Advanced Anti-Fouling Coatings to Improve Coal-Fired Condenser Efficiency

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CONTRACT NO: DE-FE0031533
Period of Performance: 1/1/2018 – 12/31/2021
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National Energy Technology Laboratory
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Wednesday, May 12th, 2021

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Project Objectives

Ease U.S. energy transition through immediately deployable, high impact technology suitable for existing power plants.
Focus on Coal due to high carbon emissions and economic pressures.

- **Develop a widely adaptable surface treatment 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.**

Impact of Fouling on Power Plant 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.

Even a 2% loss due to fouling or deposits can lead to $1M + in additional fuel consumption per year.

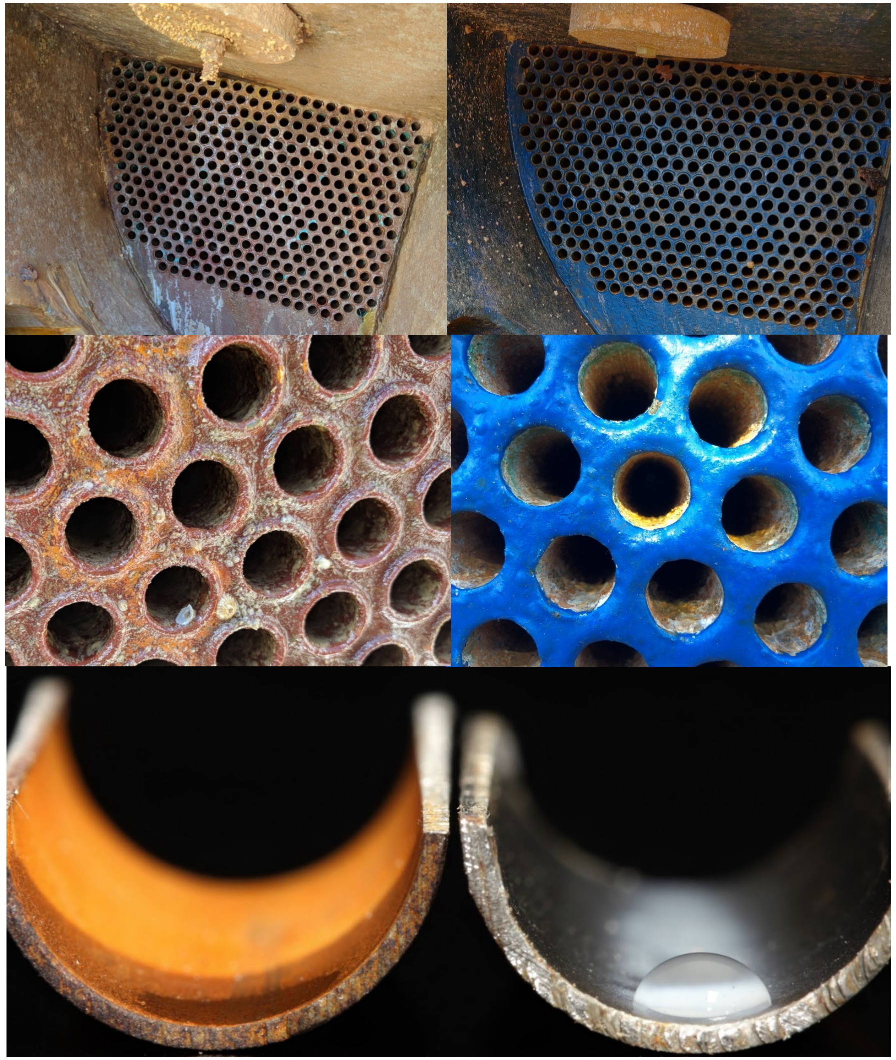
Technology Alternatives

Improvement	Limitations
Epoxy/ceramic coatings	Biologicals can still attach to the coating, limits heat transfer.
Increased cleaning when possible	Repeated opening and closing leads to equipment wear and tear (coatings, gaskets)
Apply an ablative coating	Ablative coatings must be monitored and reapplied periodically
Biocides/corrosion control agents	Biocides have environmental impact, corrosion control only suitable for closed loop systems
Re-tubing with titanium/corrosion resistant alloys	Cost prohibitive

Even a 2% loss due to fouling or deposits can lead to $1M + in additional fuel consumption per year.

