

# Novel Corrosion Sensor for Advanced Energy Systems

DOE UCR (DE-FC26-03NT41807)

---

Heng Ban, Associate Professor

University of Alabama at Birmingham

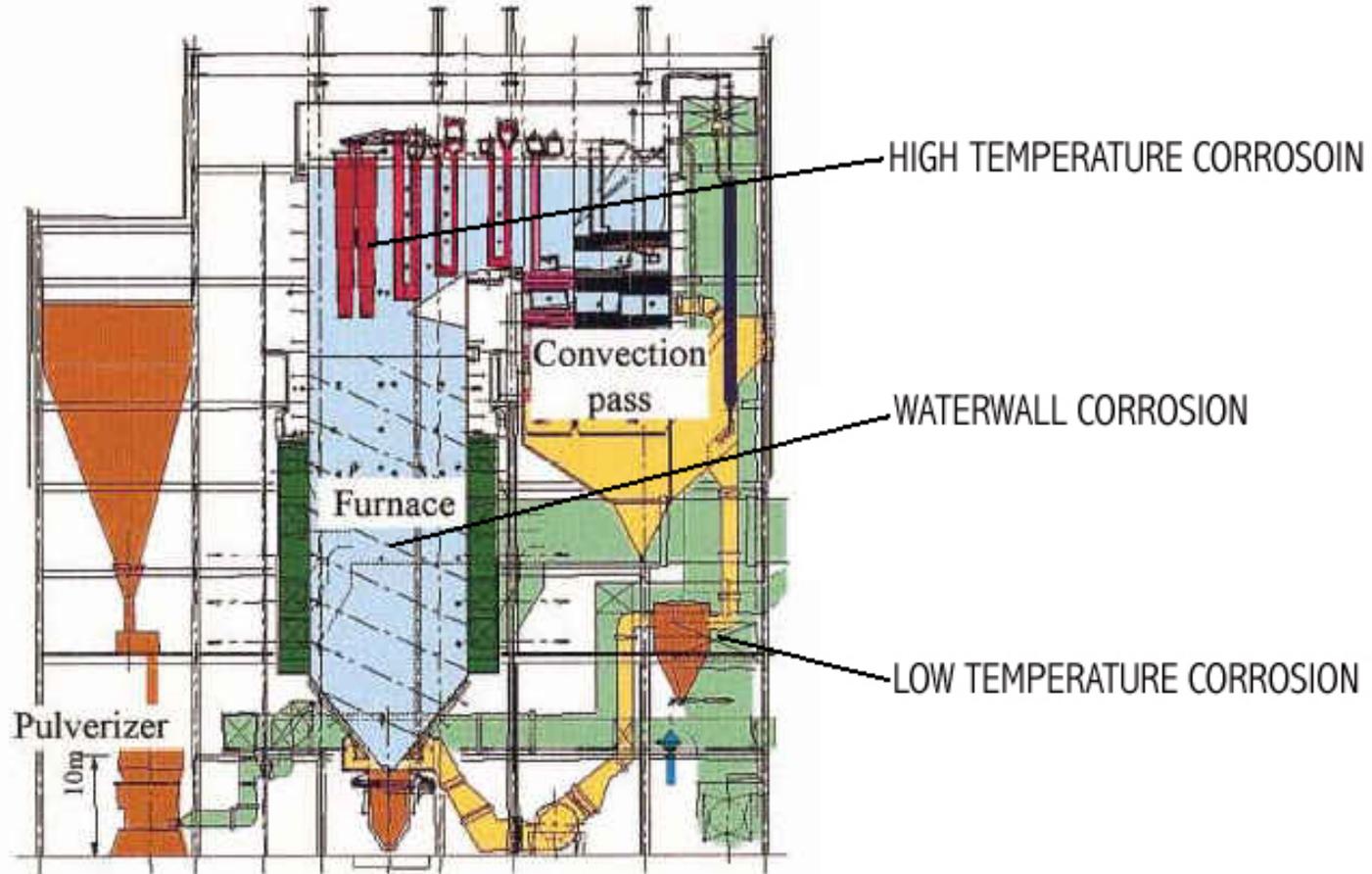
Department of Mechanical Engineering

1150 10<sup>th</sup> Avenue South, Birmingham, AL 35294-4461

Tel: (205) 934-0011, Fax: (205) 975-7217, [hban@uab.edu](mailto:hban@uab.edu)

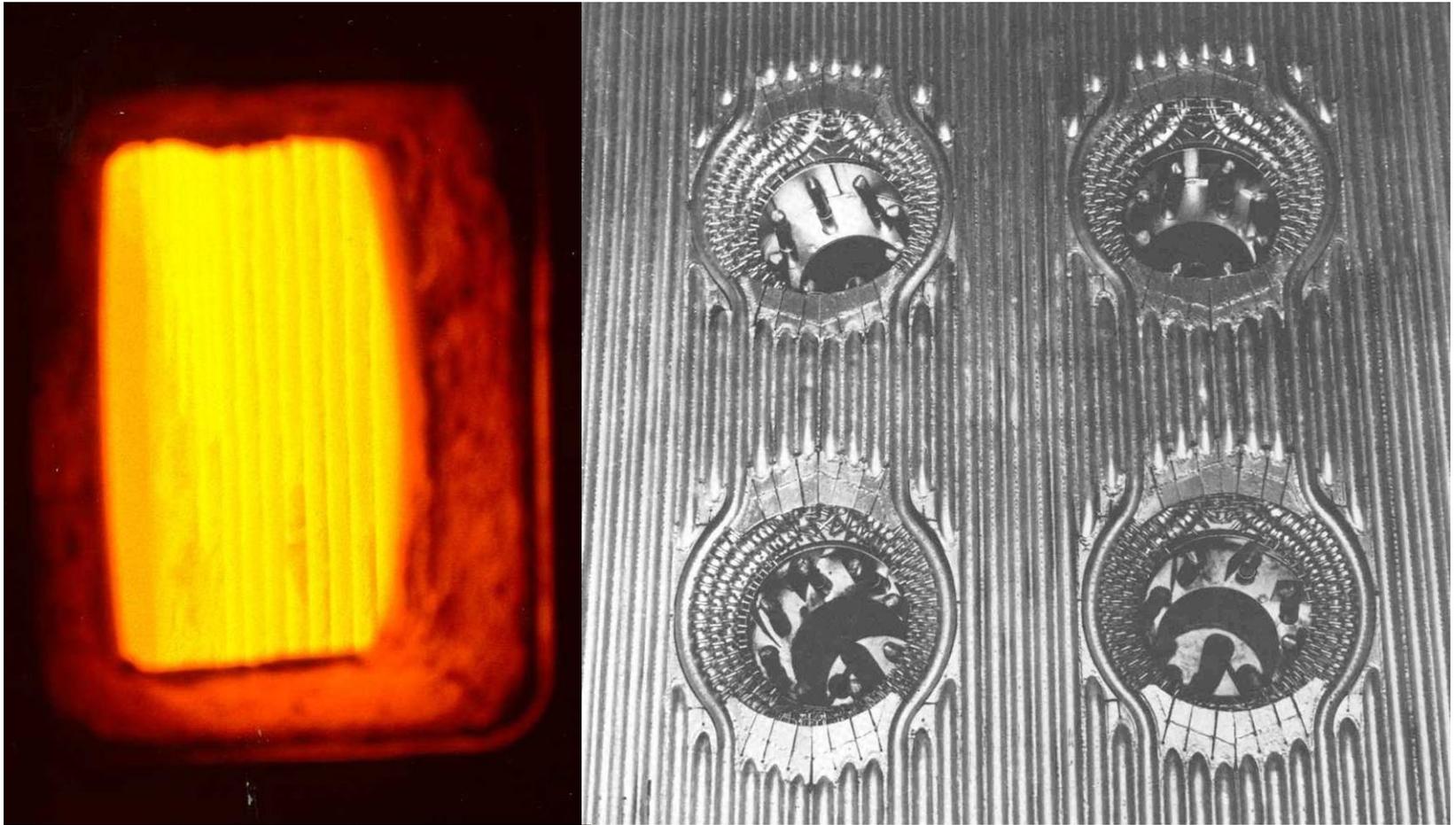
# Fireside Corrosion is a Serious Concern for Fossil Fuel-Fired Steam Generators

