Energy & Environmental Research Center (EERC)

FE0031810
Wastewater Recycling Using a Hygroscopic Cooling System

Christopher Martin

2021 Integrated Project Review Meeting – Water Management

May 17, 2021

Project Team

Technical Team and Contacts:

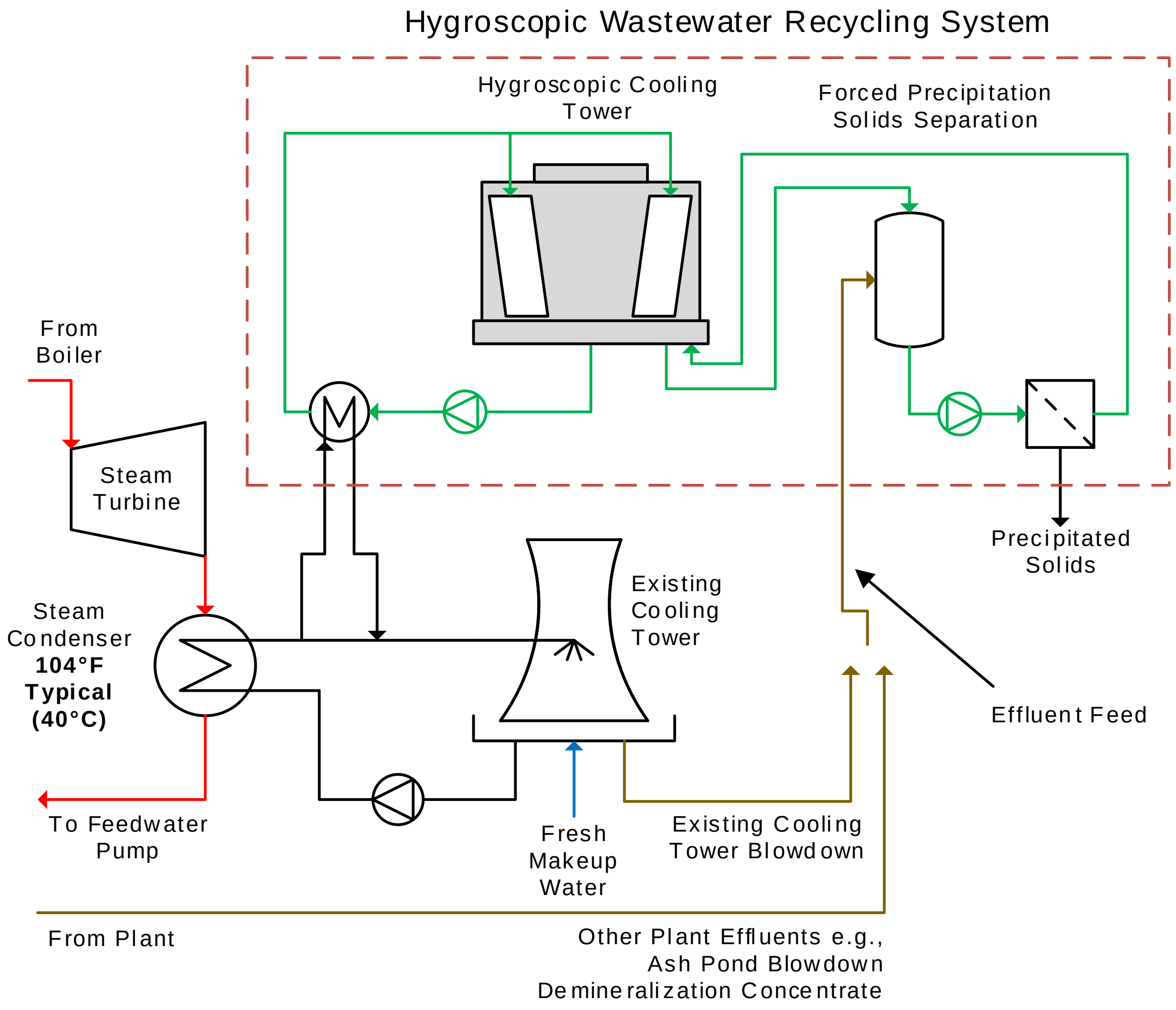
- **Energy & Environmental Research Center**
  Christopher Martin, Ph.D.
- **Baltimore Aircoil Company**
  Yohann Rousselet, Ph.D.
- **Great River Energy**
  Patrick Schwartz, P.E.

Project Sponsors:

- **Department of Energy, National Energy Technology Laboratory**
  Barbara Carney, Program Manager
- **North Dakota Industrial Commission Lignite Energy Council**
  Michael Holmes, Vice President of R&D

Overview

- **Objective:** Test the feasibility of using the EERC's hygroscopic cooling technology to provide zero liquid discharge (ZLD) treatment of power plant effluent.
- **Goals:** significantly improve the cost effectiveness of ZLD treatment while improving the water use efficiency of existing coal power plants. Techno-economic targets compared to conventional thermomechanical ZLD:
  - 75% reduction in operating costs.
  - 50% reduction in capital costs.
- **Challenges:** sustainable, non-fouling operation; and cost-effective ZLD throughput within the limits of the heat source temperature and ambient conditions.



