Nanocomposite Surface Treatment for Energy Efficiency Improvement in Coal Fired Condensers

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Project Objectives

Improve the efficiency and reliability of existing coal-fired power plants through gains in condenser operation.

- Develop a widely adaptable system capable of in-place installation with minimal disruption or specialized equipment.
- Reduce maintenance requirements through prevention of biofouling.
- Improve heat transfer performance / rate of condensation.
- Decrease carbon emissions through reductions in fuel use.

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Impact of Fouling on Condenser Performance

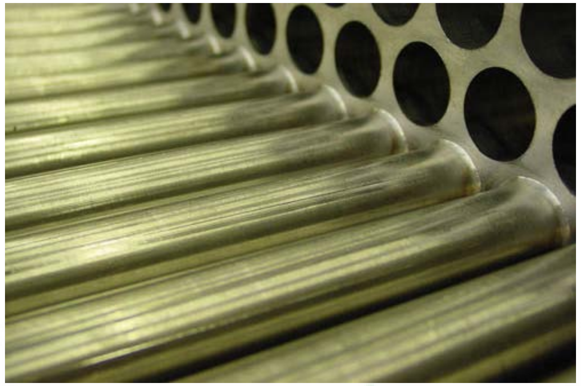
- Fouling can cause 2 – 5% efficiency loss in power plants
- 0.25% of Industrialized GDP lost due to fouling
- 2.5% of industry carbon emissions due to fouling losses
- Condensers tightly connected to overall plant efficiency

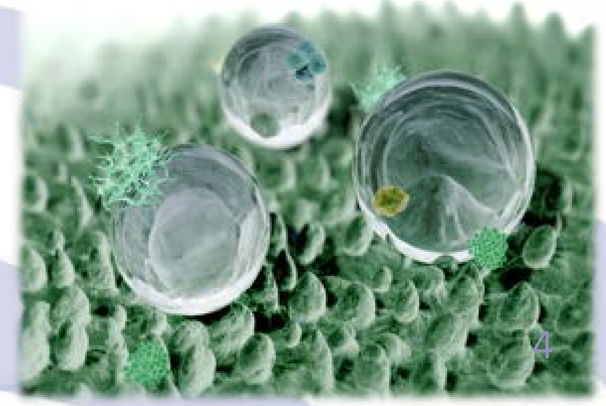
Heat Transfer Efficiency Gains =

Fuel Savings & Generation Capacity.

Technology Alternatives

Technology	Limitation
Increase Frequency of Cleaning	Increased Downtime, Increased Maintenance Costs
Chemical Treatment of Water	Environmental Regulations
Ablative/Anti-Fouling Marine Paints	Effective at Corrosion Control but Limits Heat Transfer
Retubing with Corrosion/Fouling Resistant Alloys	High Capital Expense Cost
Surface Patterning/Texturing	Operational Durability, Application on Existing Equipment





Oceanit Approach - HeatX™

- Treatment vs. Traditional Coating
- Water-Based, Nontoxic
- No VOC
- Brine & Hydrocarbon Compatible
- Long Workability, Quick Curing

Materials

Application

- Minimal Surface Preparation (NACE 4)
- Methods Variable based on Geometry (Spray, Micropigging, Dipping)
- Ambient Curing
- Fast Process, Minimized Downtime

Services

- Plate & Frame
- Shell & Tube
- Plate & Fin
- Factory & Field Application

Benefits:
- Corrosion Protection
- Fouling Resistance
- Improved Heat Transfer
- Reduced Fuel Usage

Limitations:
- Temperature Limit of 450°F
- Cleaning Solvents

Current Project Status and Key Performance Benchmarks

Property	Milestone Target	Achieved
Material Durability	Capable of lasting for multiple years under condenser conditions	Equal to or greater than epoxy in terms of durability, wear and abrasion resistance, chemical compatibility
Material Performance - Fouling	Reduction in fouling – by biologicals, corrosion, etc.	Visible disruption in biofilm formation and adhesion, increased time between required cleanings 6-fold.
Material Performance – Heat Transfer	Demonstration of heat transfer improvement through promotion of dropwise condensation in low-pressure steam conditions.	Droplets formed on treated surfaces roughly 100-fold smaller, leading to a maximum effective heat transfer coefficient 50% better in laboratory conditions.
Material Application	Application in-situ to actual condenser unit	Applied to key condenser unit in electric generation plant. Post-application, certified by NACE-qualified inspector
Efficiency Improvement	0.5% improvement in condenser performance	Up to 10% improvement in condenser performance
Economic Impact	Significant effect on plant operations as determined by commercial partner	Virtual elimination of required annual maintenance, reduction in downtime by over 30 days.

Project Updates

Project Development Flow

Laboratory Development

Necessary Benchmarks and Technical Challenges

- Coupon and Benchtop Studies
- Formulation Optimization
- Materials Performance in Simulated Conditions
- Application and Surface Preparation in Simulated Conditions

Industry Subscale Pilot Demonstration

Necessary Benchmarks and Technical Challenges

- Field Trials on Low-Risk Equipment.
- Performance in Actual Conditions
- Application and Logistics of On-Site, In-Place Techniques.
- Go/No-Go economic viability from industry partners

Full Deployment & Commercialization

Necessary Benchmarks and Technical Challenges

- Performance Guarantees for High-Risk Equipment
- De-risking through Pilot Case Studies
- In-Field Efficiency Data Collection for Long-Term Monitoring
- Long-Term Commercial Agreements with Coal Industry.