---



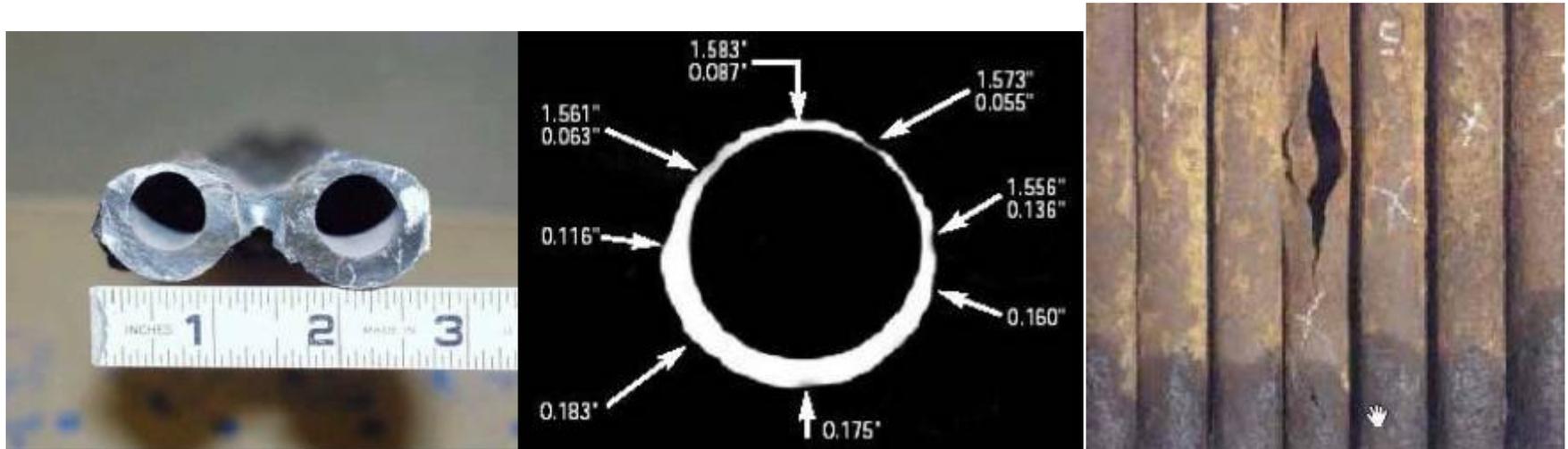
# Water Tubes in a Coal-Fired Boiler

---



# Boiler Tube Fireside Corrosion

---



Tube failure is the leading cause of boiler shutdowns, costing electric utilities \$6.9 billion/yr in USA.

Concerns due to:- low emission combustion mode  
- use of opportunity fuels

# Corrosion Mechanism and Rate

---

- Mechanisms are not well understood.
- Corrosion rate is closely linked to the behavior of mineral matter in coal, and conditions in the furnace.
- Furnace wall tubes experience heat flux  $\sim 200\text{-}500 \text{ kW/m}^2$ , temperature  $\sim 350\text{-}400 \text{ }^\circ\text{C}$ .
- Metal depletion rate  $\sim 10\text{-}500 \text{ nm/hour}$ .

# Why Corrosion Monitoring

---

- Diagnoses of corrosion problems
- Advanced warning of system upsets leading to corrosion damage
- Determination of inspections and /or maintenances
- Estimation of the equipment lifetime

# Corrosion Monitoring Methods

---

- **Off-line, non-continuous measurement**
  - Visual Inspection
  - Radiography (X-Ray)
  - Ultrasonic Testing
  - Weight-loss Coupon
- **On-line, continuous measurement**
  - Electric Resistance (ER) Technique
  - Electrochemical Noise (ECN) Technique

