Zero Liquid Discharge Markets

Hot Topic Hour 2/25/16

Hosted by the Mcilvaine Company

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Overview

Format of ZLD program by Mcilvaine

- This discussion will be recorded.
- The recording and ppts will be sent to subscribers to various market report and tracking system subscribers.
- More detailed decision systems by industry will be continually expanded.
- End users in power, mining, water treatment and other industries have free access to many Mcilvaine services.
- Custom market research on ZLD is supplied.

ZLD Broader Definition

- Zero Liquid Discharge is typically considered to be elimination of all water discharges.
- The elimination of water discharges to waterways is a broader definition which includes water reuse.
- Treated municipal wastewater is being widely used in power plants.
- Sewage sludge is combusted in coal-fired power plants.

ZLD narrower definition

- Environmental regulations have mandated true ZLD wastewater treatment in a large number of industries, including power, manufacturing, refining, mining, pulp and paper and chemical processing. This means all industrial wastewater at a site is reduced to dry solids and recycled or sent to a landfill. Any useable water recovered from the waste treatment process is reused in the plant.
- Typically, large flow rates of wastewater are preconcentrated using a falling film evaporator, a membrane process such as reverse osmosis or both.
- Volumes of concentrated wastewater range from 3 to 100 gpm (0.01 to 0.38 m3/minute) containing 100,000-300,000 mg/l total solids. This volume is then reduced to dry solids using a forced-circulation crystallizer.

Markets

- The ZLD market is far larger than the $250 million/yr., which is appearing in many articles.
- China has thousands of coal-fired power plants and coal-to-chemicals plants which will employ ZLD at a cost of more than $ 10 billion
- Chinese power plants have some ZLD systems using evaporators but are leaning toward the cheaper route of using flue gas to evaporate liquid in the sludge.
- The spray drier approach is being pushed by Mitsubishi, URS, and other international companies.
- Coal-fired power plants can opt for calcium sulfite scrubbing and chemical fixation of sludge rather than gypsum production and wastewater treatment.
- The latest intelligence is that local Chinese companies are developing their own spray drier technologies and it is likely that this will be the option adopted by most plants.
- This decision guide is intended to help guide Chinese coal-fired plants and others to make the best choices among several options among three options
  - Evaporation and crystallization
  - Spray dryer with flue gas
  - Chemical fixation of high liquid containing sludge

Return to T of C

Distribution of Crystallizer ZLD

- Over 800 ZLD systems have been installed since the 1980s.
- The issue of brine disposal is a growing challenge for both the municipal and industrial sectors, partly due to the proliferation and cost competiveness of desalination systems. Whether in the Kenya Coal Seam Gas produced water treatment plant in Queensland or brackish water desalination systems in Texas, brine represents a major cost center for operators.
- A survey by the International Desalination Association in 2012 indicated that over 98 percent of inland desalination facilities in the United States dispose of waste brine through deep well injection, evaporation storage or municipal sewage discharge, as opposed to some form of treatment.
- Brine disposal costs show considerable variability. In the oil and gas sector for instance, the typical disposal method is deep well injection, costing operators $3 to $6 million. In formations with challenging geology and long transportation pathways, this cost can be much higher. In the Marcellus region, disposal costs range as high as $20 million because produced water has to be transported hundreds of miles offsite.
- Despite these high costs, the primary incentive for going ZLD remains regulation. Instead of seeing growth in areas such as brine treatment for brackish water or tight oil/gas-produced water treatment, growth in ZLD and brine treatment systems in recent years has been seen in coal-to-liquids plants in Inner Mongolia and chemical plants in India, where sensitive downstream environments have led to the regulation of industrial discharges.

Modest numbers of crystallizers installed in the U.S.

- There were about 15 wastewater crystallizers in operation in North America as of 2011, most of which were installed since 1989. Previous to this period, most plants involved in ZLD concentrated their liquid wastes to 20-30% total solids using a falling film evaporator of the seeded type and discharged a liquid brine to solar ponds.
- With increasing regulations on liners and monitoring wells, the construction cost of solar ponds has increased dramatically, making crystallizers a cost-effective alternative.

India

- The ZLD market is concentrated in certain locations like Tamil Nadu, Gujarat, Orissa, Maharashtra, and Andhra Pradesh.
- Stringent implementation of water discharge laws and the social responsibility of the corporate world for environmental clearance will be the major drivers of this market.
- In the next 5 years, there will be few crucial mergers in the ZLD market and many small participants would phase out leading to consolidation of ZLD market.
- Low-cost technologies will dominate the ZLD market as currently it is very expensive for widespread adoption, both from fixed and operating cost points of view.
- Textiles, distilleries and breweries, and power and petrochemicals would be the major end users of this ZLD market.
- Large pharmaceutical plants in India are required to achieve ZLD.
- 500 electroplaters obtained government financial assistance to employ ZLD.
- Tanneries and Distilleries are also employing ZLD.

China

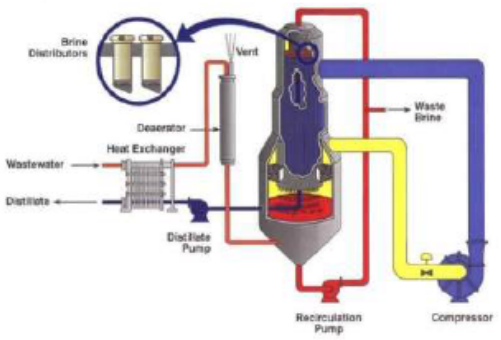
- Major market for ZLD for power and coal to chemicals.
- ZLD will most probably find more applications in China in the drought-stricken regions and in environmentally sensitive areas.
- The central government has already decided that any new desalination project bordering the Bohai Sea should integrate a ZLD design. We can expect that the mineral rich region of Qinghai and Inner Mongolia to face the same constraints.
- In urban areas, communities are more and more aware of the environmental risks.
- Greenfield projects may also have to consider the ZLD options to obtain approval.
- Recently Fujia Dahua Petrochemicals operation in Dalian[9]has been threatened to be closed under public pressure over the risk their effluents can cause to the environment.
- ZLD projects are still relatively rare in China, however the recent example of Yunnan Yuntianhua's coal-to-chemical project shows that under specific circumstances this solution can address a number of environmental issues. But before expecting that this expensive and energy intensive technology would be largely employed, businesses will more likely favor better water management, higher recycling rates and effluents discharge control.

Evaporation/Crystallization

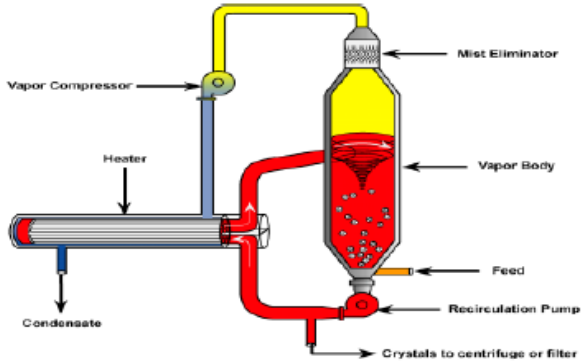
GE combines Evaporation and Crystallization

Evaporator and Crystallizer Technology Summary

Evaporator

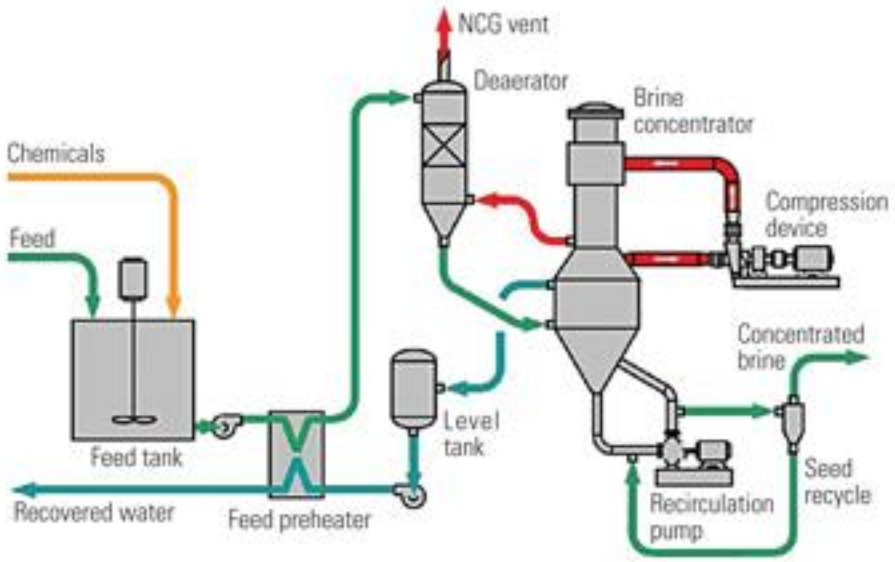


Crystallizer



ZLD is achieved through the combination of evaporation followed by crystallization

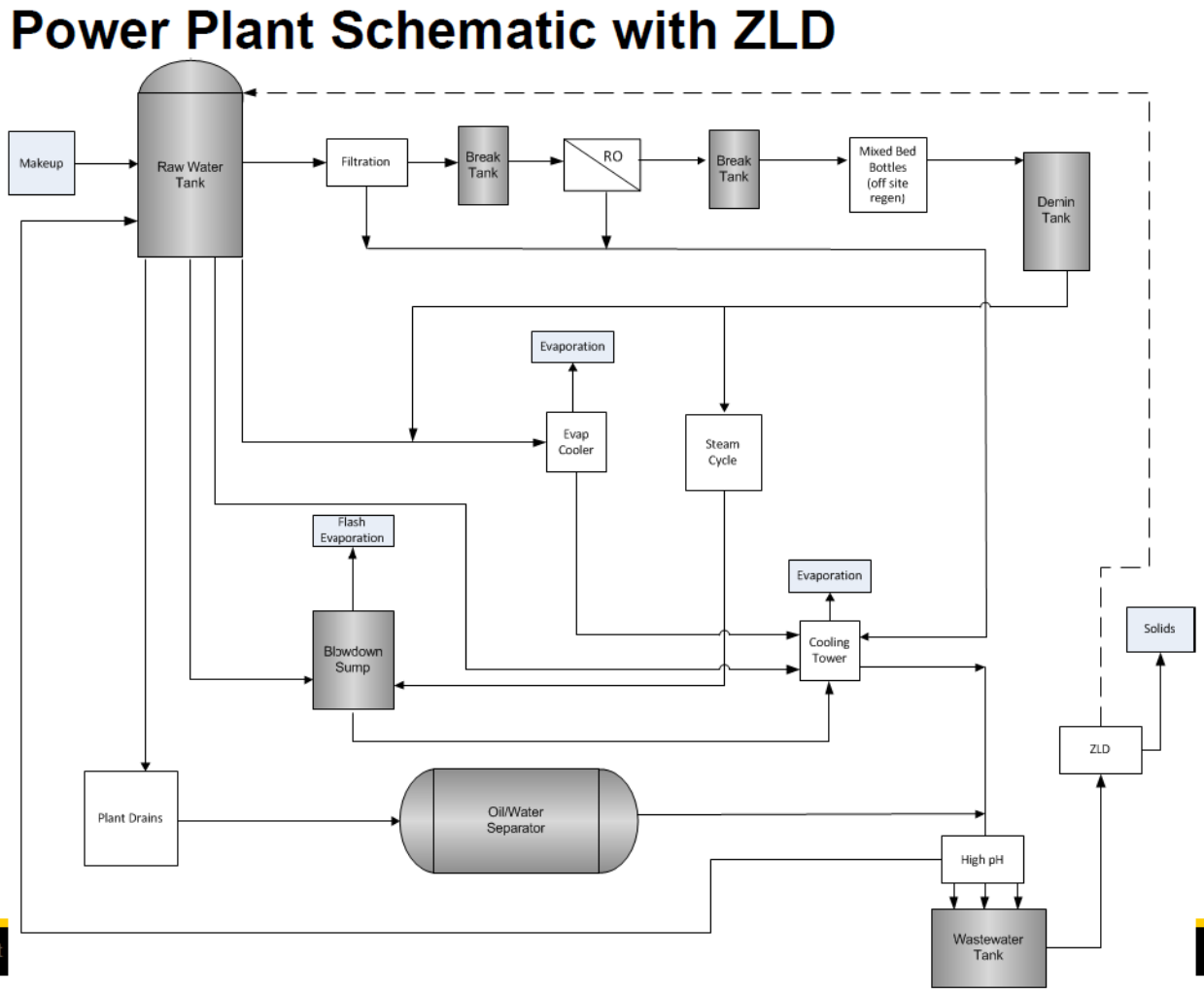
Falling Film Evaporator



Evaporation process. Most of the water evaporation occurs in a falling film evaporator (inside the brine concentrator vessel) that is seeded with calcium sulfate to minimize scale formation. The process also requires a lot of electricity to operate the vapor compressor, about 18 to 35 kWh per metric ton of water evaporated.

Return to T of C

Kiewit analysis of ZLD



Evaporation Pond

Evaporation Pond

- Lined pond
  - Liner with leak detection installed to prevent percolation of water and heavy metals into soil
- Works by using solar evaporation to concentrate wastewater
- Ponds are typically used in sections and following evaporation solids sludge are periodically removed via bulldozer
- Large square footage requirement
- Aeration can be added to improve efficiency

Deep well injection

Deep Well Injection

- Wastewater is concentrated and pumped to deep aquifiers
  - Wastewater theoretically never interfaces with low TDS aquafiers
- Approximately $3-4M capex per wall
- Wells rarely take as much water as expected
  - Downhole Chemistry
  - Porous formations
- High Pressure pumps

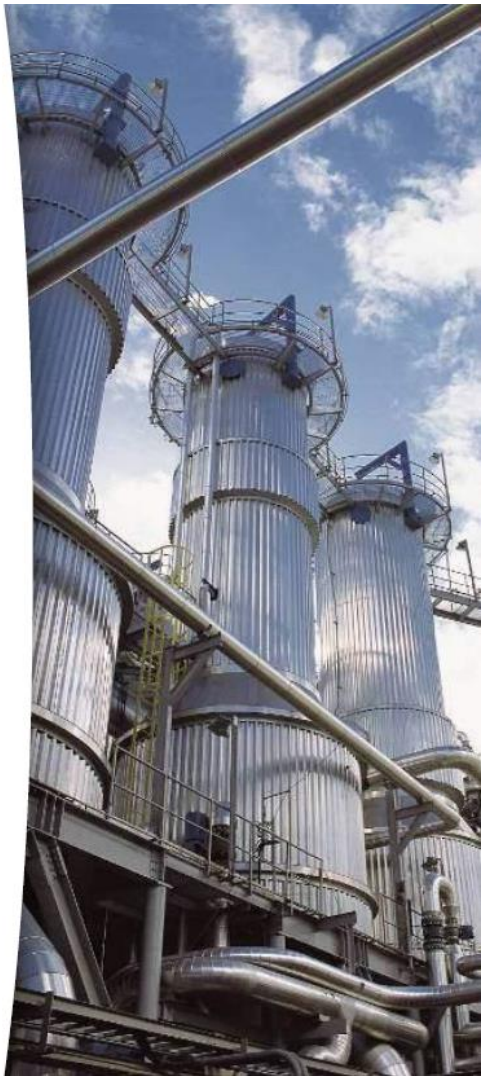
Veolia vacuum approach

The CoLD® Crystallization Process

HPD® Evaporation and Crystallization

McIlvaine Hot Topic Hour
August 15, 2013

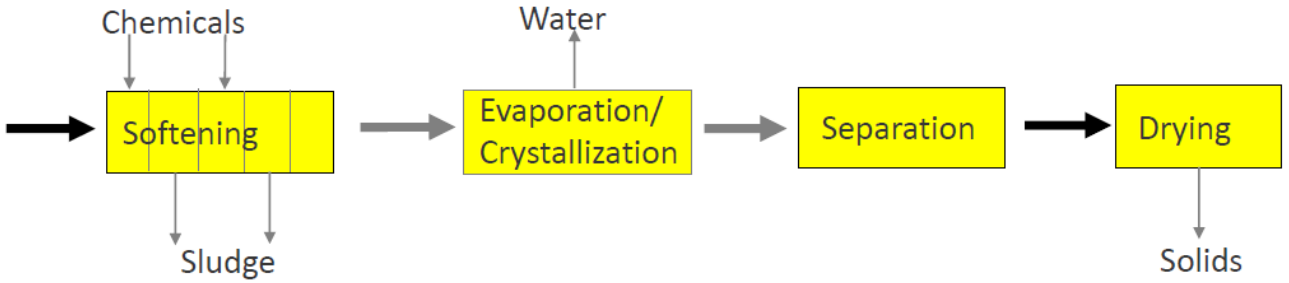
VEOLIA WATER
Solutions & Technologies



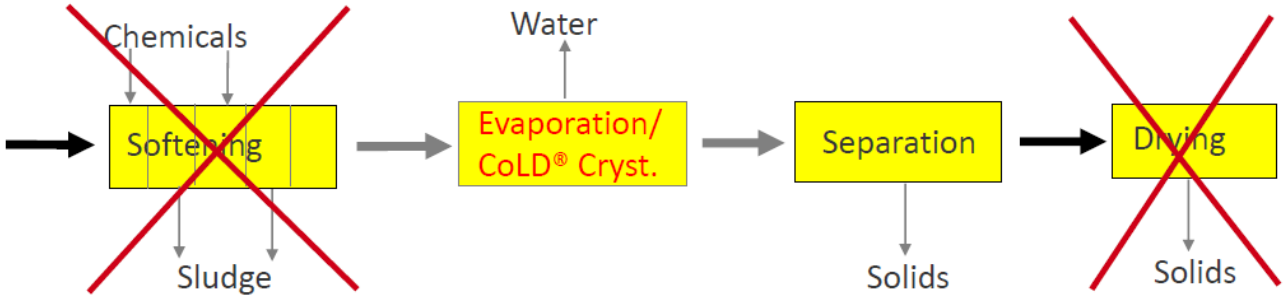
Eliminates Chemicals

CoLD® Process eliminates chemicals, reduces solids disposal and equipment footprint.

