To	Peter Hartz **|** City of Watertown, Wisconsin
From	Jon Butt, PE & Spencer Davis **|** Mead & Hunt
Date	May 8, 2024
Subject	Revised Sludge Dryer Information Summary & Biogas Utilization Evaluation City of Watertown, Wisconsin | Wastewater Treatment Plant Project No. R4666751-222127.01
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Executive Summary

The City of Watertown, Wisconsin (Watertown) owns and operates a municipal wastewater treatment plant (WWTP). Normal operation of the treatment process produces sludge. Primary solids and waste-activated sludge are processed on site in anaerobic digesters. Digested sludge is periodically removed and dewatered for land application.

This technical memorandum contains information on various sludge-drying technologies that can help the WWTP reduce the volume of sludge for disposal. It also summarizes the evaluation of using excess biogas from anaerobic digestion to support sludge drying. Projected energy usage and costs can be found in the main part of this technical memo and therefore were not included in the executive summary.

There are multiple sludge dryers on the market. All sludge dryers can be divided into two general types – convective or conductive. Within these types, you can separate technology based on physical attributes, as described below.

- Drum Dryers – This style of dryer usually consists of a round outer shell with the sludge contained within. In some applications, the outer shell rotates to help tumble the sludge. In other cases, internal paddles, blades, or augers move the sludge through the shell. Drum dryers can be either convective or conductive designs.
- Belt Dryers – This style of drying equipment usually consists of a rectangular rotating surface (belt). Sludge is deposited onto the surface using an extruder to form a nearly continuous ribbon of sludge. The belt is enclosed with a shell that contains hot air. The ribbon of sludge moves with the belt through the hot air. Most dryers of this type are conductive designs. A variation on this type of dryer uses dehumidified air instead of hot air. The warm moist air passes through a condenser to remove water and to recover energy. This type of dryer has minimal exhaust.

A summary table of the dryer equipment technologies and the preliminary design information received from each equipment supplier is attached to this technical memorandum. Highlights from the summary table are below.

- The belt dryers from Shincci and Centrysis had the lowest capital cost at approximately $1.7 to $1.8 million.
- The Bioforcetech drum dryer and Shincci belt dryer units operate at the lowest temperature, which is less than 170°F.
- The drum dryers from LCI and Komline-Sanderson had the smallest footprint at less than 200 square feet. The next closest units were the belt dryers from Centrysis and Shincci at less than 500 square feet.
- The Bioforcetech drum dryers had the largest footprint at 7,000 square feet. The next largest footprint is the Gryphon drum dryer at just over 5,500 square feet.
- A total of four Bioforcetech drum dryers would be required because of batch operation. While this requires more dryers, the increased number of units may minimize other support equipment, such as dewatered sludge storage and sludge conveyors.
- The BCR drum dryer had the lowest weight at just over 22,000 lbs (11 tons). The Bioforcetech drum dryer and Centrysis belt dryer are the heaviest units at over 43,000 lbs (21.5 tons).
- The Gryphon drum dryer was the only unit that had the sludge in direct contact with the burner exhaust.
- The Bioforcetech drum required the lowest amounts of energy (heat and/or electricity).

Biogas from anaerobic digestion can be used on site as replacement fuel for natural gas. It is estimated that it would cost $220 per day in natural gas to operate a sludge dryer. The excess biogas could replace about 25% of the natural gas needed for sludge drying at a cost savings of approximately $14,000 per year. A second option is to use biogas in a combined heat and power (CHP) system. The most common system involves an internal combustion engine and electric generator. The total average daily biogas flow rate of 29,000 cf per day (1,200 cf/hr) could power a 75 kW CHP unit at about 95% output. This unit would produce about 0.26 MMBTU/hr of hot water, enough to heat the digesters on average throughout the year and produce about 70 kW of electricity. Assuming 24 hours of operation, the electrical energy would be enough to meet the demands of several of the dryers. Natural gas would be needed to provide heat for sludge drying, so the CHP system would not yield any thermal savings through reducing the natural gas consumption. The electricity produced would offset the new demand from sludge drying, accounting for a cost reduction approaching $137 per day based on an electrical utility rate charge of $0.08/kwh.

Solar panels could be used to meet the electrical demand if biogas is used strictly for heating. The daily electricity demand ranges from around 900 kwh to 5,520 kwh depending on the dryer. A solar array with output ranging from 150 kw to nearly 1,000 kw would be necessary to satisfy the electrical demand for the dryers for a 6-hour period during daylight hours. The cost savings from the solar array would approach between $70 to $440 per day.

