# Technology Maturation of Wireless Harsh-Environment Sensors for Improved Condition-Based Monitoring of Coal-Fired Power Generation

NATIONAL ENERGY TECHNOLOGY LABORATORY

## 2019 Annual Review Meeting for Crosscutting Research

Project: DE-FE0031550

## Omni William Penn Hotel, Pittsburgh, April 9-11, 2019


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**April 11, 2019**

U.S. DEPARTMENT OF ENERGY

1865 THE UNIVERSITY OF MAINE

ELECTRICAL & COMPUTER ENGINEERING Orono, Maine

LASST Laboratory for Surface Science & Technology

ENVIRONETIX TECHNOLOGIES CORPORATION

# Presentation Outline

I. Program & Project Motivation, Goals, and Objectives
   a) Project Motivation & Purpose
   b) Project Goals & Strategic Alignment to Fossil Energy Programmatic Objectives
   c) How the project addresses the goals established by DOE HQ
II. Status at Beginning of Project: Background & Driving Question
III. Current Status of the Project: Updates & Recent Accomplishments
   a) Progress During the Reporting Period
   b) Technology Validation: tests & insertion in multiple power plants
IV. Project Next Steps & Identified Challenges
V. Concluding Remarks

# I. Program & Project Motivation, Goals, and Objectives

## a) Project Motivation & Purpose

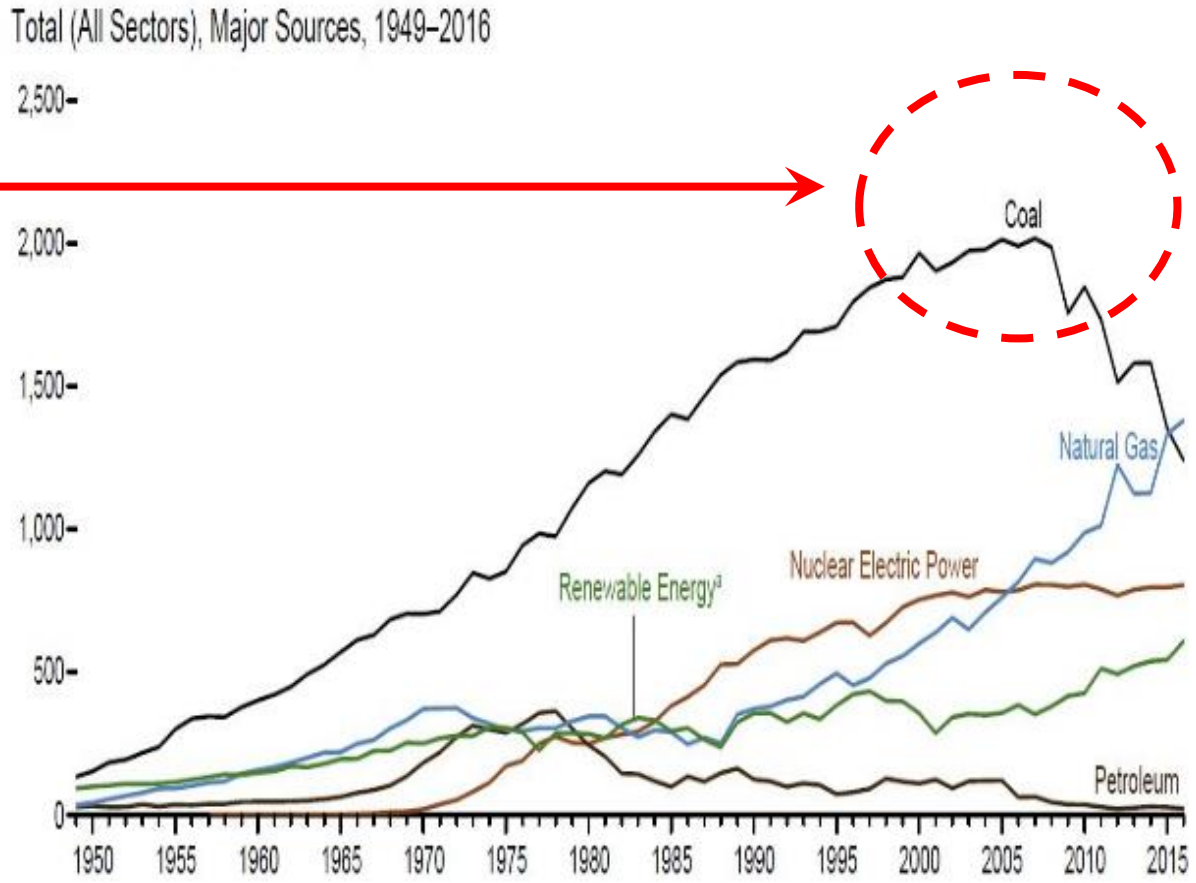
**Electricity Source in the USA (See Figure)**

- **coal usage → diminishing since the mid-2000s**

**Coal power plants →**

**Built before the 1990's & hampered by**

- ↑ operation costs
- ↑ maintenance costs
- ↑ emissions




June 2017 Monthly Energy Review, U.S. Energy Information Administration (EIA), DOE/EIA-0035(2017/6)

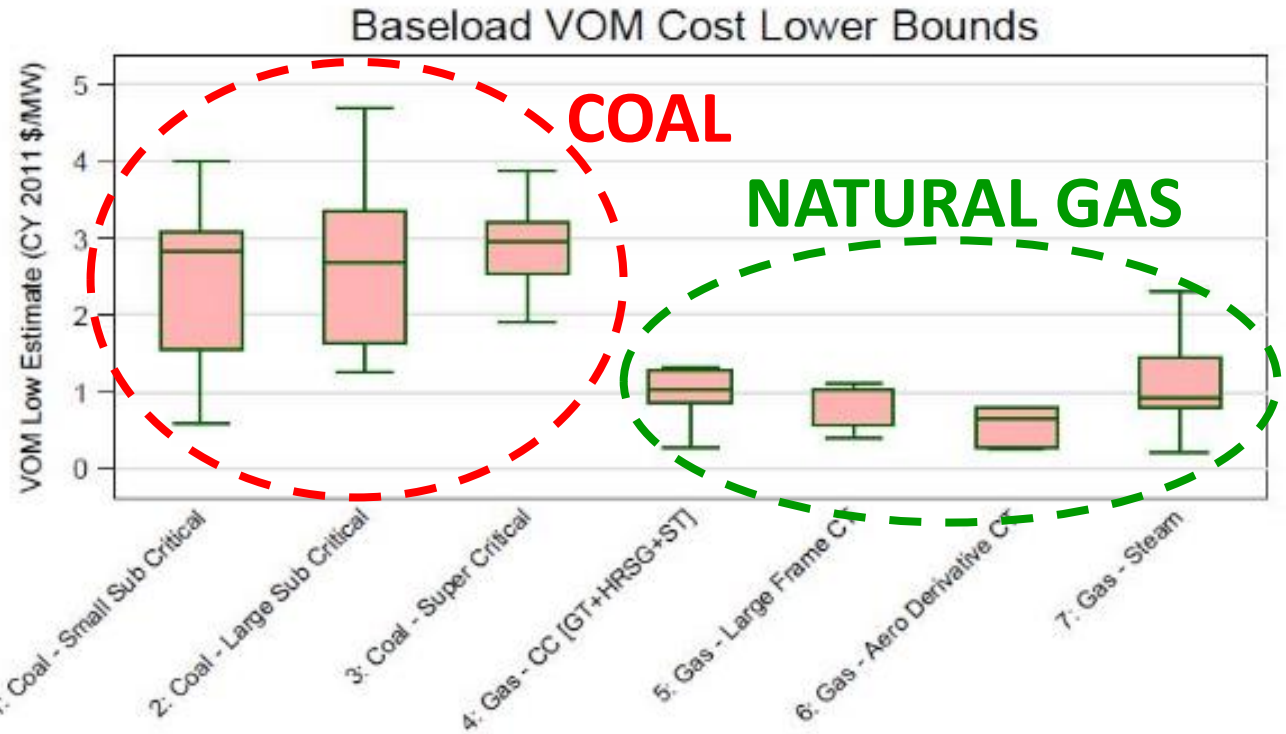
# I. Program & Project Motivation, Goals, and Objectives

## a) Project Motivation & Purpose

**Comparison:**

**Coal-Fired vs. Natural Gas Generation**

- **Variable Operations and Maintenance (VOM) Cost**
- **Coal-fired VOM consistently HIGHER than Natural Gas**
- **Reasoning for the ↓ in Coal usage wrt Natural Gas**




N. Kumar, et al, "Power Plant Cycling Costs," National Renewable Energy Laboratory (NREL), Report NREL/SR-5500-55433, July 2012

# I. Program & Project Motivation, Goals, and Objectives

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## a) Project Motivation & Purpose

- USA → COAL U.S. Energy Information Administration (EIA)
  - ✓ 21% of the world's *proven recoverable reserves* of coal (255.8 billion short tons)
  - ✓ This is only 6.5% of the potential total coal resources (identified and undiscovered)