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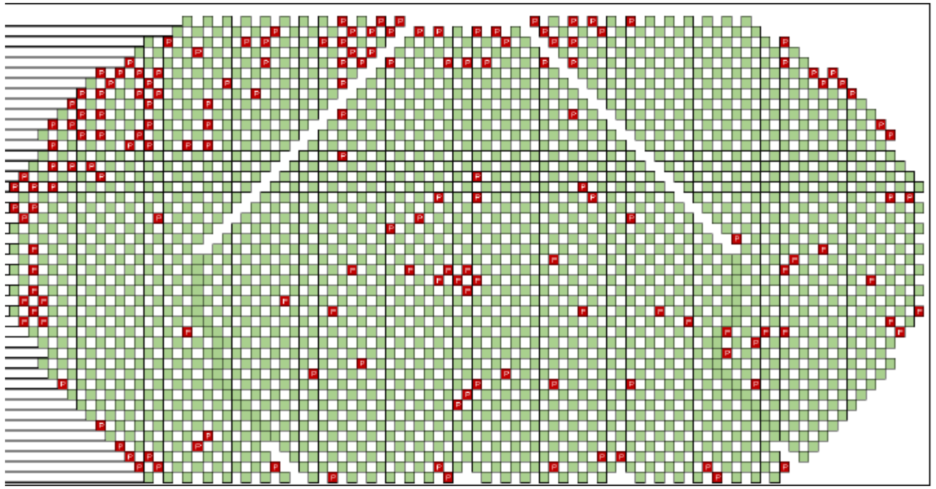
Industry Validation and Field Demonstration



Tube Blockage Prior to HeatX Application

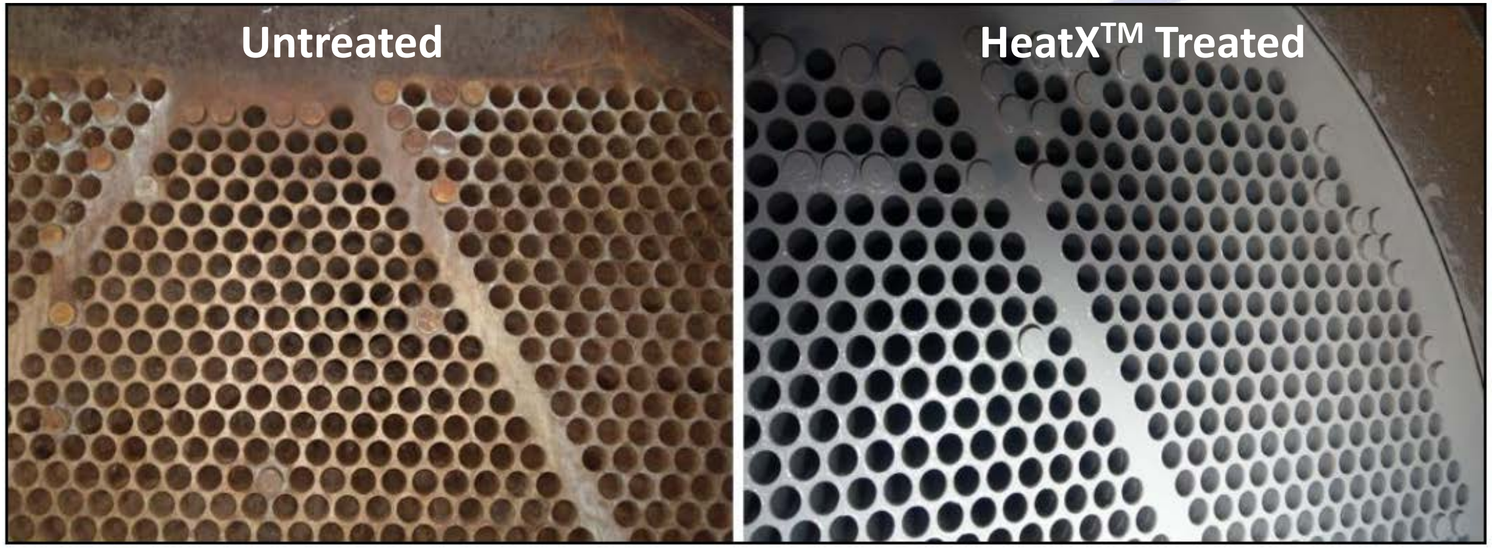
- Approximately 2.5% tubes lost per year due to blockage (about 50 tubes per year, ~10% blocked prior to HeatX application)

- Generally see consistent decline in performance due to deterioration, corrosion/fouling, requires annual inspection/maintenance for blockage.

- Zero redundancy in system, no other condensers available per equipment group.

Industry Demonstrated Operational Improvements

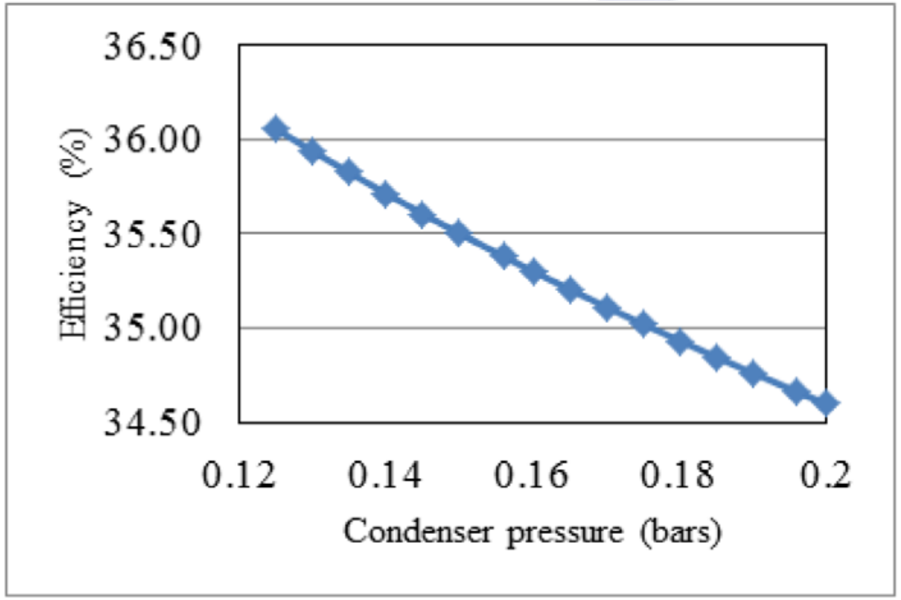
- After treatment, condenser performed at the same duty load as a fully operational control condenser, *even with 10% plugging*.
- Zero tube leaks experienced in 8 months of operation, no plugging required.