The main drivers for the plant staff to install a dryer system are the reduction of biosolids volume, reclassification of biosolids for land spreading, and potential destruction per- and polyfluoroalkyl substances (PFAS). Most of the proposed dryer systems included in this evaluation will accept the dewatered solids (~20 to 25% total solids (TS)) from the existing centrifuges and dry them to above 90% TS, achieving a 75% reduction in total biosolids volume. Additionally, these dryer systems would have sufficient pathogen reduction to produce Class A biosolids per Wisconsin Department of Natural Resources (WDNR) rules. Overall, this system would benefit the Watertown WWTP in its ability to produce, store, and sell biosolids.

Conclusions

The following conclusions are summarized in this technical memorandum:

- Sludge drying is a viable option for Watertown to decrease the volume of sludge for disposal. Sludge drying can also change the classification of the sludge for disposal.
- Multiple different types of sludge dryers can be integrated into the existing treatment process.
- The capital cost of adding sludge drying will be significant.
- Utilities (gas and electricity) will increase in support of sludge drying.
- Excess biogas available in the summer when digester heating needs are lower can be used to reduce some of the gas utility increase.
- Solar panels could help reduce some of the electrical utility when sunlight is available.
- Pyrolysis is a technology that is compatible with any sludge drying technology and has the potential of removing PFAS from the dried solids.

Recommendations

Watertown should proceed with the conceptual design of two sludge drying technologies. The conceptual design would include:

- Determining how the two chosen sludge drying technologies would integrate into the existing process
- Identifying what, if any, supporting equipment would be needed, such as air scrubbing, conveying, and temporary sludge storage.
- Identifying all utility needs.
- Determining the proper sizing of the sludge dryers.
- Developing planning-level budgets for each dryer.

The conceptual design should be based on a Gryphon-style drum dryer and Centrysis-style belt dryer. The drum dryer is recommended based on a preference expressed by WWTP staff. The belt dryer is recommended because of its small footprint and overall lower initial capital cost.

Initiating conceptual design will allow the design team to work through the multiple design details necessary to properly determine how the drying equipment can integrate into the existing sludge process, along with summarizing any support equipment that is outside the scope of supply of the sludge dryer manufacturers. Developing a conceptual design will also help Watertown develop the capital planning cost estimate needed for project budgeting.

1. Project Background

Watertown owns and operates a municipal WWTP. The wastewater treatment process is extended aeration-activated sludge. Normal operation of the treatment process produces sludge. Primary solids and waste-activated sludge are processed on site in anaerobic digesters. Digested sludge is periodically removed and dewatered for land application.

Land disposal of solids is becoming more challenging. The WWTP staff is interested in investigating drying the digested sludge to reduce the volume of sludge for disposal and reduce the amount of land needed. Dried biosolids could qualify as Class A material and make land application easier, as well as allow the opportunity for other disposal options.

Additionally, biogas is produced during the anaerobic digestion of waste solids. This biogas is used on site to heat the digesters, with excess biogas being flared. Some drying technologies can use the excess biogas as fuel either directly or indirectly.

This technical memorandum supplies information on various sludge-drying technologies to help Watertown compare its options. It also identifies the amount of energy offset possible by using the excess biogas from anaerobic digestion to support sludge drying.

2. Sludge Drying Technologies

There are multiple sludge dryers on the market. All sludge dryers can be divided into two generic types – convective or conductive. Within these types, you can separate technology based on physical attributes, as described below.

- Drum dryers – This style of dryer usually consists of a round outer shell with the sludge contained within. In some cases, the outer shell rotates to help tumble the sludge. In other cases, internal paddles, blades, or augers move the sludge through the shell. Drum dryers can be either convective or conductive designs.
- Belt dryers – This style of drying equipment usually consists of a rectangular rotating surface (belt). Sludge is deposited onto the surface using an extruder to form a nearly continuous ribbon of sludge. The belt is enclosed with a shell that contains hot air. The ribbon of sludge moves with the belt through the hot air. Most of the dryers of this type are conductive designs. A variation on this type of dryer uses dehumidified air instead of hot air. The warm moist air passes through a condenser to remove water and to recover energy. This type of dryer has minimal exhaust.