# Commercial Corrosion Probes for Low Temperature Applications

---



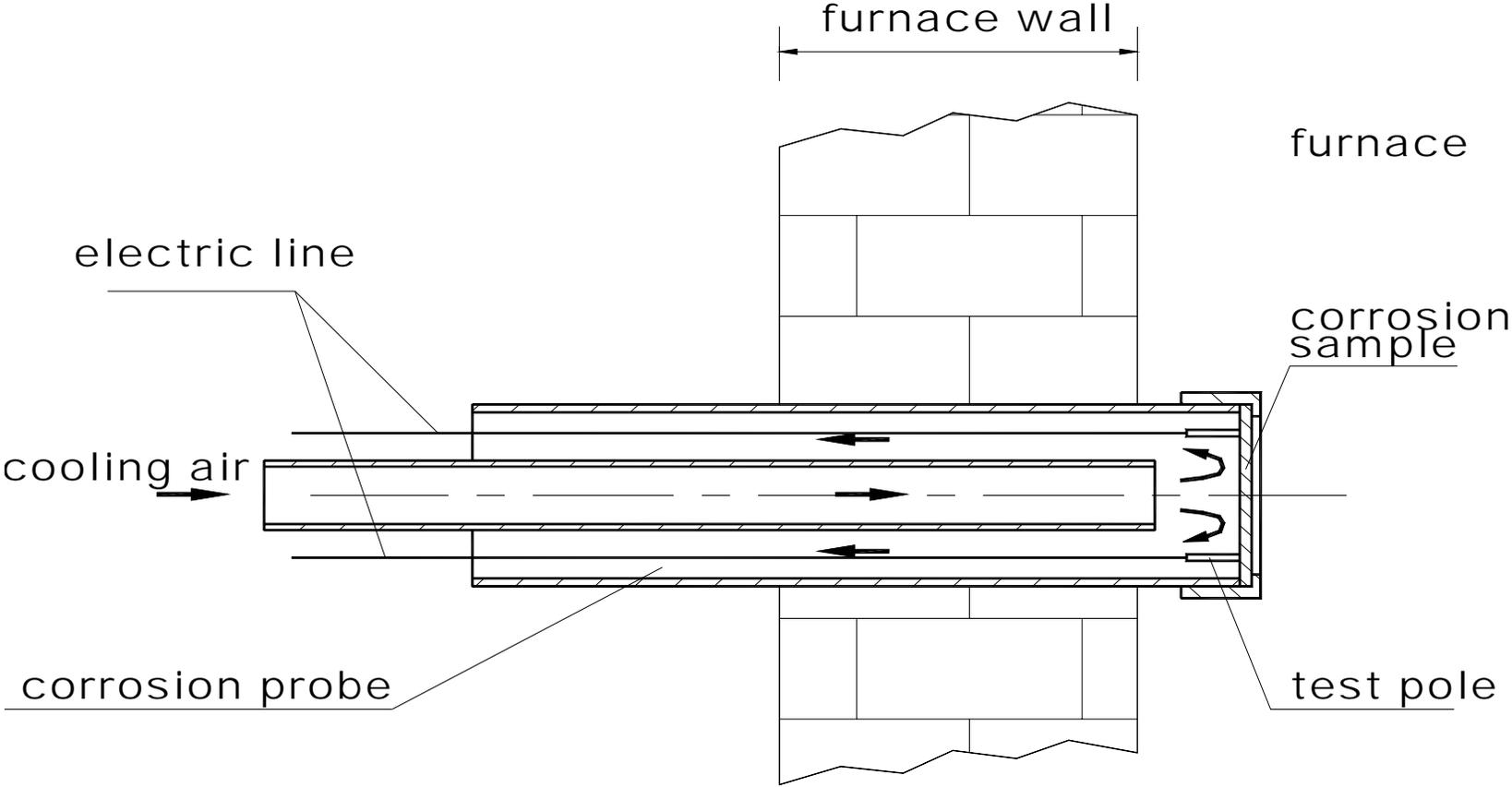
# Challenges

---

- Determine fireside corrosion rate in short-term (for example, in one day) for plant operators to minimize emission and fuel cost without destroying heat exchanging surface.
- Develop an on-line corrosion monitor to be incorporated into the plant control system.

# Schematic Diagram Of Corrosion Probe

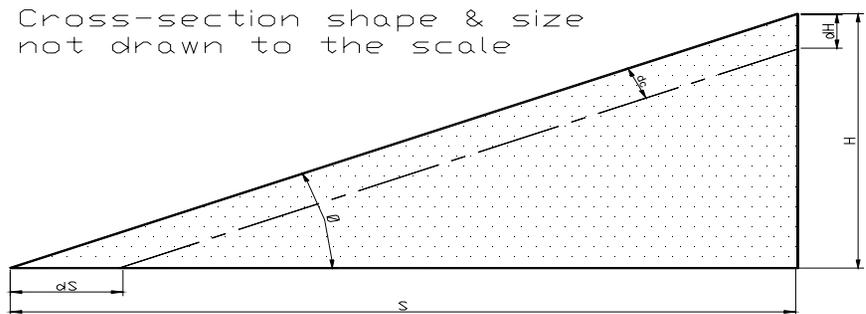
---



# The Idea: Thickness $\Rightarrow$ Area/Length

---

- Convert thickness measurement to length/area measurement. For example, 2  $\mu\text{m}$  in thickness change can be turned into a 2 mm length change (or area).
- Measure electrical capacitance change to determine the area change.



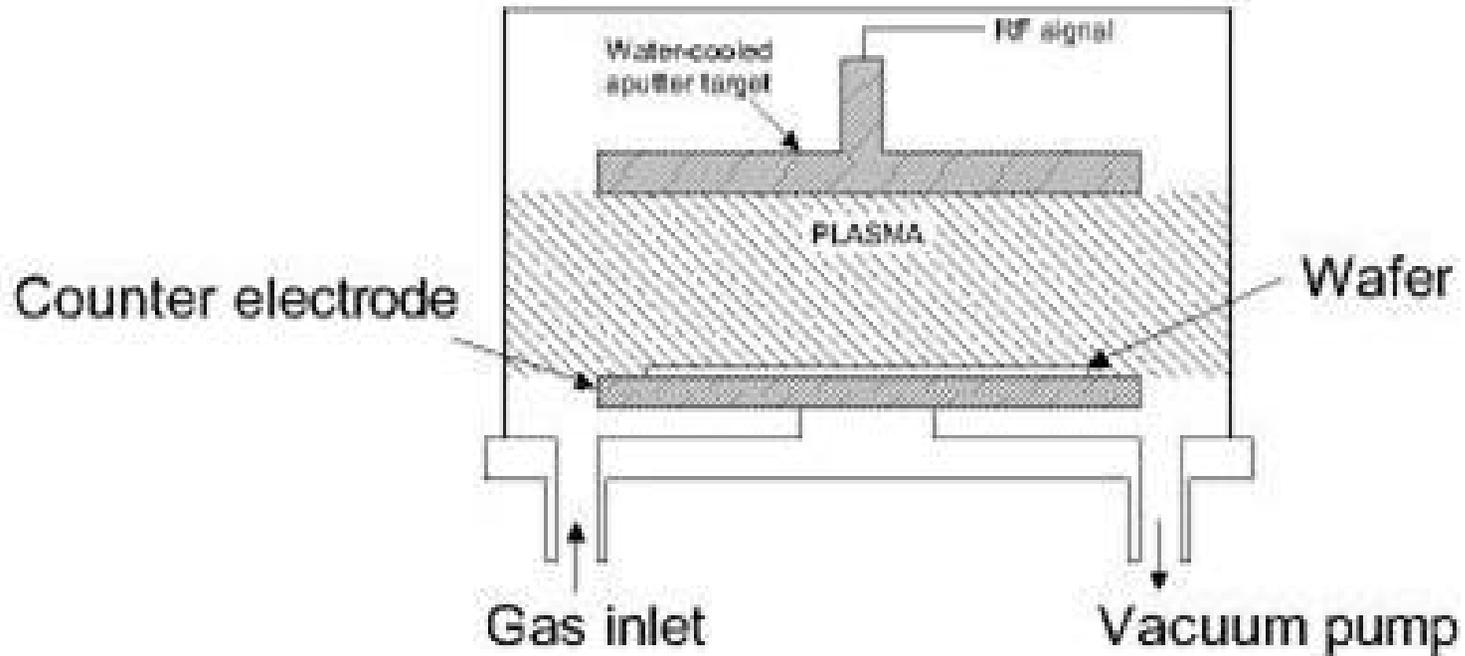
# Objectives

---

- Investigate fabrication methods for the sensor elements.
- Design and test the sensor and the electronic measurement system in a laboratory muffle furnace.
- Improve the sensor and system design for potential pilot and industrial-scale testing.