**HUGE SOURCE OF ENERGY FOR THE U.S.A. !**

**High COAL availability in the U.S. calls for (project purpose):**

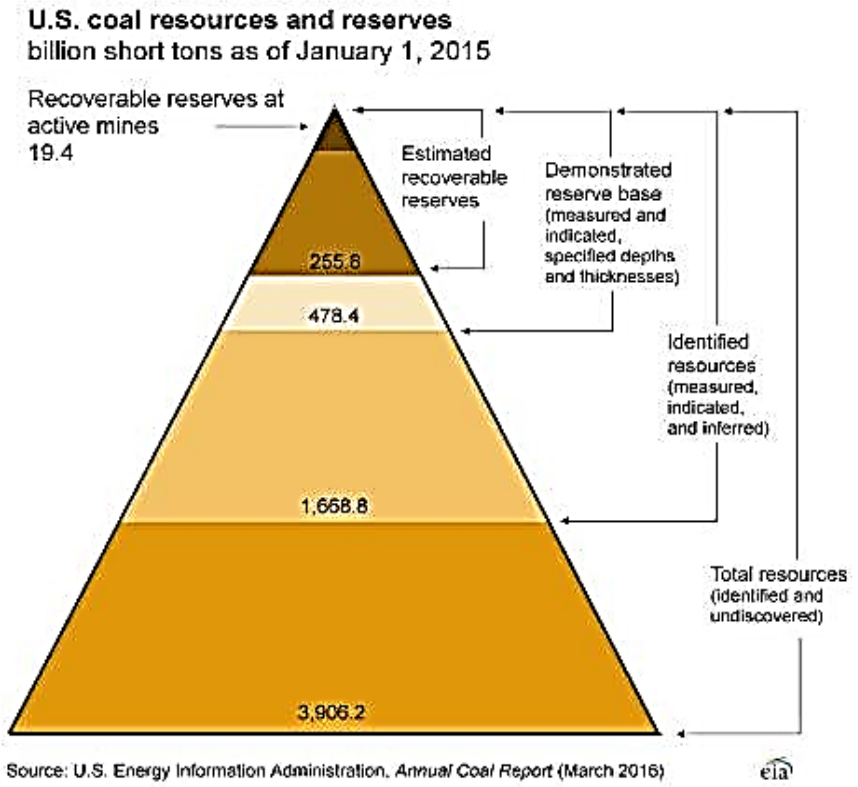
- **New advanced Technologies & Advanced Sensors**

**Target:**

- **↑ power plant efficiency**
- **↓ maintenance costs**
- **↓ emissions**

**FOSSIL ENERGY PROGRAMMATIC OBJECTIVE:**

- **Develop cost-effective, reliable technologies to improve the efficiency of new and existing coal-fired power plants.**




U.S. coal resources and reserves



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# I. Program & Project Motivation, Goals, and Objectives

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## b) Project Goals & Strategic Alignment → Fossil Energy Program

- **Usage of Harsh-Environment (HE) High-Temperature (HT) Wireless Surface Acoustic Wave (SAW) Sensor Technology to**
  - ✓ Promote reliable maintenance through Condition Based Maintenance (CBM) of critical coal-based power plant equipment
  - ✓ Promote cost-effective efficiency of power plant operations

- **Increase the HE HT Wireless SAW Sensor Technology Readiness Level (TRL) via test and implementation in Coal-based power plants:**
  - ✓ From current TRL-5 (Technology validated in relevant environment) to TRL-7 (System prototyped validated in an operational system)

    or possibly

  - ✓ TRL-8 (Actual tech. successfully commissioned in an operational system)

# I. Program & Project Motivation, Goals, and Objectives

## c) How the project addresses the goals established by DOE HQ

- **Univ. of Maine in partnership with Environetix Technologies Corp.:**
  - ✓ Identification of Power Plant Testbeds & Target Locations within power plants
  - ✓ Adaptation of Materials: Sensor Packaging & Antenna Fab. in Coal Power Plants
  - ✓ Implementation of Wireless Communication in Power Plant Environment
  - ✓ Fabrication and Test of Harsh Environment Sensors & Antennas in Power Plants
  - ✓ Deployment of Embedded Wireless Temperature Sensors Arrays and Interrogators into Power Plants
  - ✓ Investigation of Alternative Materials & Sensors for Integration into Developed System



# II. Status at Beginning of Project: Background & Driving Question

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## Status at the Beginning of the Project

- UMaine & Environetix → teamed up Penobscot Energy Recovery Co (PERC), Orrington, ME

  Municipal Solid Waste (MSW) Power Plant

- Technology transfer steps followed during the project:

  1. Material Tests
  2. Wireless HE Sensor Array tested at Economizer
  3. Wireless Sensor testing at Boiler tubes

**BEFORE**

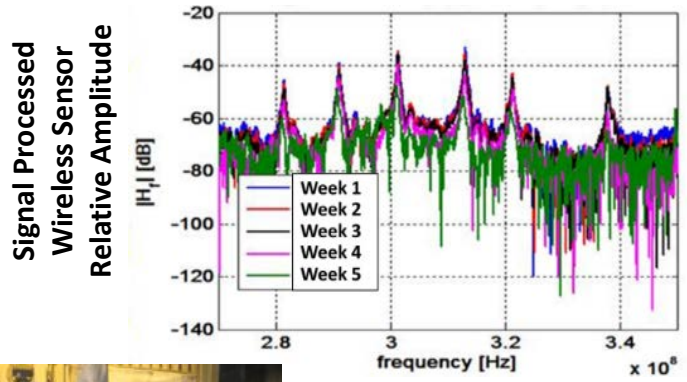
**AFTER 10 DAYS IN THE ENVIRONMENT**

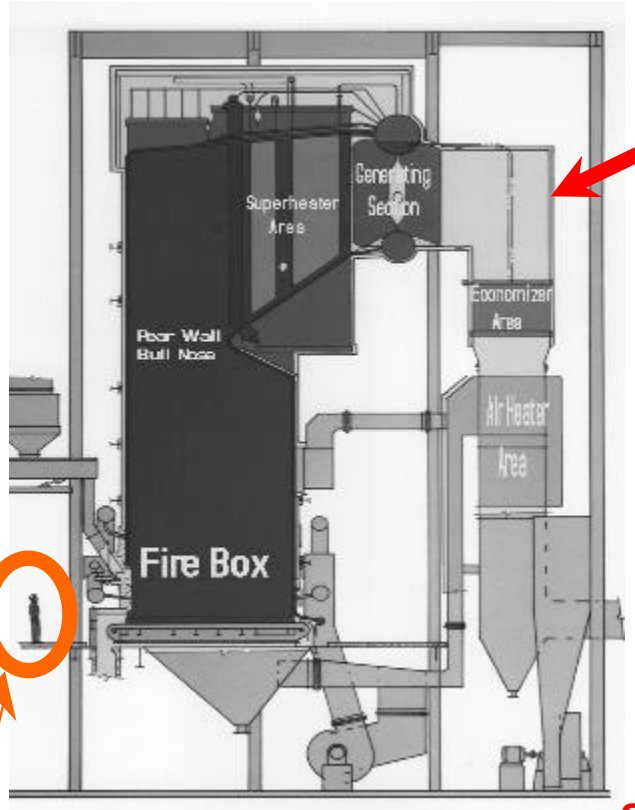

# II. Status at Beginning of Project: Background & Driving Question

## Status at the Beginning of the Project

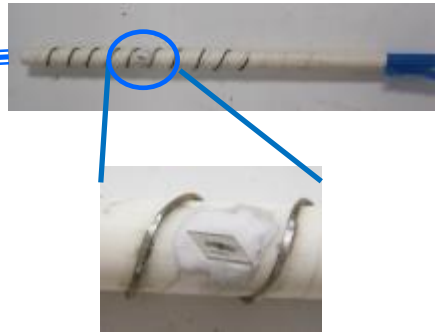
- **2. Wireless HE Sensor Array tested at Economizer**

**Array ⇒ Sensors & Antennas Design, Implementation, & Installation**




- Economizer area: easy access → Power plant in operation
- **6 tuned helical dipole antennas + SAW sensors + external sealing package**



6 dipoles + SAW sensors

monopole interrog. ant.

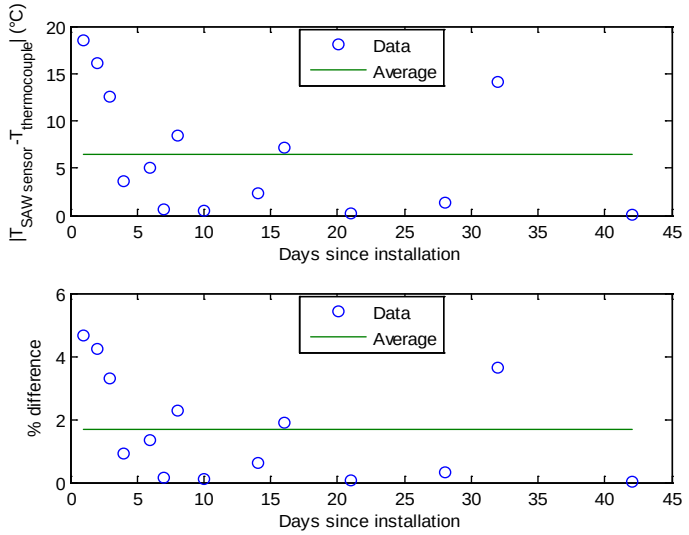
# II. Status at Beginning of Project: Background & Driving Question

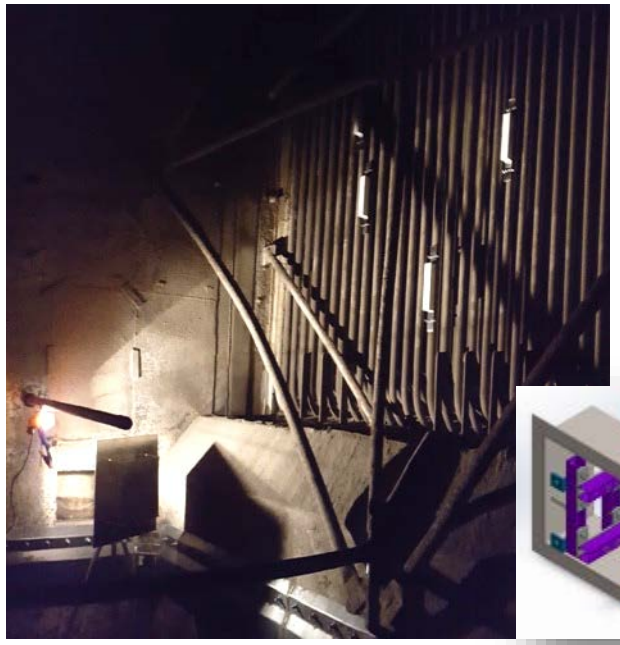
## Status at the Beginning of the Project

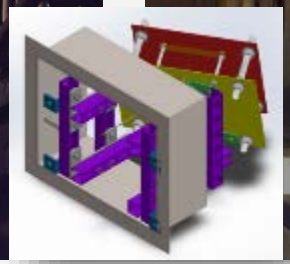
- **3. Instrumentation of Boiler Tubes ⇒ Placement of Sensor Array in Boiler Tubes**

  **⇒ Condition Based Maintenance**

- Measurement compared to economizer thermocouple
- Average differences between the daily temperatures measured: 1.7%





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# Driving Questions

**(i) Advancements in the packaging of SAW sensors & antennas ➔ coal-fired PP:**

- Long-term robust operation up to 1000 °C in a coal-fired environment;

**(ii) Wireless communication protocols and signal processing:**

- User-friendly operation in an industrial setting;

**(iii) Alternative thin films & sensors ➔**

- Next generation electrodes, substrates & sensors ➔ coal power plant needs;

**(iv) Mature wireless SAW temperature sensor technology ➔ TRL-5 to TRL-7**

- Via testing at partnering power plant facilities.