Mead & Hunt received preliminary design information from eight different equipment suppliers. The manufacturers providing information included:

- Drum Dryers: Gryphon, Bioforcetech (drum biodryer), Komline-Sanderson (paddle dryer), BCR (screw dryer), and LCI (thin film).

- Belt Dryers: Centriysis, Huber, and Shincci (dehumidifier).
- Gryphon: The product can be classified as a convective drum dryer (direct heat source) where the outer shell of the dryer rotates.
- Komline-Sanderson, BCR, and LCI: The products can be classified as conductive drum dryers (indirect heat source) where the outer shell is fixed in place. The Komline-Sandaerson unit relies on heated paddles to transfer heat to the sludge and move the sludge through the outer shell. The BCR unit relies on a heated internal screw to transfer heat to the sludge and move the sludge through the outer shell. The LCI unit uses wipers to spread a thin film of sludge onto the inner surface of the hot stationary outer shell. The wipers also assist with moving the sludge through the shell
- Bioforcetech: The unit is unique and classified as a convective drum dryer. This unit generates its own direct heat through biological activity within the sludge. The biological activity within the sludge is initiated by warming the sludge with an indirect heating source. The Bioforcetech unit operates in a batch mode requiring over 70 hours to process each batch of sludge.
- Centrysis and Huber: These belt dryers are classified as conductive dryers (indirect heat source). The Centrysis unit uses a hot water loop to provide heat for drying. The Huber unit uses hot oil. In both cases, an external unit is used to heat water or oil.
- Shincci: The dryer is classified as a conductive dryer. A more accurate description of the Shincci unit is a dehumidifier. Dry air is circulated with the sludge to extract moisture. The warm moist air passes through a condenser, where water is removed and heat is recovered. The dry air is returned to continue sludge drying. The Shincci dryer is the only unit that does not vent air from the sludge drying section. All the other dryers require venting.

A summary table of the dryer equipment technologies and the preliminary design information received from each equipment supplier is attached to this technical memorandum. Highlights from the summary table are below.

- A total of four biodryers would be required because of batch operation. While this requires more dryers, the increased number of units may minimize other support equipment such as dewatered sludge storage and sludge conveyors.
- The Shincci and Centrysis belt dryers had the lowest capital cost at around $1.7 to $1.8 million.
- The Bioforcetech and Shincci units operated at the lowest temperature at less than 170°F.
- The LCI and Komline-Sanderson units had the smallest footprint at less than 200 square feet. The next closest units were the Centrysis and Shincci dryers at less than 500 square feet.
- The Bioforcetech dryers had the largest footprint at 7,000 square feet. The next largest footprint is the Gryphon dryer at just over 5,500 square feet.
- The BCR dryer had the lowest weight at just over 22,000 lbs (11 Tons). The Bioforcetech and Centrysis dryers were the heaviest units at over 43,000 lbs (21.5 tons).
- The Gryphon dryer was the only unit that had the sludge in direct contact with the burner exhaust.
- The Bioforcetech required the lowest amounts of energy (heat and/or electricity).

More information on each dryer can be found in the summary table or the preliminary design information attached to this technical memorandum.

3. Biogas Utilization

Biogas from anaerobic digestion can be used on site as replacement fuel for natural gas.

The dryer technologies need approximately 1.5 to 1.7 MMBTU/hr of heat to dry the sludge. There are some exceptions, but most are in this range. This translates to about 1,600 cf/hr of natural gas or 16 therms/hr. At a cost of $0.58 per therm, the cost to run the sludge dryer would average about $220 per day or about $56,000 per year assuming 24 hr per day operation, 5 days per week, and 50 weeks per year. Raw biogas can be used to directly displace natural gas for sludge drying. The biogas can supply on average 0.418 MMBTU/hr of heat (hot water) assuming 80% efficiency in the boiler and a biogas flow rate of about 21,000 cf per day. This amount of energy could displace about 25% of the natural gas needed for sludge drying at a cost savings of around $14,000 per year.