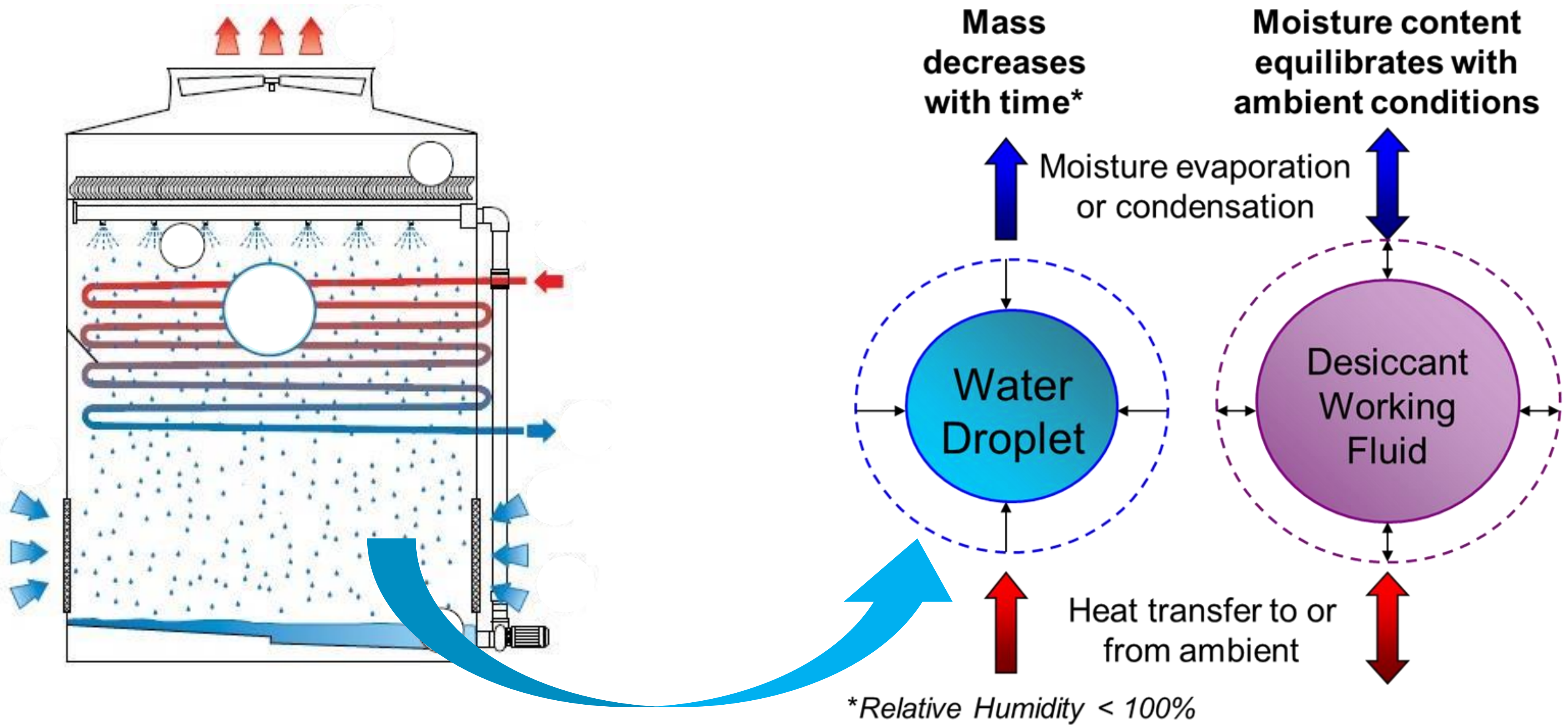
Qualitative ZLD Comparison

	Disposal-Only ZLD	Hygroscopic Wastewater Recycling	Thermomechanical ZLD
Example Systems	Evaporation ponds, injection wells	This project	Mechanical vapor compressor/evaporator; thermal brine crystallizer
Water Recovery	No	Indirectly by displacing makeup cooling water	Yes, typically high quality
Input Energy	Low, limited to pumping energy	Primary energy input is waste heat from the plant’s condenser cooling circuit; some electricity needed for tower pump and fan	High-quality thermal or mechanical energy to drive phase change
Environmental Dependence	Effectiveness is almost entirely determined by ambient conditions	Impacted by ambient conditions relative to the steam condenser temperature	Largely independent of ambient conditions