Project Approach – HeatX Surface Treatment

- **Utilizes an ultrathin (1 – 2 mil final applied thickness) nanocomposite material to prevent fouling on condenser tube interiors while minimizing effect on heat transfer.**
- **Imparts water- and oil- chemical repellency which allows for fouling/deposit release and reduced surface roughness.**
- **Wetting behavior during application allows for in-place treatment of in-service exchangers.**
- **Two-part, water-based solution with no VOCs that cures at ambient temperatures.**
- **Extensive laboratory validation in Budget Period I of project to demonstrate corrosion resistance, foul release, and increased tubular flow.**



Untreated **Treated**

Performance Versus Key Technical Benchmarks

Property	Milestone Target	Achieved
Treatment Lifetime	Increase time of required cleanings from 6 months to 2+ years	On track for 5+ year lifetime by end of project lifetime.
Improved Condenser Performance	0.5% improvement in condenser performance	Roughly 3 – 7 % improvement based on compensating for blocked tubes and decreasing condenser vacuum.
Application Process Optimization	Application in-situ to actual condenser unit	Standardized application procedures and economic performance projections possible based on power plant specifications.
Material Production and Quality Control	Sufficient volume for small condenser (20-30 gallon batches)	Volume for multiple large condensers and support exchanger equipment (100+ gallon batch)
Economic Impact and Commercialization	Significant effect on plant operations as determined by commercial partner	Over $2M in projected yearly savings based on commercial partner internal analysis of field trial.

Project Development Pathway

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

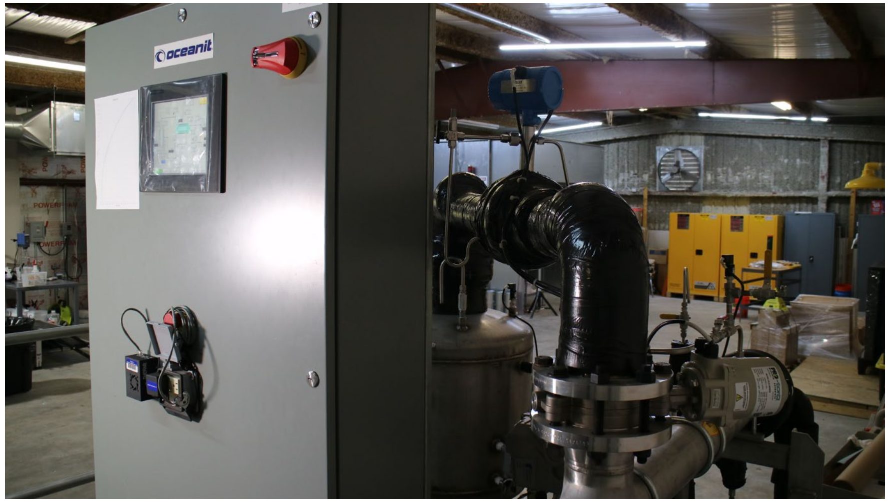
Necessary Benchmarks and Technical Challenges

- Performance Guarantees for High-Risk Equipment
- De-risking through Pilot Case Studies
- In-Field Efficiency Data Collection for Long-Term Monitoring

Project Updates

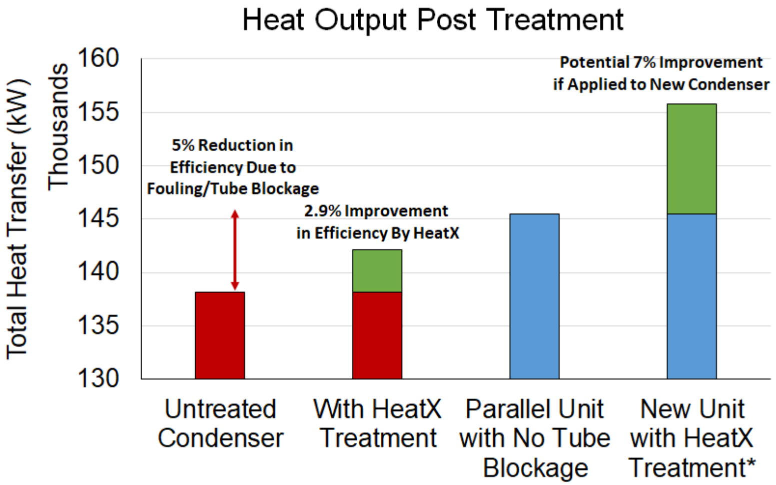
Prescriptive Maintenance Demonstration Platform