A second option is to use biogas in a combined heat and power (CHP) system. The most common system involves an internal combustion engine and electric generator. A biogas flow rate of 29,000 cf per day (1,200 cf/hr) could run a 75 kW CHP unit at about 95% output. This unit would produce about 0.26 MMBTU/hr of hot water, enough to heat the digesters on average throughout the year and produce about 70 kW of electricity. Assuming 24 hours of operation, the electrical energy would be enough to meet the demands of several of the dryers. A few, such as the Shincci and Gryphon dryers, have higher electrical usage. Natural gas would be needed to provide heat for sludge drying so there adding a CHP unit would not result in any thermal savings from reducing natural gas consumption. The electricity produced would offset the new demand from sludge drying, accounting for a cost reduction approaching $137 per day or $34,000 per year based on 24-hour operation, 5 days per week, 50 weeks per year, and $0.08/kwh. The capital cost for adding a CHP system would approach $500,000 installed not including any special gas conditioning equipment. The potential simple payback for a CHP system can be estimated by dividing the installed cost ($500,000) by the annual electrical savings ($34,000) to yield 14.7 years.

4. Additional Energy Recovery Options

All the dryers consume electricity. Solar panels could be used to meet the electrical demand if biogas is used strictly for heating. The electricity demand ranges from around 900 kwh to 2,350 kwh. The highest demand is from the Gryphon at 5,520 kwh. A solar array with output ranging from 150 kw to nearly 1,000 kw would be necessary to satisfy the electrical demand for the dryers for a 6-hour period during the daylight hours. The cost savings from the solar array would approach between $70 to $440 per day.

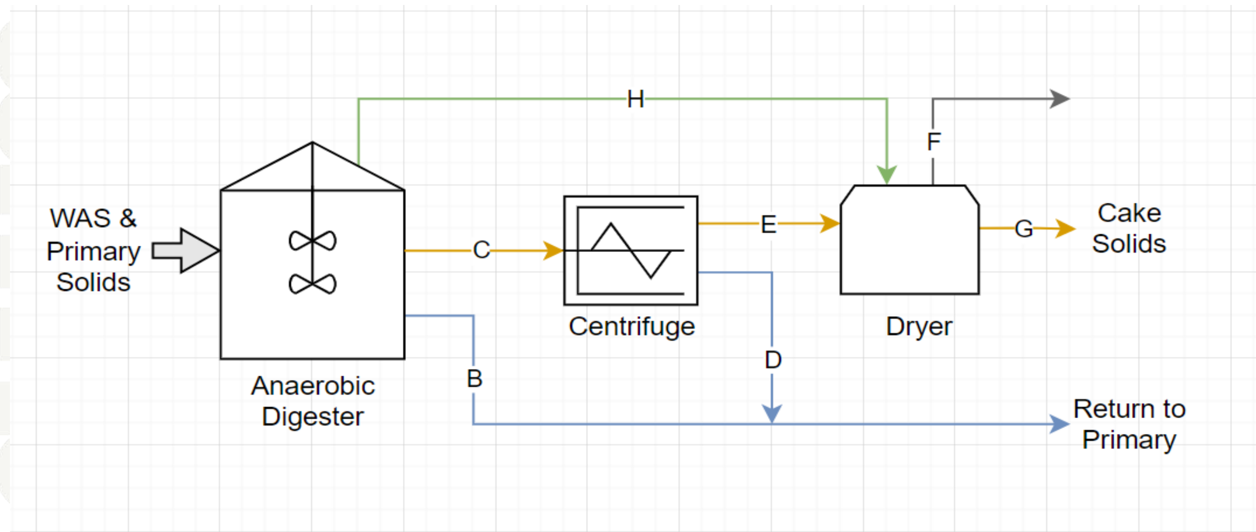
5. Dryer System Preliminary Concept

The main drivers for the Watertown POTW to install a dryer system are the reduction of biosolids volume, reclassification of biosolids for land spreading, and potential destruction of PFAS. Most of the proposed dryer systems included in this evaluation will accept the dewatered solids (~20 to 25% TS) from the existing centrifuges at the Watertown WWTP and dry them to above 90% TS achieving a 75% reduction in total biosolids volume. Additionally, these dryer systems would have sufficient pathogen reduction to produce Class A biosolids per WDNR rules. Overall, this system would benefit the Watertown POTW in its ability to produce, store, and sell biosolids.

A new biosolids dryer system can be integrated into the existing Watertown WWTP biosolids system. Further preliminary engineering would be necessary for confirming the location, utilities, process connections, biosolids storage, and other design factors.

