water Feed – The volume of water within the plates of the six modules plus the precipitation tank is approximately 250 gallons. Since the final volume of brine within the system at the end of batch processing must be greater than this "working" volume, batch operation that converts 97% to mineral-free water must process about 9,000 gallons.

   In order to keep the feed storage tank a reasonable size (e.g., 1,500 gallons), batch processing will occur in two stages—one in which brackish water is continually fed to the feed storage tank to keep the stored volume at 1,500 gallons, followed by a second stage in which the brackish feed is turned off and the volume in the feed tank decreases.

   The processing of a 9,000-gallon batch of brackish water occurs over seven days. For the test site (Alamogordo, NM) in April, the solar array is projected to produce steam for at least 9 hours each day (i.e., 63 hours of processing for one batch)[3]. When steam is produced by the array, the two pumps P1 and P2 operate and condensate is delivered to the product holding tank (i.e., valve V6 is open, V2 is closed). For the first 52 hours of the cycle, V1 is open and brackish water from Well No. 3 is fed to the feed storage tank at a volumetric flow rate that matches the rate that condensate is delivered to the holding tank (i.e., the volume of water in the feed tank is constant). For the last 11 hours of the cycle, the brackish water feed is turned off (V1 is closed) and the volume of water in the feed tank decreases.

   Throughout the seven-day test period, the data points shown in Table 3A will be recorded at minute intervals. Raw data will be collected via cellular transmission in a database for real-time processing and viewing of instantaneous performance metrics such as GOR and process conversion rate. At least once per day, samples of feed water and product water will be taken, conductivity manually measured and recorded. The feed water will be withdrawn downstream of P1, and the product, upstream of V6. All samples will be stored for post-test lab analysis. The volume of water supplied to the solar array will be logged (based on change in tank level) and the daily solar conversion efficiency calculated. For system controls, the temperature of the brine leaving the precipitation tank is used during steam production to optimize brine flow rate with steam production.

[3] For BGNRDF in April, the sun is above the horizon for an average of 13 hours per day, with minimal shadowing from mountains approximately four miles to the east.

Table 3A - Instrumentation List for Test Plan

Thermistor Temperature Measurements

0-150 C Inline 10K thermistor, ETP10076

Data Point	No.	
1	1	Brine Supply to Modules
2	1	Well Supply
3	6	Preheated Brine Leaving Modules
4	1	Hot Brine Return
5	6	Discharged Brine from Modules
6	1	Steam Supply to Precipitation Tank
7	1	Product Delivered to Tank
8	1	Ambient
9	2	Evaporative Cooler brine supply/return

Turbine Flow Meters with Pulse Outputs

0-20 gpm sensor with flow indicator, GEMS 155481

P1	6	Brine Supply to Modules
P2	6	Discharged Brine from Modules

Tank Liquid Volume - Ultrasonic Level Sensors

0-117 inch range, FLOWLINE LU80-5101

1	1	1500-gallon Brackish Water Feed Tank
2	1	1500-gallon Product Holding Tank
3	1	300-gallon Condensate Tank for Solar Collectors

Additional Sensors

Upward-looking thermopile, Apogee SP-510-SS

1	1	Pyranometer Global Horizontal Solar Insolation

Table 4

Average GOR 10.1

		Hour 1 (of 63 operating hours)				Hour 52 (of 63 operating hours) (well feed to tank is turned off)				Hour 63 (last operating hour)			
		T	mDot	C (*)	TDS	T	mDot	C (*)	TDS	T	mDot	C (*)	TDS
		degC	kg/s	pct	mg/l	degC	kg/s	pct	mg/l	degC	kg/s	pct	mg/l
1	Brackish water/brine input to DGD modules	28.0	1.574	0.130	4,076	28.0	1.574	0.676	8,890	28.0	1.574	4.272	44,769
2	Brackish water feed from BGNDRF Well No. 3	10.4	0.147	0.130			0.000				0.000		
3	Preheated brine leaving condensing plates of DGD modules	90.8	1.574	0.130		90.8	1.574	0.676		90.8	1.574	4.272	
4	Brine at max temperature supplied to wicks of DGD modules	96.0	1.589	0.129		96.0	1.589	0.670		96.0	1.589	4.232	
5	Brine flowing off wicks of DGD modules and returned to 1500 gallon tank	34.4	1.427	0.143		34.4	1.429	0.745		34.4	1.436	4.684	
6	Atmospheric pressure steam supplied by solar array to seeded storage tank	101.0	0.014	0.000		101.0	0.014	0.000		101.0	0.015	0.000	
7	Product condensate to holding tank	28.0	0.147	0.000		28.0	0.146	0.000		28.0	0.139	0.000	
8	Product condensate returned to steam-generating solar array	28.0	0.014	0.000		28.0	0.014	0.000		28.0	0.015	0.000	