Basic Flowsheet for FGD ZLD



CoLD™ Flowsheet for FGD ZLD



Veolia says cost is lower

Economic comparison of FGD ZLD Options

Facility Comparison

- Conventional ZLD: 350 gpm capacity, Softening, Evaporator, Crystallizer
- CoLD ZLD: 350 gpm capacity, Evaporator, CoLD® Crystallizer

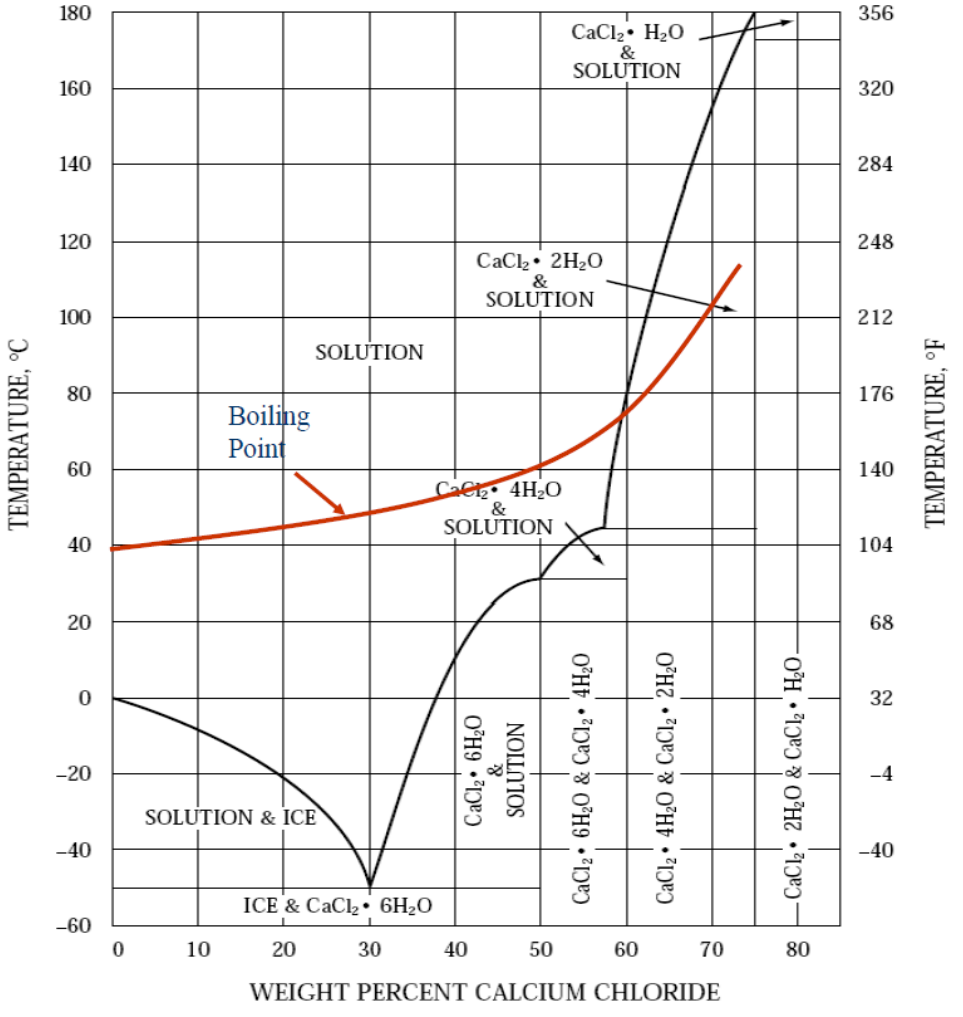
Economic Comparison

	Conventional	CoLD
Cap - Amor	$5.4MM	$5.4MM
O&M	$2.8MM	$2.8MM
Chemicals	$6.3MM	$250k
Disposal	$4.5MM	$1.0MM
Energy	$1.8MM	$2.3MM
Total Opex	$15.4MM	$6.4MM
Net Annual Cost	$20.8MM	$11.8MM
$/gal	$0.125	$0.071

Advantages of lower boiling point

Phase Diagram of Calcium Chloride

Under vacuum, the boiling point is lower and a solid phase can form at a lower concentration

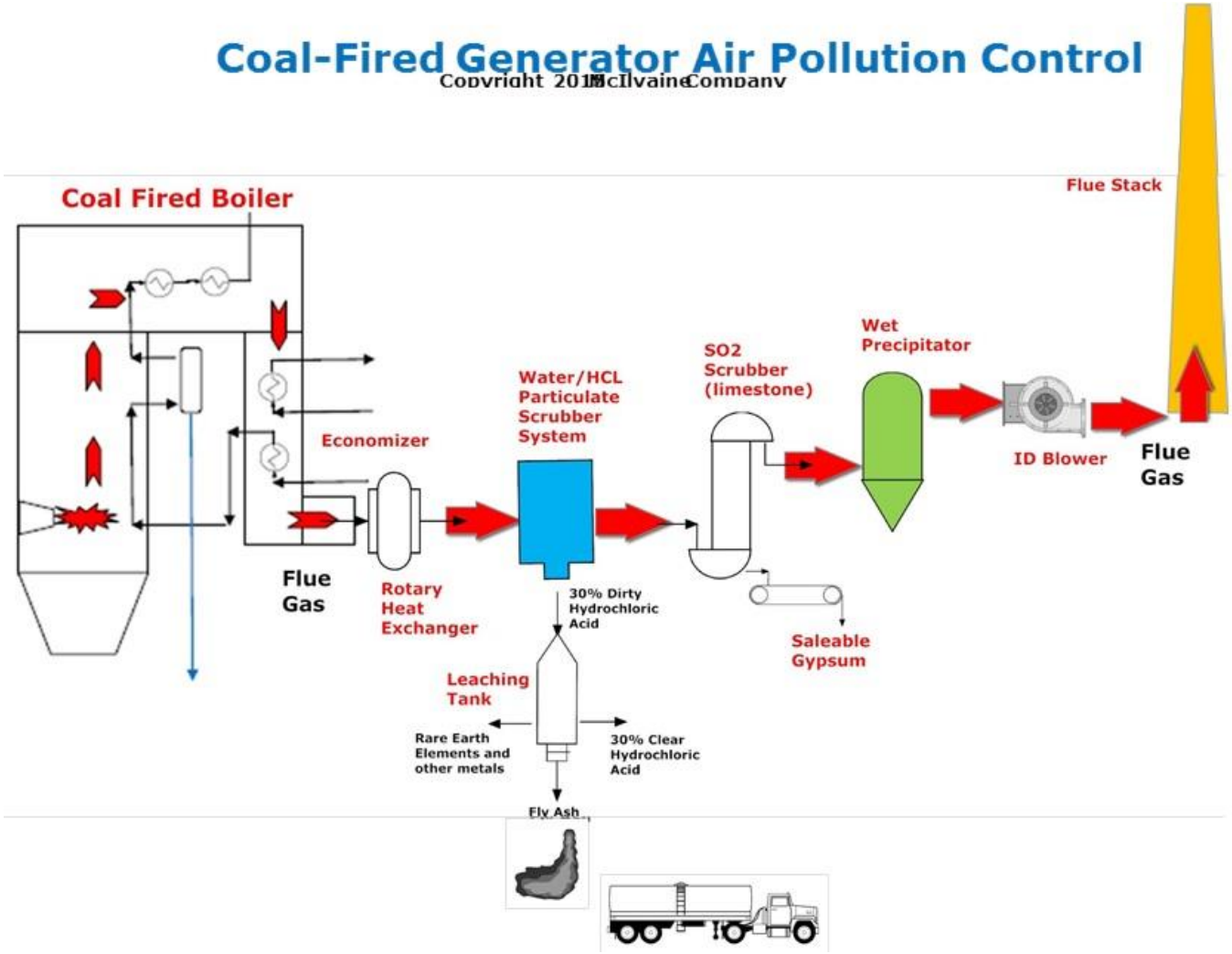


Spray Dryer alternative

Holistic approach needed

- Before power plants elect the spray dryer option they need to take a holistic approach which includes
  - Alternative ways to use the heat of the flue gas
  - The ultimate fate of solids and impact of additional metals on the environment depending upon final use of flyash
  - The consideration of all wastewater and not just FGD
- Extracting more heat from the flue gas for reuse is a big opportunity which may have advantages over using this heat to dry sludge.
- A very large potential to extract metals and rare earths from flyash could radically change the ZLD choice.

If coal plants recover rare earths the ZLD approach will be changed



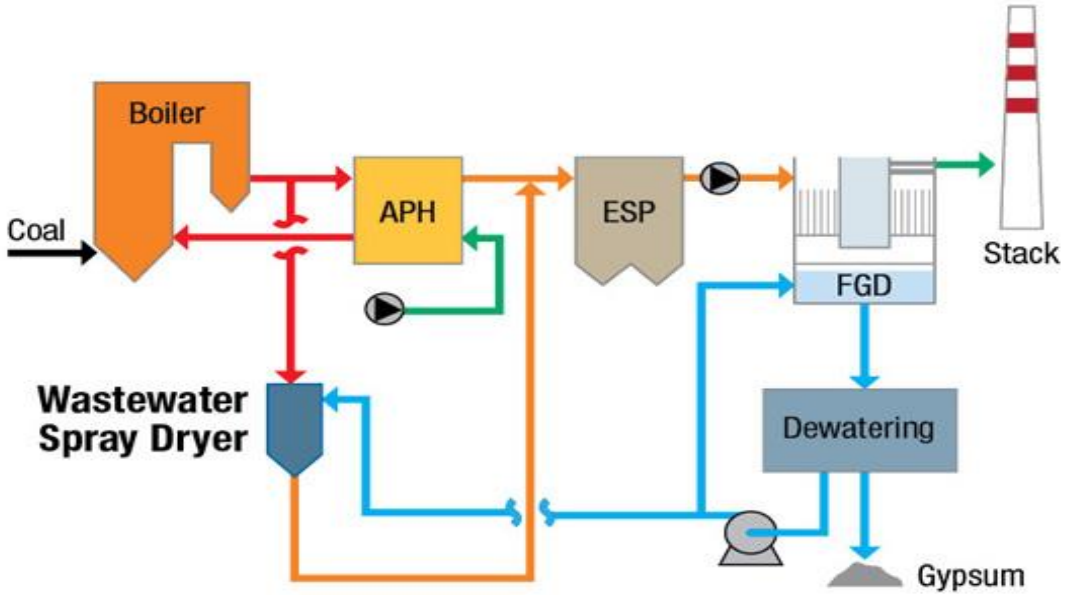
Advatech ZLD offerings

- **Wastewater Evaporation System (WES)**
  - Direct injection of wastewater into ductwork
  - Salts collected with fly ash in particulate control device
  - 10 commercial installations w/ 50 yrs of cumulative operating experience

- **Wastewater Spray Dryer (WSD)**
  - Patented Process
  - Slipstream spray dryer bypassing air heater
  - Salts collected with fly ash in particulate control device
  - Application of MHI standard gas cooler design & WES experience
    - ✓ 90 commercial installations, 20 years experience

Truly Zero Liquid Discharge Technologies

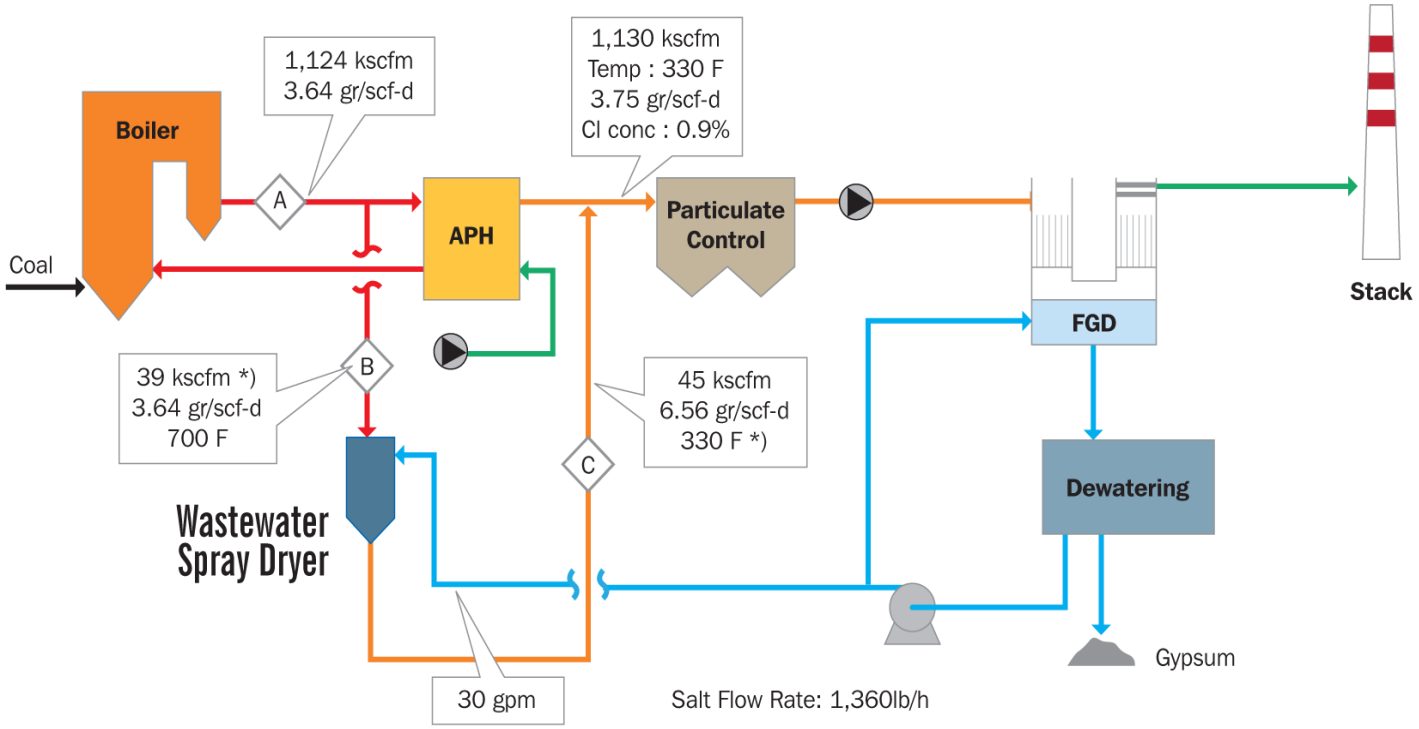
WSD Overview



Advantages

1. Differential pressure across heater provides motive force for flue gas passing through the WSD (no fan required)
2. Use of flue gas from upstream of the air heater reduces amount of gas required for evaporation
3. FGD wastewater is evaporated in a controlled environment that can be isolated for maintenance/repair
4. Salts & trace elements from wastewater are collected in the existing particulate control device for disposal, etc. with the fly ash

Typical WSD PFD for 500 MW Coal-fired Boiler



*) WSD Outlet Flue Gas Temperature is controlled in order to keep the temperature above the sulfuric acid dew point.

4% of Flue Gas Bypasses AH | 3% Increase in Particulate Loading | ~0.4% Impact to Heat Rate

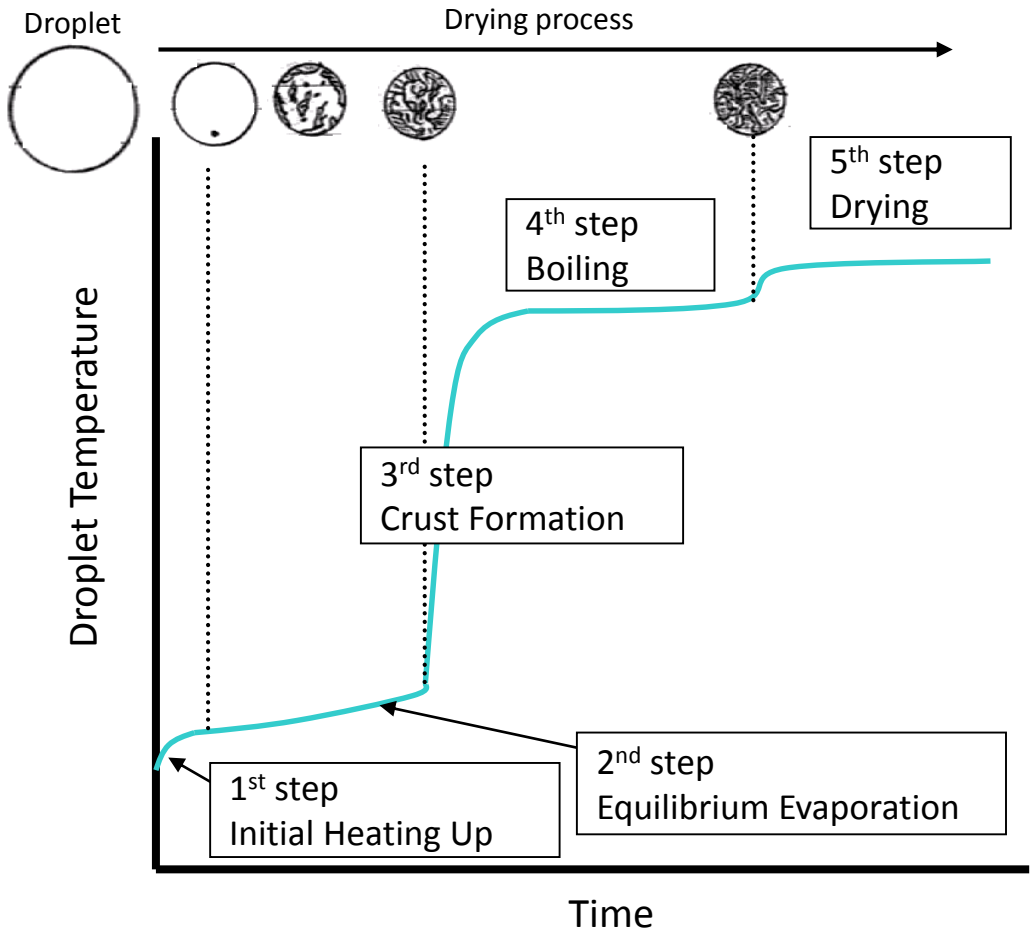
4% of Flue Gas Bypasses AH
3% Increase in Particulate Loading; ~0.4% Impact to Heat Rate

Possible concerns for WSD technology ??

- **Evaporation CFD model for the wastewater**
  - Affect the evaporation by wastewater composition ?
- **Captured in particulate control device**
  - Can be corrected by particulate control device ?

✓Verified by these questions by pilot testing

MHI's Droplet Evaporation Model



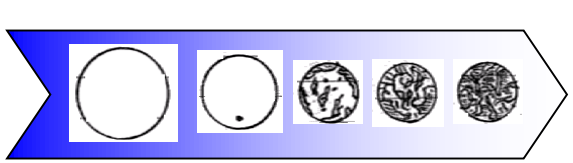
Process of Solution Droplet Evaporation

- ✓ 1st step: Initial heating up by hot flue gas
- ✓ 2nd step: Evaporation at the wet bulb temperature with elevated boiling point
- ✓ 3rd step: Crust formation that inhibits water evaporation (droplet temperature increases)
- ✓ 4th step: Boiling remaining water
- ✓ 5th step: Drying solid

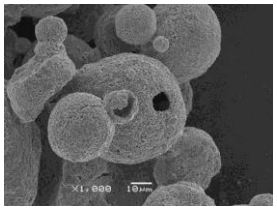
Droplet Evaporation Model Incorporated into CFD Software

Questions Cleared Up by Pilot Testing

- **Evaporation model simulates evaporation process**
  - Gas temp., moisture content profiles in pilot testing agreed with CFD model

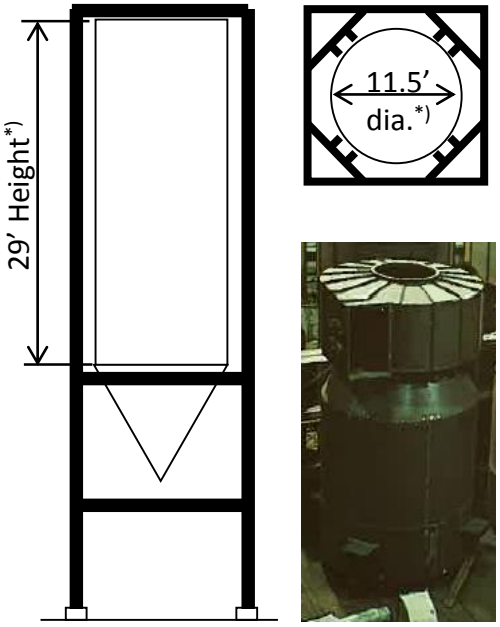


- **The Dried Salts should be Easily Captured by the Existing Particulate Control Device**
  - Dried salt particle size in range of fly ash (10-60 um)

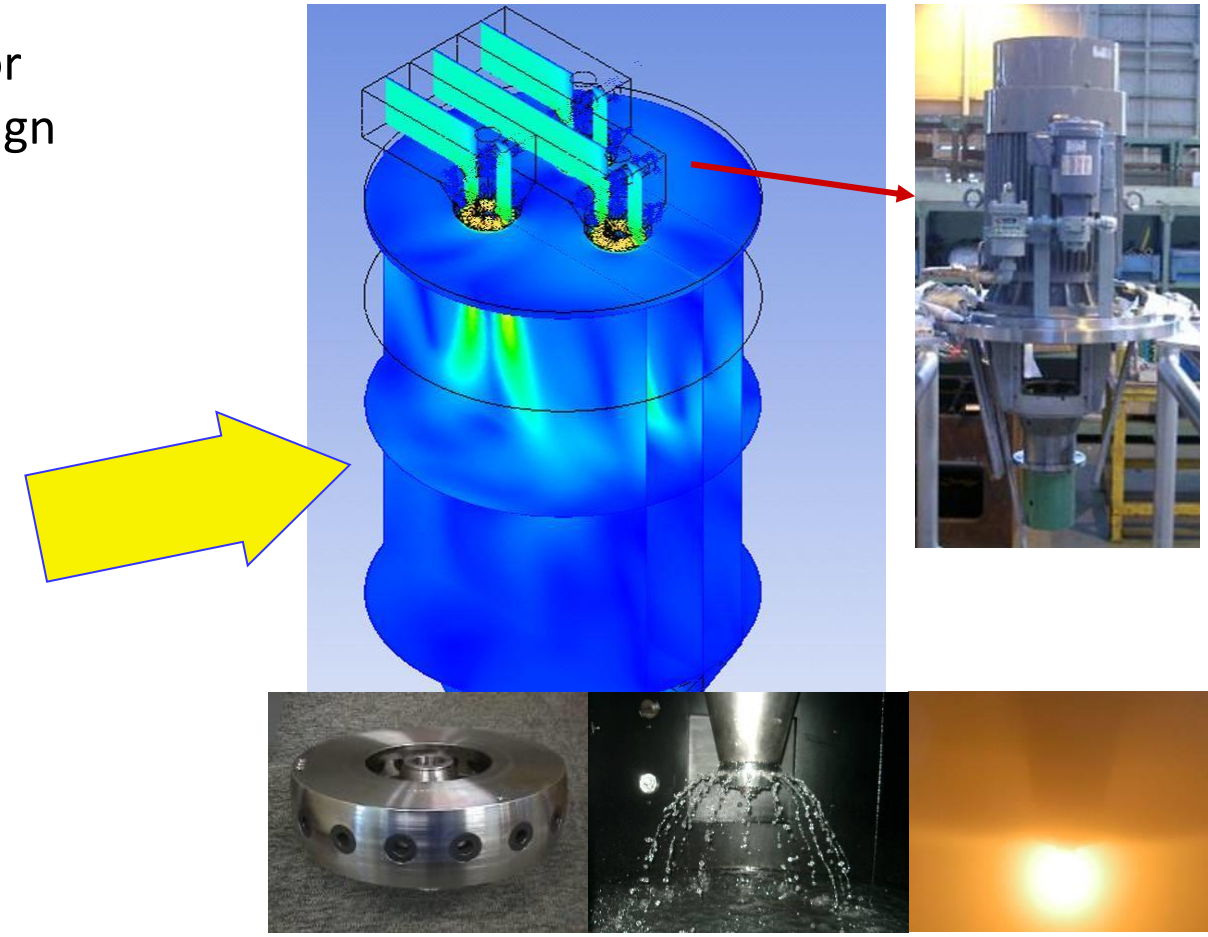


Commercial Design of WSD

- Applied CFD model for commercial WSD design



Small Scale WSD for Low-Cl Coal Application (11 GPM)