Figure 1 below shows a high-level process flow diagram (PFD) of a dryer system integrated at the Watertown WWTP. The new dryer system would receive dewatered sludge from the existing centrifuges directly or using a silo for buffering. Watertown has expressed interest in using biogas generated from the existing anaerobic digester in the proposed dryer system. The biogas is currently used in a boiler to produce heat for return to the digester. The dryer systems proposed are able to accept biogas as an energy source for drying the sludge either directly or indirectly. The convective systems, such as the Gryphon drum dryer, can direct fire the biogas to heat the sludge; the conductive systems, which use thermally heated oil or water, can use biogas in the system’s boiler. Entirely electric systems such as the dehumidifier would require a combined heat and power engine to use the biogas. The biogas generated by the anaerobic digesters is not currently sufficient to heat the digesters and provide all the fuel necessary for a dryer system, therefore supplemental natural gas would be required to maintain system operation (except electric systems), especially in cold months.

There are several locations where the new dryer could be located, depending on the size of the system pursued and the suitability of the existing infrastructure, including the existing centrifuge room or the biosolids storage shed, as biosolids storage needs would be reduced.



A	B	C	D	E	F	G	H
WAS	**Digester Effluent**	**Digested Sludge**	**Centrifuge Decant**	**Centrifuge Solids**	**Dryer Evaporate**	**Dryer Solids**	**Biogas**

Figure 1. Sludge Dryer Process Flow

6. PFAS Destruction

Watertown has indicated interest in potentially removing PFAS from dewatered sludge. PFAS are an emerging contaminant of particular concern. These chemicals do not break down readily within the wastewater treatment process. These chemicals are extremely stable and resistant to many different types of treatment.

Typical convective or conductive sludge drying systems are not able to remove or destroy PFAS. Two potential processes that have shown an ability to affect PFAS concentrations in sludge are pyrolysis and super-critical water oxidation.

Pyrolysis is a process where either dewatered or dried sludge is heated to a very high temperature in a vessel devoid of oxygen. Organic matter subject to high temperature without oxygen volatilizes instead of into a syn gas, leaving behind a solid substance referred to as biochar. Biochar exhibits properties similar to activated carbon. Current testing has shown that biochar produced by pyrolysis is often free of PFAS compounds. Further testing is needed to determine if PFAS compounds are destroyed or are transferred into the syngas. Pyrolysis is a complimentary technology to sludge drying and can be added to any dryer system.

The supercritical water oxidation is a new treatment technology that was developed at Duke University. The primary goal of this technology is to eliminate any organic sludge. The core of this technology involves superheated water under high pressure (>374 °C and 3200 psi). Any organic material that is injected along with oxygen into the high-pressure superheated water oxidizes into water vapor, carbon dioxide, and minerals. Preliminary testing indicates that any PFAS compounds introduced into supercritical water with oxygen are destroyed. This treatment process requires pumping the organic sludge so that it can be injected. The sludge concentration is limited to between 12-18% solids. This treatment process should be considered as a direct replacement for sludge drying but can be compatible with sludge dewatering. It is worth noting that there is almost nothing to dispose of from this process. Any vaporized water and carbon dioxide would be vented to the air. Only a small amount of condensed water and minerals require disposal. This process does include some energy recovery that can help offset some of the operating costs.

7. Conclusions and Recommendations

The information presented within this technical memorandum on the various sludge drying technologies supports the following conclusions and recommendations.

Conclusions

- Sludge drying is a viable option for Watertown to decrease the volume of sludge for disposal. Sludge drying can also change the classification of the sludge for disposal.
- Multiple different types of sludge dryers can be integrated into the existing treatment process.
- The capital cost of adding sludge drying will be significant.
- Utilities (gas and electricity) will increase in support of sludge drying.
- Excess biogas available in the summer when digester heating needs are lower can be used to reduce some of the gas utility increase.
- Solar panels could help reduce some of the electrical utility when sunlight is available.
- Pyrolysis is a technology that is compatible with any sludge drying technology and has the potential of removing PFAS from the dried solids.

Focus on Energy offers several rebate and incentive programs that can help reduce the overall capital cost of CHP and solar systems. The size of any rebate or incentive will be dependent on the final design and equipment selected.

Recommendations

Watertown should proceed with conceptual design of two sludge drying technologies. Conceptual design would include:

- Determining how each sludge dryer would integrate into the existing process.
- Identify what, if any, supporting equipment is needed, such as air scrubbing, conveying, and temporary sludge storage.
- Identifying all utility needs.
- Proper sizing of the sludge dryer.
- Developing planning levels budgets for each dryer.