* NaCl equivalent

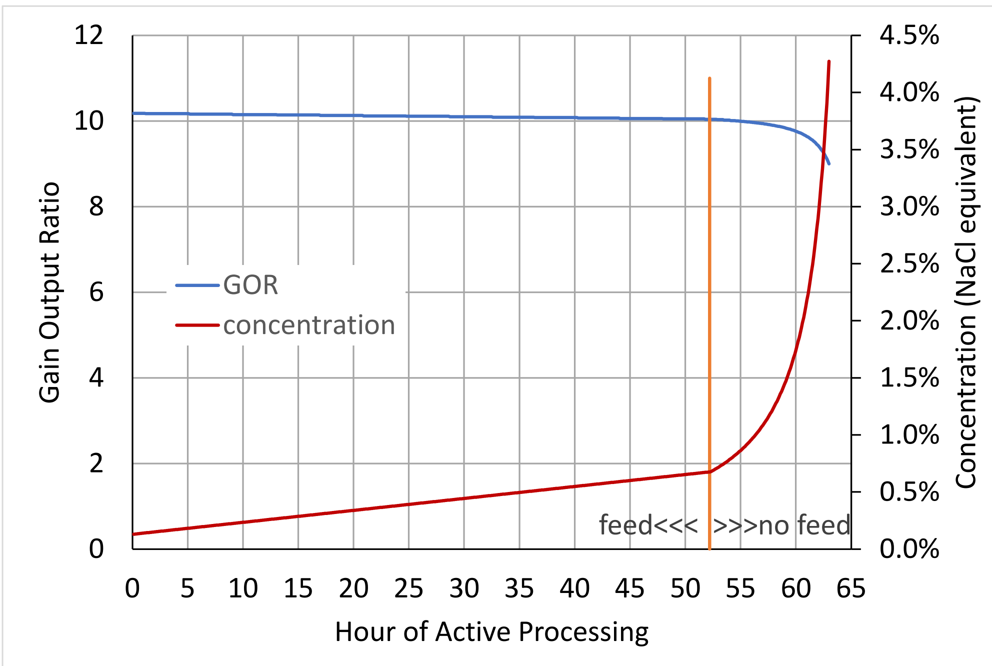


Figure 19 – Change in GOR and Brine Concentration During 63 Hours of Processing

Process State Points During Operation

Table 4 shows conditions at the eight state points in Figure 11 at (1) the start of processing a new batch of brackish water, (2) hour 52 when the brackish water fed to the feed storage tank is turned off and (3) hour 63 when processing is complete. Also shown in this table is the 10.1 Gain Output Ratio[4] (GOR) for the process averaged of the seven-day test.

Figure 19 shows the time variation in GOR and salt concentration (NaCl equivalent) throughout the 63 hours of active processing.

Project Readiness - Implementation

Fabrication of DGD Modules

During a four-month period beginning February 2022, a five-person crew at AILR set-up a manufacturing line for wick/plate assemblies and fabricated the 210 plate/wick assemblies required for Yuma. This work occurred in the following stages:

- 32 assembly templates were made that secured individual plate blanks with guides that located the cover plates and spacers to be bonded to the blanks; two sets of templates were made—one set that accepted blank plates, and a second that accepted plates with components bonded to one face.
- A hot-air edge press was designed, fabricated and tested to seal ends of plate blanks.
- Approximately 230 wicks were cut to their final geometry from 51" wide roll stock using the Zund X-Y CNC cutter at Princeton University
- Using the Princeton X-Y CNC cutter, approximately 330 plate blanks were cut to final geometry from 4' x 8' sheets; Upper and lower cover plates were also cut to final geometry; (This work was performed at a constant 18°C to eliminate dimensional variations introduced by thermal expansion.)
- Ancillary components such as the wick sheaths and silicone spacers were cut in manually operated stations.
- Plate-to-plate fluid seals were molded off-site by a contact fabricator.
- Using the hot-air edge press, the ends of all plates were thermally sealed.
- Plate blanks were secured in the first assembly templates, adhesive beads manually applied, cover plates positioned and weighted for the 24-hour adhesive cure time; once cured, the plates were secured in the second assembly templates and a nearly identical gluing operation was performed on the plates' second side.
- The fabricated plates were pressure tested; plates with leaks were repaired or, if repairs were not possible, the plates were rejected.

Except for the tasks identified as occurring at Princeton University, all work was performed at our Hopewell shop shown in Figure 20.

Allowing for the minor design changes that will be made to the edge spacers, the Yuma protocol for fabricating plate/wick assemblies will be reproduced at our Hopewell shop for the BrineZero demonstration proposed for BGDNRF.

[4] Gain Output Ratio is the net mass of product water divided by the mass of steam required to drive the process

Figure 20 – AILR's Hopewell Shop and Lab

Assembly of Containerized Processor

The assembly of the containerized processor is a straightforward operation for mounting components, running piping and wiring, and installing and connecting instrumentation.

One critical requirement will be transportability. The containerized processor will be fully functional upon completion in Hopewell, NJ and then trucked to the test site. The plate stacks will be securely anchored to the reinforced floor through welded steel beams. For shipping, the modules will also be anchored to the ceiling. However, these connections will be removed on-site to allow for thermal expansion of modules. The containers will have doors along the long container side to allow individual plate stack access so that modules can be serviced, removed, and replaced without taking the entire system apart. Drawings of the containerized assembly appear in Appendix B.