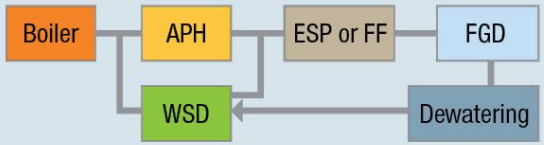


Larger Scale WSD for High-Cl Coal Application (200+ GPM)

Larger Scale WSD is Commercially Available

Comparison of WSD to Traditional WWT

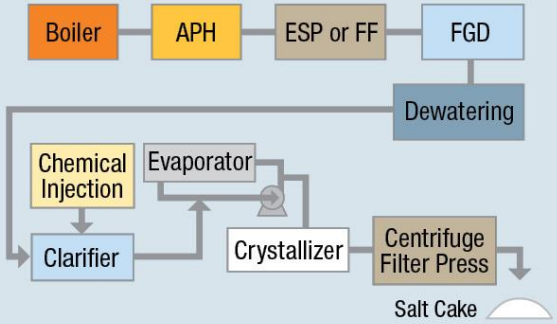
WSD



Pros
- Low capital & operating cost
- No chemical or biological treatment required
- Small footprint (easy to retrofit)
- Does not need to operate continuously
- Fully isolatable for easy maintenance
- Handles wide range of dissolved solids content
- Dissolved solids & trace elements captured in existing solid waste stream

Cons
- Slight impact to heat rate (around 0.5%)
- Slight increase to PM loading on particulate control device (<5%)
- May limit the volume of water that can be treated

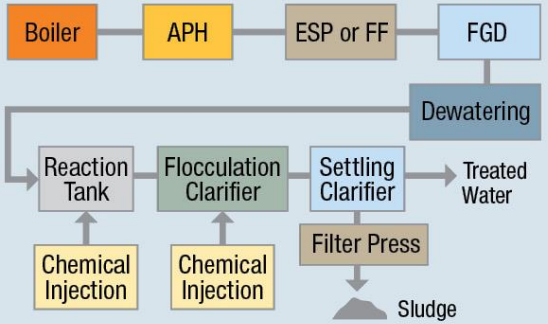
Evaporator/Crystallizer



Pros
- Can be retrofitted (moderate footprint)
- Handles high concentrations of dissolved solids
- All dissolved species separated from water

Cons
- Energy intensive
- (Pre)chemical treatment required
- High capital & operating cost (exotic alloys)
- Solid waste stream to dispose of
- Can act as bottleneck

Conventional WWT



Pros
- Significant operating experience

Cons
- Large footprint (difficult to retrofit)
- Requires chemical addition
- High capital & operating cost
- May require biological treatment & still not meet future discharge limits
- Sensitive to chloride levels
- Not applicable for high dissolved solids
- Hazardous solid waste stream to dispose of
- Treated water stream to dispose of/reuse

Summary

- Patented WSD has been developed based on years of experience in the design / operation of WES and Flue Gas Cooler, and validated through pilot testing and CFD modeling.
- Due to its simplicity, the WSD is one of the most economically attractive ZLD options.
  - Approximately 1/10th the cost of traditional WWT
  - Uses waste heat to evaporate the wastewater stream
  - Salt particles are collected in the existing particulate control device so a new waste stream is not generated
- WSD can be applied for wide range of wastewater and even be used to reduce the amount of wastewater that goes to a more traditional wastewater treatment process.

Fossil-fired Power Plants

U.S. plants must meet ELG

- Coal-fired power plants that discharge flue gas desulfurization (FGD) wastewater will be significantly impacted by the proposed Effluent Guidelines for the Steam Electric Power Generating Category published by the U.S. Environmental Protection Agency (EPA) in June 2013. The proposed Effluent Guidelines will enforce new discharge limitations on various metal species in certain waste streams (i.e., mercury, arsenic, selenium) and nitrates/nitrites. There are a number of treatment technologies available for the reduction of metal species' concentrations including, but not limited to, physical/chemical treatment, biological treatment, and thermal evaporative or zero liquid discharge (ZLD) systems. Coal-fired power plants with newer wet FGD applications usually include existing physical/chemical wastewater treatment facilities, which remove mercury and arsenic through precipitation and filtration. In order to be in compliance with the Effluent Guidelines, these stations will likely require further treatment to remove remaining nitrates/nitrites and selenium via biological treatment or a ZLD approach.

Sega has helped plants for 316 B

- **Representative Projects:**

- *KCP&L Company, Lake Road Generating Station, St. Joseph, Missouri; Hawthorn Generating Station, Kansas City, Missouri; Iatan Generating Station, Weston, Missouri; Independence Power & Light, Missouri City Station, Independence, Missouri*
- Sega managed the one-year long Impingement Mortality sampling project at a group of five Missouri River power plants located in the Kansas City region. Sega teamed with staff from Golder Associates (sampling management) and Three Rivers Environmental Assessments (sampling contractor).
- *Trigen – Kansas City, Kansas City Energy Plant, Kansas City, Missouri*
- Sega managed an effort to identify and summarize the potential implications of the proposed 316(b) Phase III Rules on a district energy production plant with a once-through cooling water intake structure on the Missouri River. Sega teamed with staff from Golder Associates.
- *Electric Energy Inc., Joppa Generating Station, Joppa, Illinois*
- Sega managed the development of a 316(b) compliance implementation plan (CIP) and preparation of the Proposal for Information Collection (PIC) document. Sega teamed with and supervised staff from Golder Associates (subcontractor).
- *Electric Energy Inc., Joppa Generating Station, Joppa, Illinois*
- Sega managed the Impingement Mortality study, including year 1 sampling, documentation, reporting, and assessment for need of year 2 sampling. Sega supervised staff from the subcontractors Golder Associates, EA Engineering, and Three Rivers Environmental Assessment (TREA).
- *Electric Energy Inc., Joppa Generating Station, Joppa, Illinois*
- Sega managed the Impingement Mortality study for year 2 sampling, documentation, and reporting. Supervised staff from the subcontractors Golder Associates, EA Engineering, and Three Rivers Environmental Assessment (TREA).
- *City of Chanute, Kansas*
- Sega provided Spill Prevention Control and Countermeasures Plan (SPCC Plan) investigations, analysis, and recommendations for City facilities: Power Plant 1, Power Plant 2, Power Plant 3, Municipal Airport, and the City Complex. After review of SPCC Plan, responsibilities included the development of plans and specifications for construction of the SPCC Plan recommendations which included foundation replacement and concrete secondary containment.
- *City of Ames, Iowa*
- Sega provided Spill Prevention Control and Countermeasures Plan (SPCC Plan) investigations, analysis, and recommendations for the Combustion Turbine No. 2 Plant. Responsibilities included oversight of the development of plans and specifications for construction of the SPCC Plan recommendations which included a truck unloading containment for the existing fuel oil system.
- *City of Garnett, Kansas*
- Sega provided Spill Prevention Control and Countermeasures Plan (SPCC Plan) investigations, analysis, and recommendations for City facilities: Power Plant, Airport, substations, and the Maintenance Shop.
- *Veolia, Kansas City, Missouri*
- Sega provided Spill Prevention Control and Countermeasures (SPCC) Plan investigations,.

Comparison of alternatives by S&L

- Sargent & Lundy analyzed alternatives to meet the ELG for a 500 MW coal-fired unit that fires bituminous coal (approximately 2.4% sulfur) is assumed to be equipped with a forced oxidation, wet limestone FGD to remove sulfur dioxide (SO_2) from the flue gas through means of contact with limestone slurry scrubbing liquor. The FGD system on this unit is assumed to collect approximately 97% of the SO_2 and a similar percentage of the hydrogen chloride (HCl) in the flue gas. The SO_2 chemically reacts with the slurry and forms mainly calcium sulfate ($CaSO_4 \bullet 2H_2O$), also known as gypsum, which is a main component of wallboard gypsum. The chloride becomes a dissolved solid and the chloride concentration continually increases until equilibrium is reached in the FGD system's closed slurry loop. As this chloride concentration continues to increase, the slurry becomes more and more corrosive to the metallic materials of construction of the absorber. The FGD system requires a chloride purge stream to be discharged from the FGD absorber, via the gypsum dewatering system, a two stage hydroclone system, to control chloride levels to below the absorber material's corrosion limits. the scrubber vessel was initially designed for 8,000 ppm chlorides and, based on the operating chloride equilibrium level, constructed with Stainless Steel, 317 LMN (S317226).

Comparative Costs

Table 3-1: ZLD System Costs

ZLD System	Brine Crystallizer/ Evaporator	Wastewater Spray Dryer	Fixation Stabilization
Equilibrium Chlorides (ppm)	8,000	8,000	8,000
Design Blowdown (gpm)	81	81	81
Installed Capital Cost	**$36.8M**	**$25.0M**	**$17.0M**
O&M	**$3.7M**	**$1.8M**	**$1.6M**
Net Present Value (NPV)	**$88.9M**	**$51.9M**	**$40.2M**

Materials cost comparison

Absorber Modification Options	Material Cost ($/ft^2)	Installation Cost ($/ft^2)[1]	Final Installed Cost ($/ft^2)
Vinyl Ester Lining	28	66	94
C-276 Wallpaper	41	58	99
Acid Resistant, Ceramic Tile Lining	48	58	106

Cost of materials varies with chlorides

Absorber Modification Options	Design Equilibrium Cl^- (ppm)	Excursion Cl^- $(ppm)^2$	Blowdown Rate (gpm)
Vinyl Ester Lining	50,000	100,000	13
C-276 Wallpaper	50,000	100,000+	13
Acid Resistant, Ceramic Tile Lining	50,000	100,000+	13

1. Calculations based on case study assumptions listed in Section 2.
2. Equilibrium chloride level is a very design-specific variable. These values are examples of chloride levels, but in no way are indicative of all systems.

Cost comparison of evaporator, spray dryer, and fixation

ZLD System	Brine Crystallizer/ Evaporator			Wastewater Spray Dryer			Fixation Stabilization		
Base ZLD Cost									
Equilibrium Cl^- (ppm)	8,000			8,000			8,000		
Design Blowdown (gpm)	81			81			81		
ZLD Installed Cost	$36.8M			$25.0M			$17.0M		
ZLD O&M	$3.7M/yr			$1.8M/yr			$1.6M/yr		
Costs for Reduced Blowdown									
New Absorber Liner	**Vinyl Ester**	**C-276**	**Tile**	**Vinyl Ester**	**C-276**	**Tile**	**Vinyl Ester**	**C-276**	**Tile**
Equilibrium Cl^- (ppm)	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Design Blowdown (gpm)	32	32	32	32	32	32	32	32	32
Liner Installed Cost	$3.2M	$3.4M	$3.6M	$3.2M	$3.4M	$3.6M	$3.2M	$3.4M	$3.6M
Liner O&M	$0.1M/yr	$0.1M/yr	$0.1M/yr	$0.1M/yr	$0.1M/yr	$0.1M/yr	$0.1M/yr	$0.1M/yr	$0.1M/yr
Reduced ZLD Installed Cost	$21.1M			$14.3M			$9.8M		
Reduced ZLD O&M	$2.3M/yr			$1.3M/yr			$1.4M/yr		
NPV	**$58.4M**	**$58.6M**	**$58.9M**	**$38.4M**	**$38.6M**	**$40.0M**	**$33.6M**	**$33.8M**	**$34.1M**

Fixation is lowest cost if just FGD wastewater is evaluated

- Any ZLD system would be highly plant-specific, and the results above represent a hypothetical unit constructing a new ZLD wastewater treatment system specifically for the FGD blowdown and relining the existing absorber vessel. Typically, a ZLD system would treat all wastewater from the plant. However, this is beyond the scope of this discussion.
- The FGD blowdown flow rate by operating at 20,000 ppm or 50,000 ppm chloride rather than the base 8,000 ppm level significantly reduces the cost of the ZLD systems, and the lowest net present value ZLD system for both chloride concentrations would be to install a fixation stabilization system and reline the absorber with a vinyl ester liner.
- The reduction in the overall ZLD system cost would offset the cost of the absorber liner modifications. As mentioned previously, outage costs are not included for the relining of the vessel, as it was assumed that the lining work would be completed during an already planned outage. It should be noted that if the duration of the lining work extended the outage, the costs would be significantly impacted

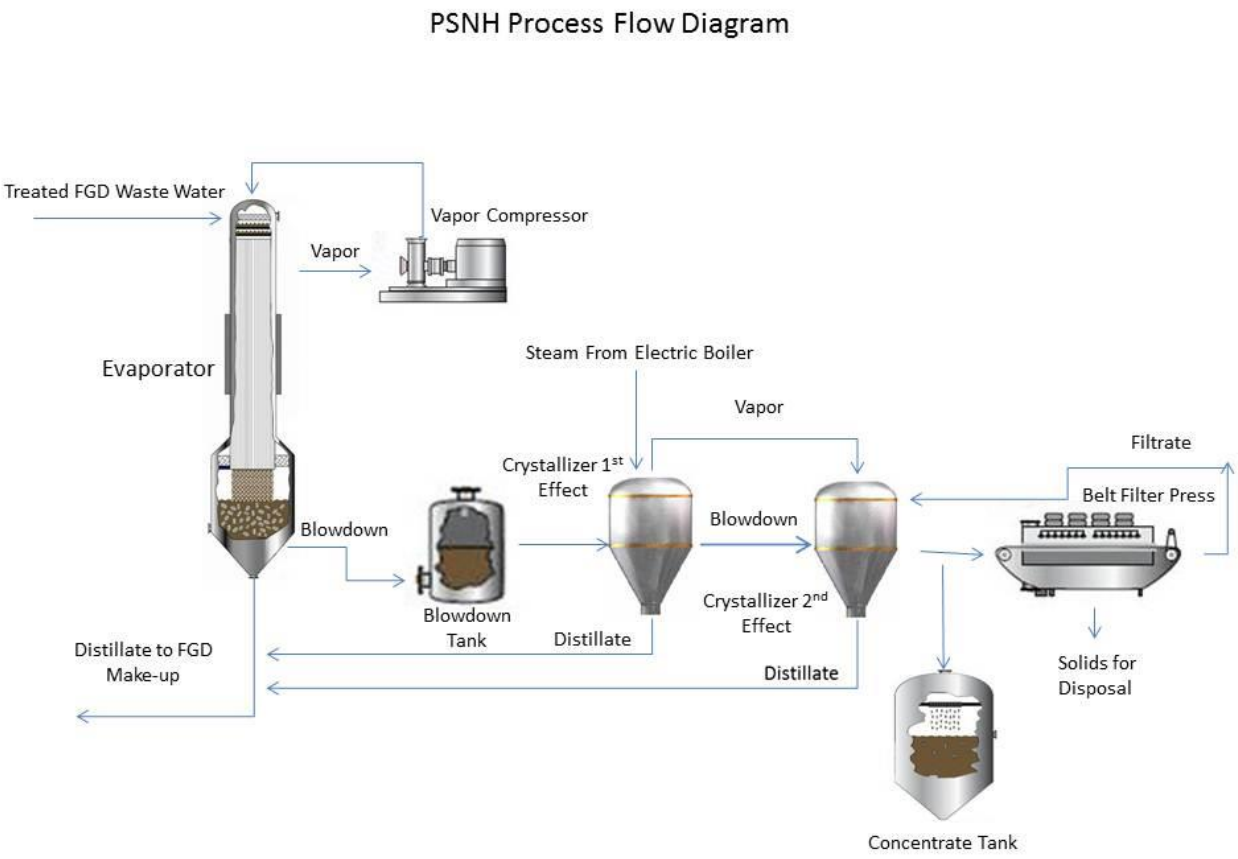
Duke Energy has a ZLD system from GEA

- Duke Energy ha installed a Zero-Liquid Discharge treatment system, provided by GEA Processing Engineering Inc., for Flue Gas Desulfurization Wastewater at their Mayo Plant, located near Roxboro NC.
- Duke Energy selected the Partial Zero-Liquid Discharge solution which consists of falling film evaporator technology (Primary Evaporator [PE]) for total of 370 GPM feed with a forced circulation evaporator (Secondary Evaporator [SE]) in order to reduce the FGD blowdown volume significantly. A following Brine Cooler [BC] decreases the brine temperature prior to storage. The resulting concentrated brine will be mixed with Mayo Plant fly ash and disposed in a new on-site landfill with leachate control. The distillate water will be used in the Plant systems, reducing the make-up water demand.
- Three parallel trains of Primary Evaporators with feed of 150 GPM each (3x40%) FGD blowdown as well as two 100% Secondary Evaporators are utilized. A brine cooler system reduces the brine temperature for easier handling as well as to lower cost materials of the brine system.

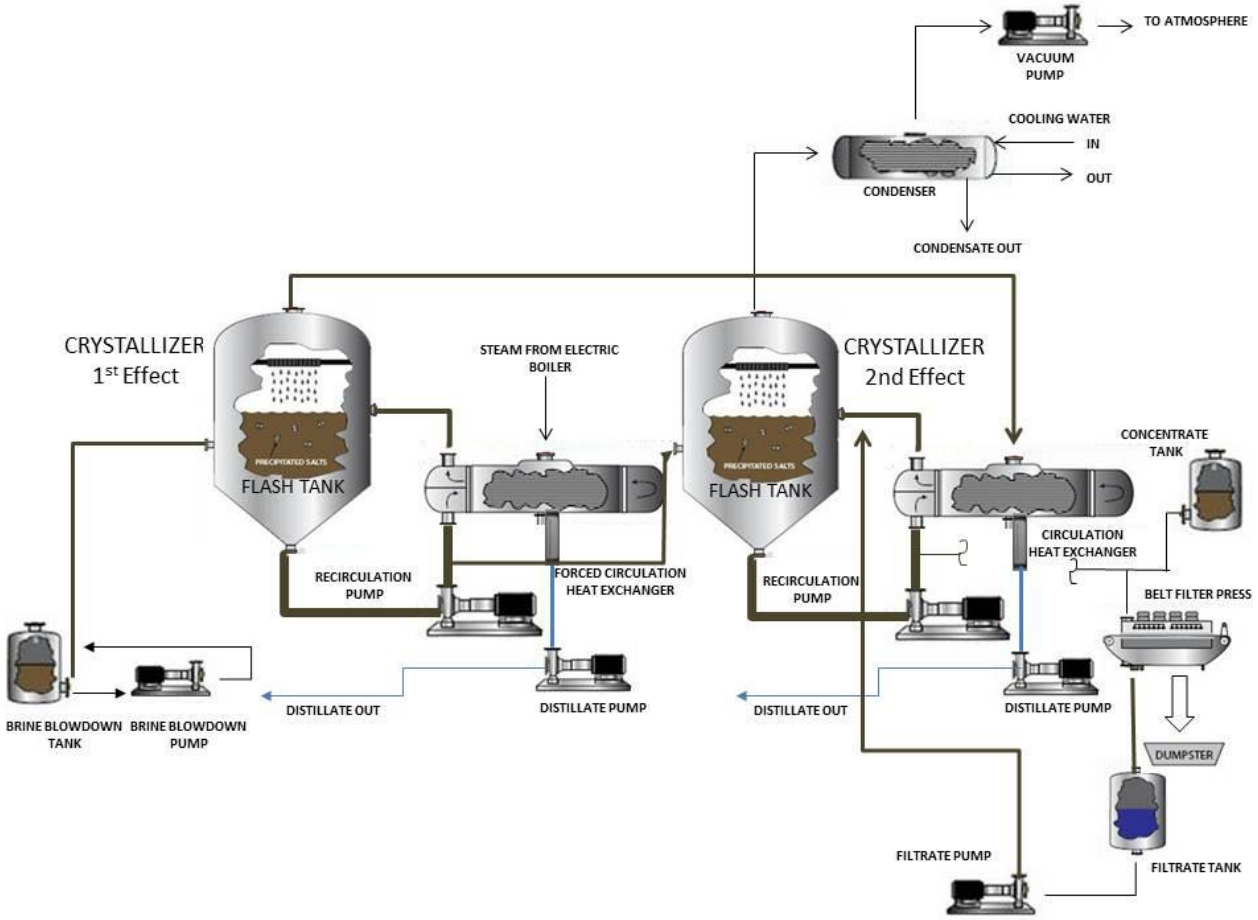
New Hampshire FGD ZLD

- Merrimack Station is Public Service of New Hampshire's (PSNH) largest power plant. Merrimack Station produces enough energy to supply 190,000 New Hampshire households, and employs more than 100 people under normal operating conditions. Guided by state and federal clean power laws, PSNH and its customers have invested millions in environmental initiatives to reduce emissions at Merrimack Station. The plant today meets or exceeds all environmental regulations; and, with the completion of the Clean Air Project in 2013, it will be one of the cleanest coal-fired power plants in the nation.
- **Project Overview**
- PSNH implemented a major project at their Merrimack Station to reduce mercury emissions from Units 1 and 2. Liquid effluent from the FGD and heavy metals removal process requires treatment and recovery for re-use as scrubber makeup. The Zero Liquid Discharge (ZLD) process is designed to treat the wastewater. The solid discharged from the ZLD process is then landfilled.
- Aquatech provided a 65 GPM (15 m^3/hr) Brine Concentrator and an 8 GPM (1.8 m^3/hr) Two-Effect Crystallizer and a 1 x 100% Belt Filter Press. Aquatech's integrated solution includes physical/chemical and evaporation technologies that will enable customers with scrubbers to achieve greater environmental responsibility.