# Physical Vapor Deposition: Thin Film Sputtering

---



# Sputtering Deposition



Wedge-shaped Coating

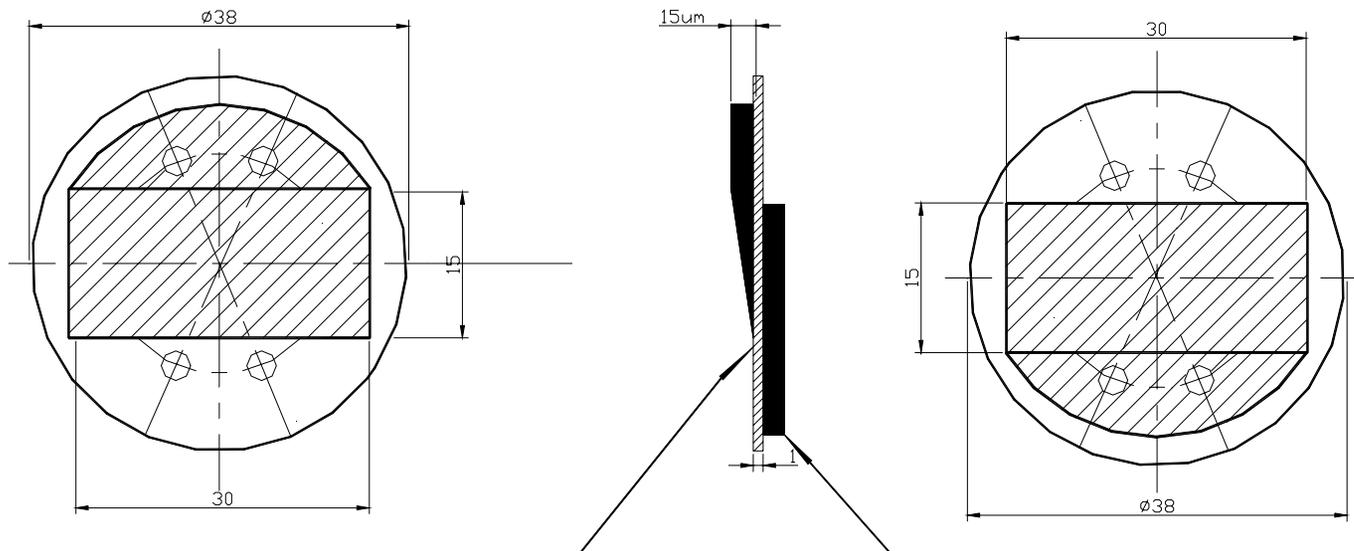


Backside coating

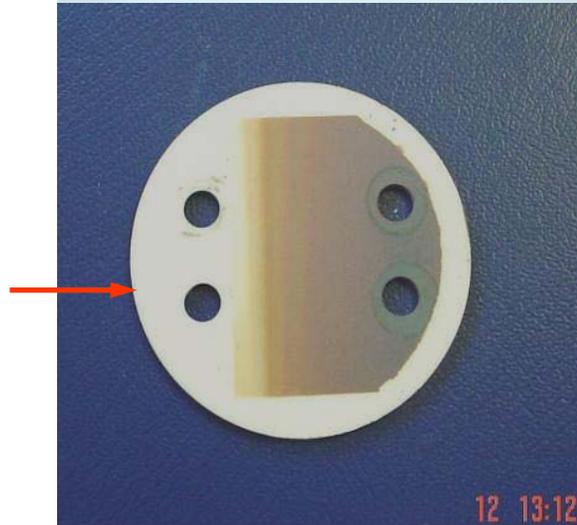
# Sensor Element Design

---

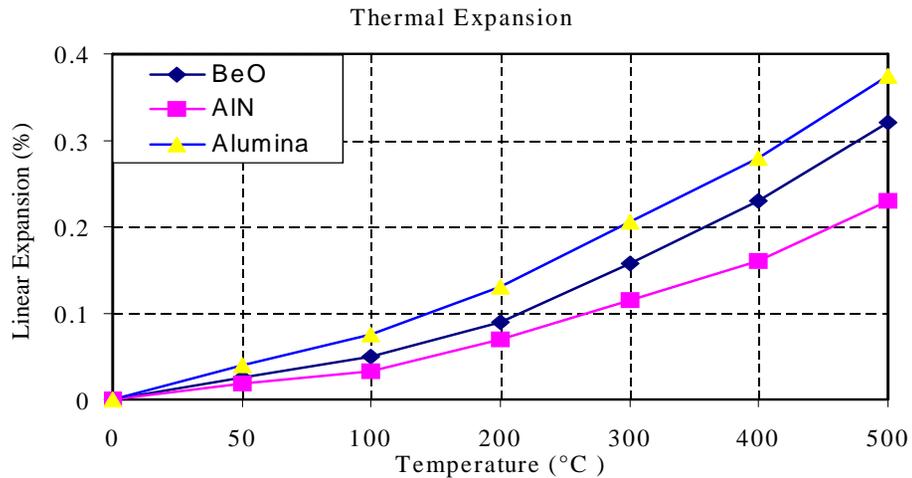
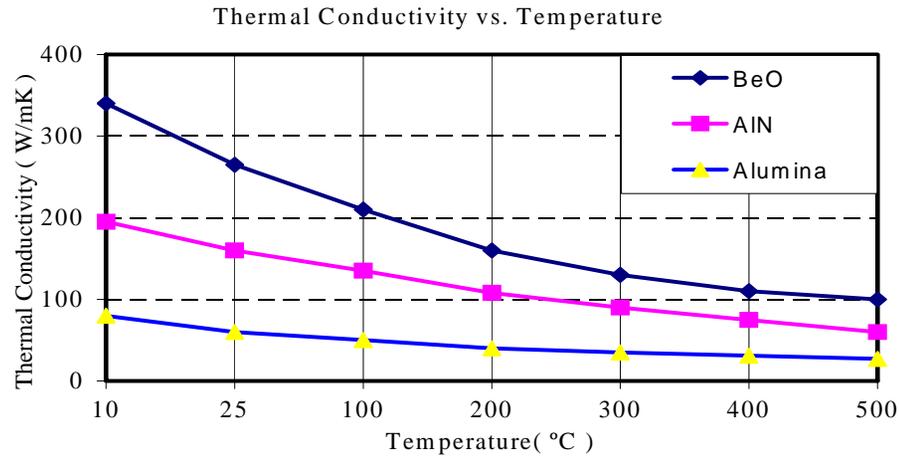
Coating not drawn to scale