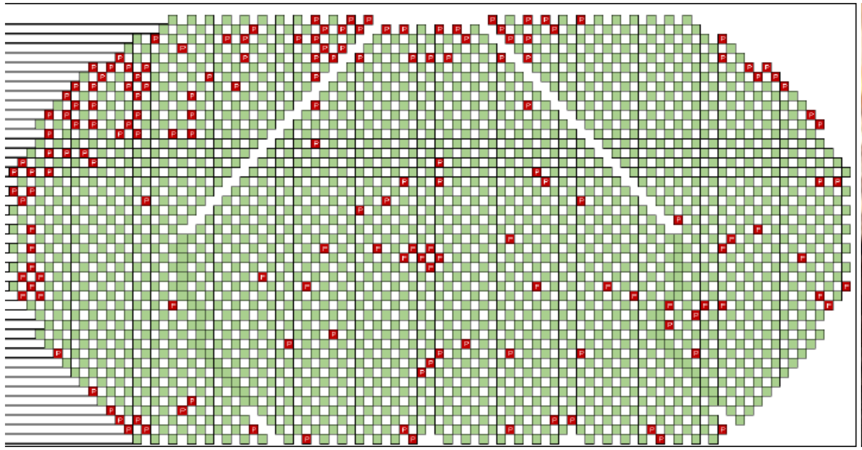
- Design of custom data monitoring equipment to pair with HeatX deployment.
- Simulate past and future deployments based on operating parameters to maximize use of HeatX enhanced capacity.
- Provide estimates of future performance gains and changes in operator behavior.



Validation of Previous Deployment Data

- Previous field trial showed that HeatX compensated for up to 10% tube losses/blockages when compared to full retubing.
- Highly worn and irregular tubing due to corrosion pitting.