PSNH FGD ZLD – process flow



PSNH crystallizer



Nalco solves ZLD foaming problem for PSNH

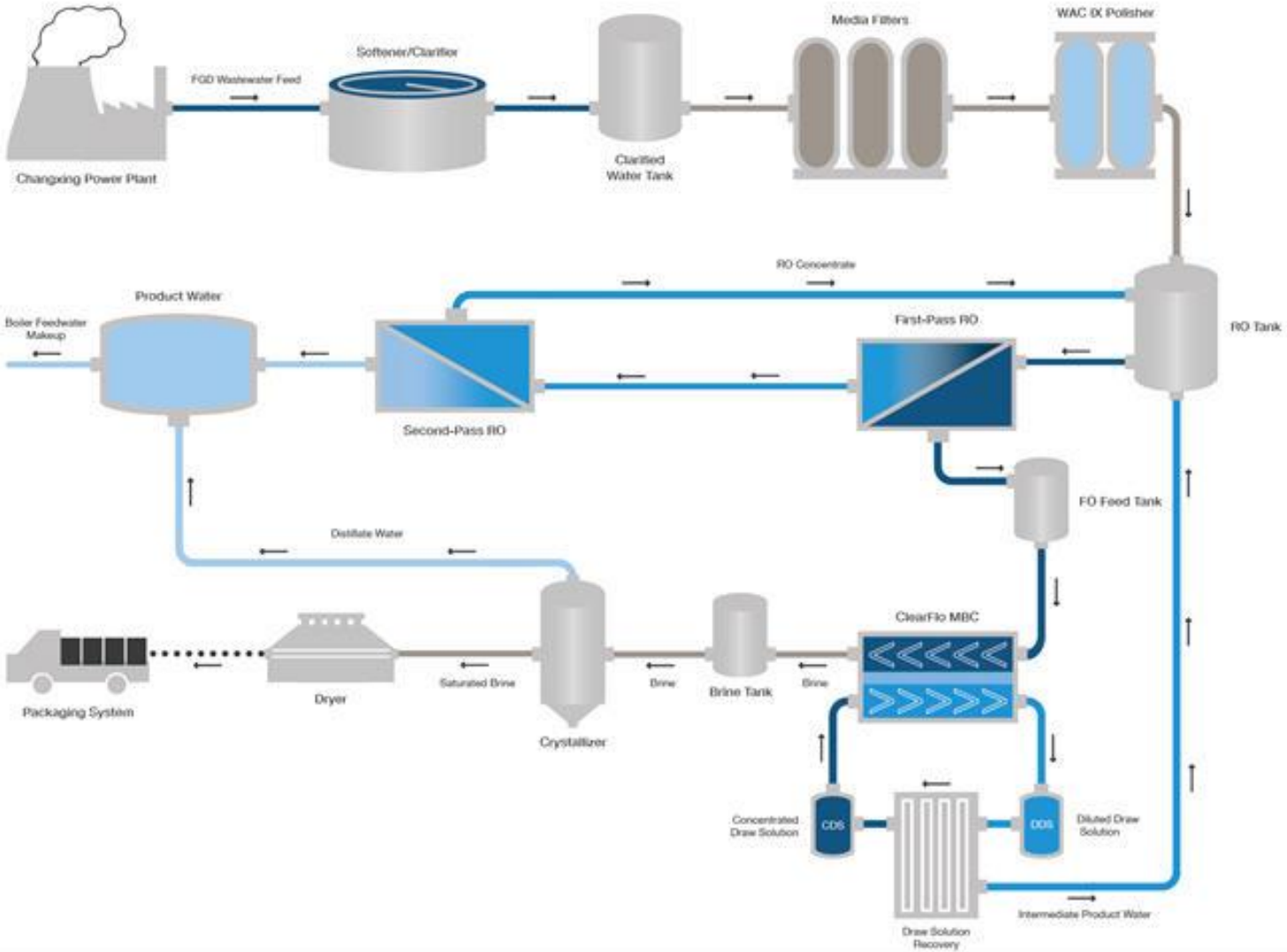
- After determining what had changed, through lab analyses and an understanding of crystallizer operation and chemistry, the team was able to narrow down the root cause of the foaming, elevated TOC levels. More importantly, once the root cause was identified, the plant made the necessary corrective actions and modifications, cleaning of the ZLDS equipment, optimize crystallizer and filter press operations, and improve cooling tower biocide program, to significantly minimize the potential for a repeat occurrence.

Changxing ZLD Started in 2015

- Huaneng Group, China's largest power producer, has constructed a 1.3 GW state-of-the-art ultra-supercritical coal fired power plant at the Changxing Power Station in Zhejiang Province.
- The plant uses Oasys' technology to treat the wastewater from flue gas desulfurization (FGD).
- The system desalinates up to 650 cubic meters of wastewater a day. Startup was early 2015.
- Several important design decisions were made to optimize the system for stable performance over the expected wide range of water quality and flow conditions, including:

  - Complete softening of the FGD wastewater was required due to the high concentration factor required for ZLD, in order to minimize opportunities for scaling in pre-concentrating RO system and for premature saturation of minerals in the crystallizer. Stoichiometric softening in a contact clarifier was combined with weak acid cation (WAC) ion exchange polishing.
  - MBC process flexibility was maximized so that the wide range of feed flow and water quality could be managed. To accomplish this, the team defined four design cases for flow and incoming TDS. The RO and FO components of the MBC were then designed to produce stable brine TDS, allowing flow and overall recovery to float as necessary.
  - To maximize turndown ratio the FO component of the MBC was split into three trains. This configuration allows operation of the MBC at flows from 60% to 110% of design maximum.
  - Operating with a shared draw solution recovery system, the FO section of the MBC is laid out as three parallel trains where any configuration of the trains may be in service at one time. The FO MBC concentrates wastewater dissolved solids from approximately 60,000 mg/L in the RO concentrate to 220,000 mg/L or higher. The MBC does the brine concentration work of a thermal or mechanical evaporator with the simplicity and modularity of a membrane system.

Changxing process with FO



Return to T of C

Operating ZLD systems from Mcilvaine GTCC Supplier program

Operating Facilities	ZLD Supplier	Location	Size (MW)	Startup
Altamonte – Edison	Degremont	Italy	757	2006
Colusa – Pacific Gas & Electric		California	712	2010
Jack County – Brazos Electric	Aquatech	Texas	620	2011
Magnolia – City of Burbank		California	387	2005
Sherman – Panda Power	GE	Texas	750	2014
Red Hawk – Arizona Public Service	Veolia	Arizona	1,060	2002
Riverside – City of Riverside		California	96	2011
Rocky Mountain – Xcel		Colorado	705	2004
Roseville – City of Roseville		California	162	2007
Russell City – Calpine		California	635	2013
Temple – Panda Power	GE	Texas	760	2014

New ZLD projects from Mcilvaine GTCC supplier program

Project	Location	Size (MW)	Expected Startup
Bowie CCGT - Southwestern Power Group	Arizona	500	2016
Stonewall CCGT - Green Energy Partners/Panda	Virginia	778	2017

Veolia IGGC ZLD in Spain

- Based on the PRENFLO™ gasification process, the plant uses a mixture of local coal (from ENCASUR) with a high-ash content and petroleum coke produced at a nearby REPSOL refinery as feedstock.
- Veolia Water Technologies worked with ELCOGAS to implement a new, more effective water treatment system for the plant..
- The process offers a reliable, robust solution to achieve the objectives of the plant for maximum water reuse, Zero Liquid Discharge (ZLD), and use of the best available technology. The proprietary CoLD® Process, utilizing HPD® evaporation and crystallization technology, was developed to overcome challenging wastewaters such as IGCC gray water that may contain chloride, ammonia, organic acids, cyanides, sulfides, silica, and heavy metals including mercury and selenium. It provides a solution without the complications and costs of pretreatment and drying equipment to attain a ZLD facility
- The CoLD® Process requires no chemical or filtration pretreatment of the gray water prior to evaporation that adds cost and complexity to the process. The gray water is fed directly to an HPD® MVR evaporator in which the bulk of the concentration takes place. The vapors generated are sent to a vapor washing system in order to protect the vapor compressor from foaming events and carryover that are common with certain wastewater streams. Concentrate from the evaporator is sent to the CoLD crystallizer where chlorides and other solids are removed from solution. What makes this process unique is that at the lower temperature in the COLD crystallizer, the highly soluble solids will crystallize at relatively low temperatures. These solids are then sent to a filter press for disposal and the filtrate is recycled back to the crystallizer. Volatile compounds (formic acid, ammonia, cyanide and hydrogen sulfide) which condense into the distillate produced from the evaporator and CoLD crystallizer are removed by an integrated stripping system. This allows the distillate quality to meet the recycled water specifications.

Aquatech GTCC ZLD

Colusa

- In December 2010, the Colusa Generating Station, a 660-megawatt power plant located near the town of Maxwell in Colusa County began commercial operation. This facility incorporates the latest technology and environmental design to reduce emissions and dramatically lower water usage compared to conventional natural gas power plants. Cleaner burning turbines will allow the facility to use less fuel and emit 35 percent less carbon dioxide than older plants. The Colusa Generating Station will serve PG&E's comprehensive energy strategy to meet California's future energy needs with cost-effective and clean power supplies.
- The Colusa Generating System will be dry cooled – preserving local water typically needed for power generation. The facility will capture steam generated during operation which will be condensed back into water and recycled through the plant to produce additional power.
- Further, water will be recycled through a Zero Liquid Discharge system that cleans potential wastewater for reuse throughout the plant. Aquatech was awarded a contract from Gemma Power Systems for this equipment.
- The equipment that Aquatech provided included: Potable Ultrafiltration 300 GPM (68 m^3/hr); Wastewater Ultrafiltration 500 GPM (114 m^3/hr); Reverse Osmosis 60 GPM (14 m^3/hr); Wastewater Reverse Osmosis 30 GPM (7 m^3/hr); Forced Circulation Crystallizer; 10 GPM (2.2 m^3/hr)

Brazos Electric : 2 systems from Aquatech

Doosan-Chihuahua 435 MW CC Power Plant Power Plant Boiler Feed Water Make-up

- Contract : 1999
- Start: 2001
- Owner: Electricidad Aguila de Altamira S. de R.L. de C.V.
- Client Mitsubishi Heavy Industries
- Engineer DHT
- Location Chihuahua, Mexico

- Scope: Design, fabricate, supply, installation supervision, commissioning and training of the water treatment systems, consisting of 3 main process technologies: Demineralization System Zero Liquid Discharge Waste Water Treatment
- Domestic Sewage Treatment o Equipment: dual media filters, R.O system, Decarbonator, CIP system, Chemical dosing system, heat exchanger, Demineralizer, Neutralization system and a wastewater system.
- Feed water: Well water Feed
- Water TDS:1500mg/l
- Permeate Conductivity 20 µS/cm
- Permeate flow: 220 gpm
- Demineralized Water: 14 MΩ-cm
- Capacity: 317,000 GPD

ZLD outsourced by California CGTT, use of treatment chemicals is critical

- George Davies, combustion turbine department manager for Turlock (CA) Irrigation District's Walnut Energy Center, explained that
- Walnut is a 250-MW, 7EA-powered 2 × 1 combined cycle with a "state-of-the-art" ZLD system. It also is the only power plant that has outsourced ZLD o p e r a t i o n and maintenance to a third-party services firm (CH2M Hill subsidiary Operations Management International, known as OMI).
- Dan Sampson, Nalco Co's (Naperville, IL) power-industry technical consultant spoke about the challenges presented by ZLD.
- Sampson offered a few rules-of thumb: Developers, he said, are prone to buy the lowest-price system designed to handle the required flow. One problem with this approach is that the reference water analysis for design work usually is uncertain and any deviation from design almost always translates to a loss in capacity.
- Consequently, ZLD systems almost never meet their nameplate ratings. For decision-making, assume the following:

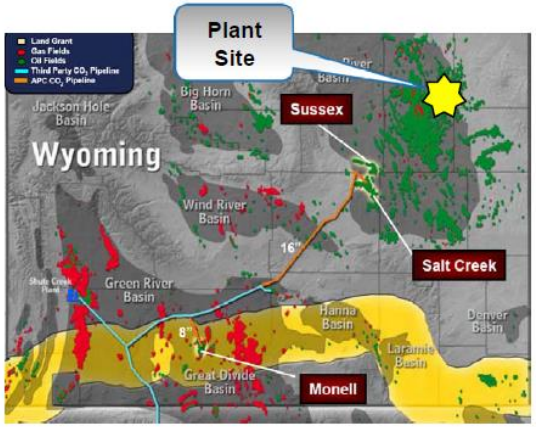
  - Mechanical reliability, 75% to 95%; assume a nominal 80%.
  - A 20% degradation in output between system overhauls/cleanings.

B&W Oxyfuel with ZLD

babcock & wilcox power generation group

B&W and Black Hills: Project Overview

- 100MWe Oxy-fuel pulverized coal greenfield plant located in Campbell County, Wyoming
- Application submitted to the DOE for CCPI-3
- Plant in-service by 2016
- Project Team:
  - Black Hills Corporation, host utility
  - The Babcock & Wilcox Company
  - Air Liquide Engineering and Construction
  - Battelle, Pacific Northwest Division



Black Hills Demonstration Project

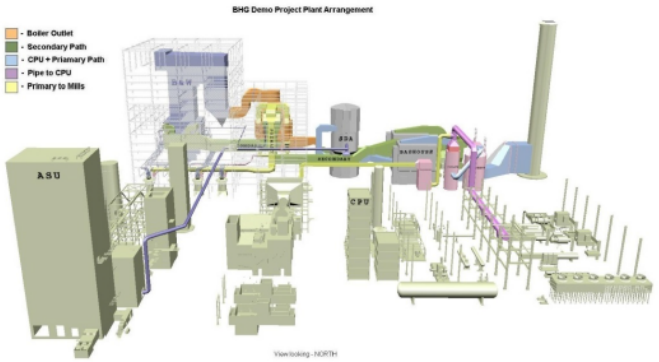
Milestone	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
Selection	★										
Award		★									
Engineering											
NEPA and Permitting											
Procurement											
Installation											
Commissioning and Startup											
Test Period											
Monitoring											

Near Zero Emissions - in fact no emissions to air or water

babcock & wilcox power generation group

Project Scope and Technical Details

- Pulverized coal fueled boiler with 2400 PSI/1050F/1050F steam cycle
- Air Separation Unit (ASU)
- Compression and Purification Unit (CPU)
- 100 MWe net electric output
- Heat integration of ASU/CPU w/ steam cycle
- Near Zero Emissions Plant (NZEP) for SO_2, NO_x, PM and Hg
- Low raw water usage with dry cooling
- High altitude operation
- Zero Liquid Discharge (ZLD)
- Mine-mouth site using low-rank sub-bituminous Powder River Basin coal
- 1 million tons/yr CO_2 storage
- Use CO_2 for EOR or deep saline storage



Coal can be greener than wind or solar

- Locate coal plants where there is a need for EOR e.g., Saudi Arabia
- Use Oxycombustion
- Burn 20% biomass
- Inject all gases through EOR
- ZLD and use of municipal treated wastewater
- Net reduction in CO_2 and water contaminants per MW
- By-products to include hydrochloric acid, sulfuric acid , rare earths, precious metals, flyash for cement
- No other technology comes close

Refinery

Iraq refinery will have Veolia system

- Iraq´s State Company for Oil Projects (SCOP) and their EPC contractor HDGSK, a joint venture composed of Hyundai Engineering & Construction Co., Ltd., GS Engineering & Construction Co., Ltd., SK Engineering & Construction Co., Ltd., and Hyundai Engineering Co., Ltd., have selected Veolia´s HPD® evaporator technology for the Karbala Refinery project.
- Veolia´s proven track record and its project execution capabilities to deliver a modularized solution were instrumental in securing this important contract.
- Veolia's system will be divided into two steps: the first step is a Brine Concentrator based on calcium sulfate seeded slurry and driven through a single Mechanical Vapour Recompression (MVR), and the second step is a Zero Liquid Discharge (ZLD) Brine Crystallizer driven through two stages of single MVR. The combined system will eliminate all liquid waste discharge and will produce a waste solid product discharge from a centrifugal separation process. Waste solids from the plant will be routed to a landfill for disposal. The process distillate quality recovered from the process will be routed internally to the refinery for reuse.
- The plant will have a capacity of 55 m^3 /hr and is scheduled for delivery in August 2016. The Karbala Refinery ZLD facility will rely on the high mechanical availability of Veolia´s system to maintain the refinery´s water treatment operations.

Doosan Petrochemical ZLD

- The SEP project, a greenfield synthetic rubber plant, is a joint venture between Saudi Basic Industries (SABIC) and Exxon Chemical Arabia, Inc
- Contract Year: 2013
- Start-Up Year: Expected 2014
- Owner: Al-jubail Petrochemical Company (Kenya) Daelim Industrial Co, Ltd. Al-Jubail -Saudi Arabia

- Scope Design, manufacture, and supply of :
  - two (2 x 100%) Demineralized Water Units
  - one (1) Secondary Waste Water Treatment Unit,
  - Spare parts for construction, commissioning & startup
- Provide field services for:
  - Installation & QC Inspection Supervision,
  - Start-up, testing and commissioning services
  - Operator training
  - Effluent (Demin) Quality: pH @ 20 0C: 7.5 - 8.5; TDS 0.1ppm; SS: none; Conductivity:

Oil and Gas

ZLD in SAGD

- The heavy oil recovery process, referred to as SAGD (Steam Assisted Gravity Drainage), requires 100% quality steam to be injected into the well (i.e., no liquid water).
- To produce 100% quality steam using once-through steam generators, a series of vapor-liquid separators are required to separate the liquid water from the steam. The 100% quality steam is then injected into the well. The separated water is then either disposed of via deep-well injection or, if deep well injection is not possible, the separated water may be taken to Zero Liquid Discharge (ZLD) using a Brine Concentrator and/or a salt Crystallizer.

Veolia – produced water, Chevron

- The Chevron San Ardo project involves treatment of produced water for the purposes of discharge to recharge basins and production of Once Through Steam Generator (OTSG) make-up water. The project goal was to achieve water quality suitable for recharge basins discharge, while achieving 75% water recovery across the treatment system and minimizing the volume of produced water requiring re-injection. The treatment process includes pretreatment for free oil removal followed by OPUS™ technology (patent pending) to achieve the discharge water quality and a Series Softening System for generation of OTSG make-up water. The OPUS™ technology consists of multiple treatment steps such as heat exchange, degasification, chemical softening, media filtration, ion exchange softening, and a double-pass RO system to meet the effluent water quality requirements.
- The solids generated from the system are dewatered and disposed in a landfill. The San Ardo project involved process design, basic engineering, equipment procurement, and construction management. The advanced water treatment system is operated by Veolia Water North America.