# III. Current Status of the Project: Updates & Recent Accomplishments

## Identification of Power Plant Testbeds: Coal, MSW, & Steam Plants

- **Coal power plant identified and contact established during the past reporting period:**
  - ✓ **Longview Power: identification of locations for materials and sensors testing**
  - ✓ **One round of materials test performed**
  - ✓ **Sensor testing & second round for material testing for antennas underway**
- **PERC power plant:**
  - ✓ **Materials antenna fab. & testing ⇒ Ongoing tests**
- **UMaine Steam power plant:**
  - ✓ **Sensor resilience, packaging tests, wireless ⇒ Ongoing & prep. testing**



# III. Current Status of the Project: Updates & Recent Accomplishments

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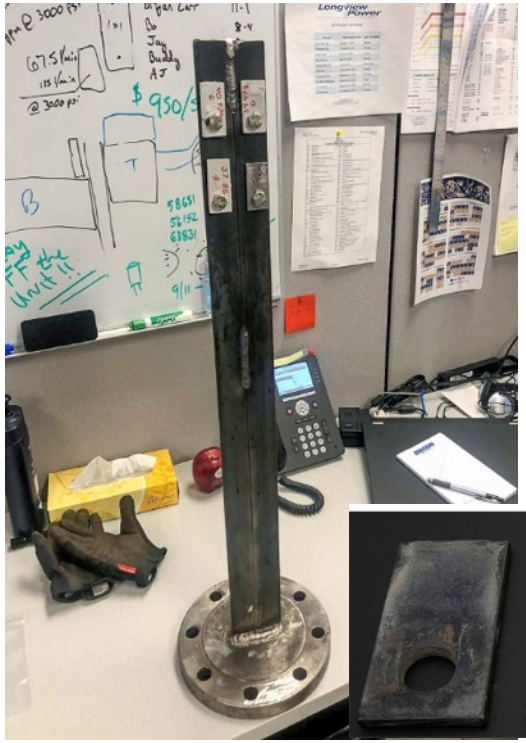
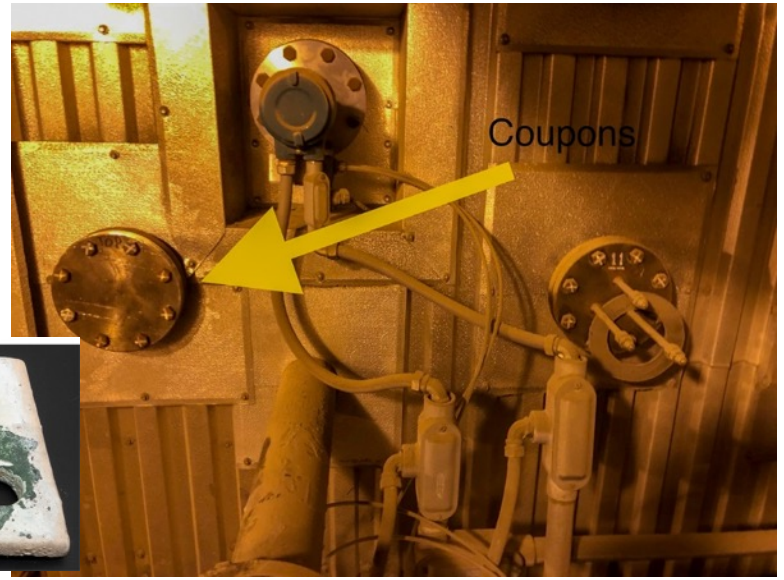
## Longview Power Plant, Maidsville, WV: coal-based power plant

- **1st Round material tests for antenna fabrication ⇒ coupons of low-carbon steel:**
  - ✓ Coated with diverse anti-corrosion ceramic layers ($Cr_2O_3$, $Al_2O_3$, $ZrO_2$) and sealant
  - ✓ All materials passed first inspection ⇒ further RF tests required for surface oxidation level

Corrosion of untreated carbon steel coupon



Treated carbon steel coupons inserted into Selective Catalytic Reduction (SCR) inlet for corrosion/erosion test



# III. Current Status of the Project: Updates & Recent Accomplishments

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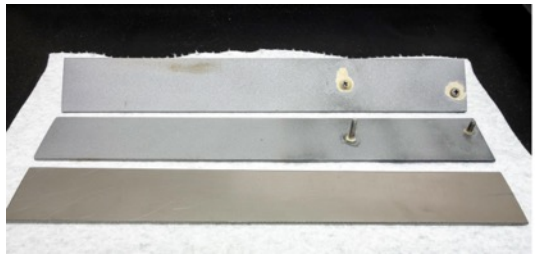
## Longview Power Plant, Maidsville, WV: coal-based power plant

➢ 2nd Round material tests ⇒ Harsh environment antenna components (for RF test)

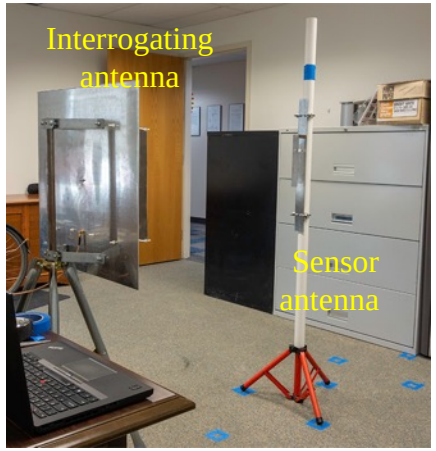
- ✓ Antenna radiating plates (brazed connection points)
- ✓ Baseline measurements acquired with a reference antenna PRIOR to anti-corrosion treatment
- ✓ After treatment ⇒ measurements retaken ⇒ coating layers do NOT affect antenna performance
- ✓ Plates under test now at Longview ⇒ after weeks/months will be checked for RF performance



Before coating

After coating

RF test set up for antenna plates




Mounted in fixture for testing at Longview

# III. Current Status of the Project: Updates & Recent Accomplishments

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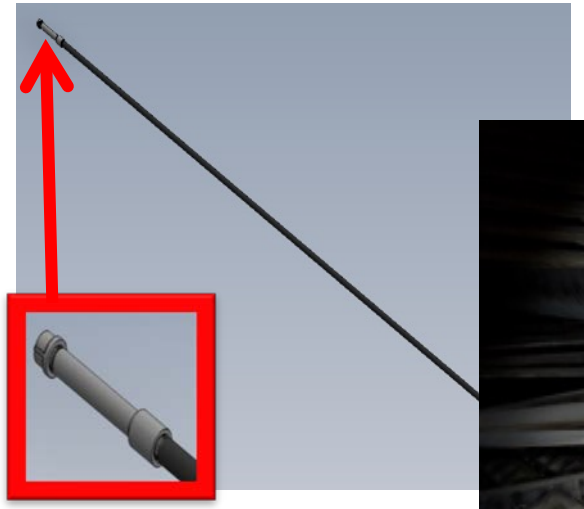
## Longview Power Plant, Maidsville, WV: coal-based power plant

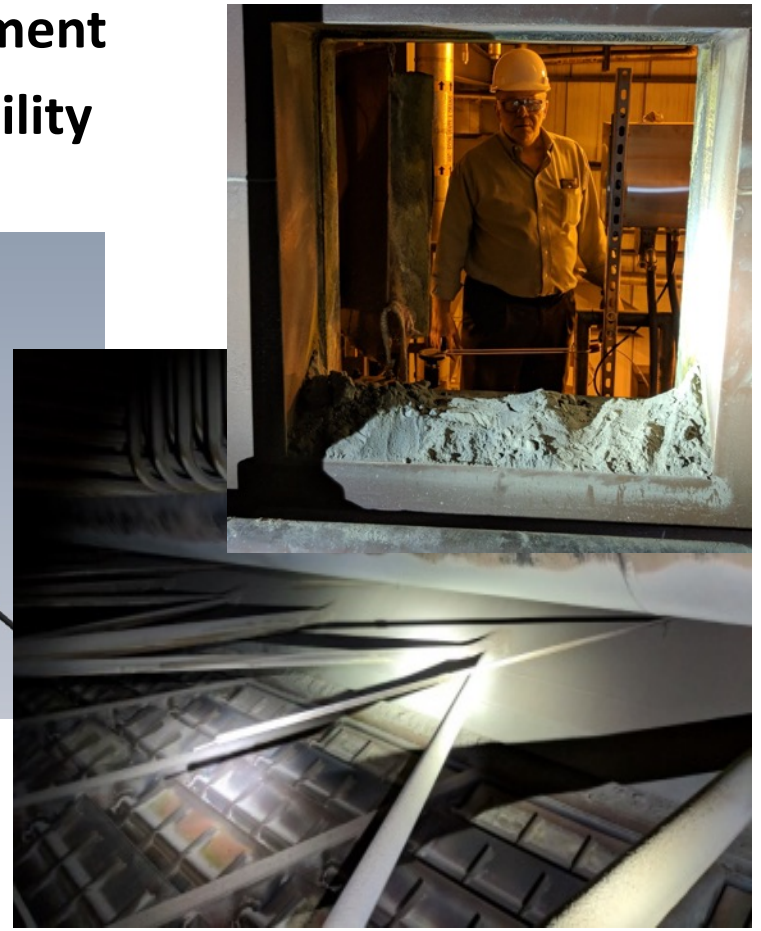
- **SAW sensor probe prep. & testing ⇒ @ super heater pass damper (~500°C, after boilers)**
  - ✓ Goal: verify stable operation of sensor probe in targeted environment
  - ✓ Establish REMOTE WIRELESS data acquisition & monitoring capability