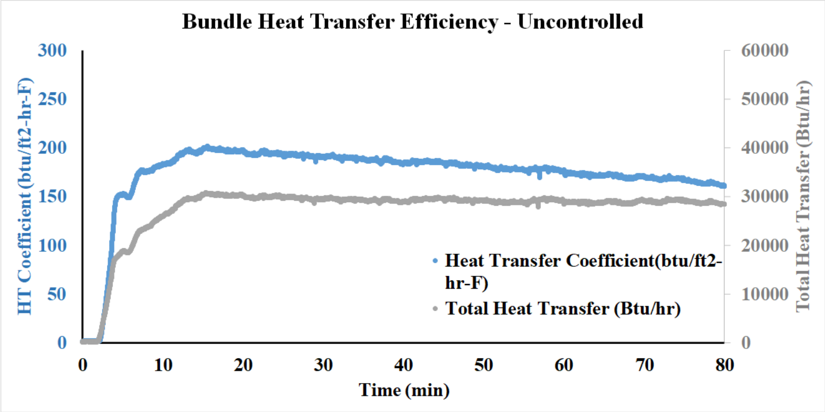


Validation of Previous Deployment Data

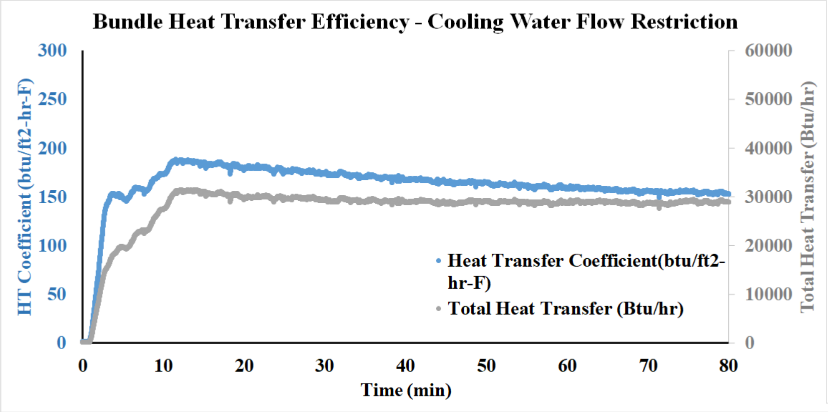
- 10% tube loss mimicked through blockage of one tube in 8 tube system.
- HeatX application optimized for ideal coverage on interior of small diameter U-tube configuration.
- System parameters of condenser were run as close to field as possible.

Validation of Previous Deployment Data

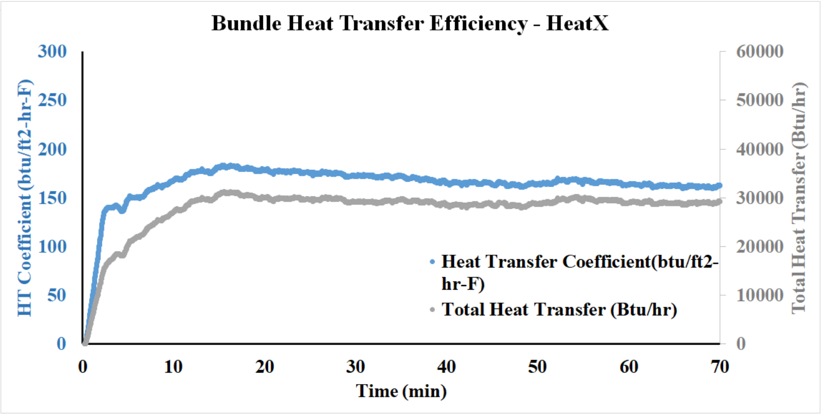
- Adding in the tube block to simulate loss of heat transfer surface area shows an overall drop of 6.7% in heat transfer coefficient/total heat transfer.
- HeatX application combined with process optimizations brings performance back to **97% of design rated, in the absence of any fouling.**
- **Consistent with field trial data (5% deficit prior to HeatX application, 2.1% deficit after HeatX).**
- **Requires system optimization in the absence of fouling to achieve near parity.**



Baseline Performance = 100%



"Fouled" Performance = 93.4%



HeatX Performance = 97%
(and stable backpressure)