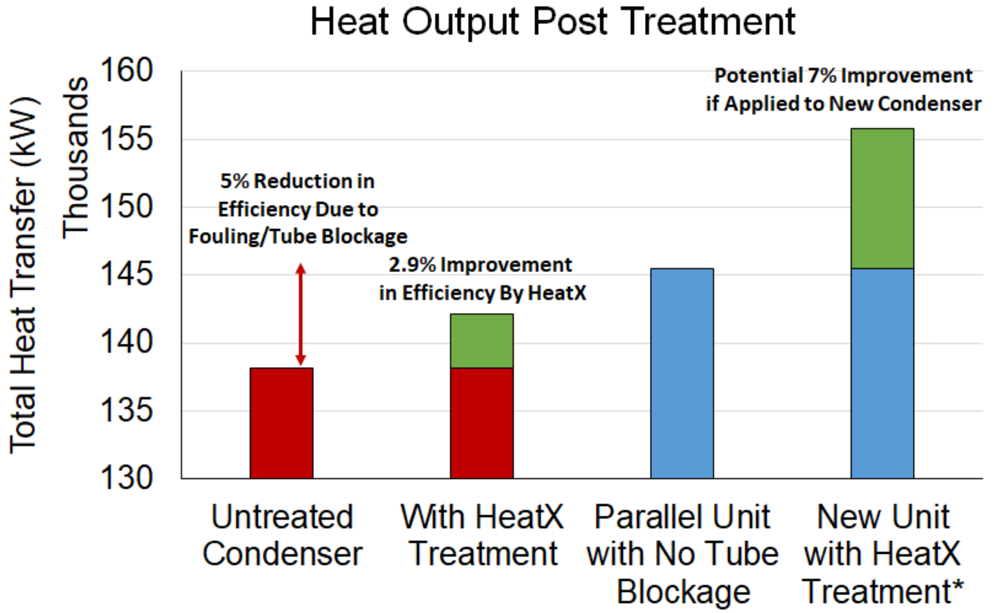


- Treatment completed in 14 days, typical retubing/cleaning would take 45 days.
- Saved an estimated $1M in yearly costs due to reduced downtime, maintenance, and improved condenser capacity.

HeatX™ Efficiency Improvements

- Better Heat Transfer
  - HeatX allowed for nearly 3% more steam to be condensed over 8 months than before treatment.
- Lowered Temperature in Condenser
  - HeatX reduced operating temperature in condenser by 10°C.
  - HeatX also reduced temperature rise of cooling water by 5°C (significantly increased capacity).
- Lowered Pressure in Condenser
  - Not directly measured, but 10°C drop would result in condenser pressure decrease of ~0.09 psi.
- Overall Improvement in Condenser Efficiency
  - 0.09 psi backpressure reduction could increase output by 7%





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Commercial Partner Targets

Large Scale Coal Plants > 2000MW Generation	Small Scale Coal Plants < 200MW
Target: 1 Deployment on Secondary System	**Target: 3-4 Deployments on Primary Systems**

Target: 1 Deployment on Secondary System

Large Scale Coal Plants
> 2000MW Generation

- Newer installations with fouling mitigation strategies in place.
- Risk averse, shutdowns/delays highly costly.
- Existing efficiency metrics and benchmarking.
- Significantly enhanced economic benefits due to capacity and plant load factor.