Program Alignment

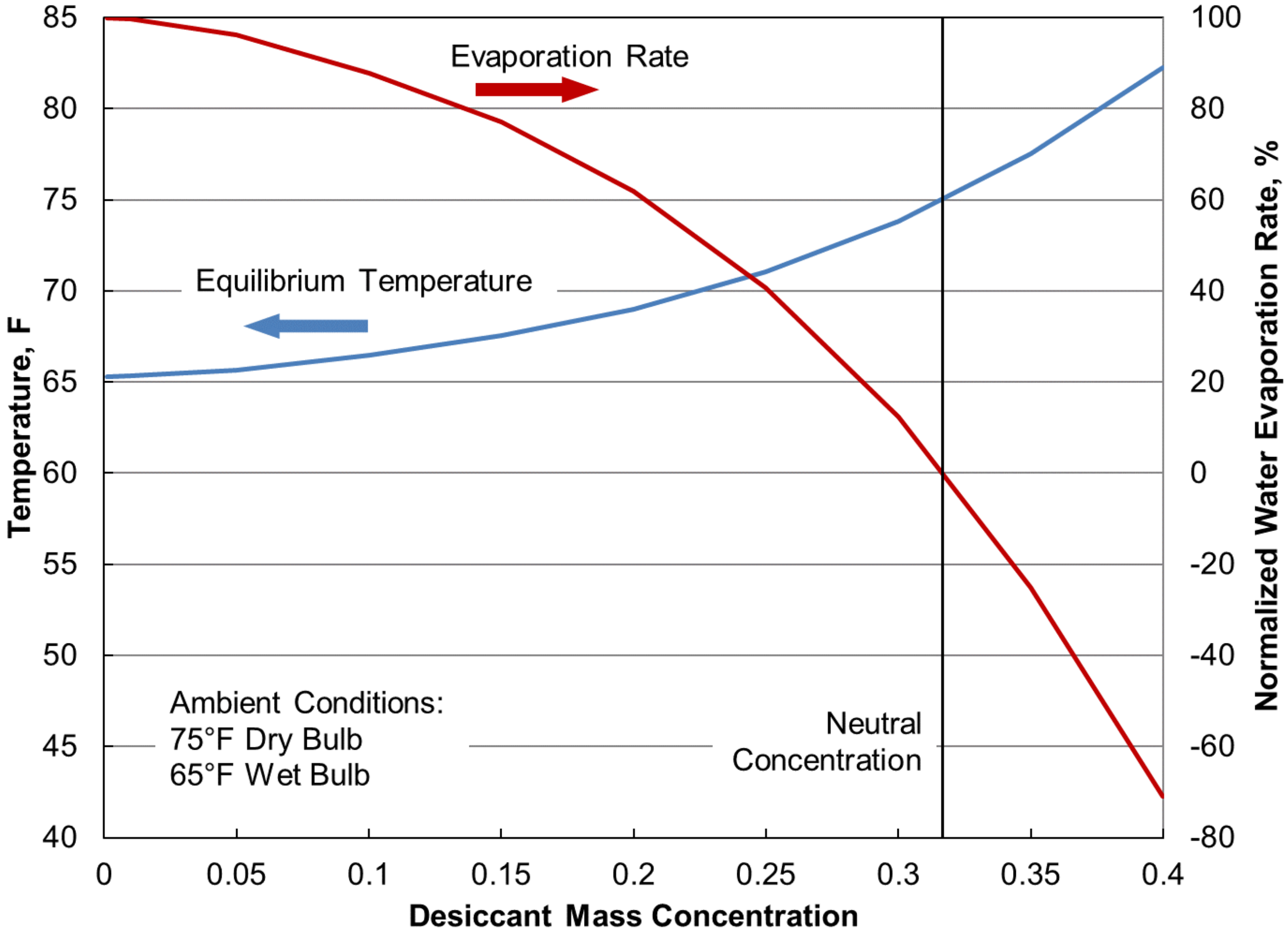
Improve Water Use Efficiency and Reduce Water Quality Impacts	• ***"Research is desired that lowers the overall water usage and/or impact on water quality from power plants through advances in cooling technology."*** This concept addresses both concerns since it recycles plant wastewater to provide productive cooling for the power plant while eliminating the need for effluent discharge.
Near-Term	• ***"Emphasis is placed on near-term solutions that have the potential to assist existing coal-fired power plants to operate in a more water efficient way."*** The hygroscopic concept does not involve the complete replacement or reengineering of an existing plant's cooling system and can be added to augment the existing cooling system and/or address effluent treatment needs.
Economically Viable	• ***"New methods will need to be economically viable in the near term."*** Since the technology will be an add-on system, it can be added to a plant in proportion to the need and/or optimized to generate the most favorable payback for a given site's conditions.
Complementary to Existing Fleet	• ***"Technologies are requested that can enhance the flexibility, efficiency, and maintainability of existing recirculating cooling towers."*** Hygroscopic wastewater recycling supports this objective since it works with existing cooling towers to improve the plant's overall water-use efficiency.

Hygroscopic Cooling

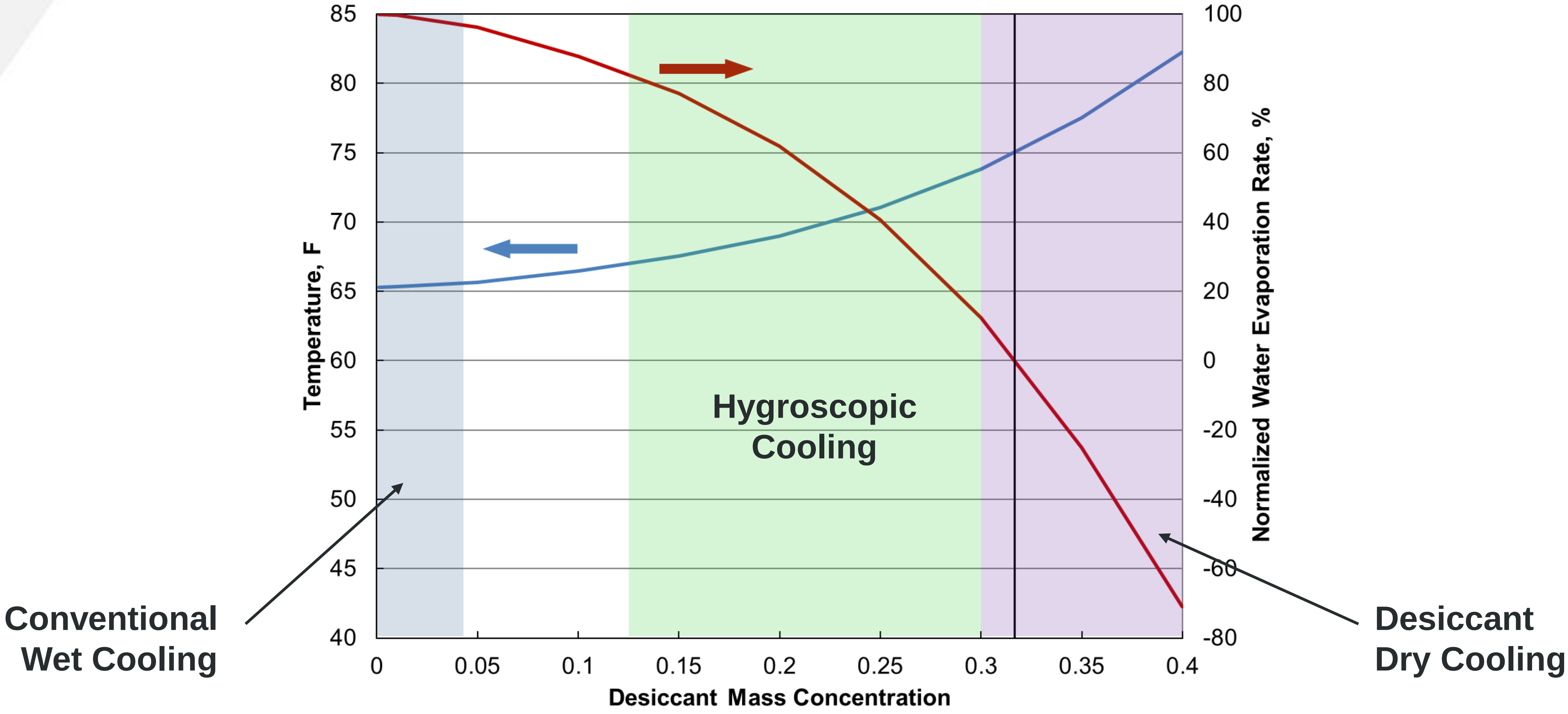


With hygroscopic cooling, pure water is replaced with a desiccant solution to control the sensible-to-latent heat transfer ratio.