Installation of Solar Array

To prepare the site, a front-end loader first scrapes the site flat and a bed of high-albedo gravel is spread over the installation area to limit weed growth and enhance solar radiation reflection. Next, the layout of the entire field is precisely marked to locate each manifold's connections to the ground. The installation of earth anchor, leveling of the locating nuts, securing of the panels, and interconnecting the steam/condensate piping then follows the same procedures as previously described for the Freestone array.

We anticipate array installation at BGNDRF to be completed in 4 days with a crew of two.

Data Acquisition and Remote Communication

The system's performance is monitored and recorded through cellular-connected microcontrollers customized for the application. Pumps, control setpoints, and all datapoints are accessible and controlled over the cellular connection. Live data will be viewable, pushed over the API to a local database and plotted in real time. Project stakeholders will be able to live-stream data.

The data acquisition system and controller has been thoroughly tested in both the Yuma and Freestone field trials. Few modifications will be required for the BGDNRF demonstration.

Permitting/Approvals

We have coordinated with the BGNDRF Facility Manager, Dr. Malynda Capelle, to provide all requisite permitting information, including a plan for site preparation and system installation, a team member information document for site access authorization, a use application for connecting our concentrator to their water source, a review for compliance with their water discharge permit, and a jobsite hazard analysis. These items have been conditionally approved, and if selected as a finalist, we will finalize our test window at BGNDRF.

System Commissioning

Once installed, the commissioning of the steam-generating solar array will proceed independently of the BrineZero processor. The solar array will be 40% filled with water manually to verify the controller and solenoid valves are operating properly. The array will produce steam with the exit valve throttled to maintain 4 to 5 psi so that the integrity of all steam-loop gaskets/seals can be confirmed. Steam production by the array will be repeated over several days with steam vented to ambient. The array will be charged with water from Well No. 3 for these commissioning tests so that a beneficial, thin layer of scale can form on the inner walls of the solar tubes[5]. During this procedure, sensor readings and data acquisition will be verified.

The containerized BrineZero processor will arrive on-site prefabricated. The internal plate stacks and interconnecting plumbing will be leak tested upon arrival to ensure integrity following shipping. External steam and brine connections will be completed. A cold flow test will be performed with well water pumped from the 1,500-gallon feed tank, through the stacks of condensing plates, to the precipitation tank, through the brine return line to the wicks, and back to the feed tank. This test must confirm that there are no leakage paths where the feed water crosses over to the external surfaces of the condensing plates (i.e., the condensate collection weirs should remain dry). All pumps will operate on power provided by the unit's PV array, confirming this system's operation.

In the last commissioning procedure before solar operation, the six parallel flows from the precipitation tank to the modules will be balanced. Finally, the connection to the steam-generating solar array will be completed, and the combined, fully operational system will be started.

All instrumentation, data acquisition, system controls and operating procedures will be verified in at least one week of BrineZero operation under conditions that duplicate the judged test before commencing the judged test.

[5] An earlier page note discussed the 10% enhancement in performance provided by thin scale layers on the inner surfaces of the solar tubes.

Performance Metrics to be Validated

The proposed demonstration will operate a BrineZero processor that is driven by steam supplied by a solar array. This integrated system will operate under conditions that replicate the operation for an early market-entry application: a blowdown concentrator for a 100-ton cooling tower driven by a solar thermal array.

Both the solar array and the BrineZero processor have independent commercial applications addressing separate energy and water needs. Furthermore, the critical need to attract strategic partners and/or investors to accelerate commercialization requires that both technologies address markets that are much larger than blowdown from small cooling towers. Recognizing both the independence of each technology and their ability to address problems in much larger markets, separate performance metrics are identified for each.

Steam-Generating Solar Collector

The single most important metric for the steam-generating solar collector is the levelized cost of the supplied thermal energy (i.e., Cost of Thermal Energy—COTE). For industrial customers, a gas-fired boiler would be the competing technology. Since an industrial customer that installed a steam-generating solar collector would probably still need a gas-fired boiler as back-up, the COTE for steam supplied by solar collector must be less than the COTE for steam provided by the boiler (with no credit for avoiding the capital investment in a boiler)[6].

Natural gas prices have been extremely volatile in recent years (partly due to disruptions caused by the war in the Ukraine). Assuming the average price paid by industrial customers for natural gas in 2023[7] represents future prices, the COTE for steam provided by an 80%-efficient gas-fired boiler is $0.0196 per kWh-thermal. (For reference, the 2023-average Cost of Electricity for industrial customers was $0.0806 per kWh-e).