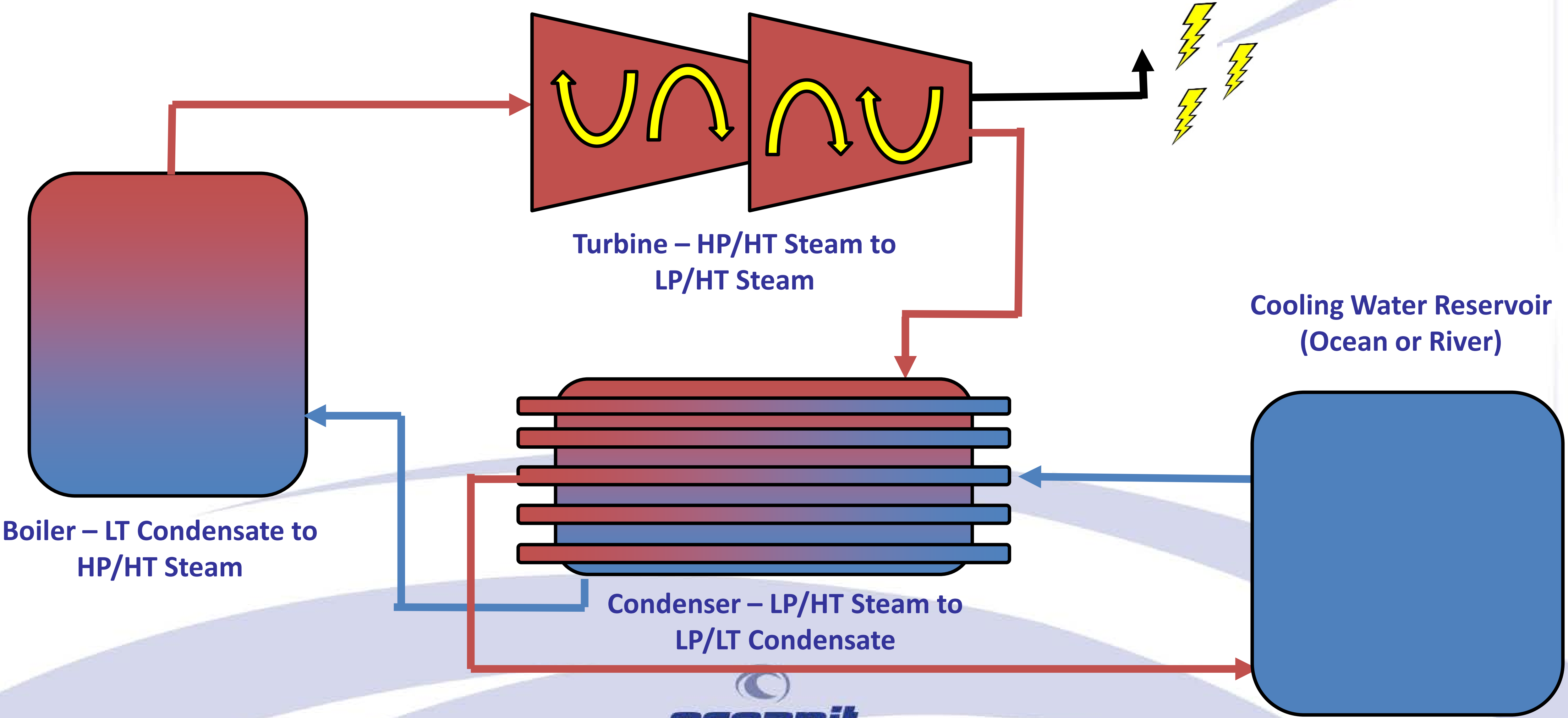
Target: 3-4 Deployments on Primary Systems

Small Scale Coal Plants
< 200MW

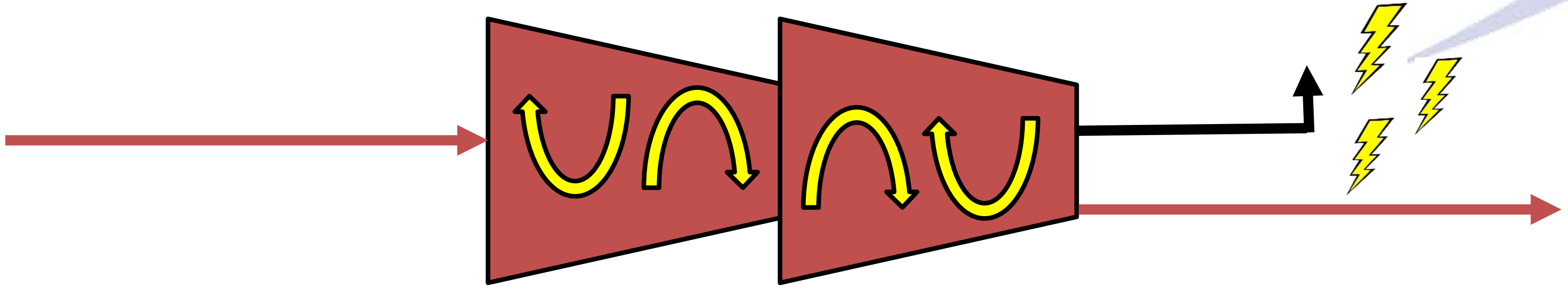
- Older plants, often with planned shutdowns/sunsetting.
- More sensitive to high initial capital costs.
- Less capacity for cleaning (more likely to run in sub-optimal condition).
- Limited ability to collect efficiency data.