# Capacitance Sensor

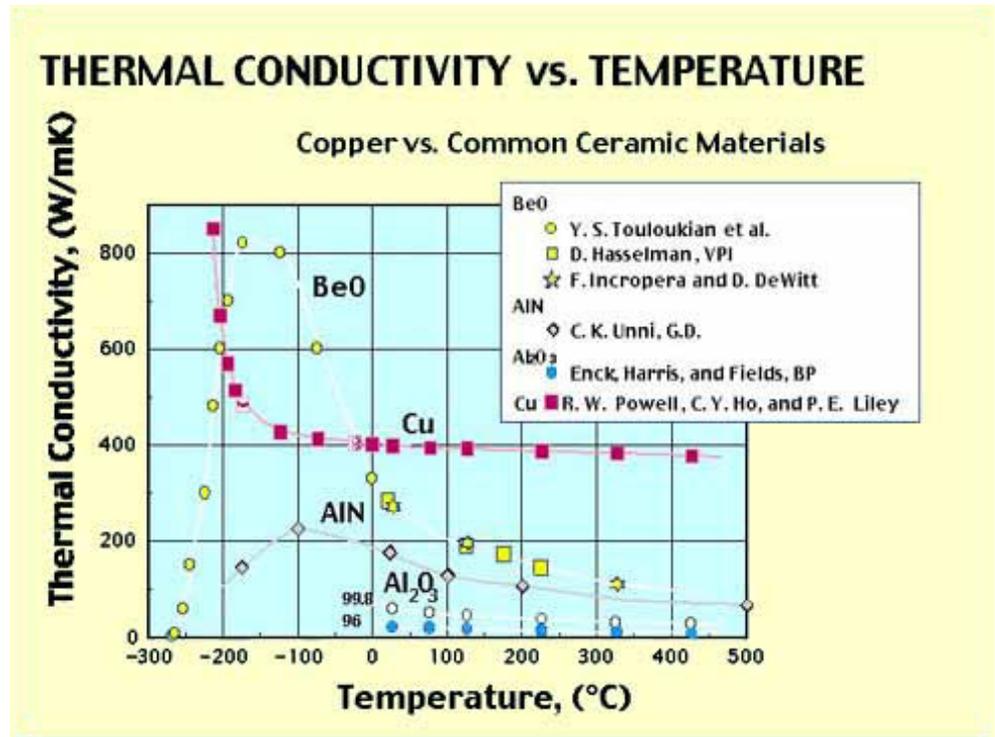


# Thermophysical Properties



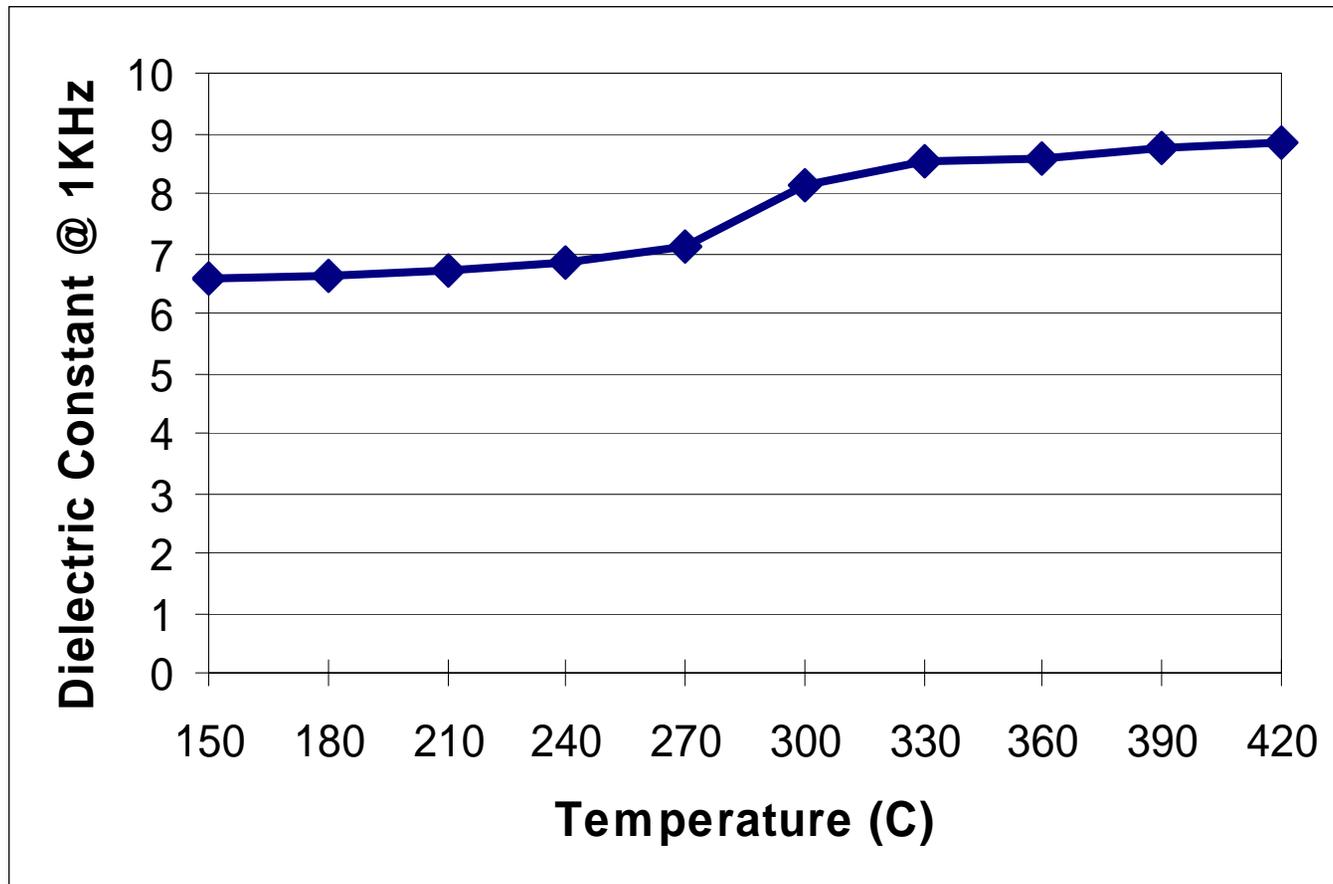
# BeO, AlN, and Alumina Substrate

- High thermal conductivity
- Thermal expansion
- Dielectric constant
- High electrical resistivity
- High flexural strength
- Excellent surface characteristics
- Toxicity (BeO)