The levelized COTE supplied by a steam-generating solar array is projected to be between $0.014 and $0.015 per kWh-thermal when the array operates in locations with high insolation (e.g., central California, the Southwest)[8]. This projected cost is about 25% below the cost of thermal energy supplied by a natural-gas boiler. The critical metrics that must be validated if this projected levelized COTE is to be realized are: (1) the selling price of an installed, fully functional, steam-generating array is equal to or less than $350 per peak kilowatt-thermal, (2) maintenance costs are equal to or less than $1,000 per year (for an array of 40 panels), and (3) the solar conversion efficiency for the steam-generating array is no worse than that for a conventional evacuated-tube collector delivering 170°F hot water.

The metric for the array's solar conversion efficiency will be the most straightforward to confirm. The critical performance parameters for calculating conversion efficiency will be

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[6] Technologies are available for high-temperature thermal storage, and development is reducing their capital cost. Our assumption that the solar collector is backed up by a natural-gas boiler is a "worst case" assumption in that it does not require the availability of a low-cost means of storing thermal energy.
[7] $4.59 per thousand cubic feet (https://www.eia.gov/dnav/ng/hist/n3035us3m.htm)
[8] The preceding costs are levelized values based on 5% cost of capital and 30-year array lifetime.

measured: (1) global solar insolation, and (2) useful thermal energy output (as inferred from measured condensate production). Using this data, the array performance will be added to the data shown in Figure 10. This metric is confirmed if the new data falls on or above the line for AP-20 with 170^{o}F supply temperature.

Regarding the installed-cost metric, based on the Bill of Materials shown in Table 3 for the BGNDRF array and the assumption that 64-person-hours are required to install the 14-panel array with auxiliary steam distribution, the installed cost for the BGNDRF array is $350 per peak kW-thermal[9]. Since larger commercial arrays should have lower per-peak-kW installed cost than the BGNRDF array, the successful operation of the BGNDRF array as designed and within the budgeted labor will confirm the installed-cost metric.

Given its relatively short duration, the BGNDRF will not be able to confirm the preceding target for annual maintenance. However, the demonstration can uncover possible operational problems that might create maintenance needs. The execution of the BGNDRF as planned without unforeseen problems would be a necessary (but not sufficient) condition to validate the metric for maintenance.

(Our steam-generating solar collectors will compete favorably against flat-plate, evacuated-tube, and non-imaging CPC collectors. Our commercialization partner—Tevesa Energy—estimates in their letter of support a 50% reduction in project installed cost for an array of our collectors versus conventional evacuated-tube collectors.)

The BrineZero DGD Processor

The most important metric that determines the BrineZero processor's commercial competitiveness is its Levelized Cost of Water (LCOW). This metric depends on the processor's field of use. Two applications are considered: (1) recovery of water from cooling tower blowdown (a low TDS application—4,000 ppm TDS feed brine), and (2) volume reduction for the brine discharged from inland desalting plants for brackish water (a moderate TDS application—30,000 ppm TDS feed brine).

For the first application, our industrial partner, XXXXXX, estimates that a 97% reduction in tower blowdown will incur $10,000 per year in water savings for the typical owner of a 300-ton cooling tower who operates the tower at 5 Cycles of Concentration (CoC). These annual savings equate to a LCOW of about $2.00 per cubic meter of recovered water.

XXX also recognizes that there is a subset of tower owners for whom water recovery from blowdown has a much higher value--perhaps closer to $4.00 per cubic meter. A combination of factors impacts these tower owners including: (1) stressed regional water resources leading to high costs for make-up water, (2) high costs for pretreating make-up water, (3) environmental restrictions imposing high costs for blowdown disposal.

The value that a BrineZero processor must provide the owner if a relatively small tower (i.e., 100 to 300 tons) is then bounded by the preceding $2.00 and $4.00 per cubic meter LCOWs.

[9] The labor rate for installers is assumed to be $40 per hour.

Providing blowdown disposal at a LCOW less than $4.00 per cubic meter is a performance metric that must be met if the solar-driven BrineZero processor is to address the needs of tower owners with exceptionally high costs for blowdown disposal or make-up water. The lower $2.00 per cubic meter must be met if the BrineZero processor is to address a larger population of tower owners.

As shown in Table 5, the prototypical BrineZero processor to be tested at BGNDRF is projected to operate at a LCOW equal to $2.95 per cubic meter. The $24,353 cost of the 20' container system assumes the same BOMs shown in Tables 1 and 2, but with material costs adjusted for higher volume purchases and the addition of $4,000 in labor for the fabrication of a 6-module, containerized unit. The analysis in Table 5 also assumes that the owner of the BrineZero processor is purchasing steam from a third-party owner of a steam-generating solar array at a cost of $0.015 per kWh-thermal (i.e., a sunny location in the Southwest.)

The LCOW shown in Table 5 will motivate sales to tower owners with high costs either for make-up water, water treatment or blowdown disposal.