Developing Efficiency Metrics for Small-Scale Partners

Steam Generation Cycle



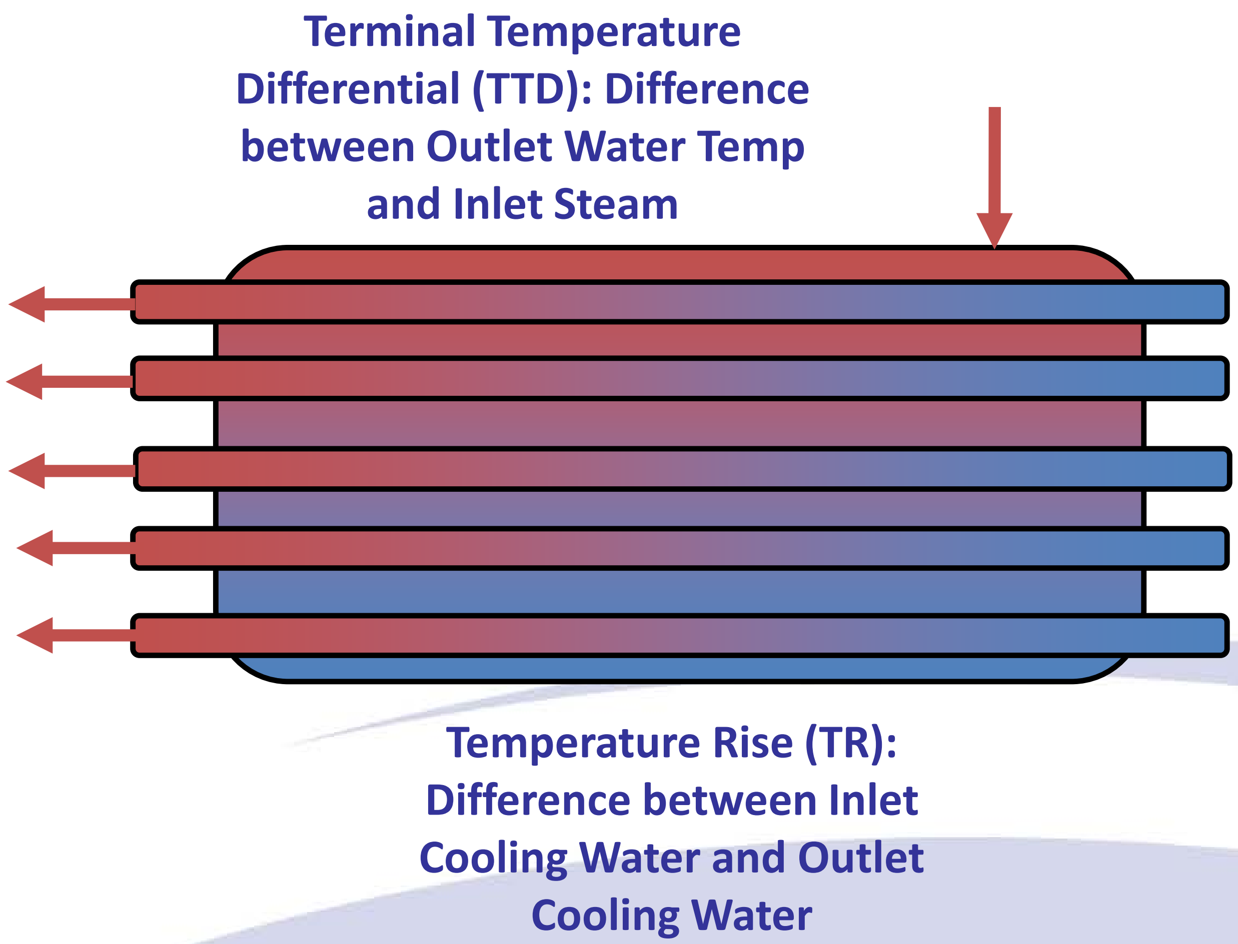
Turbine Backpressure Differential



Turbine – HP/HT Steam to LP/HT Steam

- Maximize difference between Inlet Steam and Outlet Steam.
- Change of 0.2 In Hg backpressure ~ 7% efficiency drop observed.
- Decrease backpressure by increasing the rate of condensation.

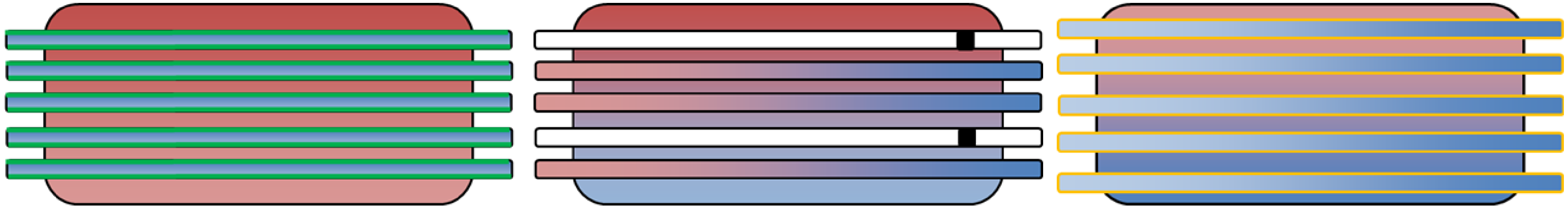
Condenser Efficiency vs. Backpressure



To minimize backpressure:

- Lower temperature within condenser.
- Temperature Rise (TR): Measures heat absorbed by cooling water.
- Terminal Temperature Differential (TTD): Measures thermal heat transfer efficiency.