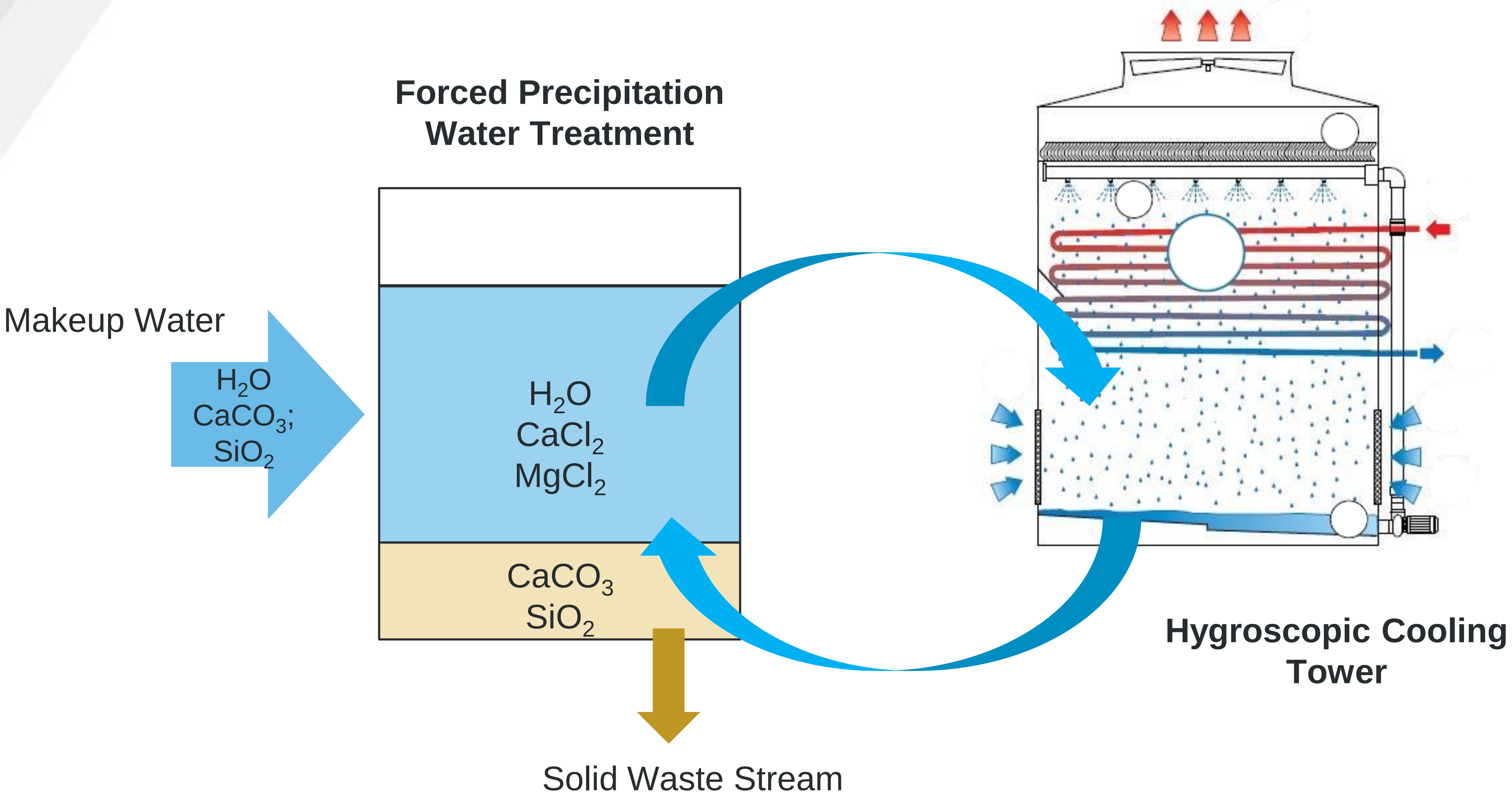
Increased Sensible Heat Transfer



Hygroscopic Cooling Regime

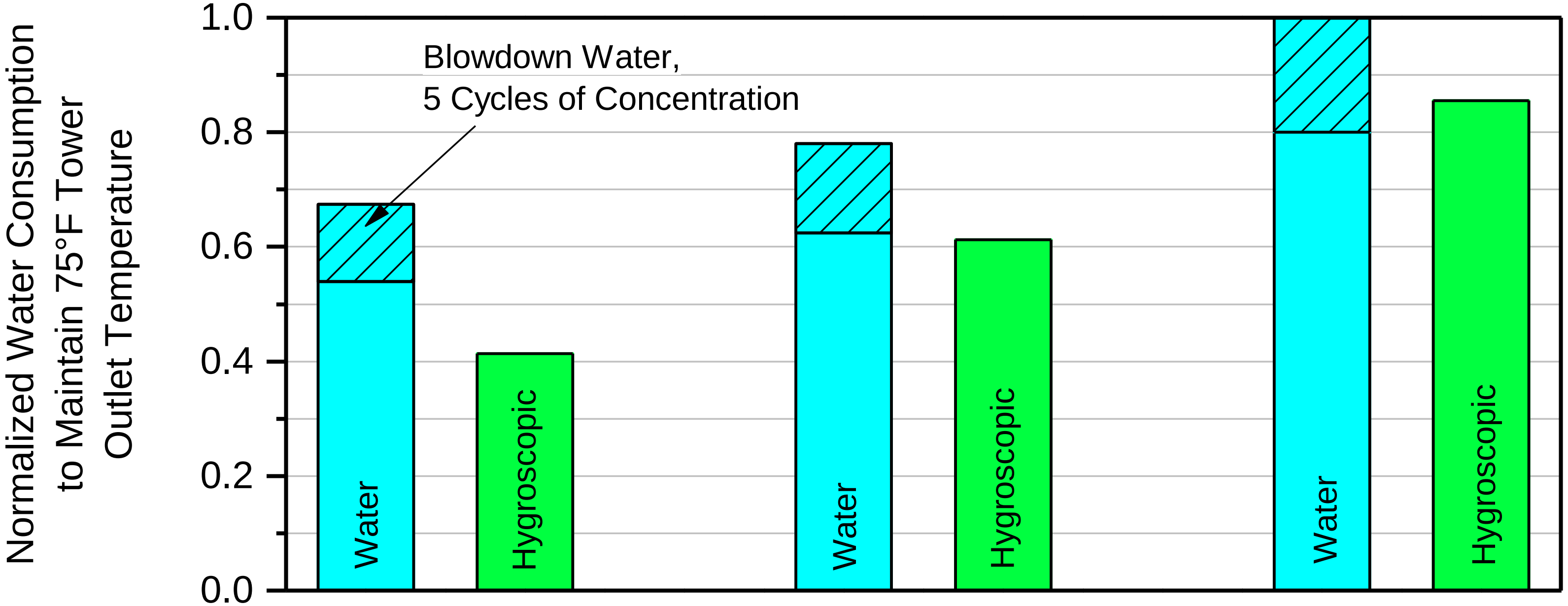


Dissolved Solids Control



Dissolved solids control is based on the decrease in solubility of common dissolved minerals when mixed with the concentrated desiccant solution. By removing minerals using forced precipitation, the blowdown stream is eliminated, and all input water is used for evaporative cooling.

Cooling Water Consumption Trends



Conditions	Cool	Neutral	Hot
Dry Bulb Temp.	60°F	75°F	90°F
Wet Bulb Temp.	54°F	63°F	67°F
Relative Humidity	70%	50%	30%

Trends show that hygroscopic cooling saves water by eliminating blowdown under all conditions, and when outdoor temperatures are cool enough, by also increasing the proportion of dry, sensible heat transfer.

Application to Wastewater Recycling

Field testing of a hygroscopic cooling tower in 2019.

Similarities Between Cooling and ZLD:

- Low-temperature evaporation of concentrated brine.
- Direct air contact process.