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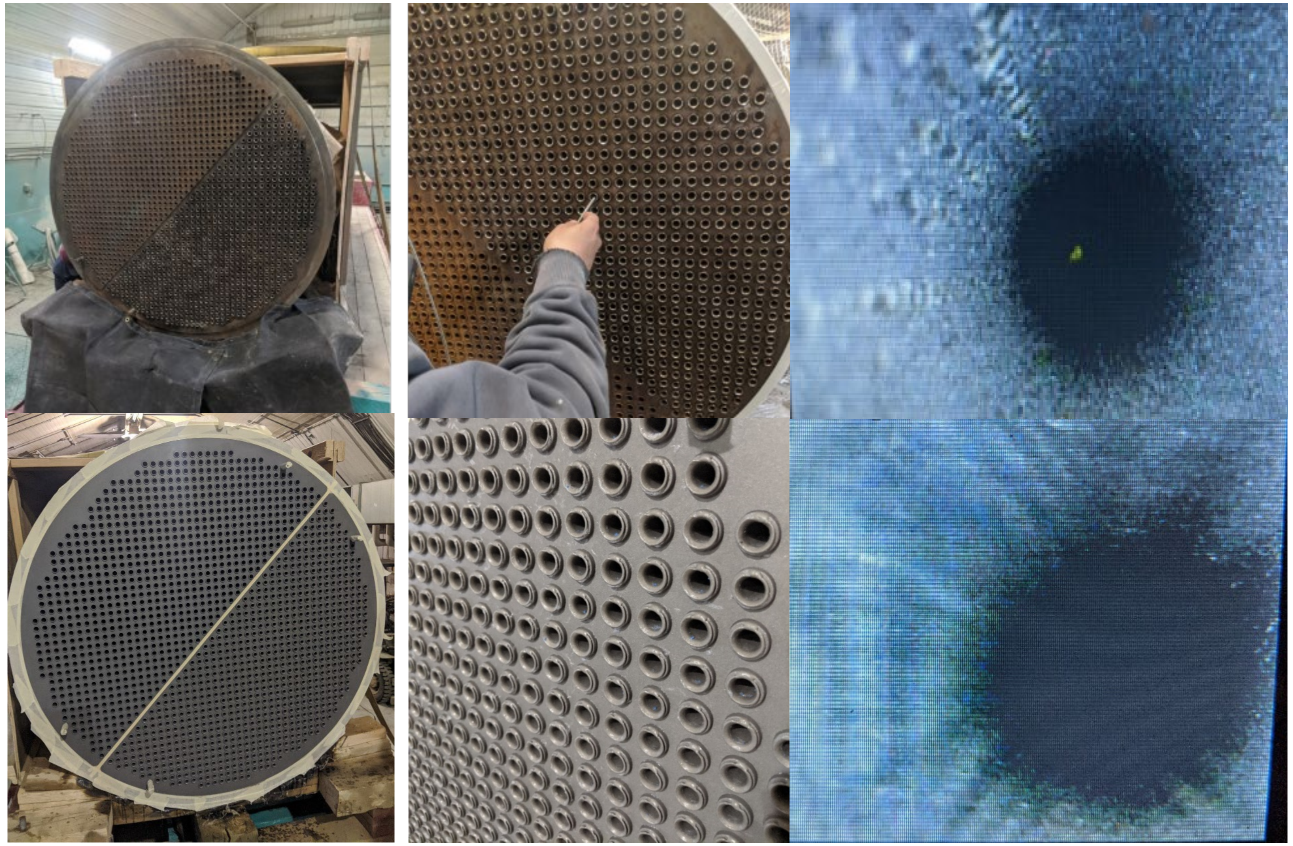
Field Deployment Activity – Application on Bundles in Extreme Conditions

- Performance demonstration of HeatX in extreme cold weather environment on produced water heat exchanger.
- Past histories of extreme buildup on tube interiors and microbially induced corrosion (MIC) leading to tube leakage and inefficient performance.
- Application was done on bundle that was ~10 years old on site.

Pre-Treatment

Post-Treatment



Field Deployment Activity – Performance

- No pinhole leaks during deployment time of 12 months.
  - Significant production loss due to a leak was reported on another bundle in same facility handling the same product.

- No signs of MIC corrosion or pitting during annual inspection.

No Treatment **Post-Treatment**

Field Deployment Activity – Pre-Install Application on New Bundles

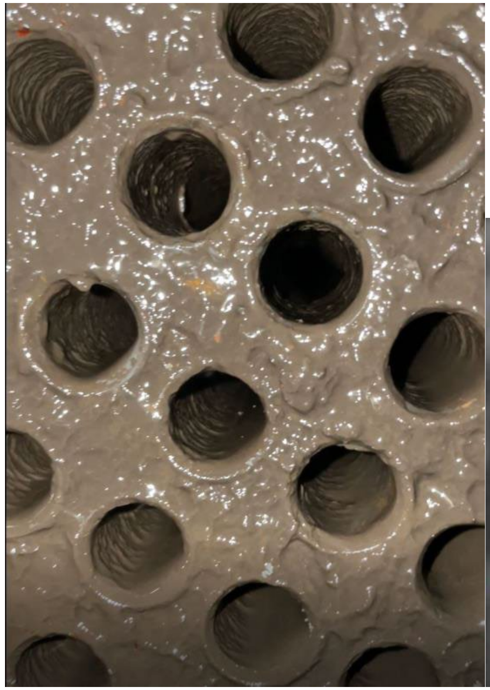
- Demonstration and establishment of delivery, packaging, logistics, leak testing and qualification capabilities for commercial orders.

- Establishment of commercial partnership with bundle manufacturer.