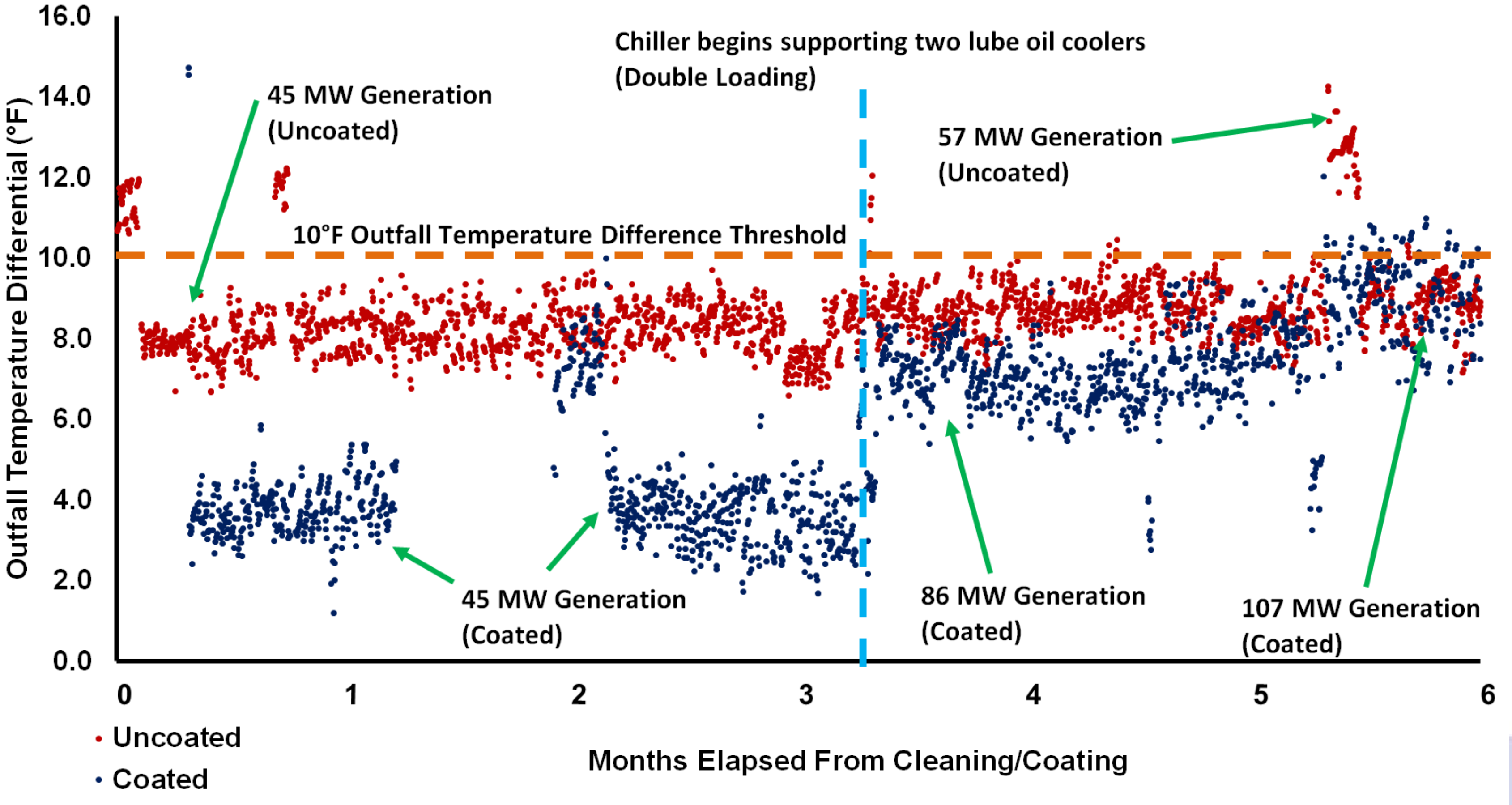
Collection of Baseline Data in Future Implementation Sites



	Tube Fouling	Tube Blockage	HeatX Enhancement
Temperature Rise (TR)	↓↓	↑	↓
Terminal Temperature Differential (TTD)	↑	↓	↓
Overall Efficiency	↓↓	↓	↑↑

- TR, TTD, Backpressure and Heat Rate all related, must monitor all aspects to properly quantify efficiency improvements.

Reduced Temperature Rise – Heat Exchanger



Outfall temperature increase from coated exchanger about half as much at same power generation

Future Implementation Site – Baseline Data

	Optimal Performing Condenser	Target Condenser (Fouled)
Capacity of Rated Performance	98.19%	85.93%
Condenser Vacuum (mm Hg)	-87.4	-85.65
Condenser Temperature (°C)	45.28	47.58
Condenser TTD (°C)	5.74	7.52
Cooling Water TR (°C)	8.95	11.08
Condensate Flow Rate (TPH)	340	296

- Combined Effect of Tube Blockage/Restriction & Fouling
- 1.75mm Hg backpressure increase results in a 3.6% heat rate penalty (increased kJ/kWh)
- Unit must be throttled back due to unacceptably high condenser temperature at full load.
- Currently cleaned every 6 months, extended shutdown every 2 years.