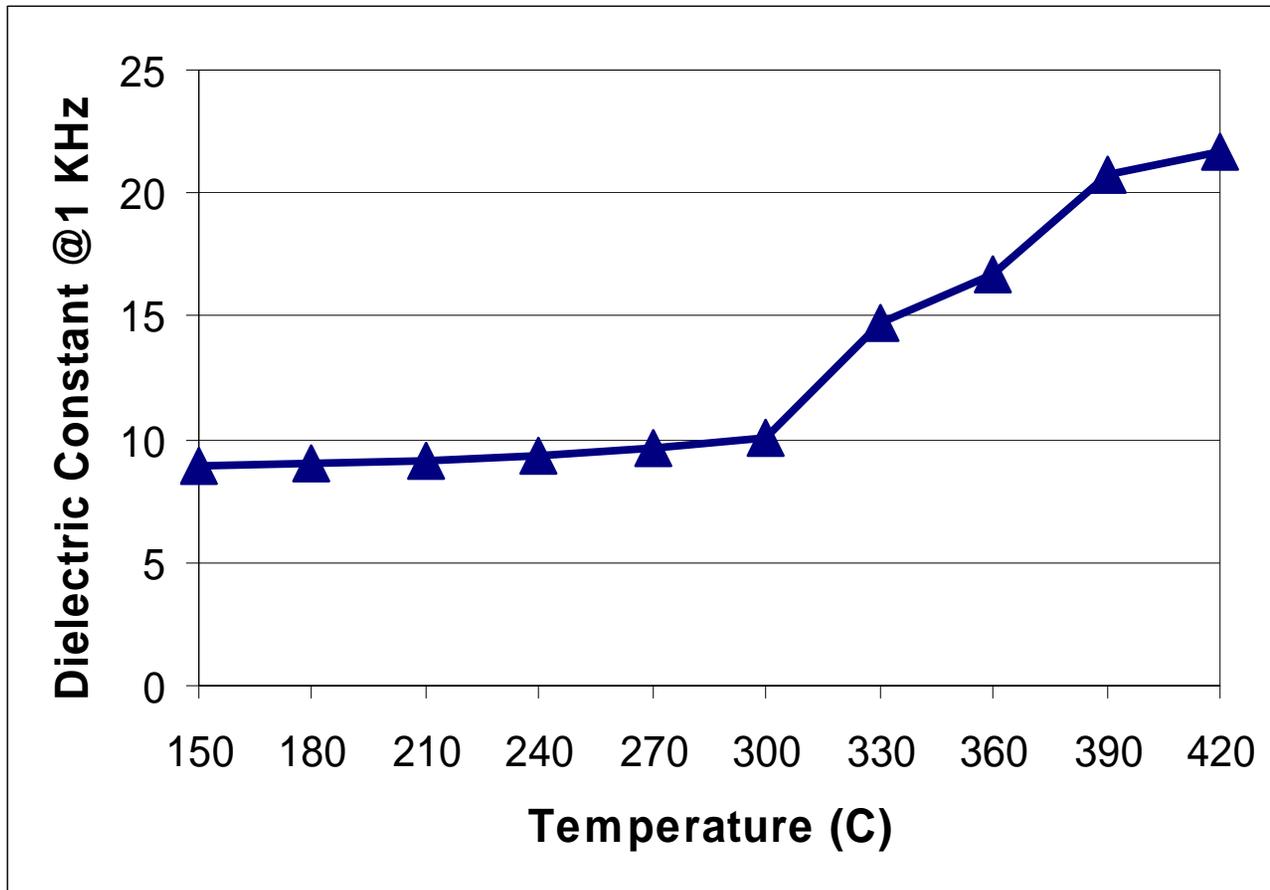
# Dielectric Constant of BeO

---



# Dielectric Constant of AlN

---



# Capacitance Measurement

---

Multi-frequency  
0.0001 pF – 99999  $\mu$ F  
4-wire measurement  
Computer connection