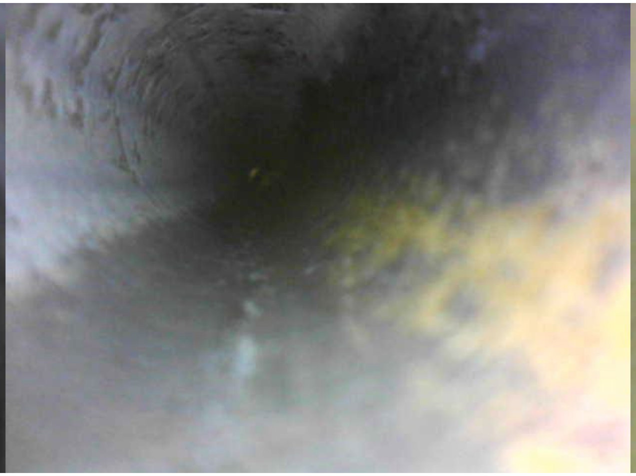
- Newly installed with no receiving issues by partner on extremely short window of < 6 weeks.

Field Deployment Activity – Small Scale Coal Plant

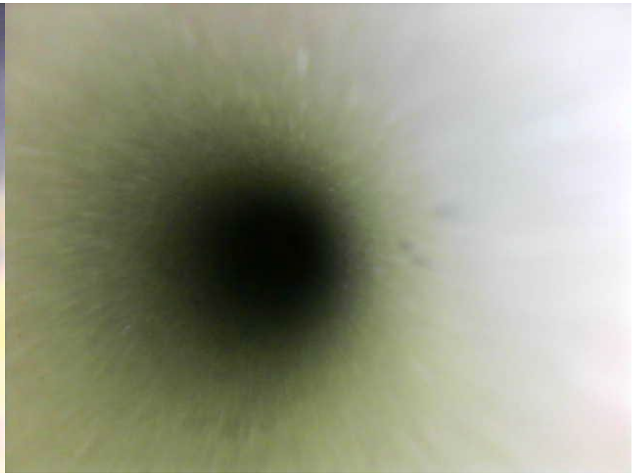
- Application of HeatX on condenser bundle –severe scaling issues that caused tube blockage, tube loss, heat rate performance loss and increase in backpressure.
- Offered turnkey solution with qualified applicator and power plant approved cleaning/application/inspection process.



Pre - Treatment



With Hydro-Jet Cleaning



HeatX Applied

Field Deployment Activity – Small Scale Coal Plant

Economic & Performance Analysis:

- Backpressure of small test unit was improved by 0.4psig after HeatX application, equivalent to a 2.6% improvement in heat rate.
- Extrapolated to their primary unit, a 500 MW rated plant, they concluded that it would **provide savings of $2.125M and lower emissions by 150,000 Tons per year.**

Unit Parameter	Value (Current)	Value (Post HeatX)
Design Capacity (GW)	**0.5**	**0.5**
Actual Operating Load (average GW)	**0.45**	**0.45**
Plant Load Factor	**0.90**	**0.90**
Condenser Vacuum (psig)	**-12.2**	**-12.6**
Heat Rate	**2300kcal/kWh**	**2240kcal/kWh**
Fuel Usage (lb./kWh)	**1.26**	**1.23**
Total Coal Usage Per Year (Ton)	**2.235M**	**2.181M**
Cost of Coal Per Year ($40/Ton)	**$89.4M**	**$87.275M**
CO_2 Emissions (Ton)	**6.39M**	**6.24M**

Project Next Steps and Commercialization Transition

Market Benefits & Assessment

HeatX technology is fundamentally suitable for multiple pillars of future energy development covered under the Fossil Energy Objectives.