SAW sensor mounted prior to insertion in probe

SAW sensor inserted in high-temperature 6” probe



Probe attached to existing 138” Longview tube



# III. Current Status of the Project: Updates & Recent Accomplishments

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## Longview Power Plant, Maidsville, WV: coal-based power plant

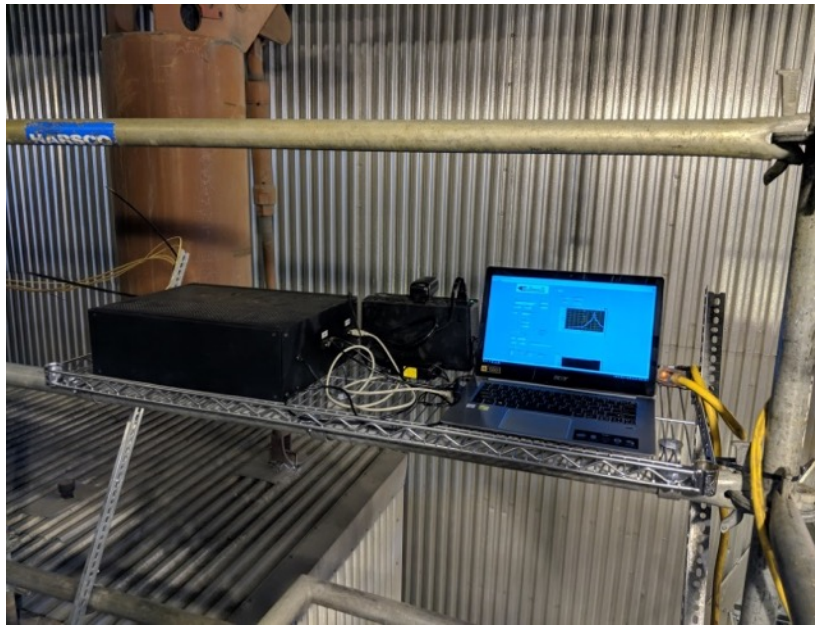
- **Mounting & insertion of probes in the super heater damper ⇒**
  - ✓**SAW sensor probes inserted & under test (Mid March 2019)**

Packaged SAW sensor probe

Probe insertion

Two probes installed at two window locations

Environetix high-temperature (EVHT) monitoring system & wireless extraction capability

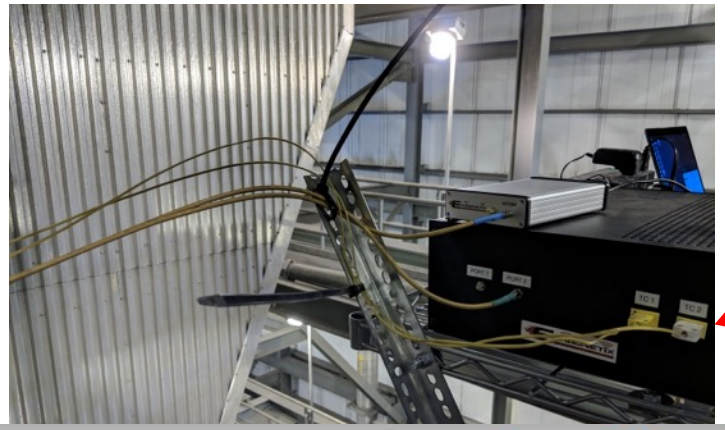


# III. Current Status of the Project: Updates & Recent Accomplishments

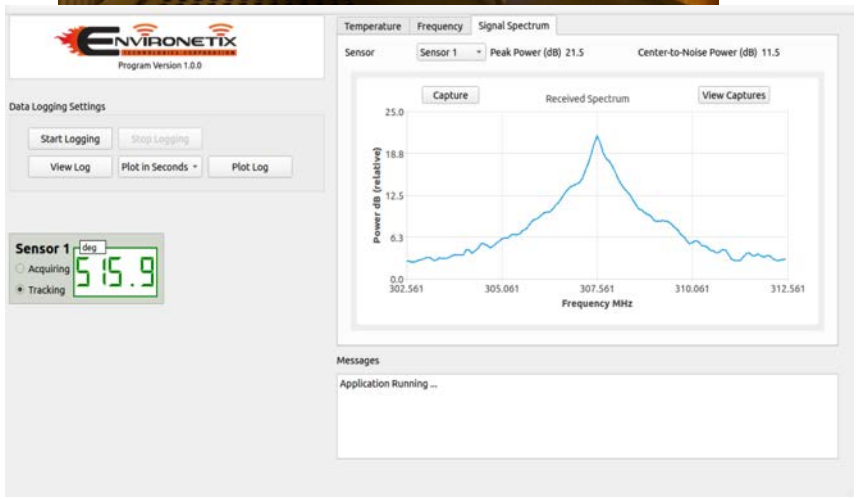
## Longview Power Plant, Maidsville, WV: coal-based power plant

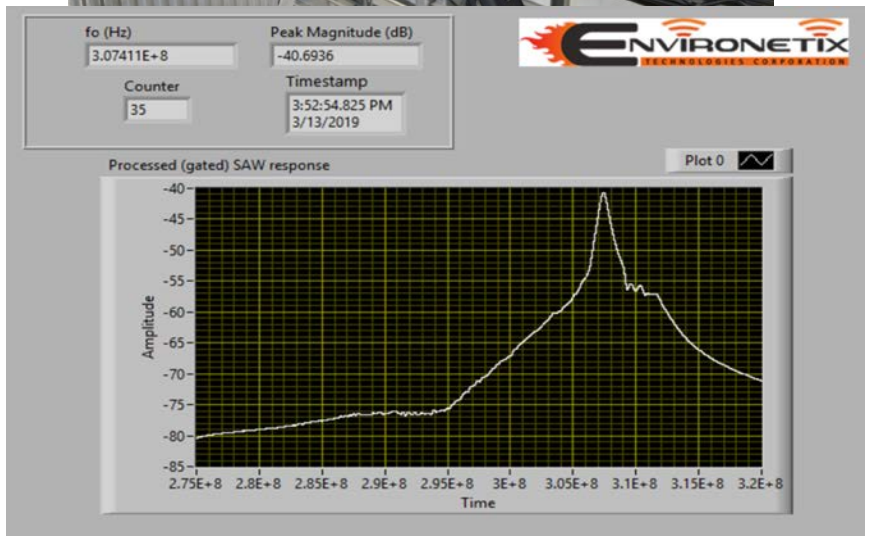
- In-situ measurements using two redundant EVHT (Environetix radar high-temp.) units ⇒

EVHT-300



EVHT-X



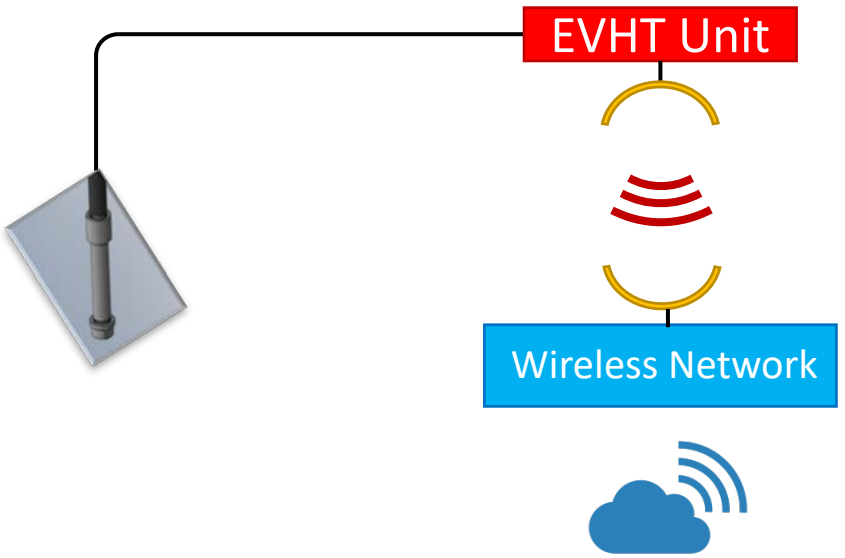
# III. Current Status of the Project: Updates & Recent Accomplishments

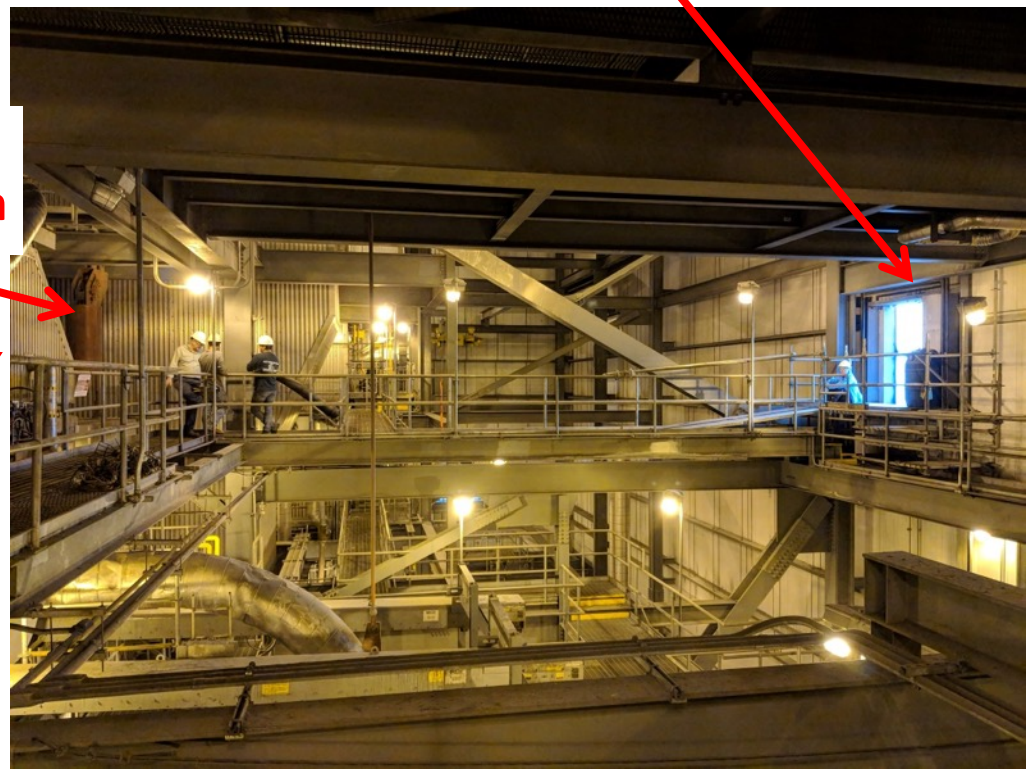
## Longview Power Plant, Maidsville, WV: coal-based power plant