Veolia offers Marcellus Shale solutions

- Flowback and produced water, in the case of the Marcellus Shale Gas Play, can be effectively treated utilizing evaporation and crystallization technology for both low and high TDS wastewater.
- A proprietary process developed by Veolia Water Solutions & Technologies provides efficient removal of sodium and calcium chlorides as well as the heavy metals commonly found in effluent generated from the produced water. Based on the wastewater composition from this region, the process eliminates the need for often expensive pretreatment of the produced water, reducing capital, and operating costs.
- Offered as a Zero Liquid Discharge (ZLD) system, this process recovers greater than 95% water recovery with the only waste as a solid salt cake suitable for landfill disposal

Saltworks Evaporator on shale fracking flowback

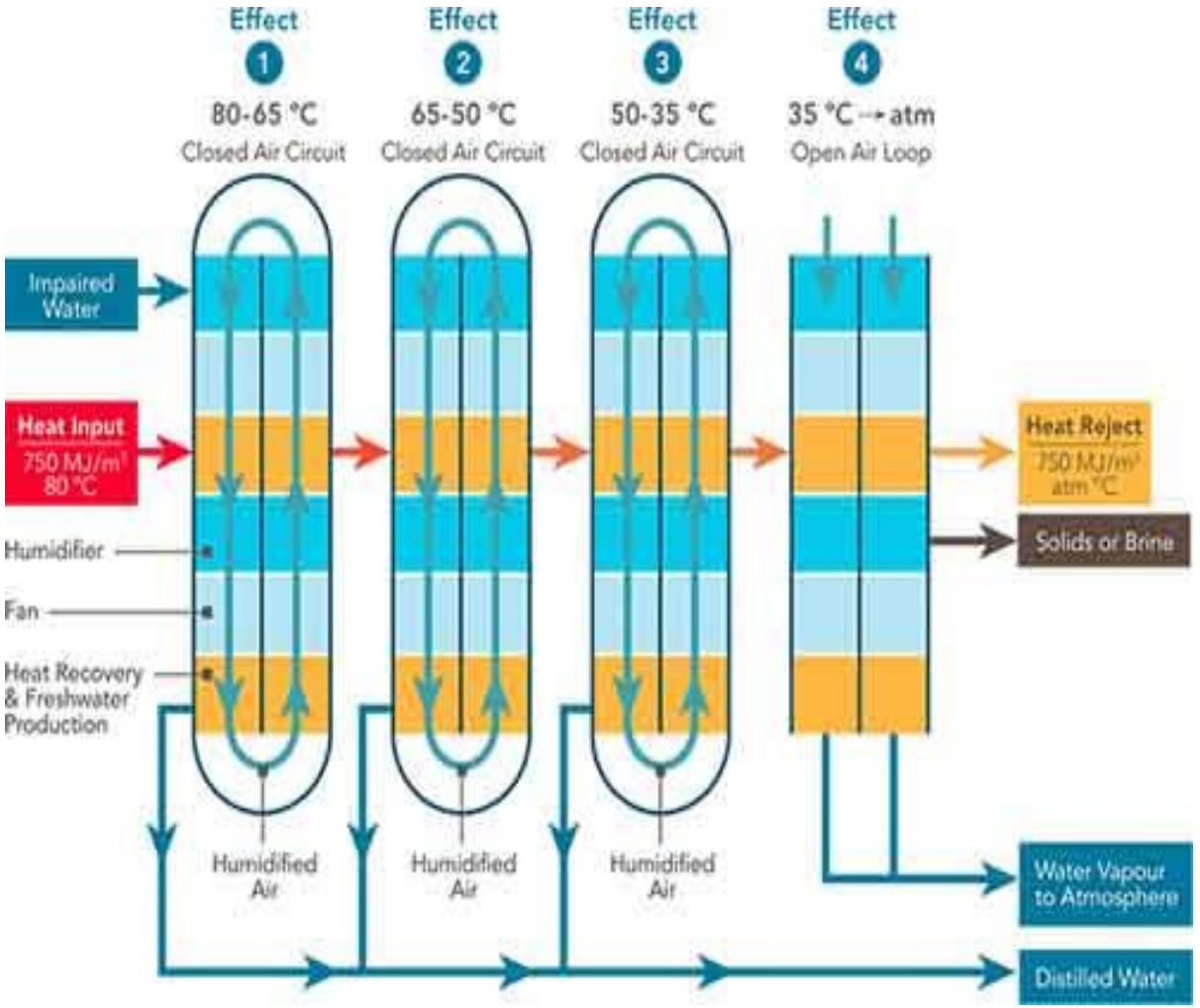
- Saltworks' SaltMaker Evaporator Crystallizer was used to treat hyper saline shale gas produced water from East Texas and Northwestern British Columbia. The project demonstrated reliable production of high quality freshwater and solids for low volume disposal. The freshwater produced can be reused in fracking or surface discharge.
- The pilot successfully and reliably produced high quality freshwater and solids. The project demonstrated that the SaltMaker can treat shale gas produced water to produce freshwater and solids for low volume disposal. Project results are as follows:

    - High quality freshwater produced ~400 mg/L TDS
    - Concentrated brine from 173,000 mg/L to 430,220 mg/L TDS (point of saturation and solids production)
    - Solids (~15% moisture) produced and reliably extracted
    - 99% recovery as freshwater produced Reliable operation with optimized automated self cleaning

Applications include:

- Shale gas-produced water
- Hydraulic fracking
- RO reject

Saltworks System

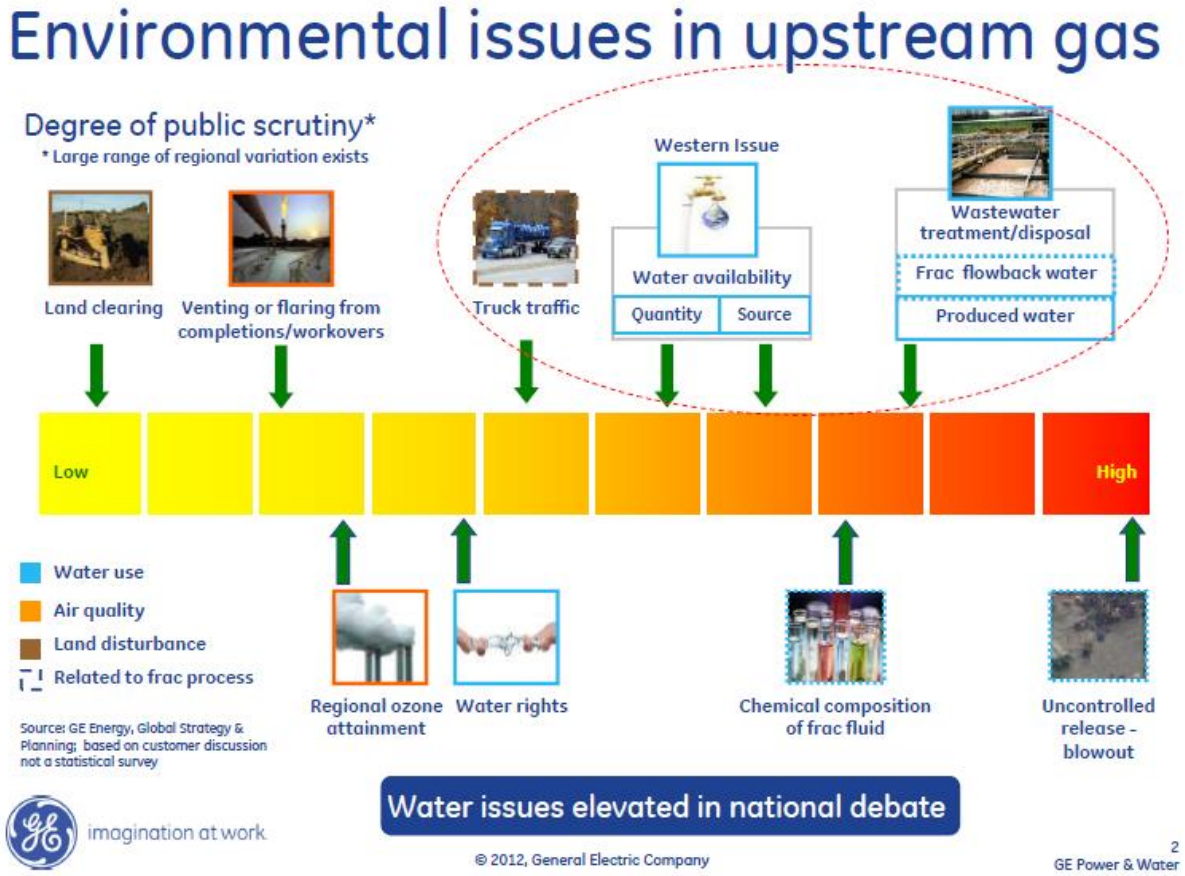


Brine Treatment Players in oil and gas

Table 1. Brine Treatment Technology Developments

Company	Technology	Comments
Aquapure	Mechanical vapor recompression (MVR)	Developers of mobile MVR units for produced-water treatment, units active in the Permian Basin
Eureka Resource	ZLD, crystallizers	Constructed centralized ZLD treatment facilities in the Marcellus region.
Memsys	Vacuum – multi-effect distillation	Partnership with Noram Engineering to develop a produced water reuse system for the Alberta Oil Sands.
Enviro Water Minerals	Selective salt removal zero discharge desalination – ion exchange, electrodialysis, nanofiltration, mechanical vapor recompression	Pilot project in El Paso, treating brine from brine water reverse osmosis system, selective removal of salts enables recovery of high-purity products.
Oasys	Forward osmosis	Commercial installation for flue gas desulfurization. Partnership with National Oilwell Varco for use in tight oil/gas produced-water treatment.

GE ZLD in upstream gas plants

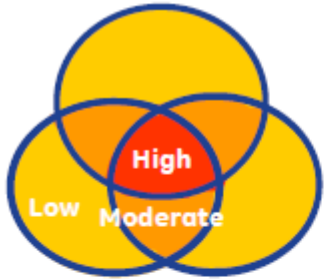


Environmental focus stronger in some regions

Large gas plays, in close proximity to urban or pristine areas with little local familiarity to the O&G industry are likely to draw the most intense scrutiny

Forces driving Environmental sensitivity

Proximity to (urban or wilderness areas)

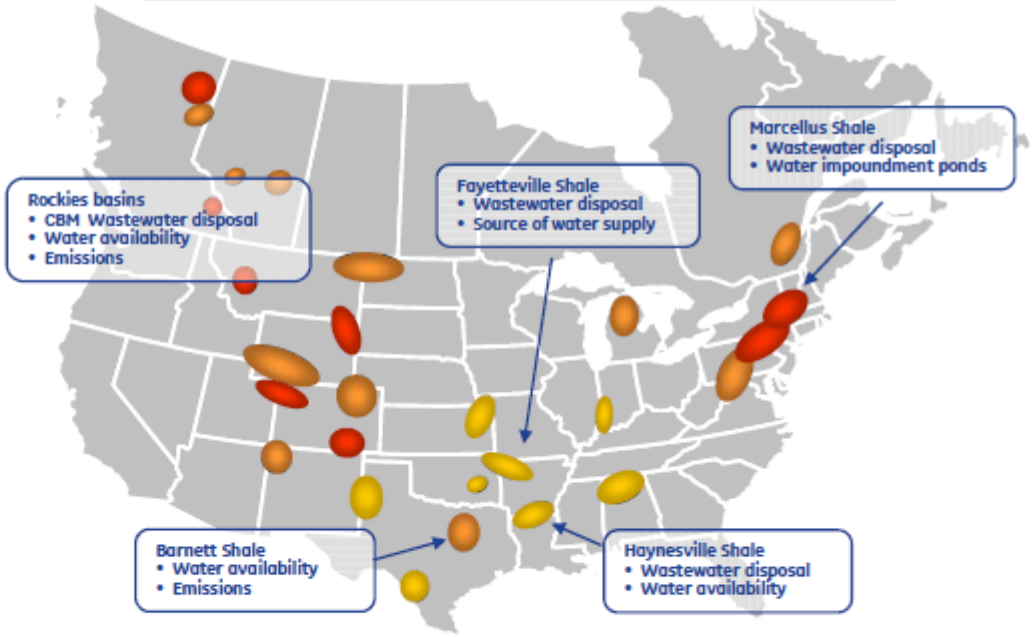


Resource (Size, concentration)

O&G industry maturity

Source: GE Energy, Global Strategy & Planning

Key Unconventional Gas Basins



imagination at work.

GE building block design

Building Block Design

imagination at work

GE systems can recover, salts, metals, and nutrients

Investing in future reuse technology

Increasing Value for Recovery

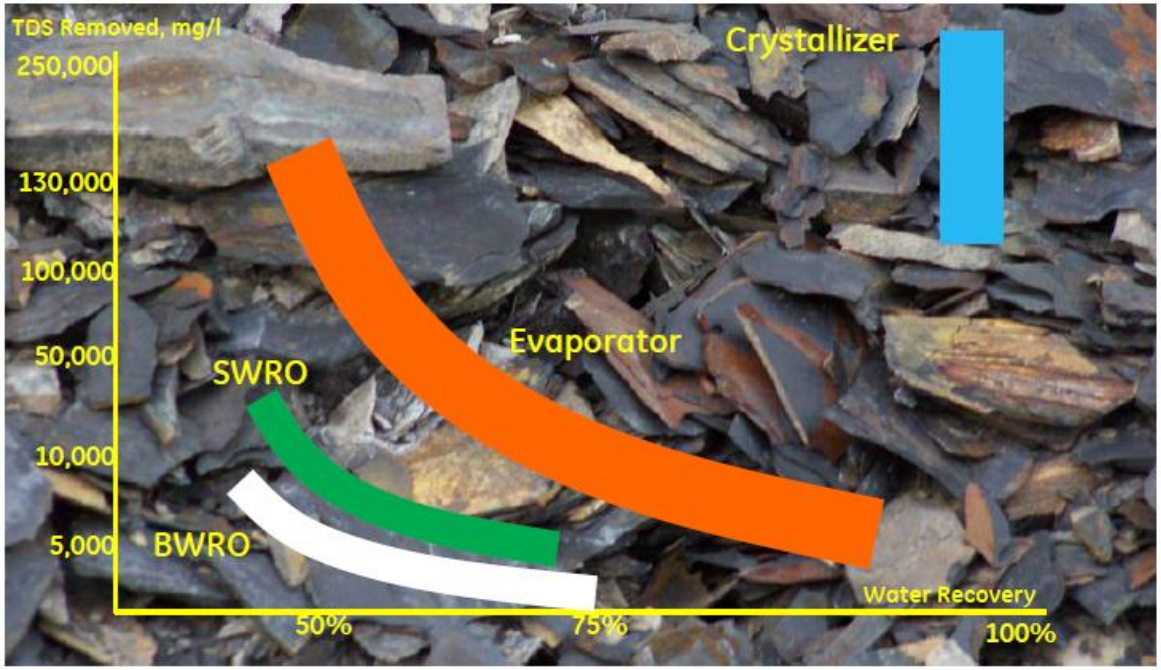
- Water priced at true cost to supply, encouraging reuse
- Energy and materials cost expected to trend upward

What Drives Reuse?

- **Past:** Water scarcity and environmental regulation
- **Future:** Value recovery & continued regulation

Frac water has high solids content where crysallizers are needed

Application of Desal Technology:
Salt Removal and Recovery in Frac Water



Ge has mobile evaporator systems

GE's Mobile Evaporator

Treat Shale Gas Frac Water at the Well Site

- Horizontal Shell & Tube Forced Circulation Evaporator
- Proprietary sequential stage MVR design with cyclonic coupling reduces energy costs by approximately 35%
- Partial Vacuum
- Completely self-contained with all ancillary equipment included within the trailer
- Single drop trailer provides maximum clearance for remote site access

imagination at work

GE reduces truck requirements

Solution Generation

REDUCE THE TRUCKS

Single Well Completion

- Completion Fluid and Materials 10 - 20 Truckloads
- Completion Equipment (pipe, wellhead) 5 Truckloads
- Hydraulic Fracture Equipment (pump trucks, tanks) 150 - 200 Truckloads
- Hydraulic Fracture Water 800 - 2400 Tanker Trucks
- Hydraulic Fracture Sand 20 - 25 Trucks
- Flow Back Water Removal 120 - 480 Truckloads (either to treatment or disposal)
- Well Production Equipment 5 – 10 Truckloads

TOTAL REDUCTION IN TRUCKING (per single well completion, 72 – 556)

Up to 42 % REDUCTION IN WASTEWATER TRUCKING COSTS AND WASTEWATER TREATMENT / DISPOSAL COSTS

Up to 9 % REDUCTION IN FRESH WATER TRUCKING COSTS

imagination at work

Coal to Chemicals (CTX)

ZLD Mandated at all Coal to Chemicals Plants

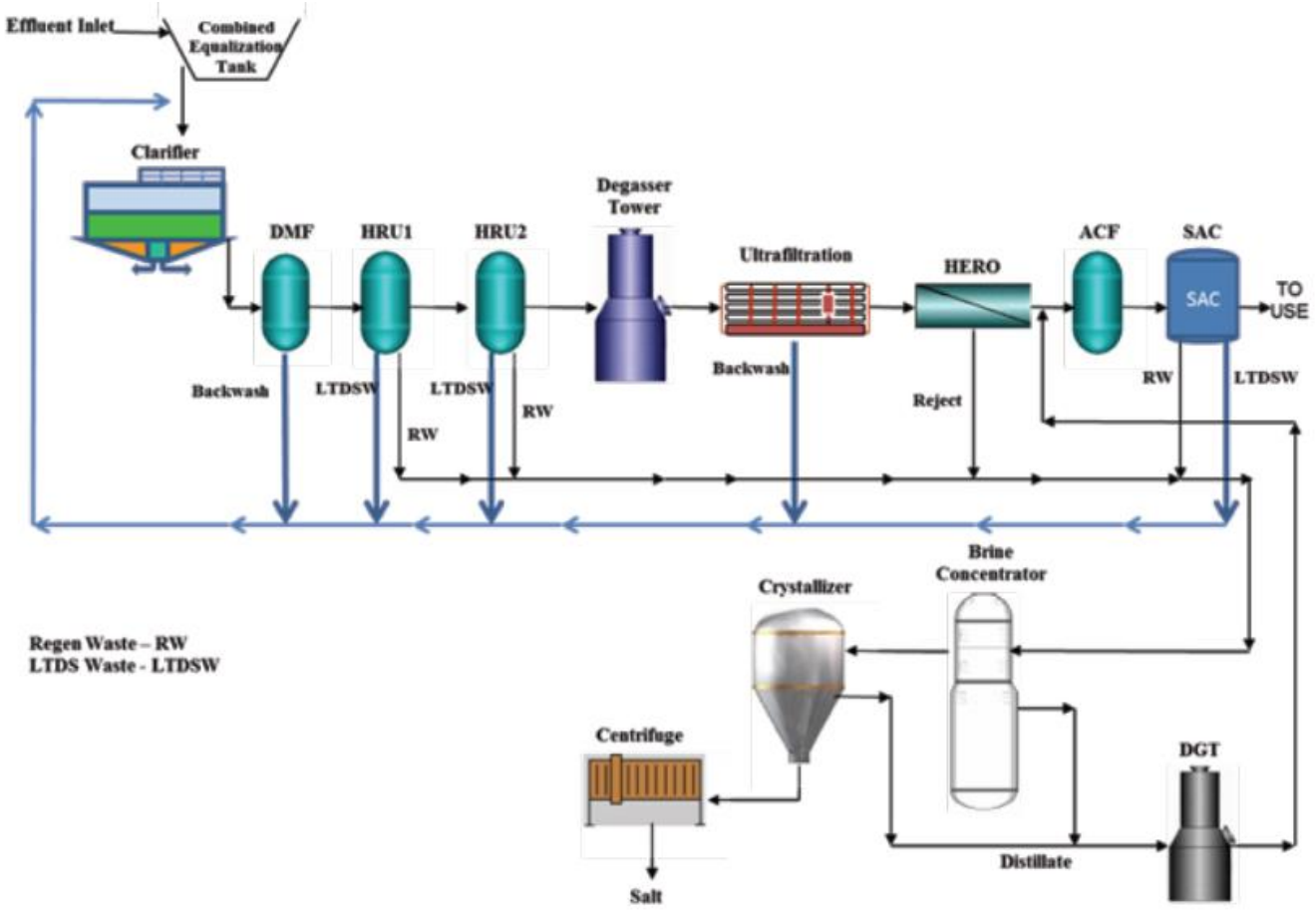
- China has limited reserves of crude oil but lots of coal, which is burned in power plants to generate electricity. Because coal is so abundant, in recent years the Chinese government has sponsored a program to create an industry where coal is used to make a wide variety of chemical feedstocks including methanol, olefins, gasoline and other liquids, and synthetic natural gas. This is often referred to as Coal-to-Chemicals or Coal to X (CTX). Each plant starts with a coal gasifier, followed by the unit operations necessary to convert the gasification products into the desired final product.
- These plants always consume large volumes of water, and because they typically are located near the coal reserves in remote and arid regions of China such as Inner Mongolia, the government has mandated zero liquid discharge (ZLD) for all new plants going forward. This means all the effluent water must be recovered and recycled back to the plant.
- Why this mandate now? The technology for ZLD has existed for 20 years, but it has been seen as an expensive option in the past. However, the Chinese economy is growing and there is a greater demand on resources; therefore the appetite for a more water-responsible approach has grown. Right now, there are a limited number of CTX plants operating in the region, with many more in the pipeline and all of which will need to meet this ZLD mandate.
- Suppliers are working to help industry in this region meet the ZLD requirement with water recovery systems, generally membranes followed by an evaporator leveraging pre-treatment technologies to enable high recovery. There is also focus to create a non-leachable solid that can be disposed or used as a by-product.