Table 5

97% Blowdown Reduction for 100-ton tower		
number of DGD Modules	6	
average maximum water production	2.24	gpm
cost of electricity	$0.110	per kWh
cost of thermal energy	$0.015	per kWh
system capacity factor	0.90	
hours per day of operation	10.0	
amortization period	15.4	
cost of container system to installer	$24,353	
cost to install	$1,800	
project developer profit	30%	
cost of container system to end user	$33,999	
annual maintenance increment (over tower)	$1,000	
annual condensate production	1,672	m3
annual electrical energy cost	$181	
annual thermal energy cost	$1,721	
OPEX	$1.63	per m3
CAPEX	$1.32	per m3
COW	$2.95	per m3

The performance metrics that must be validated in the test at BGNDRF if the BrineZero processor is to claim the LCOW shown in Table 5 are: (1) efficiency of operation (i.e., Gain Output Ratio), (2) the processing capacity (i.e., average gpm of product) (3) the installed cost for the processor (dollars-per-gpd of capacity), and (4) O&M costs (dollars-per-year). As with the solar array, the efficiency metric will be the most straightforward to validate. The data acquisition system for the demonstration will provide minute data on the level of liquid in both the product tank and the condensate tank. These level measurements will be converted first to flow rates and then to GORs. A value close to 10 for the GOR averaged over the week of the test (which approximately equals our projected GOR) will validate this efficiency metric.

The 6-module BrineZero processor is designed to recover 97% of the water from 9,000 gallons of blowdown in 63 hours of operation. This operation is equivalent to the 2.24-gpm average production rate shown in Table 5. This average production rate is a metric that will be validated by the measured volume of product produced during the 7-day test.

If the product water from a BrineZero processor for tower blowdown is to be used as tower make-up water its TDS mineral content should be less than 500 ppm. The condensate produced in the 7-day demonstration must have a mineral content less than 500 ppm (approximately equivalent to 700 μS/cm) to validate the metric for purity.

The validation of the metric for installed cost is not as simple as for the solar array. A single, first-of-its-kind fabrication of the containerized BrineZero processor will incur significant costs that will not burden a future processor produced in moderate volumes. We again apply a "necessary but not sufficient" condition to partially validate the installed cost metric: the BGNRDF BrineZero processor operates without problems that would require a significant cost increase to the BOMs shown in Table 1 and 2.

Lastly, the maintenance metric will also be addressed on a "necessary but not sufficient" basis: the operation of the BGNRDF BrineZero processor during its relatively short operation must not encounter any unexpected maintenance needs. In particular, possible failure mechanisms for the BrineZero processor are (1) fouling of the wicks by precipitating minerals that escape the seeded precipitation tank, and (2) scale formation on the interior passages of the condensing plates. Specimens of critical surfaces will be sent to either Princeton University or commercial labs for SEM imaging. The maintenance metric will be validated if this imaging fails to detect fouling or scale accumulation.

Table 6 summarizes the metrics to be validated in the test of the BrineZero processor.

Table 6 - Validated Metrics for BrineZero Processor

Metric	Criteria	Comment
Gain Output Ratio	10	no measured degradation in performance of 7-day test
Capacity	2.25 gpm	no less than criteria value
Product Quality	700 microS/cm	no greater than criteria value
Capital Cost		design requires little modification to operate longer periods
Maintenance Cost		post-test inspection does not uncover scaling or fouling of heat transfer components

As previously noted, the BrineZero technology will attract more interest from investors and/or strategic partners if it addresses the needs of markets far larger than small cooling towers. The guidelines for the SDP competition list five major markets addressable by solar desalination. A BrineZero processor would have difficulty competing in three of the five markets: the RO technology that desalts seawater in two of the markets has matured over fifty years to a very robust, low-cost source of freshwater that will be difficult to displace, and the market for treating produced water from oil and gas operations is challenged by volatile contaminants in the produced water that could disrupt BrineZero operation.

Converting brackish water into a resource for domestic and agricultural use represents a tremendous market for any technology that can solve the inland brine disposal problem. As noted on the website of the Texas Water Resources Institute[10],

[10] https://twri.tamu.edu/publications/txh2o/2014/summer-2014/everybody-is-talking-about-it/

As Texas' population continues to multiply and with drought never far out of the picture, the use of brackish groundwater to meet future water supply needs is gaining interest…Within these aquifers are more than 880 trillion gallons of brackish groundwater. If converted to freshwater, that amount of water could maintain Texas' current water consumption levels for about 150 years.

Upgrading inland brackish water to meet standards for irrigation is the core rationale of the start-up Global Water Innovations (GWI). GWI's ability to sell projects to inland farms (who until recently were in desperate need for crop irrigation water) is severely limited by the high cost of RO/EDR waste brine disposal. As explained by Mr. Clark Easter—CEO of GWI:

Brine disposal costs are generally well over $10 per cubic meter for transportation and deep well injection, and can be as much as $25 per cubic meter for thermal distillation using traditional technologies…Our research has led us to conclude that no established company is yet able to meet GWI's target of $4.00 per cubic meter for ZLD brine treatment.

A BrineZero processor for tower blowdown could be adapted to concentrate RO/EDR waste brine, which will have TDS levels approximately 10X higher than tower blowdown. This 10X increase in feed brine concentration will degrade both the processing capacity and the GOR for BrineZero by about 10%. The combined effect of these losses will be to increase the CAPEX and the energy component of OPEX by 10%. If the maintenance component of OPEX also increases by 10%, a solar-driven BrineZero processor will have a LCOW of $3.30 per cubic meter for the RO/EDR application—well below GWI's $4.00 target.