➢ **Wireless/Remote Data Acquisition & Monitoring ⇒**

**WIRELESS NETWORK implemented for:**

- ✓ **CONTINUOUS data acquisition (at Longview Power Plant, WV)**
- ✓ **REMOTE monitoring (Maine/elsewhere)**



# III. Current Status of the Project: Updates & Recent Accomplishments

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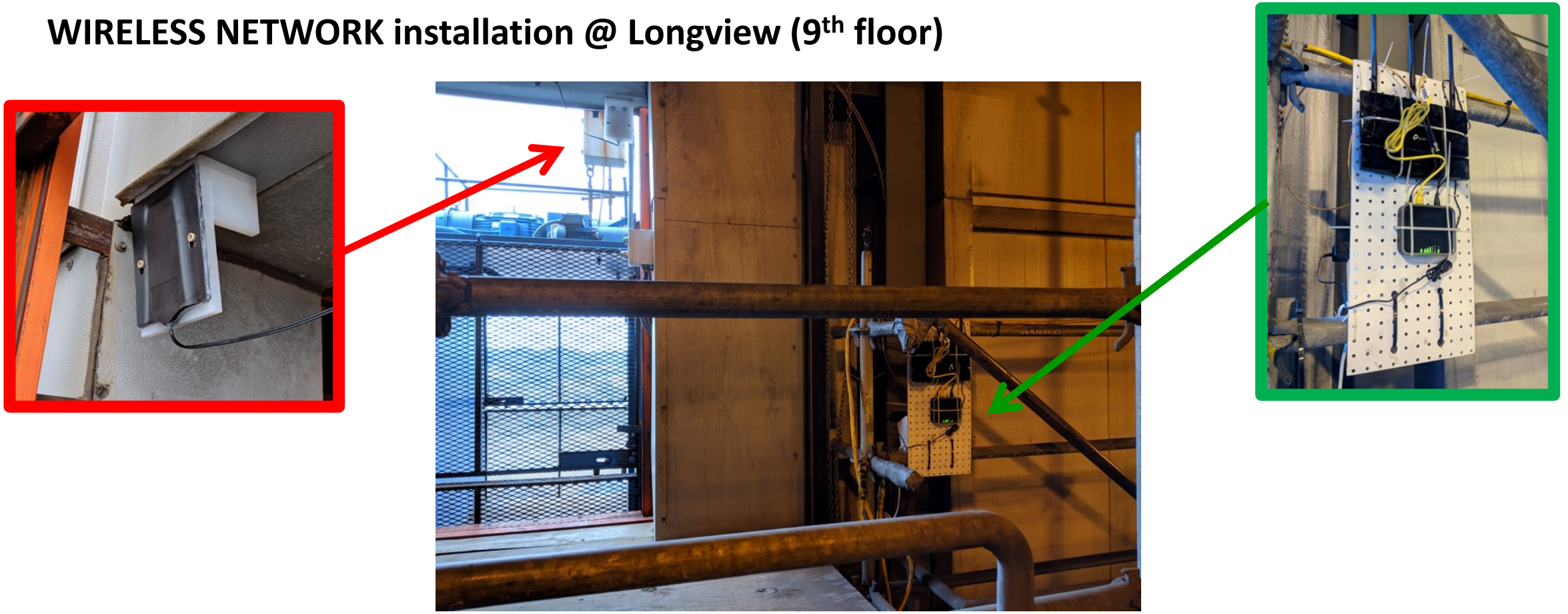
## Longview Power Plant, Maidsville, WV: coal-based power plant

- **Wireless/Remote Data Acquisition & Monitoring ⇒**

**WIRELESS NETWORK installation @ Longview (9th floor)**

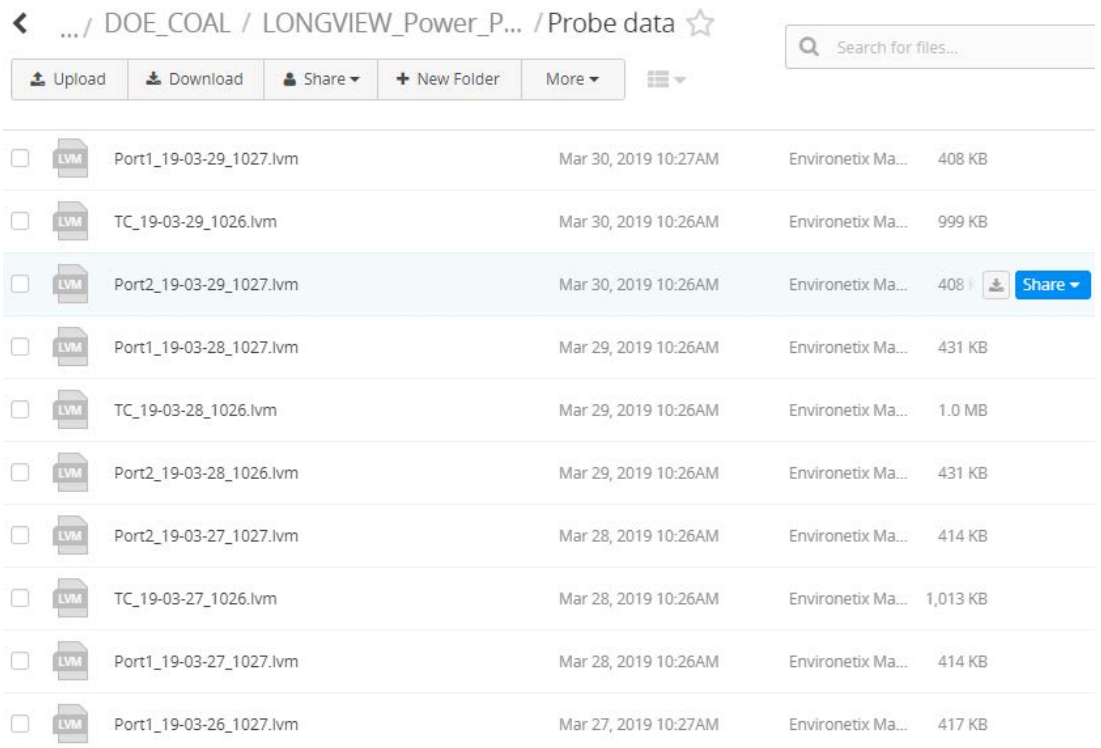


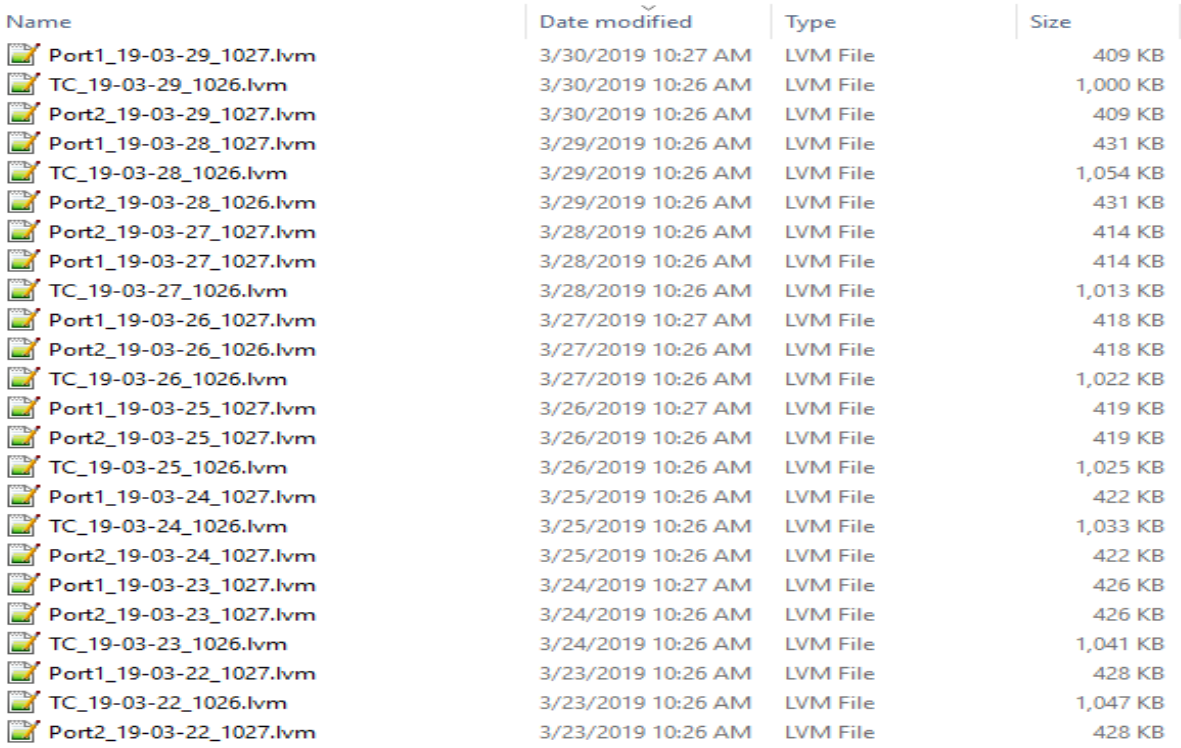
# III. Current Status of the Project: Updates & Recent Accomplishments

## Longview Power Plant, Maidsville, WV: coal-based power plant

### ➢ Secure Data Repository ⇒

- ✓ Remote sensor data constantly saved to Environetix's secure data repository
- ✓ Can be easily accessed from any allowed web browser / computer