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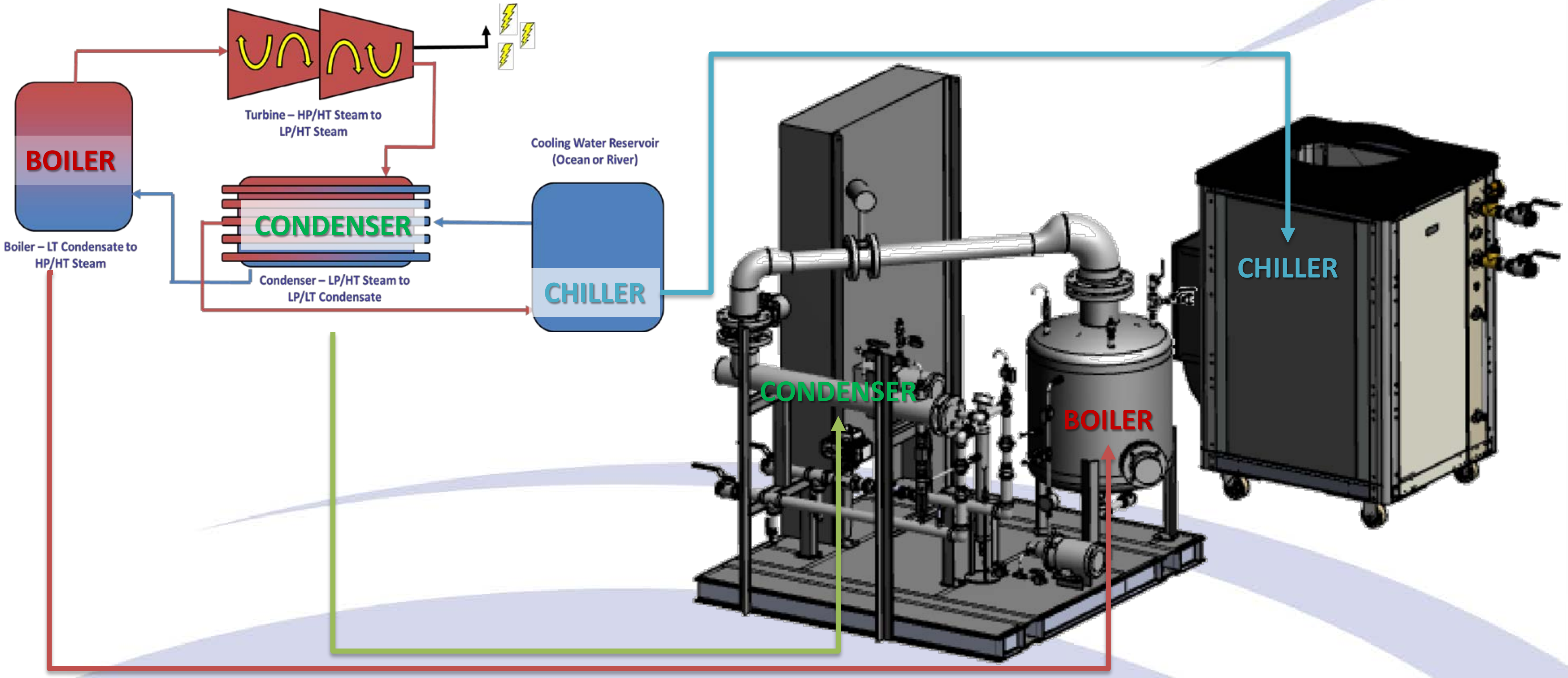
Efficiency Projections and Derisking for Large Systems