- Based on a supersaturated working fluid.

Key Differences:

- Dissolved solids content of effluent, ~100 times higher.
- Dissolved solids include high-solubility species in addition to the sparingly-soluble species typical of potable water.
- Potentially hazardous constituents.

Project Structure

Task Breakdown

- Task 1.0: Project Management and Planning
- Task 2.0: Evaluation of Wastewater-Working Fluid Interactions
- Task 3.0: Small Pilot Cooling System Design and Fabrication
- Task 4.0: Wastewater Testing
- Task 5.0: Techno-Economic Analysis

Coal Creek Station (Mike McCleary, Bismarck Tribune)

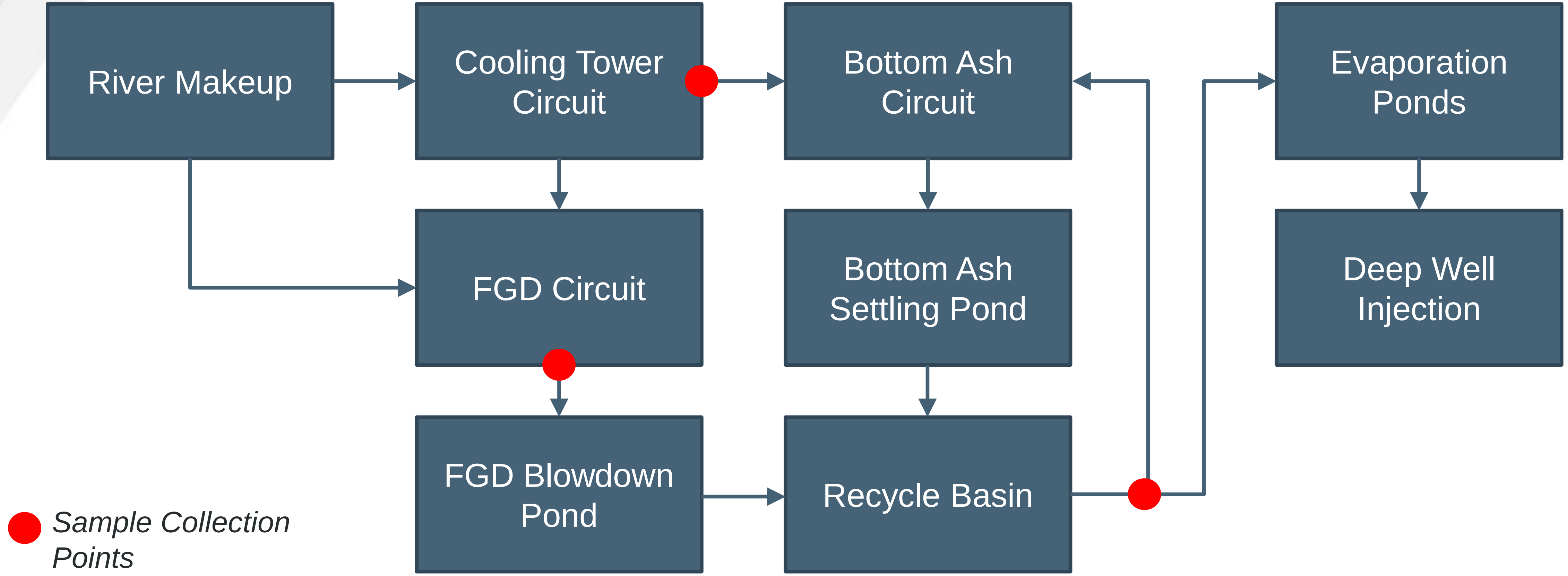
Field Test Site

Coal Creek Highlights

- Two, 550 MW units; owned and operated by Great River Energy.
- Lignite fuel from the adjacent Falkirk mine; beneficiated using DryFining™
- Evaluating the addition of CO_2 capture.
- Makeup water from Missouri River.
- Current ZLD site; water management consists of evaporation ponds and deep well injection.
- Existing condenser loop access ports.