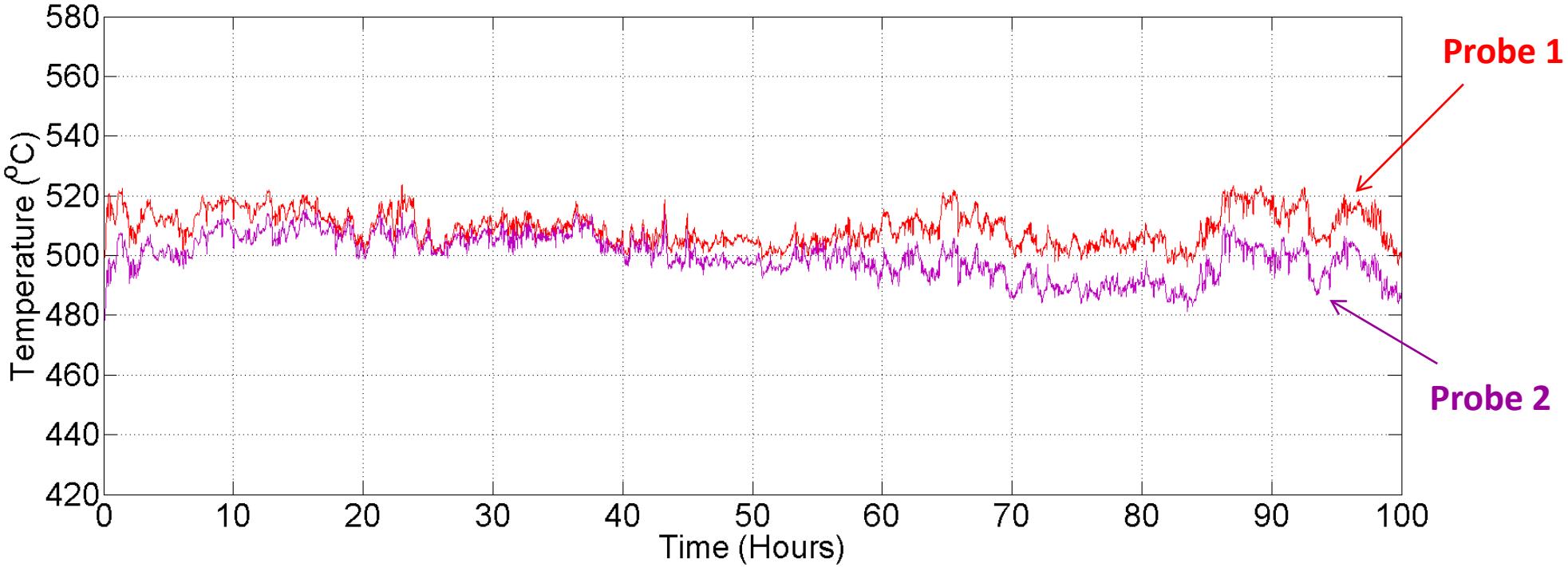



# III. Current Status of the Project: Updates & Recent Accomplishments

## Longview Power Plant, Maidsville, WV: coal-based power plant

➢ **Remotely acquired sensor data saved & plotted ⇒**

**Demonstrated operation of SAW sensors in a coal power plant environment & remote data acquisition and monitoring capability**



# III. Current Status of the Project: Updates & Recent Accomplishments

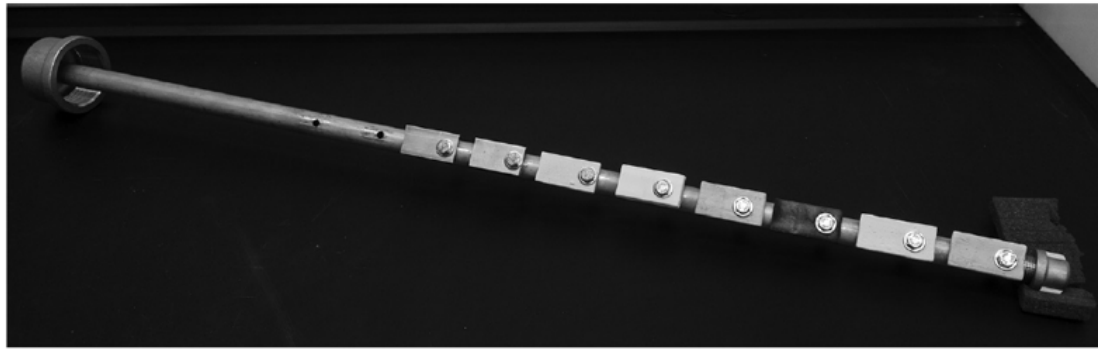
## PERC Power Plant, Orrington, ME: MSW-based power plant

➢ **Anti-corrosion coating test @ PERC ⇒ Economizer ➔ easy access (T ≈ 325°C)**

- ✓ The flue gas @ PERC → HIGHLY CORROSIVE
- ✓ Test fixture prep. & installed ➔ 8 coupons of 2 ≠ metal anti-corrosion coatings and sealants
- ✓ Economizer ➔ easy access (T ≈ 325°C)
- ✓ After 19 days ➔ Corrosion evident on fasteners (left for an additional 21 days)

Installation

As mounted



After 19 days

# III. Current Status of the Project: Updates & Recent Accomplishments

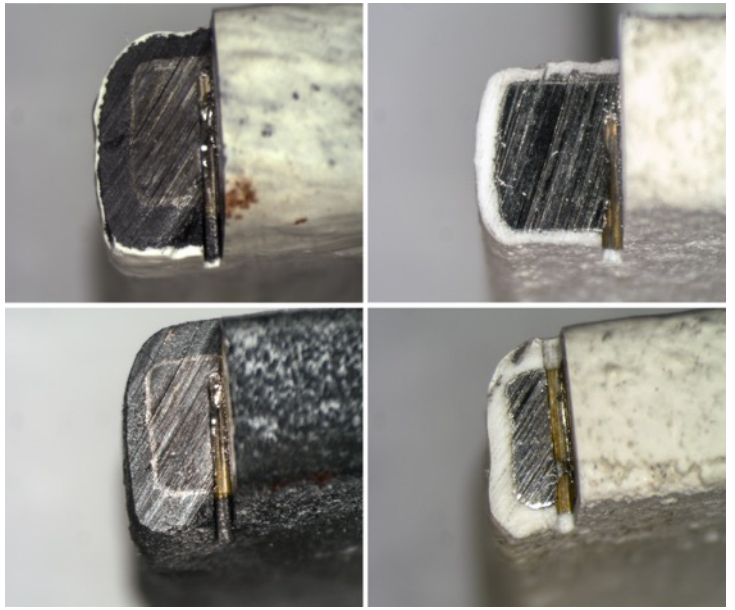
## PERC Power Plant, Orrington, ME: MSW-based power plant

➢ **Anti-corrosion coating test @ PERC ⇒ After 40 days ➔ removed for analysis @ Environetix**

- ✓ Unprotected metal coupons → highly corroded
- ✓ Coated (unsealed) coupons → slightly corroded
- ✓ Coated & sealed coupons → no visual sign of corrosion

Left to right: four coated and sealed coupons, two coated but unsealed coupons, and two bare metal coupons

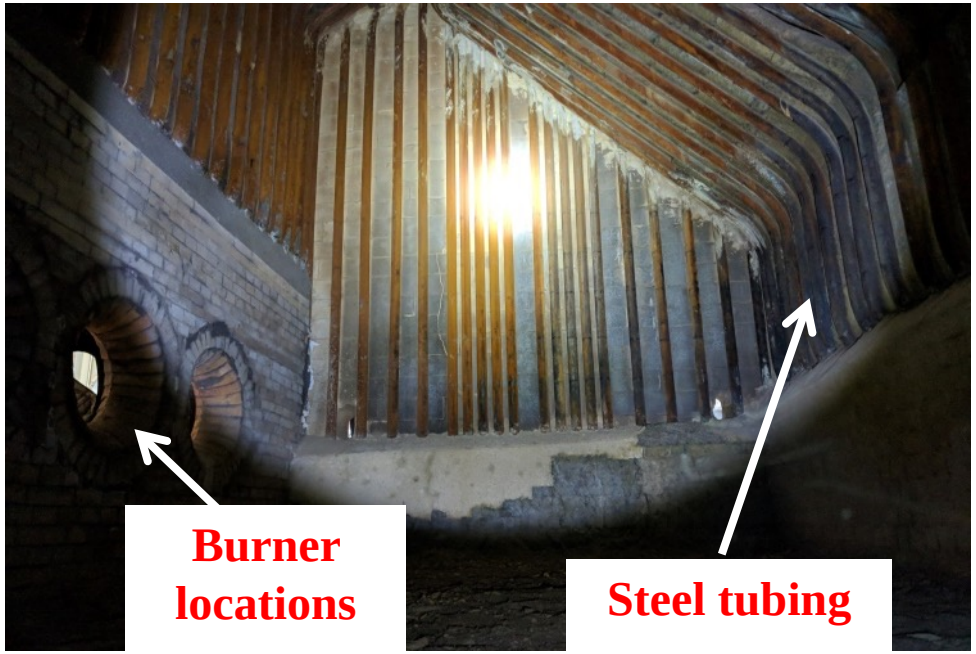
Coated & sealed samples show no sign of corrosion

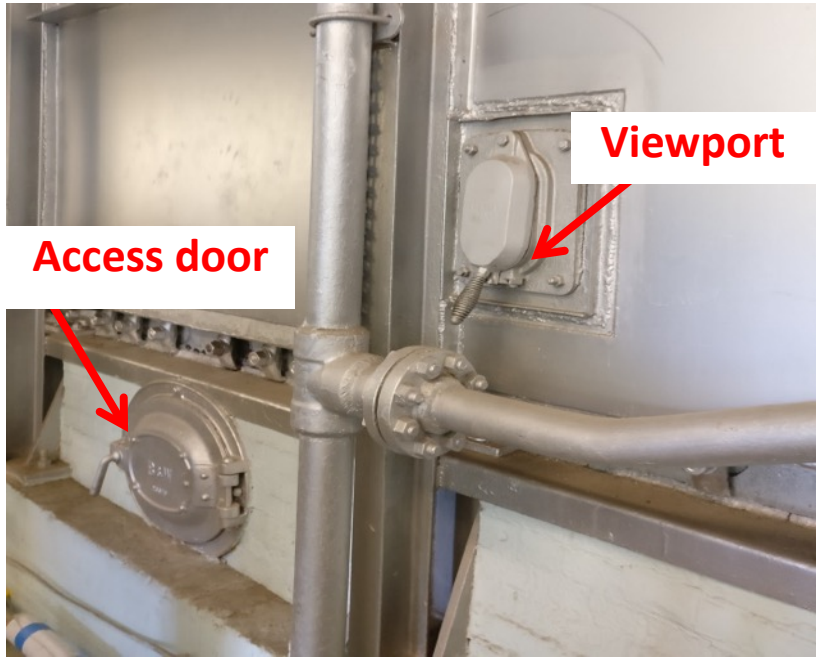


# III. Current Status of the Project: Updates & Recent Accomplishments

## Steam Power Plant, Orono, ME: natural gas & oil – based PP

- Steam Power Plant @ UMaine ⇒ Four boilers ➔ 2 natural gas & 2 oil
- Outstanding testbed ➔ Normally two of the boilers are on stand-by and can be used for:
  - ✓ Wireless sensor system → Interrogation system design & signal acquisition test
  - ✓ Packaging resilience → Thermal shock and long-term resilience