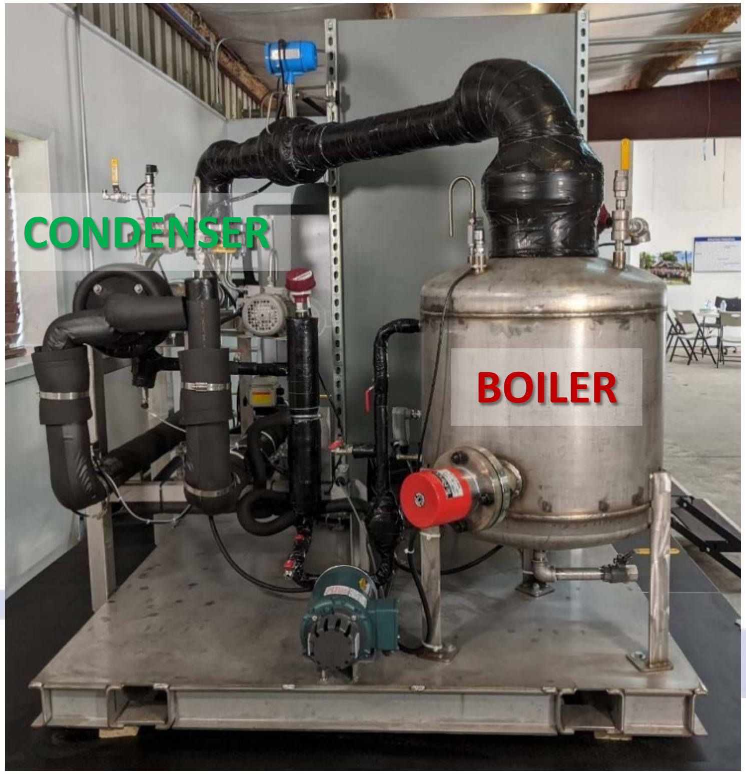
HeatX™ Subscale Performance Modeling

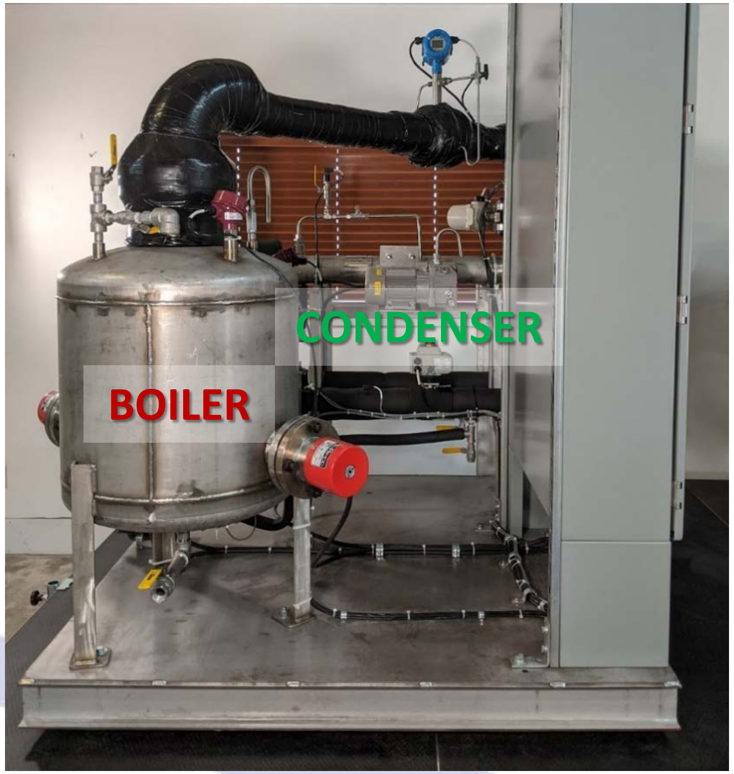


Condenser Subscale Model – Sensor and Control Elements

Sensor Element	Description	Signal	Control Element	Description
Water Heater Subsystem				
Temperature	Thermocouple at water heater heating element 1	Digital Out	Heating Coil	Digital controlled heating elements, tied to pressure in water heater
Temperature	Thermocouple at water heater heating element 2	Digital Out		
Water Temperature	Thermocouple in water heater	Digital Out		
Pressure	Pressure Transducer in headspace of water heater	Digital Out		
Water Level	Level sensor in water heater, Ultrasonic	Digital Out		
Water Level	Level switch in water heater	Display		
Steam Flow Subsystem				
Steam Flow	Flow sensor in piping connecting water heater to condenser (F Steam in)	Digital Out	Flow Control Valve	Digital Controlled, tied to pump tank level sensor
Steam Temperature	Thermocouple in piping connecting water heater to condenser (T Steam in)	Digital Out		
Condenser Unit Subsystems				
Condenser Pressure	Pressure transducer in condenser shell (P steam in)	Digital Out		
Condensate Temperature	Thermocouple in piping at condensate drain from condenser (T Condensate out)	Digital Out		
Chill Water Pressure	Pressure transducer at chill water inlet to condenser (P Chill Water in)	Digital Out		
Chill Water Pressure	Pressure transducer at chill water outlet from condenser (P Chill Water out)	Digital Out		
Chill Water Temperature	Thermocouple at chill water inlet to condenser (T Chill Water in)	Digital Out		
Chill Water Temperature	Thermocouple at chill water outlet from condenser (T Chill Water out)	Digital Out	VFD Pump Controller	Digital Controlled, tied to chill flow meter
Chill Water Flow	Flow sensor in chill water piping exiting condenser	Digital Out	Flow Control Valve	Digital Controlled, tied to chill flow meter
			Vacuum Pump	Manual Controlled
Condensate Recirculation Sub system				
Water Level	Level sensor in pump tank, Ultrasonic	Digital Out		
Condensate Flow	Flow sensor in piping connecting pump to water heater (F Condensate out)	Digital Out	VFD Pump Controller	Digital control on pump, tied to level sensor in pump tank

Condenser Subscale Model





Technical Outreach: Presentations & Publications

Completed thus far:

- 5 Technical Papers & Presentations
- 1 Hosted Technology Showcase at Offshore Technology Conference (Houston, TX)

Upcoming:

- 2021 NACE Corrosion (Salt Lake City Utah)
- SPARK webinars

SPARK DAY
Special Presentation of Advanced Research & Knowledge

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Technology To Market Plan

Market Benefits & Assessment

Key Gaps in Market Fulfilled by HeatX™

- Surface treatment is field-validated for performance and durability, ready for deployment with commercial partners.
- Material shipping logistics and qualified applicator partners established for commercial deployment.
- Economically significant savings for both generation (3-7% improvement) and operational maintenance ($1M + per year).
- Suitable for multiple MOCs, form factors, temperature conditions and fouling environments.

Coal is only the Beginning

Industry: Power Generation
Services: Sea Water, Steam
Exchangers: Plate & Frame, Shell & Tube, Condensers

Industry: Petrochemical Refining
Services: Crude Oil, Produced Water, Brine, Chemicals, Fertilizers
Exchangers: Plate & Frame, Shell & Tube, Condensers

Industry: Desalination, Water Treatment
Services: Crude Oil, Produced Water, Brine
Exchangers: Plate & Frame, Shell & Tube, Condensers

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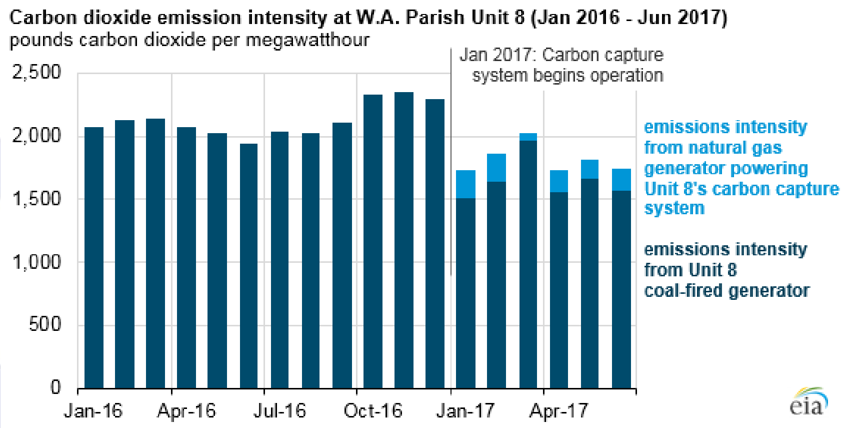
HeatX Effect on Decarbonization

- Direct effect on fuel consumption: efficiency gains allow for 3-7% reductions in fuel usage.
- Immediate deployment possible, economically advantageous for plant operators.
- Complement to standalone carbon capture technologies currently in development.



Summary & Concluding Remarks

- This project has demonstrated that field application of HeatX™ can improve condenser performance by 3-7%, and can save millions in reducing required maintenance costs.

- Allows fossil energy power generation plants to become immediately cleaner, less costly to operate, more efficient, and more competitive with other fuel sources.

- Next steps are focused on:
  - Further modeling of expected gains for new commercial partners
  - Additional field demonstrations with entire plant output data collection
  - Enhancements in application technique for vacuum-side deployment

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Questions?