Coal Creek Station (GRE)

Simplified Coal Creek Station Water Flow



Wastewater Analysis

- Samples were analyzed for major species and elements regulated under the Resource Conservation and Recovery Act (RCRA).
- Prevailing anion in these streams is sulfate with cations of Na^{+} and Mg^{2+}.
- RCRA element analysis (next slide) suggests that steady-state, precipitated solids would classify as nonhazardous waste.

	Cooling Tower Blowdown	FGD Blowdown	Recycle Basin
pH	7.29	5.33	7.79
Alkalinity, as HCO_3	75	26.5	239
Alkalinity, as $CaCO_3$	61.5	21.7	196
Ca, as Ca	712	391	734
Mg, as Mg	313	8030	1190
Sr, as Sr	6.43	1.02	13.6
Na, as Na	898	4280	1680
K, as K	59.6	492	176
Li, as Li	0.9	3.4	1.3
Si, as SiO_2	92.0	102.7	55.6
Cl, as Cl	227	1240	440
F, as F	5.8	150	6.5
Br, as Br	< 1	420	130
Sulfate, as SO_4	4200	34,900	8800
Nitrate, as NO_3	< 5	< 5	< 5
Nitrite, as NO_2	< 5	< 5	9.8
P, as PO_4	< 6.1	16	< 6.1
B, as BO_3	12	278	81
Total Organic Carbon	42.2	63.6	26.9
Total Dissolved Solids	6920	57,600	14,800

Concentration values in mg/L.

RCRA Element Analysis

Measured Concentration, mg/L

RCRA Metals	Cooling Tower Blowdown	FGD Blowdown	Ash Pond Recycle
As	0.0346	0.0285	0.108
Ba	0.5	0.17	0.31
Cd	< 0.01	< 0.01	< 0.01
Cr	< 0.05	< 0.05	< 0.05
Pb	< 0.005	< 0.005	< 0.005
Hg	< 0.0001	0.00473	< 0.0001
Se	0.014	0.45	0.017
Ag	< 0.05	< 0.05	< 0.05

Calculated* Maximum Leachate Concentration of Residual Solids, mg/L (20:1 dilution)

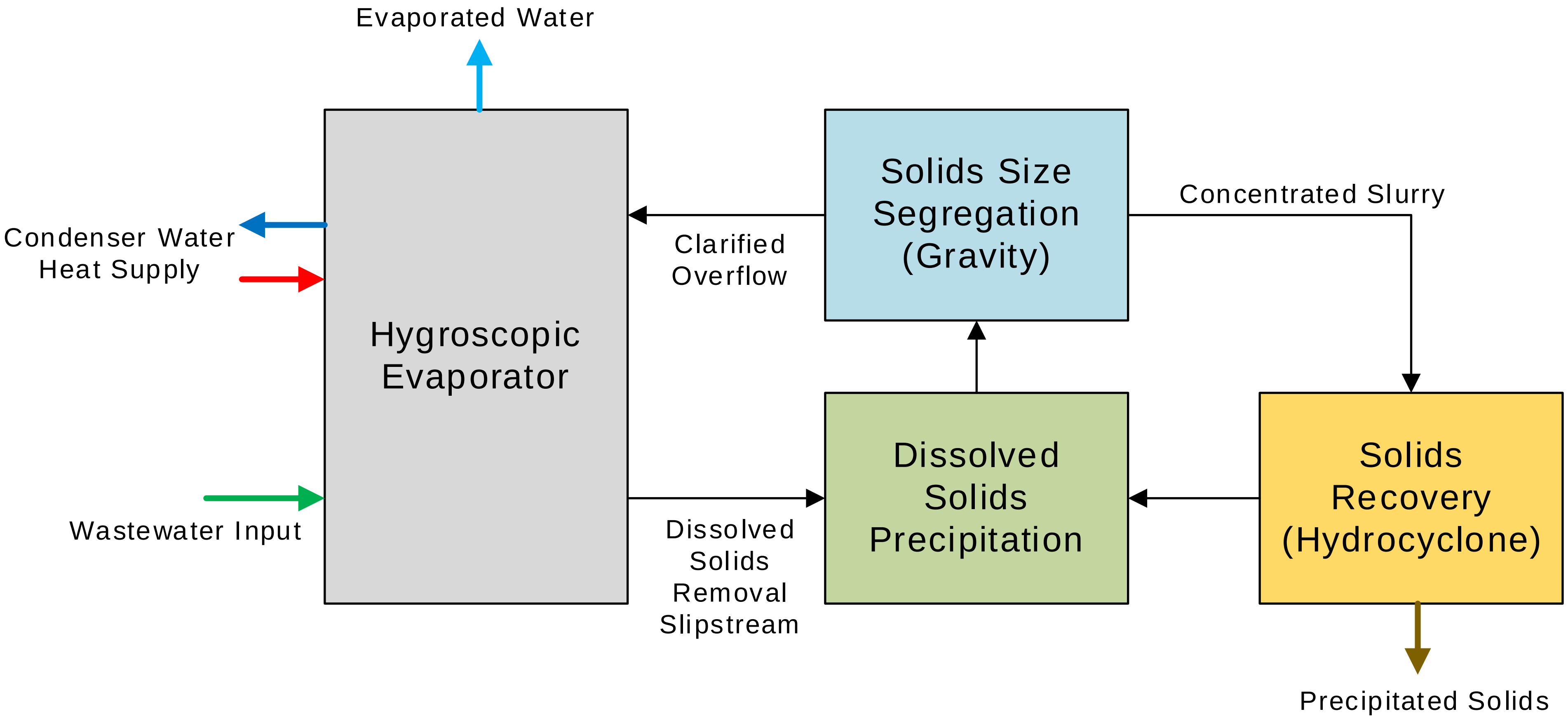
RCRA Metals	Cooling Tower Blowdown	FGD Blowdown	Ash Pond Recycle	EPA Regulatory Limit
As	0.250	0.0247	0.365	5
Ba	3.61	0.148	1.05	100
Cd	0.0723	0.00868	0.0338	1
Cr	0.361	0.0434	0.169	5
Pb	0.0361	0.00434	0.0169	5
Hg	0.000723	0.00411	0.000338	0.2
Se	0.101	0.391	0.0574	1
Ag	0.361	0.0434	0.169	5

* Less than values used in the leachate concentration calculation.