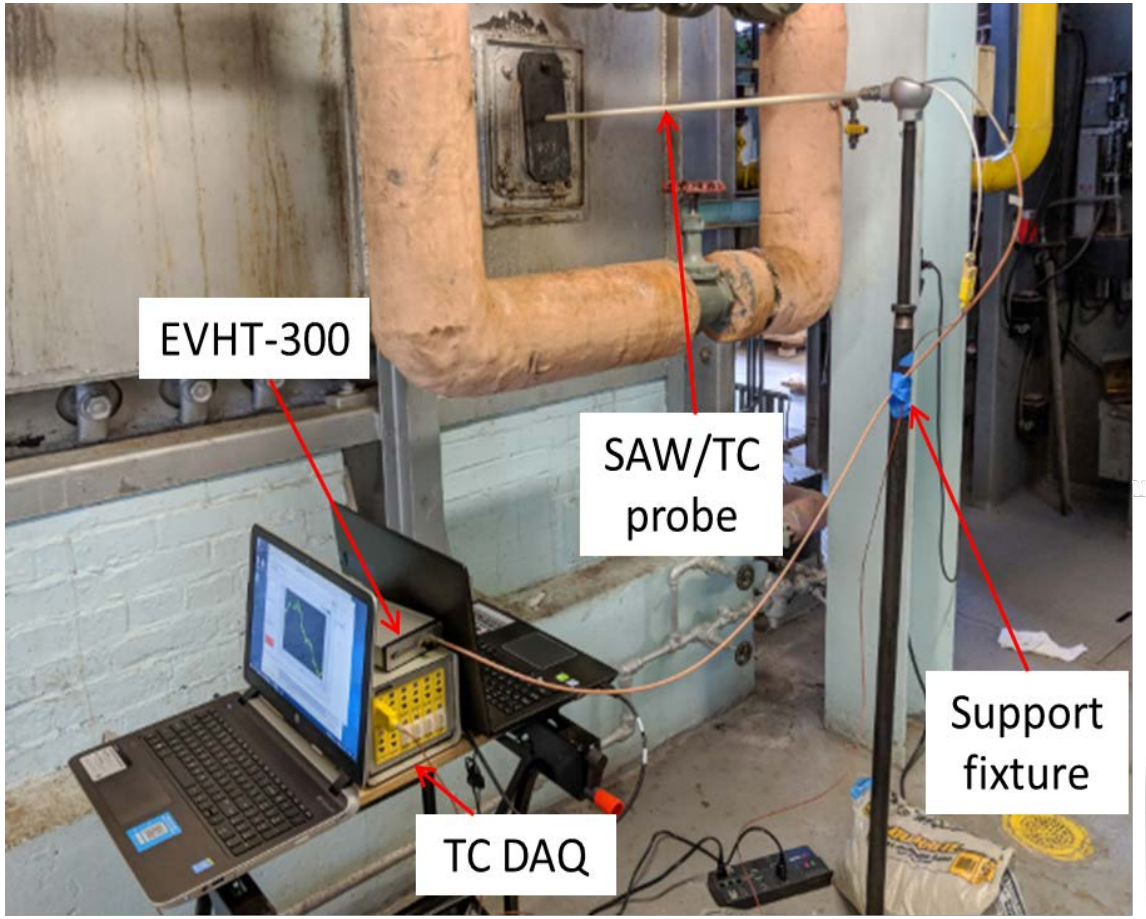


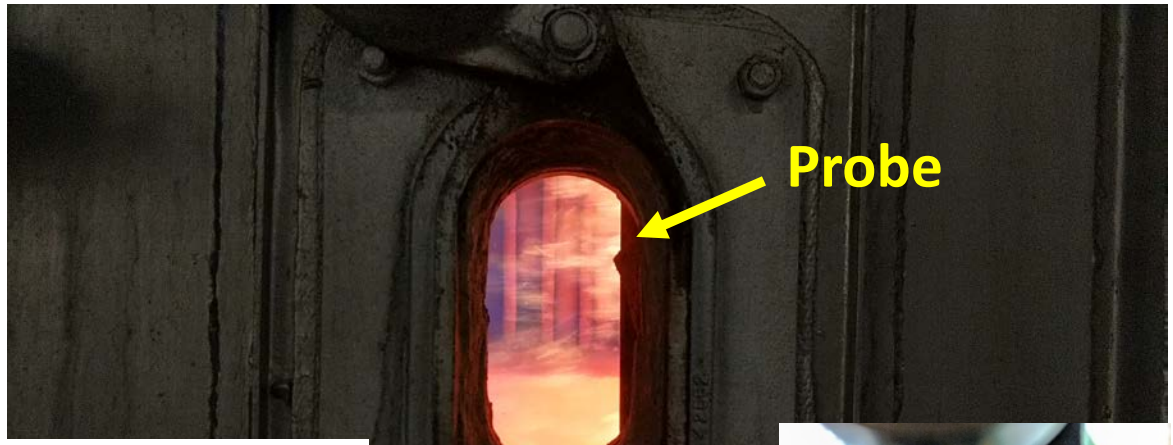



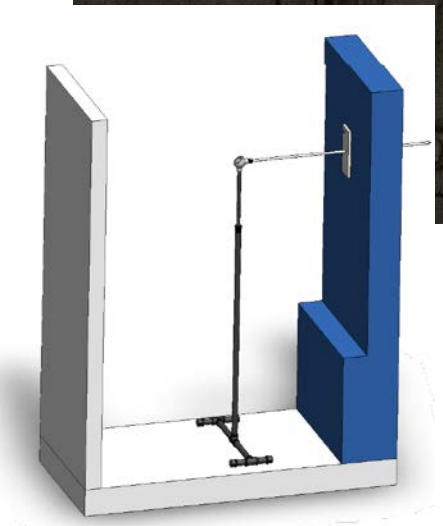
# III. Current Status of the Project: Updates & Recent Accomplishments

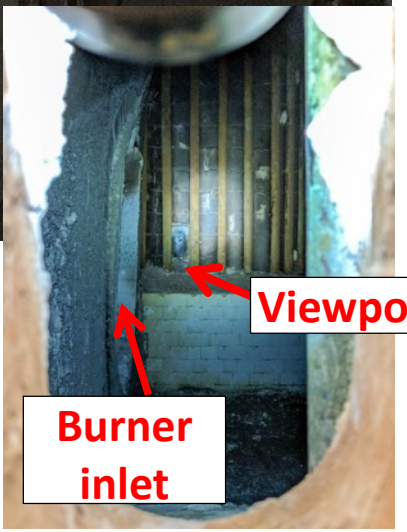
## Steam Power Plant, Orono, ME: natural gas & oil – based PP

➢ Probe installation @ Steam Plant (sensor resilience, packaging tests) ⇒ natural gas





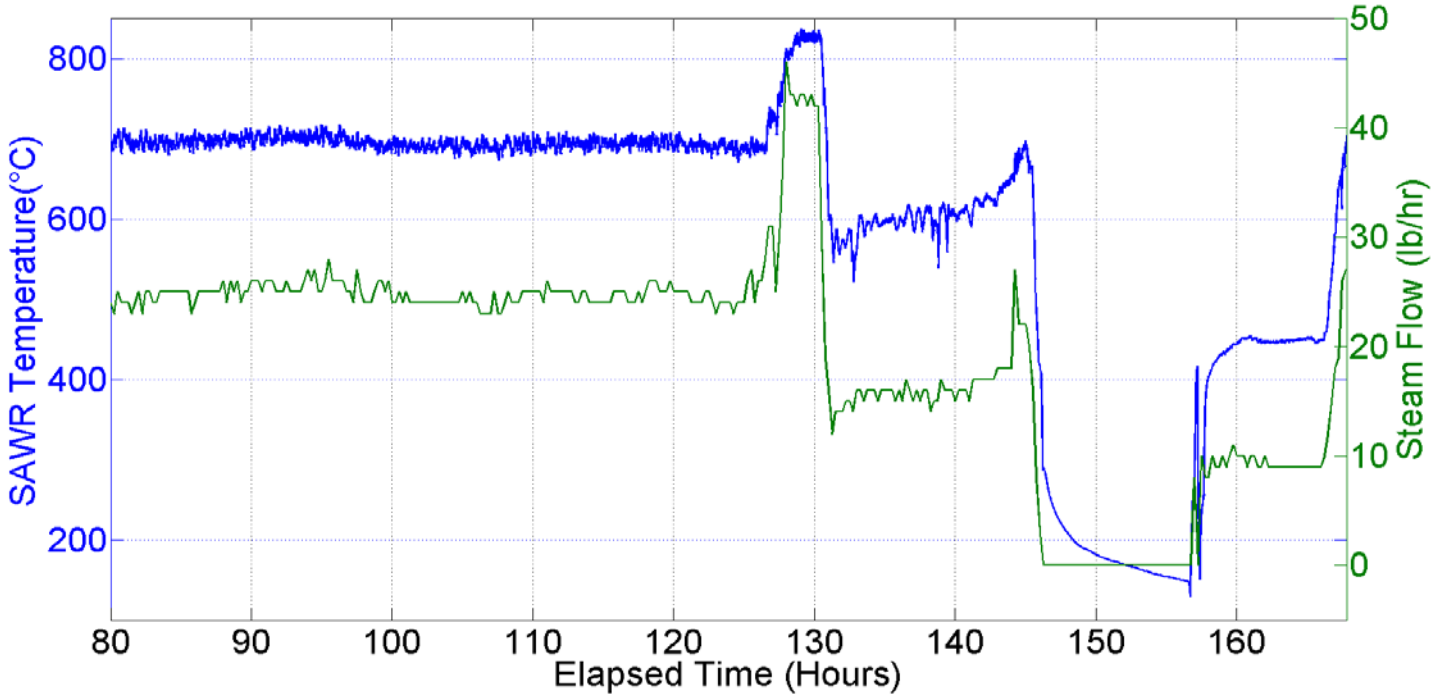
# III. Current Status of the Project: Updates & Recent Accomplishments