The conceptual design could be based on a Gryphon-style drum dryer and Centrysis-style belt dryer. The drum dryer is worth considering based on a preference expressed by WWTP staff. The belt dryer is worth considering because of its small footprint and overall lower initial capital cost.

Initiating conceptual design will allow the design team to work through the multiple design details necessary to properly determine how the drying equipment can integrate into the existing sludge process, along with summarizing any support equipment that is outside the scope of supply of the sludge dryer manufacturers. Developing a conceptual design will also help Watertown develop the capital planning cost estimate needed for project budgeting.

Parameter	Conductive Dryers			Convective Belt Dryers		Convective Drum Dryers	
	Thin Film Dryer	Screw Dryer	Paddle Dryer	Belt Dryer	Dehumidifier	Drum Dryer	BioDryer
Manufacturers	LCI	BCR	Komline-Sanderson	Centrysis	Shincci	Gryphon	BioForceTech
Model	NDS2500	IC-1800	8W-850	DLT320	SHS21600FL	1060	BFT-Q-23-874
# of Units	1	1	1	1	1	1	4
Capital Cost	$2,900,000	$4,000,000	$3,500,000	$1,814,900	$1,734,300	$3,400,000	$3,979,600
Heating Medium	Thermal Oil (392 °F)	Thermal Oil (212 °F)	Thermal Oil (380°F)	Hot Water (194°F)	Hot Air (167 °F)	Combustion Air	Hot Water (160 °F)
Footprint and Height	184 s.f. 32'8" L x 5'7" W x 5.6' H	1,200 s.f. 29'L x 7' W	193 s.f. 26'8" L x 7'3" W x 9' H	378 s.f. 12.3' H x 10.5' W x 36' L	485 s.f. 48' L x 10.1' W x 9.1'H	5520 s.f. 120' L x 46' W	7000 s.f. 125' L x 56' W
Weight	18.7 ton dry, 24.5 tons wet	22,300 lbs	35,000 lbs	43,680 lbs	17.4 tons		50,700 lbs
Output % Solids	>90%	90%	>90%	70 to 90%	90%	> 70%	70 to 90%
Use with Renewable Fuels?	Yes	Yes	Yes	Yes	No	Yes	Yes
Heat Recovery	1.4 MMBTU/hr, 176 °F water	Not included	150°F to 180°F hot water return using off-gas sprayer system	In Unit	Integral heat recovery	No	In Unit
Exhaust Gas Produced	Yes	Yes	Yes	Yes	No	Yes	Yes
PFAS Elimination?	No	No	No	No	No	No	No
Utilities Usage - Fuel	1120 wet lbs/MMBTU 1.7 MMBTU/hr @ 100% Load 6,932 MMBTU/year	928 wet lbs/MMBTU 2.3 MMBTU/hr 8,367 MMBTU/year	953 wet lbs/MMBTU 1.53 MMBTU/hr (1,530 cfh NG or 2,550 cfh Biogas) 8,147 MMBTU/year	737 wet lbs/MMBTU 1.5 MMBTU/hr NG 10,535 MMBTU/year	None	642 wet lbs/MMBTU 5 MMBTU/hr 12,094 MMBTU/year	1369 wet lbs/MMBTU 0.7 MMBTU/hr 5,671 MMBTU/year
Utilities Usage - Electricity	35 wet lbs/kWh 1296 kWh/day (54 kW) 473,000 kWh/yr	59 wet lbs/kWh 869 kWh/day 317,000 kWh/yr	15 wet lbs/kWh Est. 131 HP, 2350 kWh daily 858,000 kWh/yr	20 wet lbs/kWh 1344 kWh (56 kW) 491,000 kWh/yr	6 wet lbs/kWh 5060 kWh/day, 230 kW 1,847,000 kWh/yr	8 wet lbs/kWh 5520 kWh/day (480 V, 500 A) 2,015,000 kWh/yr	57 wet lbs/kWh ~400 kWh/day (147000 kWh/vr) 147,000 kWh/yr
Maintenance	$10,000/yr, 3 days/year	$16,785/yr	<20 min Daily, 3 to 4 days downtime annually	30 min daily, 1-3 weeks per year downtime maintenance	2 hours weekly, 2 years spare parts on hand	T.B.D.	200 hr/yr, $40,000/yr parts
Nearest Location	Charlotte, NC	Jacksonville, FL	Rockford, IL	Kenosha, WI	Yuma, AZ	Western, KY	San Francisco, CA