The planned demonstration at BGNRDF will not simulate the operation of a concentrator for RO/EDR discharged brine. However, stable, predictable operation that validates the metrics in Table 6 would be an important step towards attracting resources to advance BrineZero into the more challenging and much larger market.

Technology Scale-Up

Addressing larger markets will require significant scale-up of the 6-module BGNRDF system. Our approach to scale-up would be to retain discrete modules as the basic building block, but increase the number of plates per-module from 100 to 320 so that interconnecting plumbing is simplified. With this increased module size, a full-scale plant that has a water recovery of 95% when processing 164,000-gpd of RO waste brine would have 100 modules arranged in seven stages in series with brine concentration increasing from 8,000 ppm TDS to 193,000 ppm TDS as it is pumped from Stage 1 through to Stage 7. Table 7 shows the predicted performance of the seven stages.

Table 7

Stage		1	2	3	4	5	6	7	Total
Brine Feed Temp	C	30.0	30.0	30.0	30.0	30.0	30.0	30.0	
Brine Preheat Temp	C	91.9	91.7	91.1	90.4	89.6	88.9	88.1	
Brine Max Temp	C	95.0	95.0	95.0	95.0	95.0	95.0	95.0	
Brine Discharge Temp	C	33.4	33.7	34.2	35.0	35.8	36.5	37.3	
Brine/Condensate Delta	C	3.2	3.5	4.0	4.8	5.6	6.3	7.1	
Brine Feed	gpm	125.3	50.9	24.0	11.1	8.5	8.2	3.4	
C Input	ppm	8,000	19,327	34,729	62,289	98,208	135,064	162,235	
C Output	ppm	19,327	34,729	62,289	98,208	135,064	162,235	193,306	
BPE	degC	0.30	0.65	1.30	2.20	3.20	4.00	5.00	
Water Vapor Flux	LMH	0.380	0.369	0.350	0.322	0.292	0.268	0.238	
condensate	gpm	73.5	22.6	10.6	4.1	2.3	1.4	0.6	
Stage GOR		18.94	17.28	14.46	11.14	8.24	6.52	5.12	16.36
Q Thermal	kW-th	567.9	191.2	107.5	53.6	41.1	30.9	15.7	
Brine Recirculation	gpm	748.9	239.4	121.6	52.0	33.5	22.1	10.1	
nAssemblies		74	23	12	5	3	2	1	120
								recovery	95.9%

BPE - Boiling Point Elevation of Brine

(The very high GOR for a boiler-driven BrineZero applied to the more challenging RO-brine application is consistent with 10.1 GOR for the solar-driven BrineZero applied to tower blowdown. With the boiler-driven processor running 24/7, the LCOW is lowest when the brine feed to each stage is decreased. The processor operates at a much higher surface-area-to-flow ratio. This leads to a significantly reduced capacity per module but much higher GOR.)

The 164,000-gpd BrineZero facility for concentrating RO waste brine is projected to have a $1.29 per cubic meter LCOW. Appendix A presents the assumptions and analysis that supports this LCOW.

Business Opportunities

The two innovative technologies at the core of BrineZero—the steam-generating solar collector and the diffusion-gap distillation process—will enter the market through very different business approaches. The successful completion of the BGNRDF demonstration with validated metrics for the steam-generating solar collector could immediately be followed by commercial sales (although the first sales may need to be "incentivized" to motivate early adopters).

Although we have not prepared a pro-forma forecast of financials, we expect that the capitalization for starting up the sale of steam-generating solar arrays to be relatively small. Since all components for an array can be directly purchased from either domestic or off-shore vendors with all required modifications done by the vendor prior to shipping from the factory, we would not have to invest in manufacturing or tooling. Our principal capital demand would be for warehousing components and the associated carrying costs for inventory. With the material for a 40-panel installation being about $20,000, start-up capitalization will be well within the means of self-financing by AIL Research.

As the only sales outlet for the steam-generating array, AILR would support project developers, such as our team partner Tevesa Energy, to prepare proposals for customers. We would also train project developers to install and operate the novel solar technology. In addition to buying core components from AILR, project developers would operate under a license for AILR's patent[11].

Market entry of BrineZero processors will be much more involved and longer term. A test of the BrineZero concentrator at BGNRDF is too short to prove the technology's commercial readiness. Both XXXXX and XXXXX recognize that further development will be required.

If the performance demonstrated at BGNRDF validates all key metrics, we would follow a dual path towards market entry. In the field of use limited to cooling towers, we would work with XXX to advance the BrineZero technology. As expressed by XXX's Global Director for Technology Innovation in their supporting letter, "with [our] state-of-the-art Technology Innovation laboratory…XXX is positioned to provide…technical validation/testing for blowdown recovery solutions."