Return to T of C

Shenhua installing Aquatech system at CTX plant

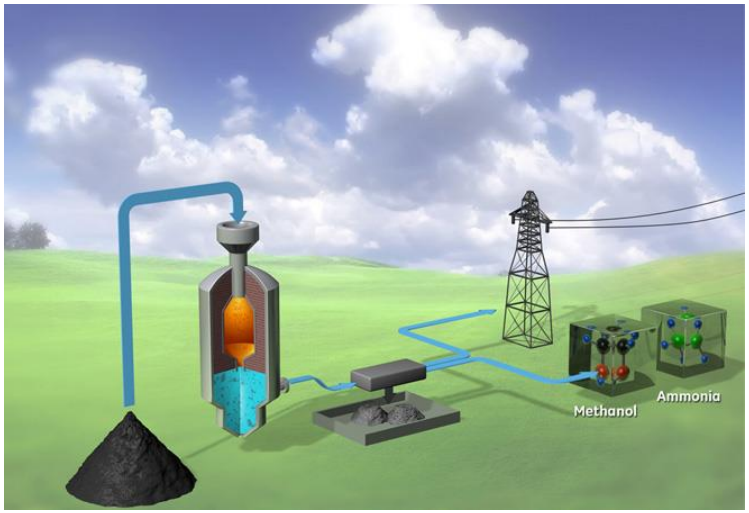
- To reduce its carbon and water footprint, and to ensure statutory compliance, Shenhua Coal Oil Chemical Co. Ltd implemented a project to construct a system to recycle water from wastewater generated by the plant and eliminate waste water discharge (ZLD). Shenhua Xinjiang selected Aquatech to design, engineer, and supply the wastewater recycle and ZLD system, and to supervise installation and commissioning.
- The CTX wastewater stream has high scaling and fouling potential due to the presence of hardness, organic species, ammonia, silica, etc. The wastewater stream is first concentrated by the HERO system, consisting of lime softening, filtration, ion exchange, ultrafiltration, and RO membranes, achieving high recovery of low TDS permeate for reuse by the CTX facility.
- HERO is a patented process, most suited for applications where feed water is high in both organic and inorganic foulants. The operating environment of a HERO system eliminates scaling and fouling by biological growth, organic species and oil and grease.
- The result is that an AquaEZ system requires less downtime for cleaning than a conventional RO based wastewater treatment system.
- The concentrated brine from the Water Recycle system is further concentrated in the ZLD system, recycling the remaining water as distillate. The ZLD system comprises a HEVAP evaporator for brine concentration and crystallizer to achieve ZLD.
- The concentrated HERO reject brine from the Water Recycle system is non-scaling. The HEVAP evaporator is designed with a very low ΔT (temperature difference between the heating medium and the boiling brine) and a high recirculation rate. The result is scale free evaporator operation and lower power consumption.
- The crystallizer is the final brine concentration step. The crystallizer further concentrates the brine from the evaporator. As concentration occurs, salts are precipitated, grown into crystals and harvested by a centrifuge. The dry salt is taken for suitable disposal.

Shenhua process flow diagram



Chinese Coal Gasification Plans Create New Opportunities

In late 2015 Sinopec launched a $20 billion coal gasification pipeline



- Gasification of coal, capture of coal bed methane and underground gasification are attractive LNG fuel sources because
  - Coal gasification is well established
  - Coal gasification is already modular
  - Coal is available in remote areas where LNG needed
  - Cost of coal gas is low
  - China, and other countries with large amounts of coal can achieve energy security

Pipelines running from Northwest China to cities in the East will provide take off points for both CNG and LNG. China has already adopted natural gas vehicles

China plans to build 50 coal gasification plants in less populated northwestern parts of the country, using the gas produced to generate electricity in the more populated areas, where smog is prevalent. Two coal gasification pilot plants have been built, three more are under construction, and 16 have been approved for construction, while the rest are in various planning stages. Eighty percent of the 50 plants are to be located in northwest China, in the provinces or regions of Xinjiang, western Inner Mongolia, Ningxia and Gansu.

Coal Gasification in Western China

The Xinjiang Guanghui LNG project receives feed gas from a large coal gasification plant. The LNG unit handles 405 MMSCFD of feed gas.

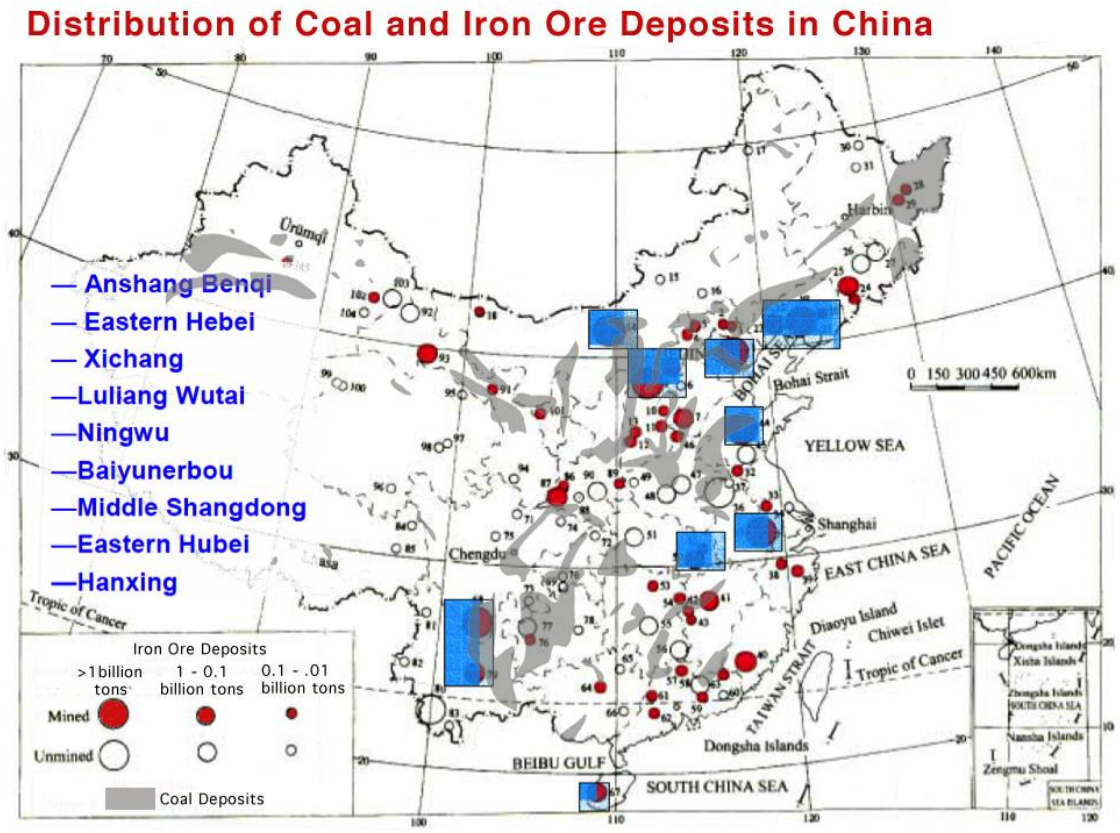
The LNG product is trucked from the site and the syngas is used for methanol plant feedstock.

Currently, there are 14 SNG projects that have been approved by the Development and Reform Commission of Xinjiang Uyghur Autonomous Region and are being constructed or will be constructed by 12 enterprises in Xinjiang, most concentrated in such areas rich in coal and water resources as Yili, Zhundong and Fuyun. According to the 12th Five-Year Plan of Xinjiang, 20 SNG projects have been listed as the construction goal of the autonomous region, with yearly gross production capacity hitting 76.7 billion cubic meters.

At present, CNPC and Sinopec are planning seven natural gas pipelines in Xinjiang to accommodate the output of Xinjiang' SNG. It is predicted that the transmission capacity of the pipeline will hit 48 billion cubic meters each year.

Return to T of C

Location of Coal and Iron Ore Deposits in China



Gray areas indicate the location of coal deposits.

Red circles indicate iron ore mines.

Open circles indicate iron ore deposits.

Blue squares locate the regions described in blue.

Coal mines and iron ores mines are located in the same areas. Coal from these mines could be gasified and liquefied for use in mining equipment.

Return to T of C

Aquatech (U.S.) sold ZLD to Yuntianhua Coal-to-Chemicals Plant

- Aquatech has been awarded a contract for a Zero Liquid Discharge (ZLD) plant for a coal-to-chemicals facility in Hailer in Inner Mongolia. The ZLD plant incorporates HERO™ (High Efficiency Reverse Osmosis) and a Thermal Brine Concentrator. The plant will treat 2400 m^3/day of wastewater and reuse 92.5% of it, producing 2000 m^3/day of process water and 220 m^3/day of distilled water for various end user applications.
- The waste streams to be treated are extremely challenging with high COD, BOD, ammonia, silica, and TDS levels that exceed 18,000 ppm. The HERO™ system is used to concentrate the feed water to a solids level of approximately 8.5% before taking it to the Brine Concentrator and subsequent evaporation pond.
- Aquatech will be supplying this project on an Engineering & Procurement (EP) basis along with Commissioning service, and is targeting to start the commissioning by mid 2011.
- The coal to chemicals plant is owned by Hulunbeier New Gold Chemical Co. Ltd. (NGCC), a Yuntianhua Chemical group company. Yuntianhua Chemical is one of China's largest state-owned enterprises with six major industries and a series of products such as chemical fertilizers, organic chemicals, new glass fiber materials, and phosphate ore mining and dressing.

Return to T of C

Shenua Ningxia - Aquatech

- Division of the Shenhua Group – China's biggest coal producer – Shenhua Ningxia Coal Industry Co. Ltd., is moving forward with developments for a coal-to-liquid (CTL) fuels conversion project, located in northwest China, a dry, water-stressed region.
- The project intends to ensure that Shenhua Ningxia complies with statutory regulations and minimizes its overall water footprint.
- Shenhua selected Aquatech to design, engineer and supply a Zero Liquid Discharge (ZLD) plant for the project, as well as supervise install and commission the ZLD plant.
- Aquatech will provide a fully integrated and automated system that it has developed for the CTX market. This system uses state-of-the-art AquaEZ™ technology, consisting of conventional UFRO, HERO™ (high-efficiency reverse osmosis), Unseeded Falling Film evaporators, as well as crystallizers at the back end to achieve complete zero liquid discharge.
- It is reported the ZLD plant aims to recycle over 55 million liters/day (2300 m^3/hr) of wastewater generated by the 4 million tons per year CTL plant and eliminate all wastewater discharge. The recycled water will be treated to a high-purity level and reused in the process facility.

Return to T of C

McWong Supplying ZLD for Coal to Petrochemicals

McWong's engineering customizes client's parameters and designs unique solutions to treat specific contents of wastewater by using mainly membrane and thermal technology in the zero liquid discharge process.

- • **Process Advantages:**

- Applicable to heavily polluted wastewater
- Applicable to highly concentrated saline wastewater
- Applicable to minimization of wastewater discharge and maximization of water reuse
- Significantly reduces downstream equipment investment, saving more than 50% of operating cost

- • **Applications:**
  Applicable to coal chemical, petrochemical, chemical, oil extraction and steel-making industries, especially in solving the discharge problem of high concentration of brine

- **ChinaCoal MENGDA- 5 Million Tons Engineering Plastics Annual Production Wastewater Treatment ZLD Project**
  The water reusing system facility in the 5 million engineering plastics annual production project of Inner Mongolia ChinaCoal Mengda New Energy Chemical Co. Ltd was EPC contracted by McWong. The overall capacity of this project is 13,200m^3/d including water from the project's own wastewater equipment and discharged wastewater from water pumping stations and desalination stations. McWong utilized its own patented zero-discharge process package (UF + RO + vibrating membrane + multi-effect evaporation concentration) technology to achieve zero discharge and recycle coal chemical industry wastewater.

McWong Teaming with U.S. Company

ZLD Solution for Coal Chemical Water Treatment

- Joined forces with NEW LOGIC RESEARCH, INC. a California company with special membrane products
- A zero-liquid-discharge and water re-use project in Inner Mongolia, China
- McWong provides turnkey engineering service, incorporates NLR membrane as one of the key processes
- Treating 13,200m3/d industrial wastewater from the production of industrial plastics from coal
- Solves regional water shortage problem with minimum energy consumption, thus saving operation costs

McWONG

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Return to T of C

Sembcorp ZLD at a Coal-to-Diesel Project in Wangqiao Industrial Park, Shanxi Province

- Sembcorp Industries (Sembcorp) will be developing a total water management plant to support a coal-to-diesel project in Wangqiao Industrial Park, located in Changzhi city in China's Shanxi province. This total water management plant will offer the most comprehensive range of water products and solutions, amongst the water facilities that Sembcorp has developed in China.
- This total water management plant will provide up to 57,600 cubic meters per day of industrial and potable water, 81,600 cubic meters per day of demineralized water and 984,000 cubic meters per day of cooling water, and treat up to 24,000 cubic meters per day of high concentration industrial wastewater and 9,600 cubic meters per day of high salinity industrial wastewater. The plant will also be capable of reclaiming up to 38,400 cubic meters per day of water from treated industrial effluent, aiming to achieve "zero liquid discharge". The plant is expected to be completed in phases between late 2014 and 2015.
- The total water management plant will serve Shanxi Lu'an Group (Lu'an), for its one million tones per annum coal-to-diesel project in Wangqiao Industrial Park, under a 15-year service agreement that Sembcorp's wholly-owned subsidiary, Sembcorp (China) Holding Co, has secured.

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Memsys/Horizon CTX project

- Memsys, a developer of a breakthrough thermal separation process based on membrane distillation, and Horizon Environmental Technology Ltd. have entered into a pilot plant agreement for a coal-to-chemical (CTX) project in northern China.
- Horizon, a leading water and wastewater technology company in China, will use Memsys' membrane distillation (MD) technology to further concentrate the wastewater or brine solution from upstream unit processes so that the capital investment and operating cost of the downstream Zero Liquid Discharge (ZLD) technology can be significantly reduced. The pilot trial was due to commence in May 2014.
- The Memsys technology is a thermal separation process based on proprietary Vacuum Multi-Effect Membrane Distillation (V-MEMD). The process can be operated using waste heat to produce a high quality distillate and treats a variety of feed water including wastewater or brine with high TDS concentration.
- Based in Germany and Singapore, Memsys is a leading-edge developer of vacuum distillation technology for various applications. Its patent-protected thermal separation modules are used for wastewater treatment in the oil, gas and steel industries, brine concentration, low temperature distillation and low energy desalination or alcohol distillation. Memsys' robust technology is based on vacuum-driven multi-effect membrane distillation (V-MEMD), a highly efficient thermal separation process in a compact, modular concept. These modules perform all steps of the membrane distillation process including a multi-effect energy recovery. Memsys' technology can be operated using waste heat to produce a high-quality distillate and effortlessly treats a variety of feed waters including wastewater feeds with high TDS content.

GE is a Major Supplier in China

GE has 150 Gasifiers in operation or underway

Installed fleet by the numbers

GE has 157 gasifiers in commercial operation ... the largest fleet in the industry ... with 95 additional gasifiers in development, engineering, or construction at 25 plants ... and a global presence in 15 different countries.

imagination at work

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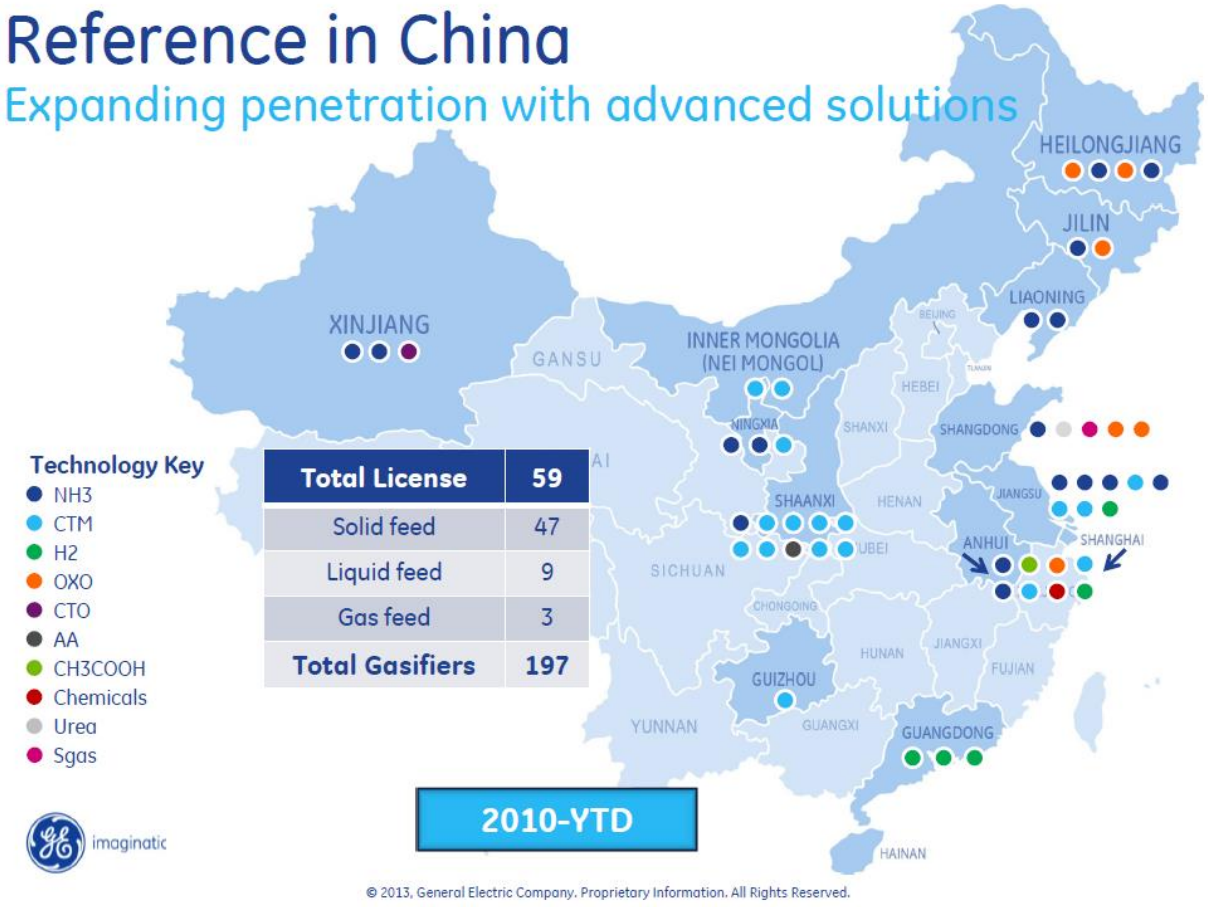
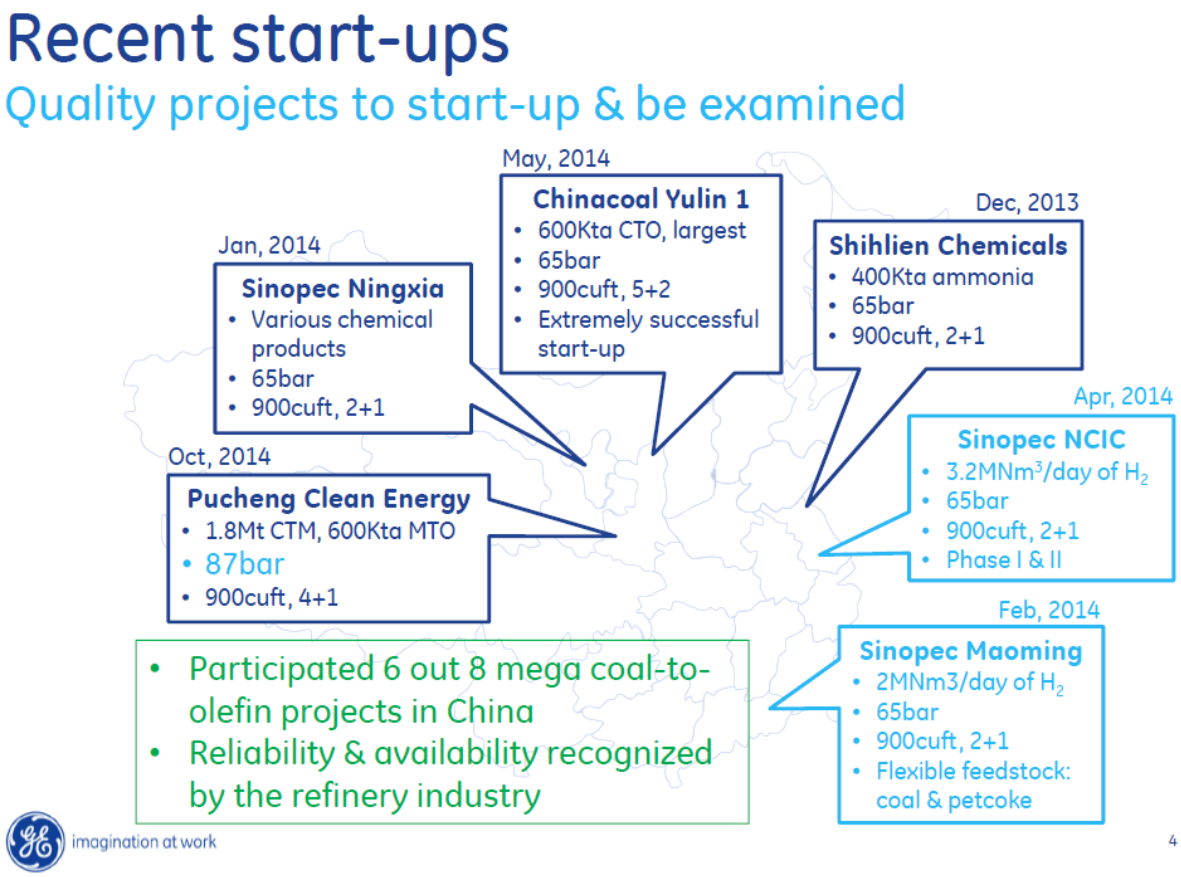
GE Gasifier Locations as of Late 2014