## Steam Power Plant, Orono, ME: natural gas & oil – based PP

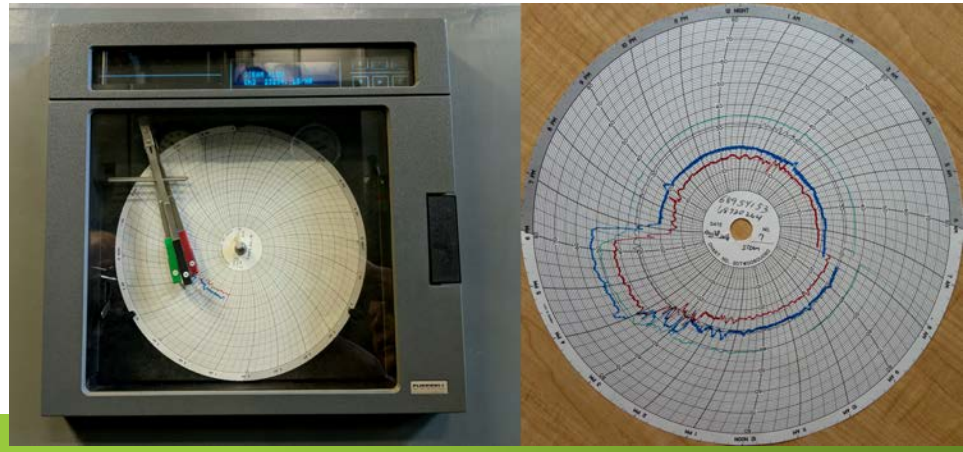
➢ **SAW Sensor Probe Measurement @ Steam Plant**

- ✓ Temperature monitored using EVHT-300 unit by Environetix
- ✓ Steam flow measured using 24-hr mechanical charts by steam plant


**SAW sensor temperature (blue) & Steam flow data (green)**




**Steam flow data recorder: UMaine steam plant**



# IV. Project Next Steps & Identified Challenges

## Power Plant Tests

- **Collect data from material tests @ Longview, PERC, and UMaine Steam Plant**
  - ✓ Verify that coating & sealants: appropriate for RF/antenna operation (Longview, PERC)
  - ✓ Continue to remotely monitor installed probes for long-term operation (Longview)
    - ❖ If necessary propose corrections
  - ✓ Finalize plan & install → harsh environment wireless sensor in boilers (Longview)
  - ✓ Proceed with testing of wireless communication in boiler environment (Steam Plant)
  - ✓ Proceed with new materials, packaging & sensors development (UMaine, Environetix)

# IV. Project Next Steps & Identified Challenges

## Identified Challenges

- **Test window opportunities in power plant boilers is very limited ⇒**
  - ✓ Power Plant is shut down for maintenance:
    - ❖ ONCE a year
    - ❖ In case of a second time ⇒ normally emergency ⇒ very short notice
- **RF operation is plagued by ⇒**
  - ✓ Harsh environment conditions (erosive, corrosive, oxidizing)
  - ✓ Shielding (metallic structures and casing)
- **Packaging is challenged by ⇒**
  - ✓ Extreme variations in temperature → material integrity & stability
  - ✓ Shock in temperature
  - ✓ Mismatch in the coefficient of thermal expansion between parts

# V. Concluding Remarks

## Summary

- **Program & Project Motivation, Goals, and Objective presented ⇒**
  - ✓ Strategic Alignment to Fossil Programmatic Objective highlighted
  - ✓ Path & strategy to achieve goals of ↑ TRL from 5 to 7 discussed
- **Status @ beginning of project discussed ⇒**
  - ✓ Background successes
  - ✓ Driving questions to project discussed
- **Current progresses presented ⇒ materials & sensors installed and under test**
  - ✓ At Longview, PERC, and UMaine Steam Power Plants → material integrity & stability
  - ✓ In-situ continuous remote wireless of high-temperature probes underway
- **Next Steps & challenges presented and discussed**
  - ✓ No expected changes from original project plan at this point

# ACKNOWLEDGMENTS


- Work presented here is the result of intensive team work. The author would like to acknowledge all my co-authors, students, Environetix personnel.

  Current work involves a large group of people: Profs. , scientists, supporting tech. staff, grad & undergraduate students, and industry: M. Pereira da Cunha[1,2], R.J. Lad[1,2], Anin Maskay[1], M. Call[1], G. Bernhardt[1], Greg Harkay[2], Suzie Sharrow[2], and Seth Braun[2]

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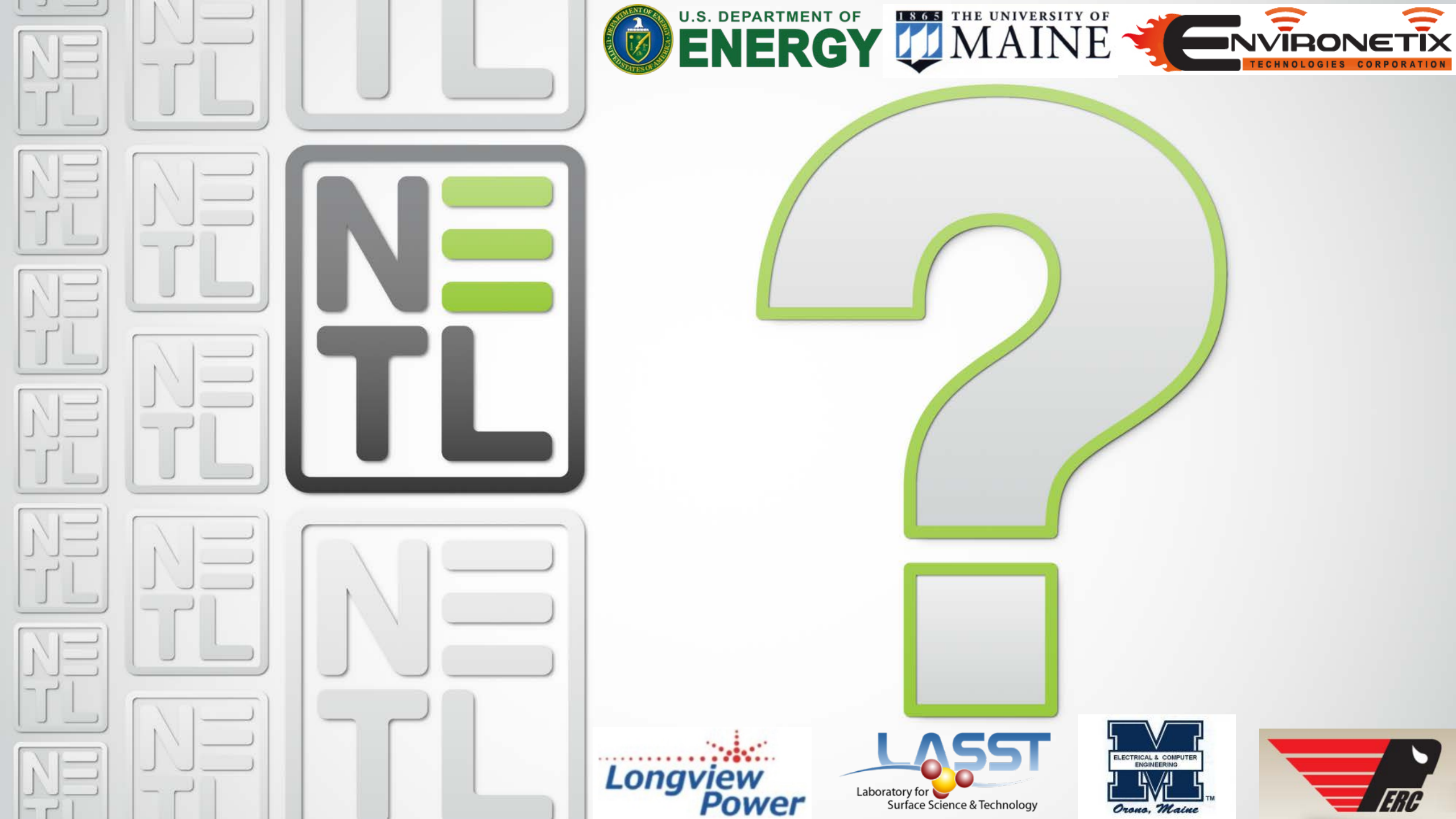
- Discussions, suggestions, and support involving our power plant collaborators listed next are greatly appreciated: (i) Jared Custer , Reliability and Performance Manager, and Anthony DelRio, Reliability Supervisor, from Longview Power Plant, Maidsville, WV; (ii) Dick Kelley, NERC Compliance Officer, Doug Britton, Safety Manager, and Mike Mains, Technical Manager, from PERC, Orrington, ME; (iii) Michael Swartz, Energy and Utility Manager, Chuck Spalding, Plant Manager, Dan Curran, Plant Supervisor, and Mike Messier Plant Maintenance and Operation, from Steam Plant, University of Maine, Orono ME.

- The entire group would like to thank NETL, the support of the NETL/DOE personnel in Morgantownand Pittsburgh, in particular Barbara Carney, program officer, and Sydni Credle, Ben Chorpening, Patricia Rawls, and Briggs White for discussions, guidance and support during the project, technology transition and tests.

# DISCLAIMER

This work is supported by U.S. Department of Energy Award #: DE-FE0031550.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