Coal and Fossil Fuel Power Generation	Petrochemical Refining, Exploration and Production	Desalination and Chemical Treatment
		
Key Benefit: Efficiency	**Key Benefit: Capital Expense**	**Key Benefit: Operational Expense**
3% reduction in fuel usage – 50MT CO_2 Emissions saved per year in U.S.	**Extend lifetime of equipment by 2+ years and avoid shutdowns.**	**Reduce costs and duration of cleaning.**

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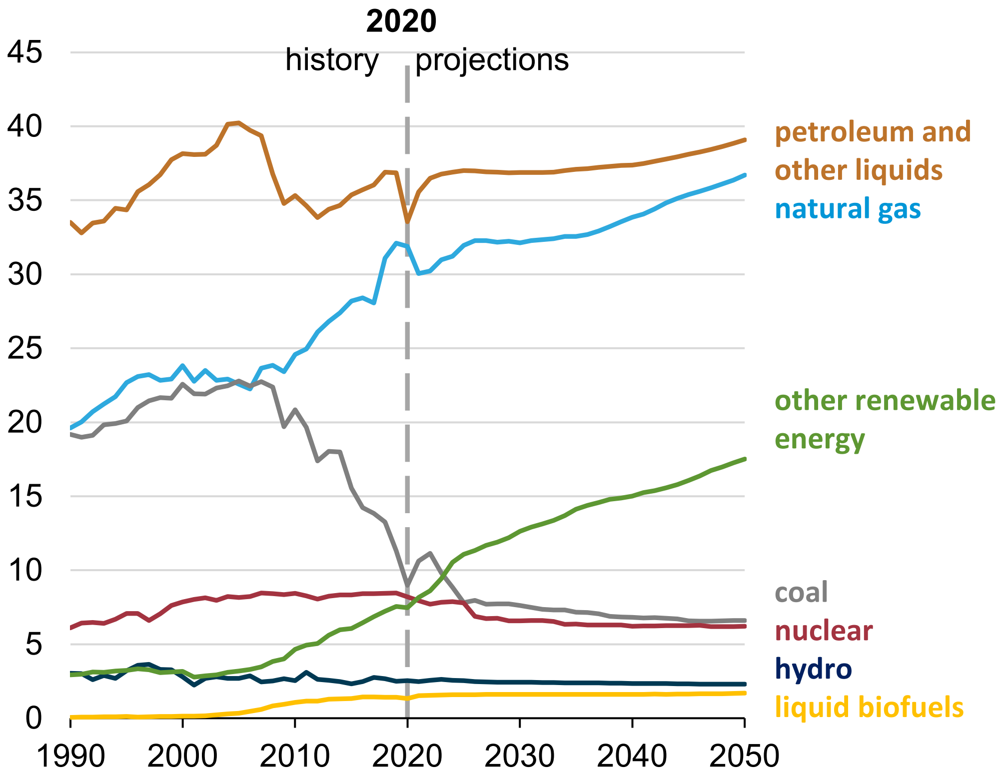
Technology-to-Market Pathway

- **HeatX is immediately deployable and validated by multiple industry collaborators in fossil energy production and generation.**
- **HeatX offers greatest benefit to existing coal plants but has demonstrated value to power plants with other fuel sources going forward.**
- **Development of monitoring equipment makes capture of efficiency improvements possible.**

Energy consumption by fuel
AEO2021 Reference case
quadrillion British thermal units



Source: U.S. EIA, *Annual Energy Outlook 2021 (AEO2021)*

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Summary and Concluding Remarks

- **Field demonstrations of HeatX completed across the fossil energy sector show realized cost savings of $2M + per year on treated exchangers and condensers.**

- **The material and the associated application techniques are qualified and de-risked by multiple fossil energy partners across both short- and long-term trials.**

- **HeatX will offer a synthesis between industry benefit (increased efficiency and lowered costs), public benefit (reduced carbon emissions and lowered cost of electricity), and U.S. Government strategic benefits (increased energy reliability, eased transition away from fossil fuels to renewables).**

- **Technical challenges have been addressed in this project, current challenges involve deployment access and scheduling.**

- **Next research steps will be focused on how to further quantify efficiency improvements and provide real-time analysis of HeatX benefits in the field.**

Acknowledgements

Acknowledgement: This material is based upon work supported by the Department of Energy Award Number DE-FE0031533.

Technology Manager
- **John Rockey**

Program Managers
- **Diane Madden**
- **Venkat Venkataraman**
- **Joe Stoffa**
- **Erik Albenze**
- **Greg O’Neil**

Contracting:
- **Patrick Mayle**
- **Ashley Reichl**
- **Sue Miltenberger**

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