For the broader desalination market, we would work with XXXXX towards market entry of BrineZero. As expressed by XXXXX's president/CTO in his letter of support "if test operation under the SDP is positive, we would very much want to work with you to bring your technology to commercial readiness…your technology could address the critical problem of brine disposal from RO and EDR desalting plants, perhaps being part of an integrated all-important, ZLD option for brine disposal."

The technical appendix to the SDP guidelines reports MVC energy consumption for brine concentration prior to ZLD crystallizing to be 20 to 25 kWh per m3 with very high capital costs for "expensive materials, such as titanium and stainless steel [required] to prevent corrosion in the boiling brine". Although many aspects of BrineZero's operation for concentrating the discharged brine from an inland RO facility for brackish water need to be confirmed, the

[11] U.S. Patent 8,459,250 protects AILR's steam-generating solar collectors through 2029. AILR expects to extend protection for another 20 years through innovations that they have developed as part of the installation and operation of large, prototypical arrays.

previously-cited $1.29 per m3 LCOW will be one-fourth (or less) than those for a MVC-based alternative.

AIL Research would duplicate an approach to market entry that we are now following with a major HVAC manufacturer interested in our liquid-desiccant technology—we would enter into both a Joint Development Agreement that identifies the tasks to be funded by our industrial partner and a Licensing Term Sheet that sets limits on the royalties to be paid by the industrial partner for exclusive access to our technology in a defined field of use[12].

[12] In addition to our know-how for BrineZero, AILR would license technology in U.S. Patent No. 9,770,673 (May 2034 expiration).

Appendix A - 165,000 GPD Facility for RO Brine Concentration Driven by Steam Boiler

Table A1 - BOM and Material/Labor Costs for 320-Plate DGD Module

item	material	no.	per unit	unit	cost
Condensing Plate (1)	2 mm Coroplast	320	$0.20	per ft2	$572
Segmented Brine Wick (1)	30 mil, treated non-woven fiberglass	320	$0.25	per ft2	$637
I/O silicone inserts	silicone or other elasomer; Noryl	1920	$0.10	each	$192
Top Slot Cover Plate; 3 mm Coroplast (2)	3 mm Coroplast	640	$0.20	per ft2	$16
Bottom Slot Cover Plate; 4 mm Coroplast (2)	4 mm Coroplast	640	$0.20	per ft2	$72
wick spreader; 8/10 mm Coroplast (1)	8/10 mm Coroplast	640	$0.20	per ft2	$4
Wick Gutters	ABS or PVC	320	$0.86	per ft	$268
Edge Spacer (2)	4 mm Coroplast	1280	$0.20	per ft2	$28
Central Spacer; 4 mm Coroplast (2)	4 mm Coroplast	640	$0.20	per ft2	$13
Top/Bottom Compression Member	6061-T6 Aluminum 4" U-Channel	4	$9.91	each	$40
Top/Bottom Compression Member Cap	6061-T6511 Al Round Bar - 2-1/2"	4	$1.30	each	$5
Sidewall Segment	1 mm aluminum sheet metal	10	$3.45	each	$35
Tie Rod	3/8" aluminum rod	13	$1.28	each	$17
Base (one per two DGD modules)	2" x 2" 16 ga. tubular steel	0.5	$74.80	each	$37
Upper Brine Feed Tube	35 mil wall, 1/2" cupronickel pipe	2	$12.00	per	$24
Adhesive	PMMA		$40.00	per assembly	$40
Sensors and wiring		1	$21.00	per assamply	$21
Miscellaneous Hardware		1	$30.00	each	$30
Labor		12	$40.00		$480
Total					$2,531

Table A2 - Direct Component/Material Cost 165,000 GPD Facility

item	no.	per unit	unit	cost
Flow Control Valve	120	$40	each	$4,800
Brine Pump	14	$120	each	$1,680
Evap Fluid Cooler	7	$2,500	each	$17,500
Main Brine Storage Tank	2	$1,408	each	$2,816
Hot Seeded Storage Tank	7	$460	each	$3,220
Hot Auxiliary Storage Tank	7	$460	each	$3,220
320-Plate DGD Modules	120	$2,531	each	$303,720
Control Panel and wiring	1	$6,500	each	$6,500
High temperature plumbing	420	$5	per foot	$2,050
low temperture plumbing	420	$1	per foot	$210
High temperature plumbing fittings	105	$5	each	$525
Low temperature plumbing fittings	105	$1	each	$105
Material Total				$346,345

Table A3 - Operating Specifications 165,000 GPD BrineZero Concentrator

Plant Capacity	164,334		GPD
Feed Brine	8,000		ppm
Discharged Brine	193,306		ppm
Recovery	95.9%		
Number Stages	7		
Number Modules	120		