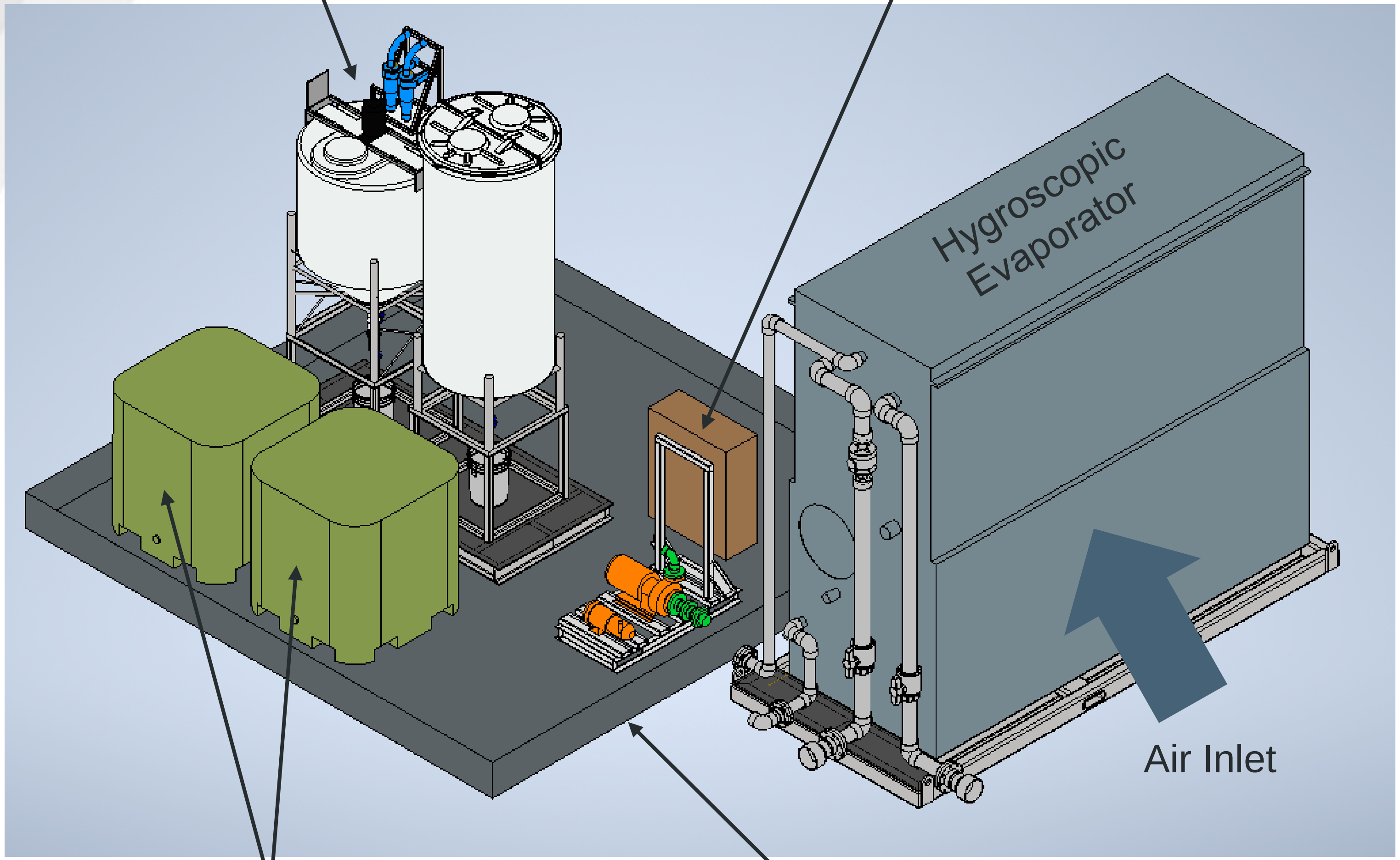
Project Status

- **Task 1.0: Project Management and Planning**—Ongoing
- **Task 2.0: Evaluation of Wastewater-Working Fluid Interactions**—Completed
  - Wastewater survey at the host site power plant.
  - Collected mixture-specific saturation and precipitate data.
  - Evaluated solids separation from concentrated working fluid.
- **Task 3.0: Small Pilot Cooling System Design and Fabrication**—Nearing completion
  - Designed small pilot system using findings from Task 2.0.
  - BAC evaluated needs and provided a cooling tower.
  - Remaining fabrication and integration activities are nearing completion.
- **Task 4.0: Wastewater Testing**—Just starting
  - Identified test location at Coal Creek Station.
  - Facility preparation work underway.
  - Field test and safety plans under development.
- **Task 5.0: Techno-Economic Analysis**—Update with field data