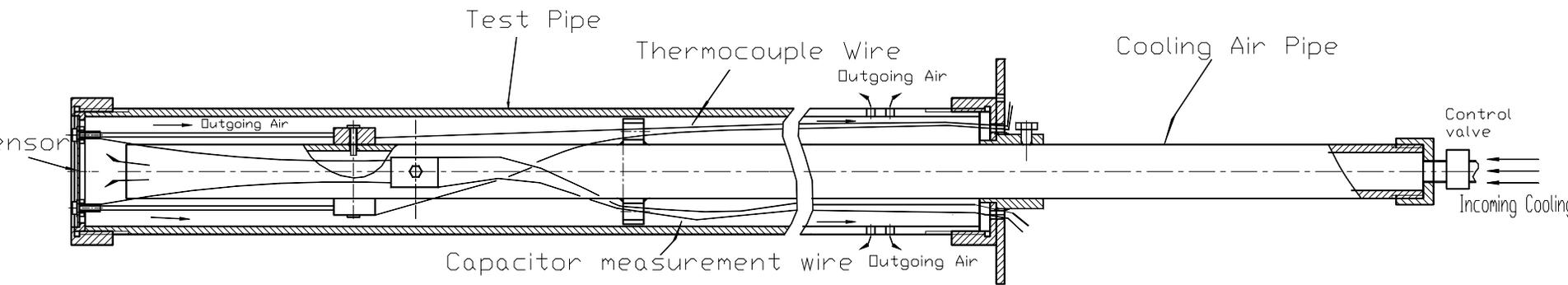


Low cost (< \$300)  
2-frequency  
4-digit, handheld



# Probe Design

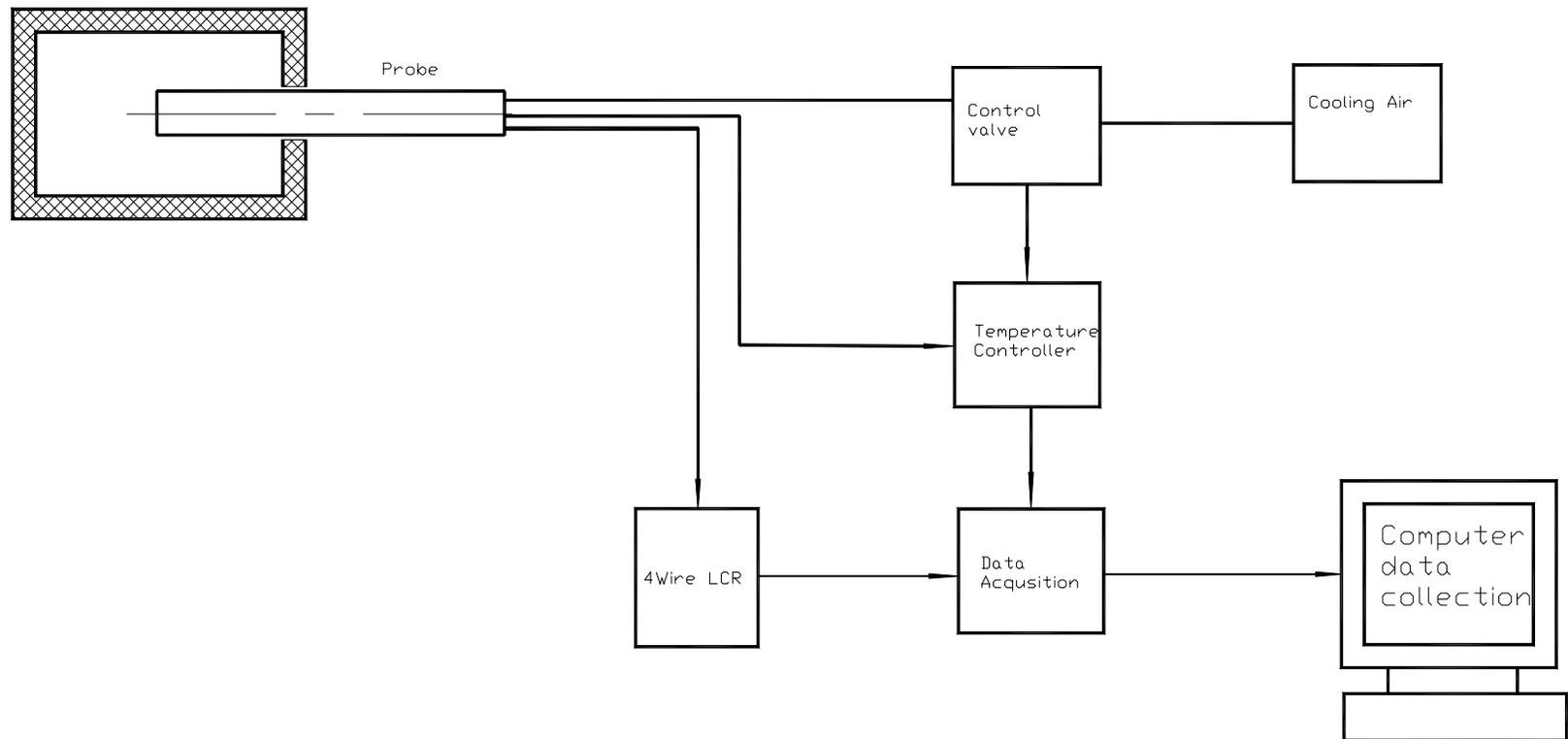
---



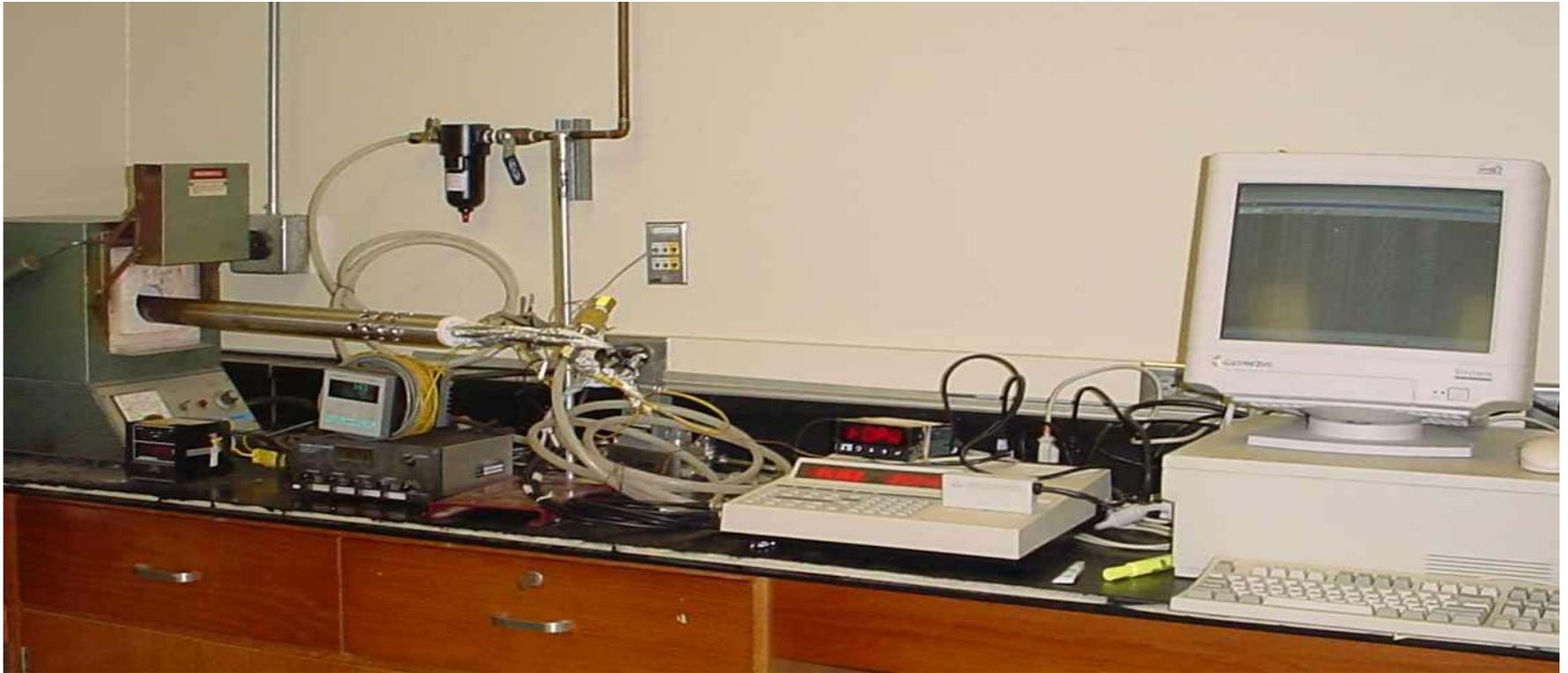
# Measurement System Diagram

---

Muffle Furnace

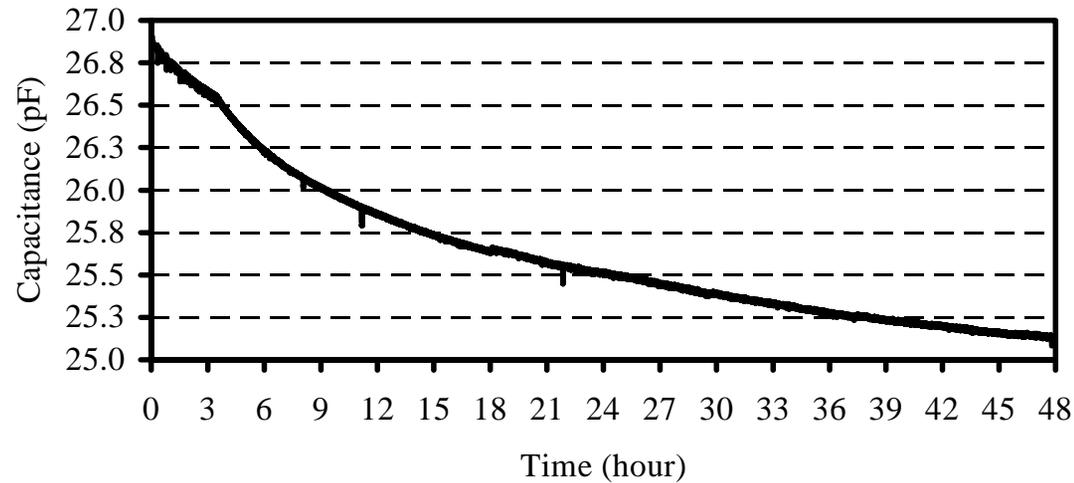


# Laboratory Setup

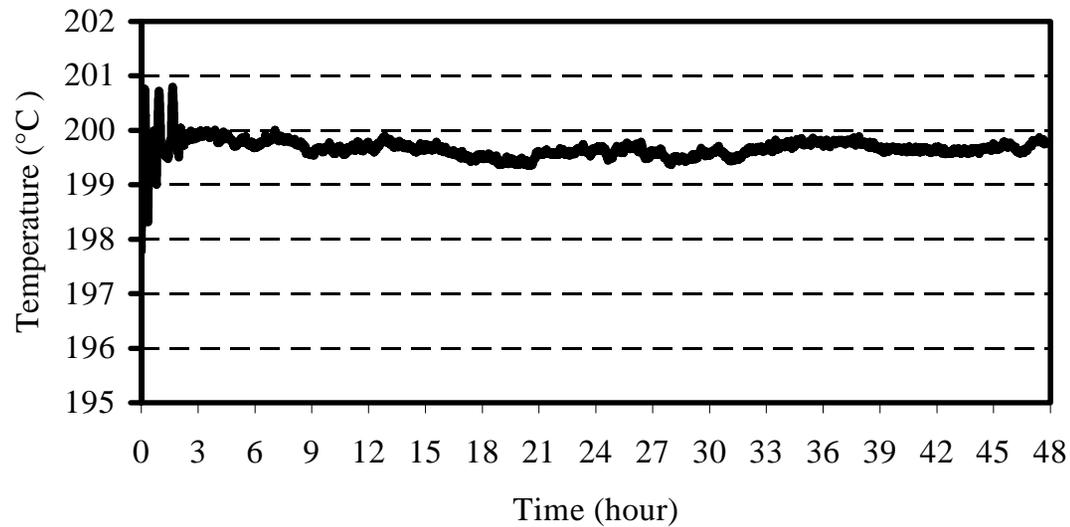


# Test Result

Capacitance change during corrosion test at 200°C