Return to T of C

Recent GE Chinese Installations



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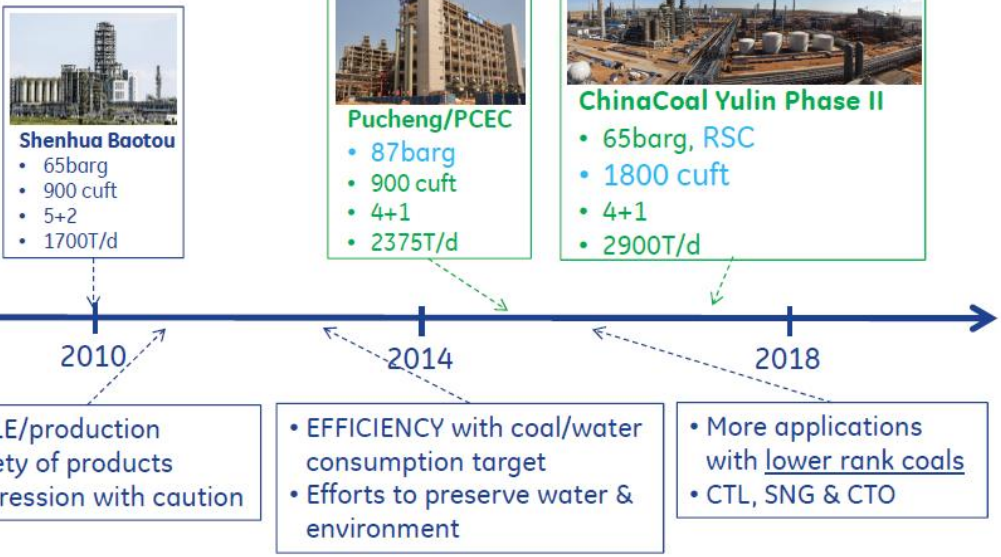
Yulin with 2018 Start Up of Four Gasifiers

Path to excellence

Tuning as progressing



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Return to T of C

Other Industries

Nalco TRASAR reduces ZLD cost at mini mill

- To minimize operating costs at this mini mill, progressively more brackish waters needed to be utilized while avoiding the operational problems — mineral scale and corrosion — associated with use of the lower quality water.
- Replacement of the membranes was avoided through the use of 3D TRASAR because the plant could utilize lower-quality water without treatment. Cost savings: $1.2 million. • The cost of operation of the pretreatment system was eliminated. • General corrosion rates were reduced from 30 - 40 mils per year (mpy) to 3 - 8 mpy • 3D TRASAR delivers a wealth of operational data through an array of on-board sensors. This data can be used to track improvements, troubleshoot problems and identify areas for improvement. • The ability to send alarms to operators through a variety of electronic means ensures upsets are identified early and addressed with prompt corrective action

ZLD at aluminum plant in China

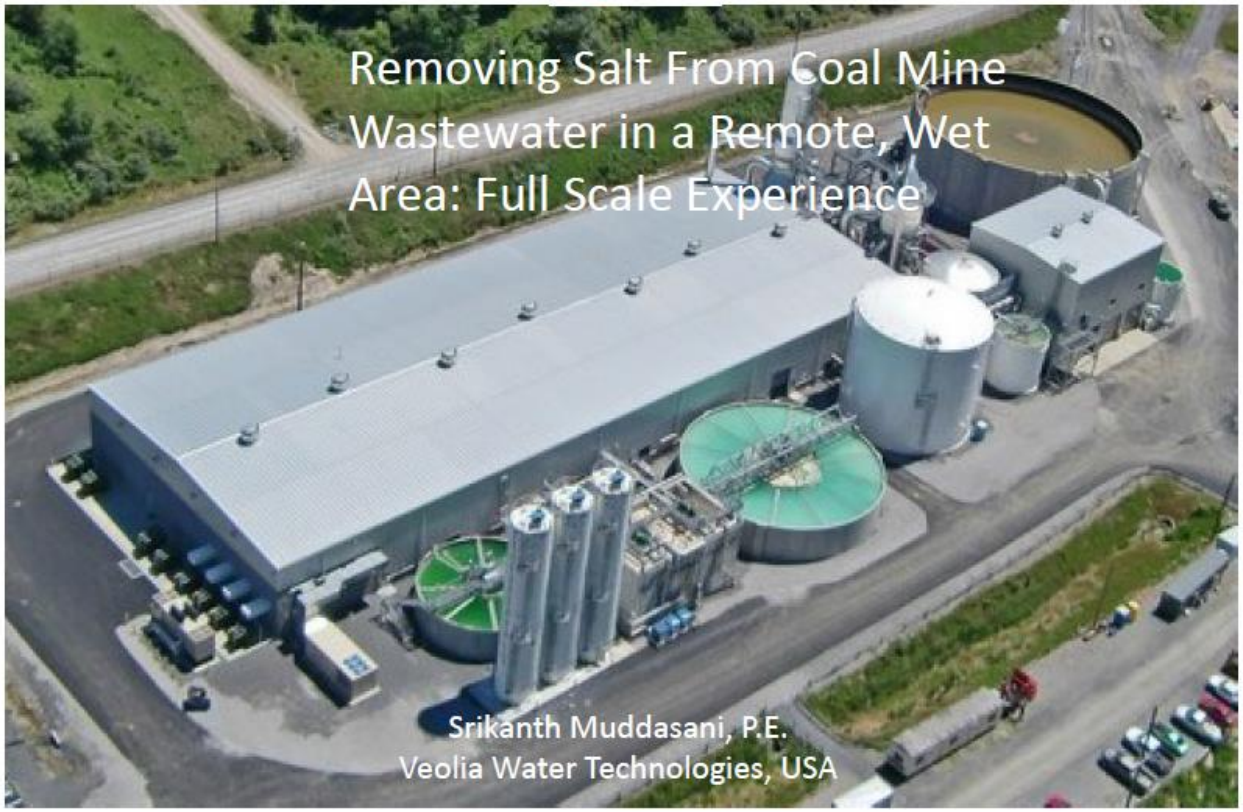
- Desalitech announced recently that it was awarded a contract by Novelis, the world leader in rolled aluminum products, to supply a high efficiency ultrapure water treatment system for a production facility in Changzhou, China to help comply with a local ordinance requiring zero-liquid discharge (ZLD) for applicable process wastewaters. The Desalitech ReFlex reverse osmosis system will reduce wastewater generation by over 70% compared to what a traditional reverse osmosis system would generate, minimizing brine flow to and the cost of the downstream evaporator.
- As freshwater resources across the globe are depleted, industries are being forced to evaluate and manage their water resources accordingly. China has set a high bar for water sustainability, regulating that new industrial facilities cannot discharge wastewater and must maintain ZLD operation. The Changzhou plant, is Novelis' first aluminum automotive sheet manufacturing facility in China, is meeting this requirement with its new ZLD wastewater treatment installation.
- The Novelis facility provides customers in China and abroad with high-quality automotive sheet for use in lightweight structures and body panels. Water is utilized in multiple processes throughout the manufacturing plant, producing wastewater streams that are collected and treated with biological, chemical and membrane filtration followed by reverse osmosis. The 2-pass ReFlex reverse osmosis system is designed to operate at 90% recovery on the first pass and 95% recovery on the second pass, sending the permeate to an ultrapure process water and to cooling towers.

Doosan-Water Treatment Plant , Florida

- Contract Year: 2013
- Start-Up Year: 2014
- Owner: City of Palm Coast
- Engineer: McKim and Creed
- Client : Wharton-Smith, Inc. - Construction Group

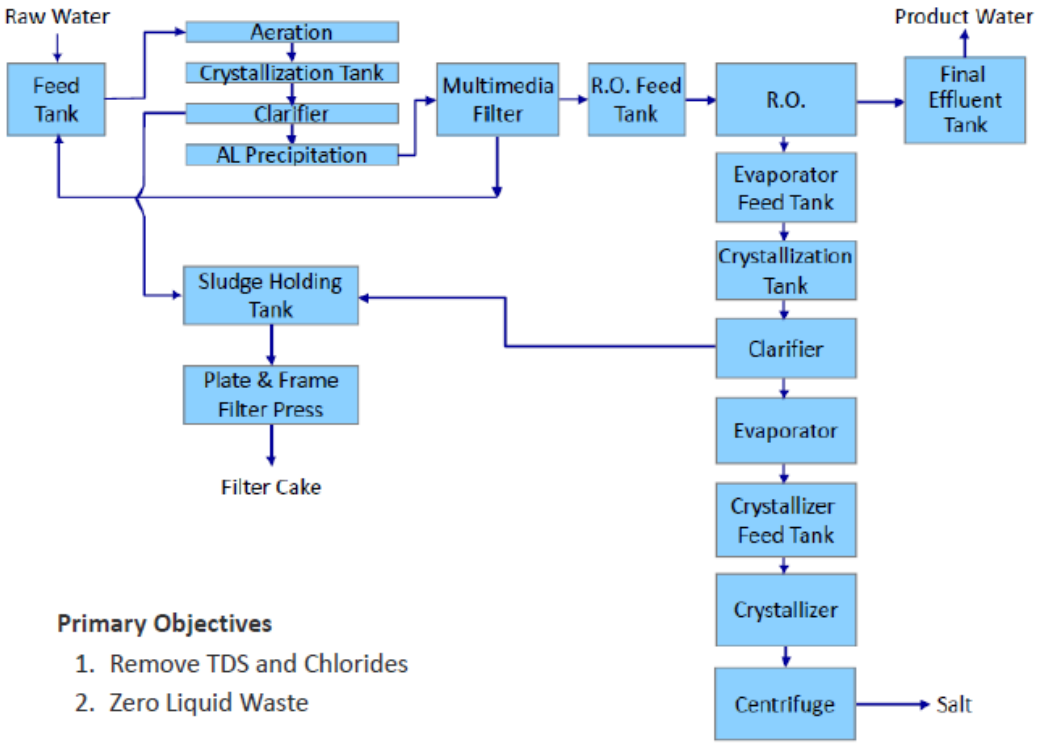
- Scope: Engineering design, manufacture, supply and delivery of one full scale Zero Liquid Discharge (ZLD) plant for treatment and reuse of preexisting RO concentrate. • Equipment includes lime clarifiers, lime and soda ash silos, UF trains, valves, and instruments.
- Provide field services for:
- • Installation Supervision,
- • Testing, Start-up and commissioning services, and
- • Training Operational Data: Water Source: RO concentrate waste from the City’s existing Nanofiltration facility
- Capacity: 1.80 mgd

Coal mine wastewater-Veolia



Veolia –mine wastewater

Process Overview



Primary Objectives

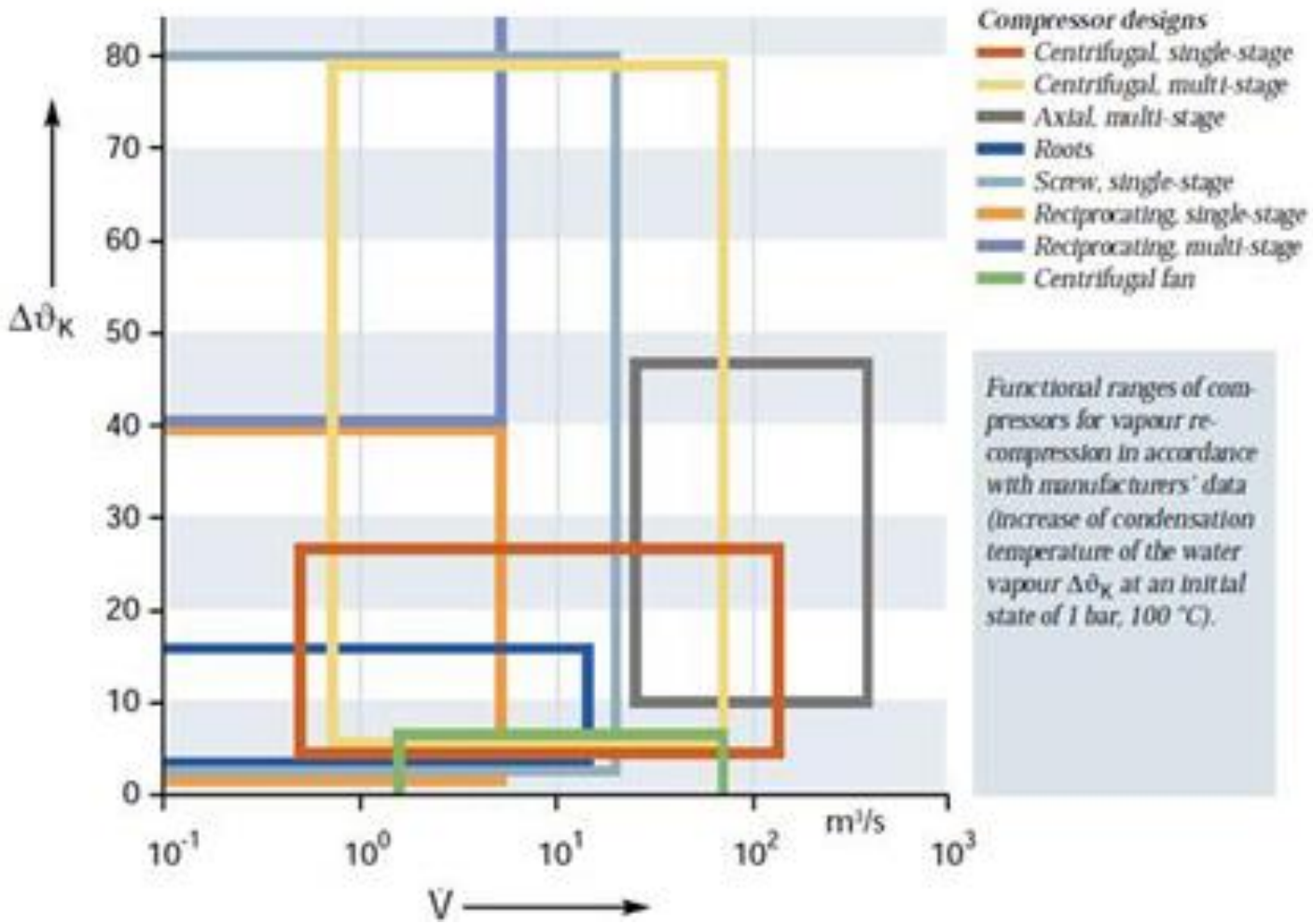
1. Remove TDS and Chlorides
2. Zero Liquid Waste

Components

Compressor selection for MVR

- When vapor compression is used for crystallizers, special consideration must be taken for compressor selection. One of the most critical parameters for specifying the compressor is accurate prediction of the boiling point rise of the brine. This is easy to determine for pure salt mixtures from literature data. However, for mixed salts it is not as easy to determine. Computer programs have been developed to predict boiling point rises and often testing can be done in the laboratory with either the actual solution or a synthetic solution.
- Another phenomenon that must be accounted for is short circuiting loss or slip. This is a result of vapor bubbles that are not released at the vapor/liquid interface and get trapped in the recirculating liquid. This can add a few degrees to the overall temperature difference that the compressor must overcome. Additionally, the proper fouled heat transfer coefficient must be used when determining the compressor requirements so that the system can meet capacity under fouled conditions. Typically vapor compressors for mixed salt applications have high compression ratios.
- For smaller systems, rotary positive displacement blowers can be used. These are rugged machines that can tolerate occasional foaming.
- For higher flow rates, a single stage centrifugal compressor is used. These machines have higher tip speeds in order to achieve the required compression ratios. Protection from carryover of mist or foam is very important for these systems. Typically two stages of mist elimination and a foam detection system are required to protect the compressor.

Compressor options vary



ExVel^{TM} Turbo Fans – MVC for Mcilvaine

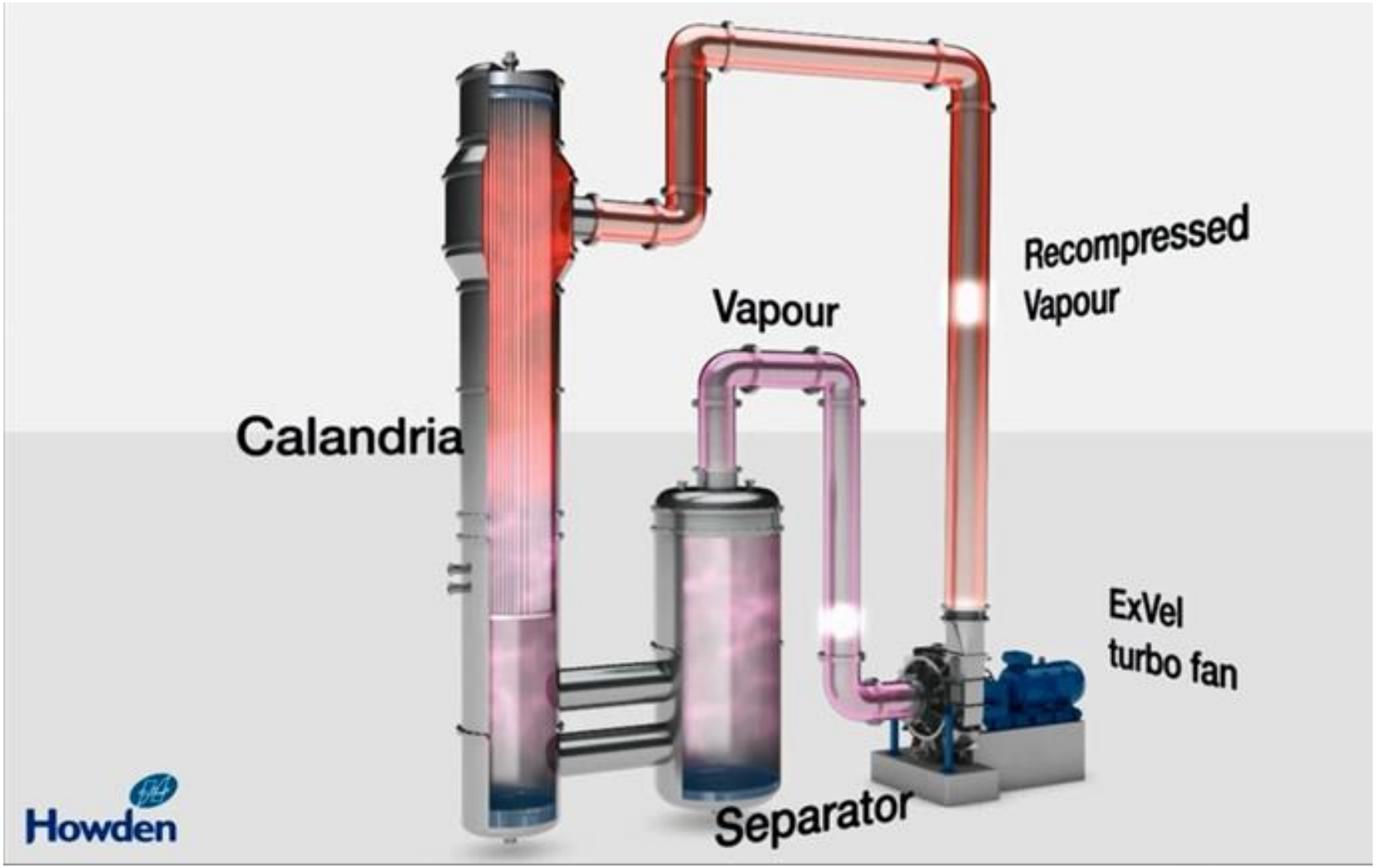
Howden Roots

J. Stoklosa, Feb. 24, 2016

ExVel™ Turbo Fans

- Howden Roots

Howden is the Leading Applications Engineer for Vapor Compressors



ExVel™ Turbo Fans

•Howden Roots

Howden Roots

Provides a complete line of Vapor Compressor products.