Stage	Modules
1	74
2	23
3	12
4	5
5	3
6	2
7	1

Figure A1 - Module Layout – 165,000 GPD BrineZero Plant

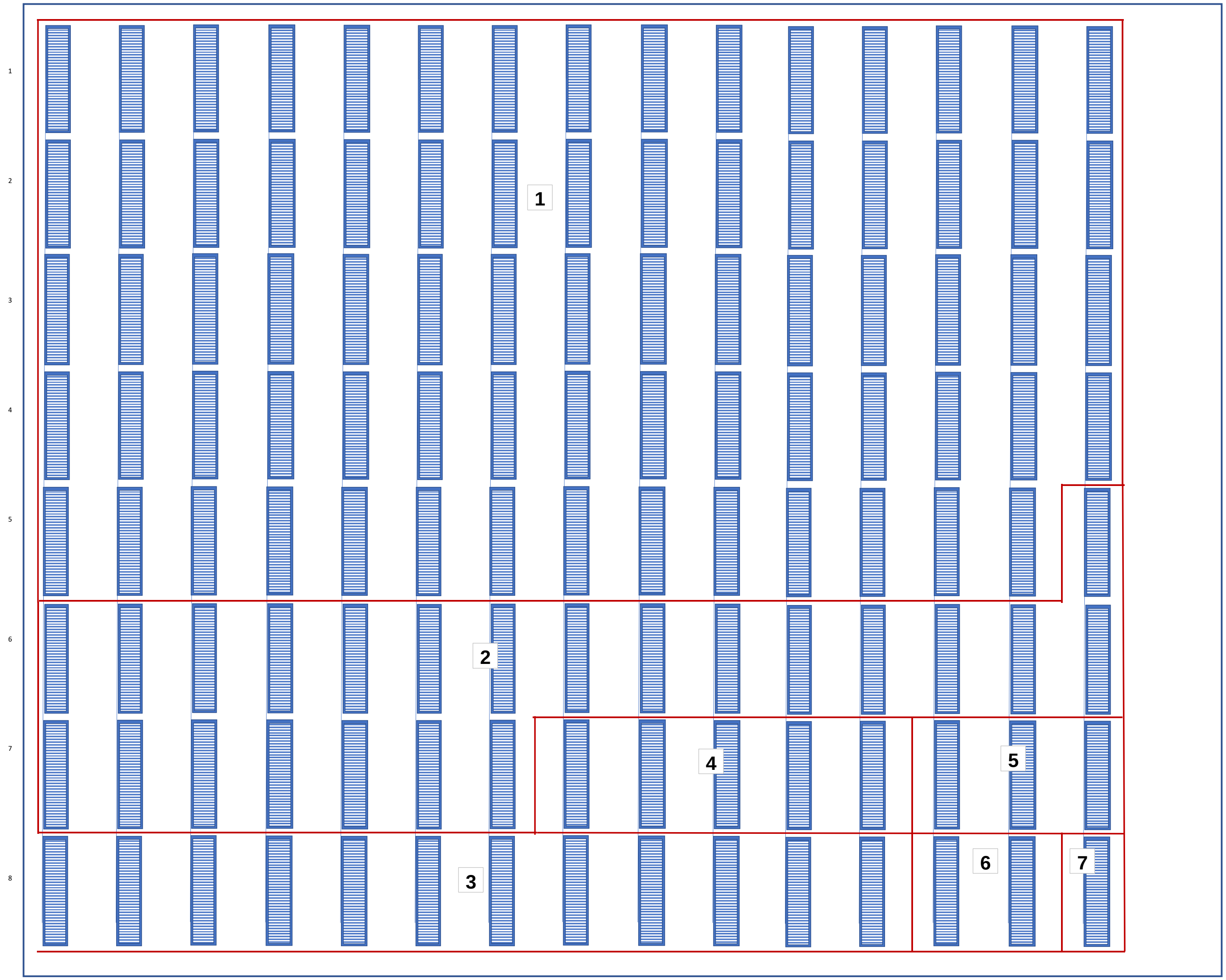

Table A4 - Levelized Cost of Water--165,000 GPD BrineZero Facility

Periods, n	30	years
Discount rate, i	7.01%	
Inflation rate	2.5%	
Capacity Factor	0.85	
Variable O&M (based on RO Desalting Plant)	$0.264	per m3
Cost escalation rate	2.5%	
Contingency	10.0%	
Land per-sf cost	$10,000	per acre
Building per-sf fab cost	$40.00	per square foot
Facility Capacity	164,000	GPD
Direct material	$346,345	per Table A2
Labor	$48,000	per Table A2
Building Area	10,000	square feet
Building Cost	$400,000	
Land Area	12,000	square feet
Land Cost	$2,755	
Contingency (applied to processor only)	$35,835	
Overnight Cost	$797,100	
1/CRF (amortization period)	16.3	years
Cost of Steam	$0.0188	per kWh-thermal
GOR (average all stages)	16.4	
Annual CAPEX	$48,993	
Annual OPEX Energy	$149,468	
Annual OPEX O&M	$50,881	
Annual Processed Brine	192,607	m3
LCOW Brine Processing	$1.2946	

All costs for pretreatment are borne by RO facility

Appendix B – Brine and Steam Piping Runs within a BrineZero Container

- Brine supply to modules
- Preheated brine to precipitation tank
- Fully heated brine returned to modules
- Brine return from modules
- Steam supply to precipitation tank
- Condensate supply