Small Pilot Process Diagram



Equipment Design and Fabrication

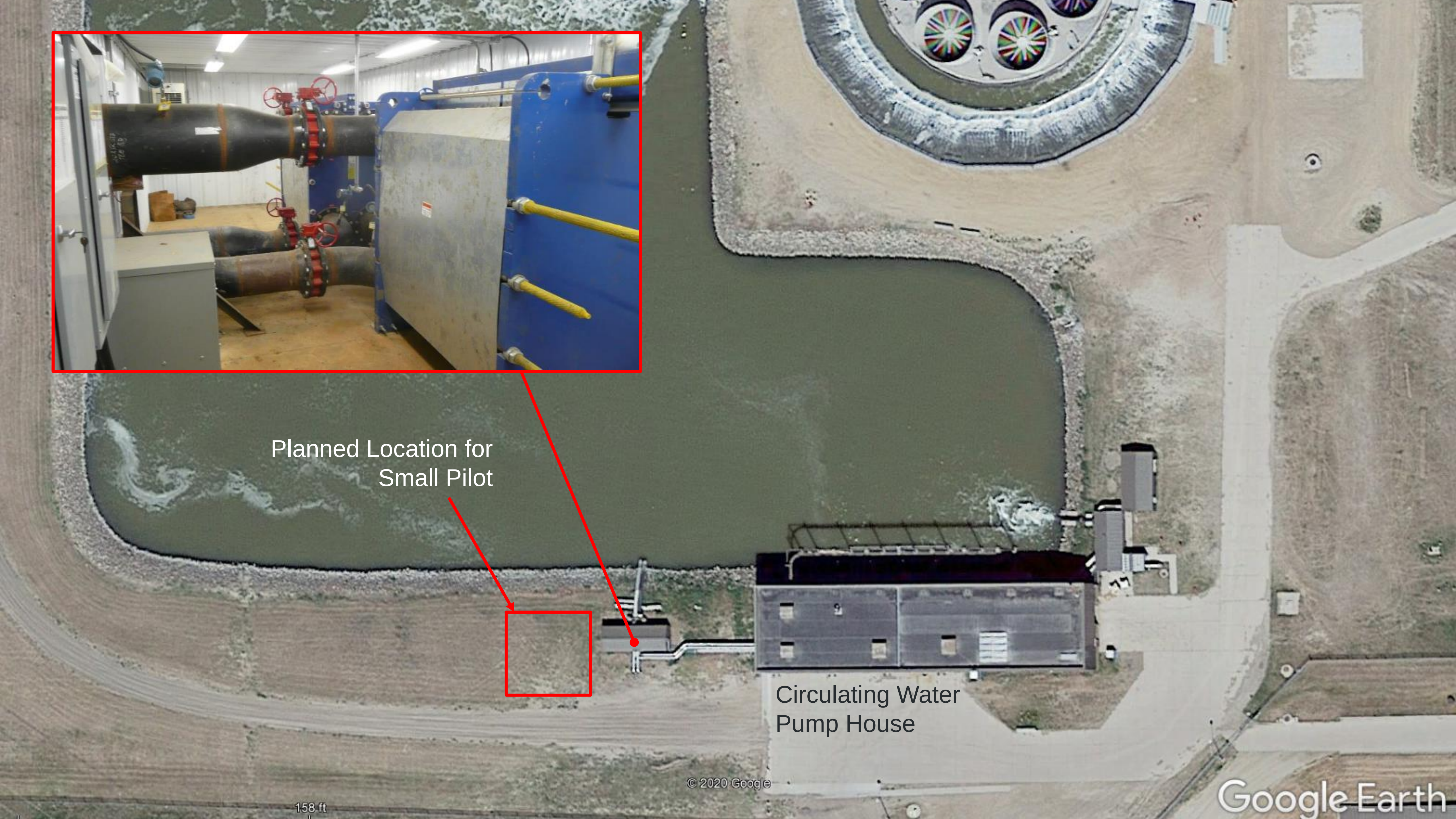


Hygroscopic cooling tower modifications underway at the EERC.

Task 4.0: Wastewater Testing

Planned Activities:

- Temporarily install the small pilot system at Coal Creek Station and perform technology readiness level (TRL) 5 testing using plant effluent and condenser waste heat.
- Current schedule for Coal Creek activities:
  - Prepare site: April 2021
  - Station Outage: 5/1/21 to 5/18/21
  - Equipment installation timeframe: 5/24/21 to 6/11/21
  - On-site testing: mid-June to mid-September
  - Equipment removal: by mid-October


Planned Location for
Small Pilot
Circulating Water
Pump House
© 2020 Google
158 ft
Google Earth

Evaluation Plan

	Performance Attributes	Performance Requirements	TRL 5 Evaluation Plan
Defined by Application	Heat source temperature	~104˚F (40˚C)	Use condenser cooling water from Coal Creek Station as the heat source.
	Effluent total dissolved solids	≥ 5000 mg/L TDS	Test with plant effluent; survey measurements show 6920 to 14,680 mg/L TDS.
Guiding Parameters	Effluent evaporation rate	≤ 50% reduction	Determine rate at maximum sustainable conditions; measure steady state fluid composition and model the annual evaporation rate.
	Solids recovery	D50 ≥ 100 μm	Collect precipitate samples for particle size analysis; evaluate dewatering of bulk samples.
	Heat exchanger fouling	≤ 0.8 $(W/m^2/K)/m^3$	Monitor the overall heat exchange coil performance, and individual fouling sensors to determine sustainable conditions.
	Materials compatibility	≤ 0.1 mil/yr	Evaluate metals by exposing weight loss coupons during Task 4.0.
Competitive Evaluation Factors	Capital cost	≤ $65,000/gpm*	Update TEA with findings: measured throughput capacity, required process steps, compatible materials, etc.
	Operating cost	≤ $8.00/kgal*	Update TEA with findings: parasitic loads, maintenance outlook, supervision, etc.

* Based on EPA’s best available technology for FGD blowdown treatment.

Wrap-Up

Wastewater recycling using a hygroscopic cooling system is believed to be a cost-effective technology to:

- Improve a power plant’s water use efficiency.
- Provide ZLD treatment for plant effluents.

Remaining Project Activities:

- Complete fabrication of small pilot system.
- Conduct wastewater testing using infrastructure and material streams at Coal Creek Station.
- Update the techno-economic assessment for hygroscopic ZLD treatment.

Technology Next Steps:

- Demonstrate the entire process including automated solids recovery.
- Evaluate effluent water chemistries for other coal types.

Acknowledgment and Disclaimer

- This material is based upon work supported by the Department of Energy Award Number DE-FE0031810.

- This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Christopher Martin, Ph.D.
Principal Engineer

Advanced Thermal Systems

cmartin@undeerc.org

701.777.5083 (office)

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

www.undeerc.org

701.777.5000 (phone)
701.777.5181 (fax)