Roots™ P-D Blowers

- to 50 kacfm, 16psig
- Rotary lobe machine
- Cast & machined impeller & casing
- 60% peak eff.

ExVel™ Turbo Fans

- to 400 kacfm, 12degC delta-T
- Centrifugal machine
- Fabricated impeller & casing
- No gear typical.
- 80% peak eff.

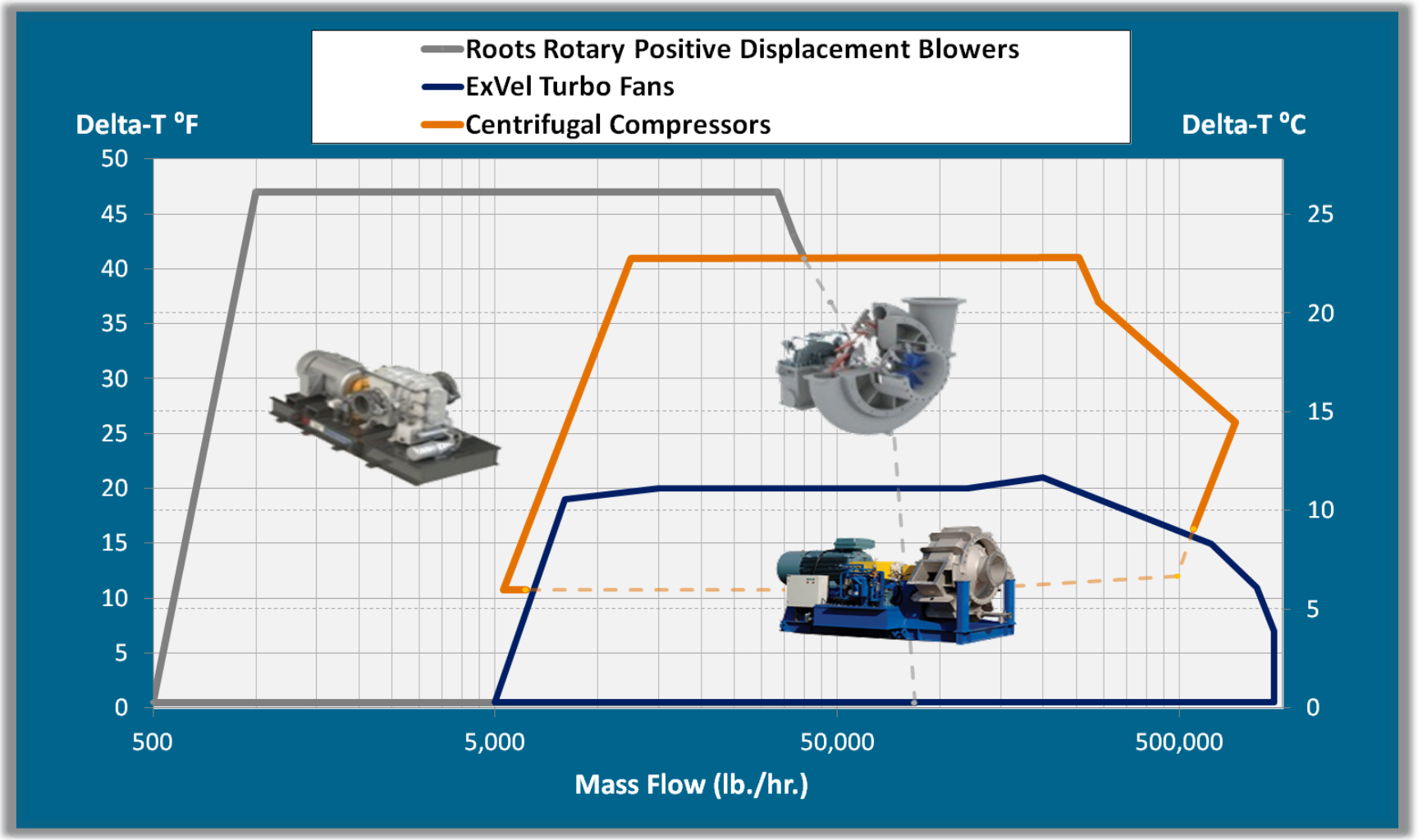
Centrifugal Compressors

- to 400 kacfm, 23 degC delta-T
- Centrifugal machine
- Cast / Milled impeller & casing
- Integrally geared
- 85% peak eff.

ExVel™ Turbo Fans

•Howden Roots

Howden Roots MVC Product Map



ExVel™ Turbo Fans

•Howden Roots

Howden Has Extensive MVC Experience in Many Industries

Thousands of units installed throughout the world.

Both Evaporators and Crystallizers.

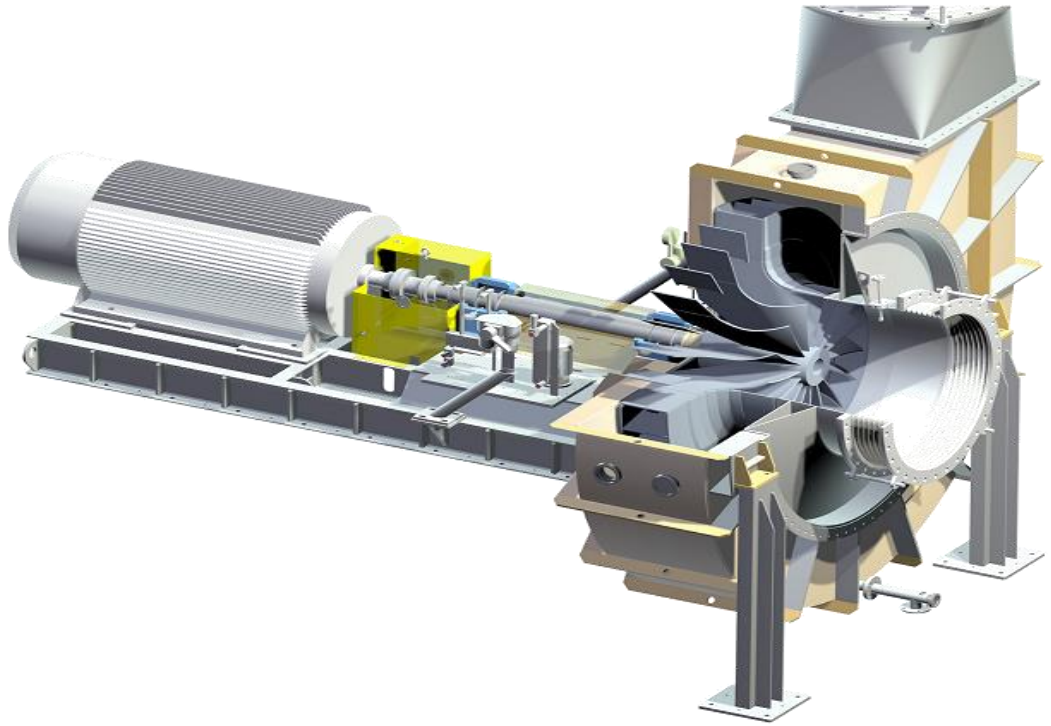
- ✓Agri-Food
- ✓Chemical
- ✓Dairy
- ✓Desalination
- ✓Distillation
- ✓Ethanol
- ✓Metals
- ✓Oil & Gas
- ✓Petrochemical
- ✓Pharmaceutical
- ✓Pulp & Paper
- ✓Waste Water
- ✓Utility

ExVel™ Turbo Fans

•Howden Roots

Howden ExVel™ Turbo Fans are ideal for MVC

- **Custom engineered and fabricated for each project.**
- **Extensive MVC application and installation experience.**
- **Proven history of durability and reliability in MVC applications**.



Howden ExVel™ Turbo Fan Value Propositions for MVC

- **Lower rotating speed**
  - Less sensitivity to fouling, condensation, erosion
  - Lower stress in rotating components
- **Fabricated from high-strength, ductile alloys**
  - High durability and tolerance for process upsets / fouling.
  - Low potential for catastrophic impeller failure due to upsets.
- **Lower CapEx**
- **Excellent total cost of ownership**
  - Good turndown range and control options.
  - Very good operational efficiency.
  - Lower spare parts cost and PM costs.
- **Howden Brand and commitment**
  - World's leading application engineer providing high quality turbo fan solutions.
  - Global resources to support our customers.

ExVel™ Turbo Fans

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Electric Utility Combined Cycle MVC ZLD, Arizona (model HAXrG-80/1902)

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Electric Utility Coal Fired FGD MVC ZLD, Italy (2-stage model 2xHBXr-40/1373)

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Electric Utility IGCC MVC ZLD (2 stage model 2xKEXr-80/1462)

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Pharmaceutical / Sanitary MVC units (model HBXrK-25/871)

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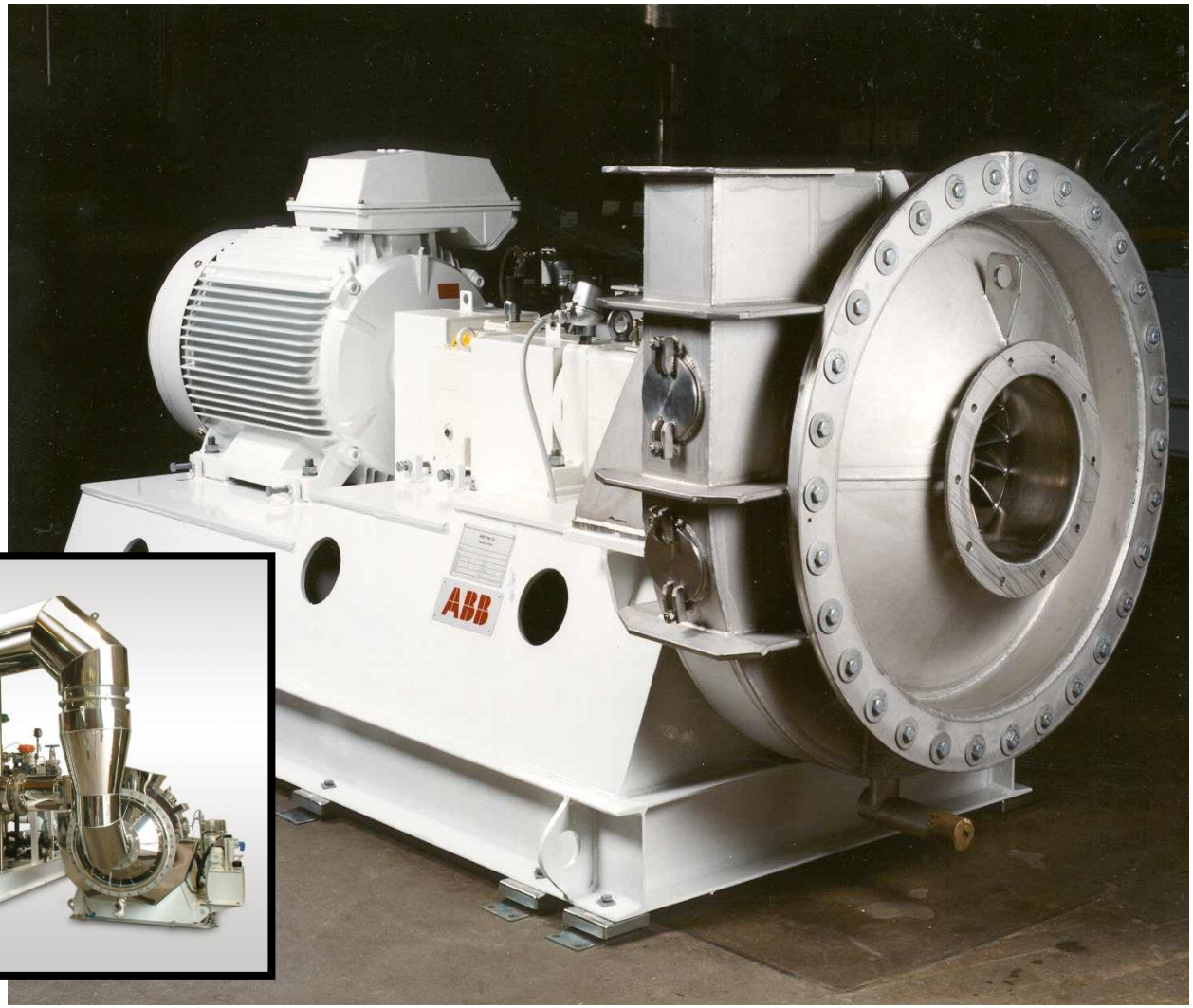

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Pulp & Paper Black Liquor MVC, Australia (model HAXrG-106/2536)

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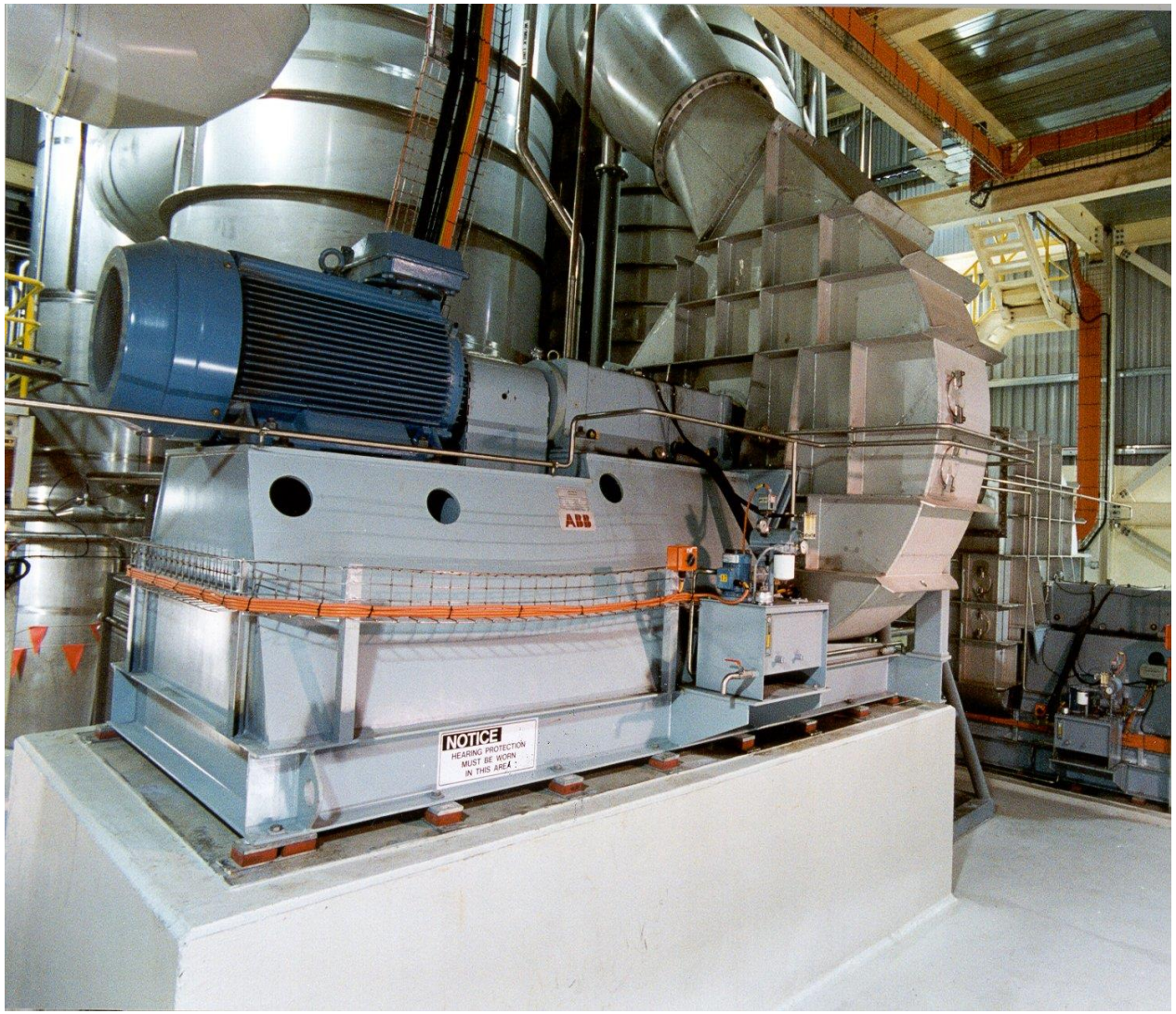
Dairy Products MVC, Australia (2-stage model 2xKEXrK-90/1730)



Andritz lamella evaporator

- The RecoVap evaporator uses proven lamella-type heating surfaces in a Mechanical Vapor Recompression (MVR) connection to minimize energy usage. Inherently non-foaming, the lamella evaporator is ideally suited for the low dry solids applications of MVR evaporation with capacities from 10 to 200 t/h in a single unit.

- MVR* evaporators operate on a “heat pump” principle. The evaporated water vapor is recompressed with a simple, low speed centrifugal fan or compressor. The fan increases the saturation temperature of the vapor. After the fan, vapor can be used as heating steam in the same unit. The recompressed vapor condenses and releases its latent heat through the heat transfer surface for further evaporation of the effluent.

Doosan ZLD

- Doosan designed a ZLD process based on High Pressure Reverse Osmosis (HPRO) and thermal evaporation technology. HPRO technology pushes water through an RO membrane at higher than normal pressure. This removes most of the salts producing a concentrated effluent which is then crystallized. Thermal evaporation technology then separates and concentrates the solids, ions and other polluted substances from the feed waste water using high temperature/pressure vapor. The evaporator is composed of a vertical tube falling film (VTFF) evaporator, a forced circulation (FC) evaporator, and a dryer/centrifuge.
- Depending on the water quality and treatment level requirements steam compression (MVR, TVR) can be combined with a variety of treatment processes to achieve the desired effluent quality
- Applications: Power plant wastewater treatment (FGD) • Oil & gas field wastewater treatment (SAGD, CSG) • Refinery wastewater treatment • Textile, dying, chemical wastewater treatment • Other industrial wastewater sectors

Degremont

- The ZLD System removes dissolved solids from the wastewater and returns distilled water to the process (source). Reverse osmosis (membrane filtration) may be used to concentrate a portion of the waste stream and return the clean permeate to the process. In this case, a much smaller volume (the reject) will require evaporation, thus enhancing performance and reducing power consumption. In many cases, falling film evaporation is used to further concentrate the brine prior to crystallization.

- Falling film evaporation is an energy efficient method of evaporation, typically to concentrate the water up to the initial crystallization point. The resultant brine then enters a forced-circulation crystallizer where the water concentrates beyond the solubility of the contaminants and crystals are formed. The crystal-laden brine is dewatered in a filter press or centrifuge and the filtrate or centrate (also called “mother liquor”) is returned to the crystallizer. The collected condensate from the membranes, falling film evaporator and forced-circulation crystallizer is returned to the process eliminating the discharge of liquids. If any organics are present, condensate polishing may be required for final cleanup prior to reuse.

Filters

- Filter presses can provide high levels of dry solids and reduce the evaporation requirements.
- Bag filters, cartridges, and cross flow membrane systems are critical to most ZLD approaches.
- Astenjohnson is a major supplier of filter cloths.

Chemicals

- Activated Carbon such as supplied by Albemarle can prevent selenium from reaching the wastewater but the effect has not been thoroughly quantified.
- Activated carbon in the recirculating slurry can capture mercury and then be separated from the wastewater.
- Chemicals such as powdered lime supplied by Enerchem can result in dry capture of contaminants when injected in the furnace.