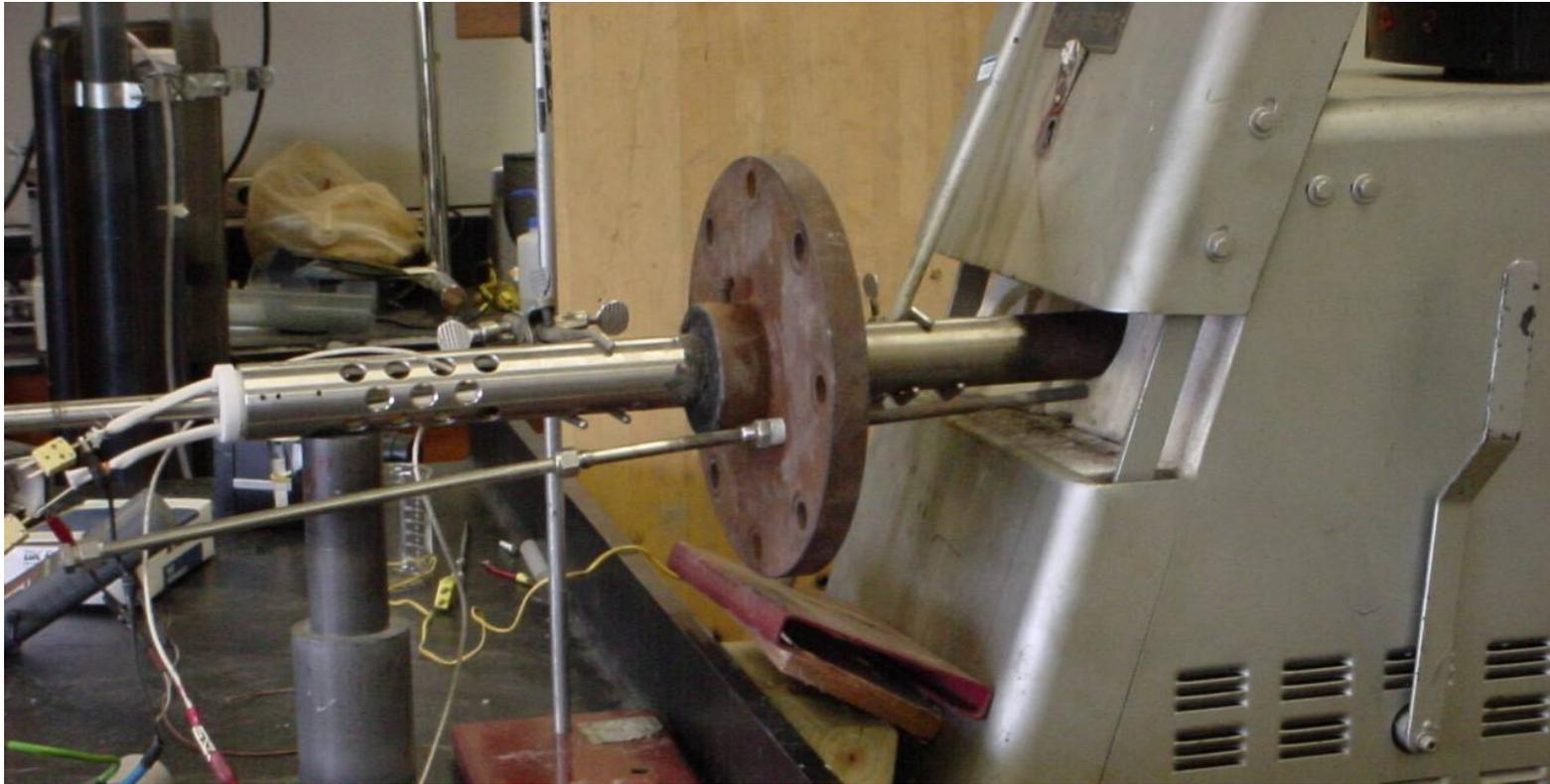


Temperature fluctuation during corrosion test at 200°C



# Probe Picture

---

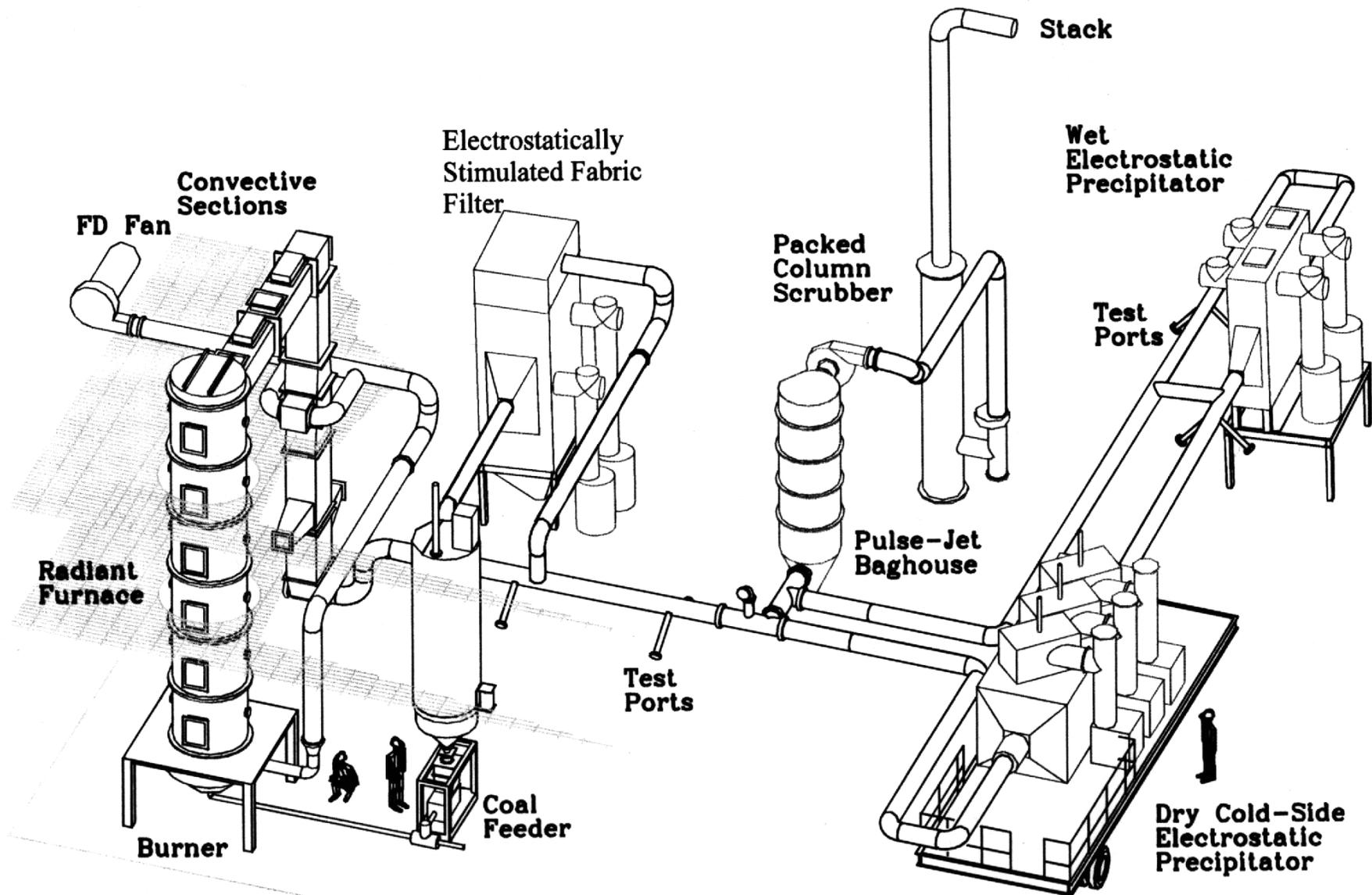


# Probe Assembly



# SOUTHERN RESEARCH COMBUSTION RESEARCH FACILITY

Birmingham, AL



# Corrosion Probe at SRI Combustor

---



# Power Plant with Biomass Co-Firing



# Probe Installation at Plant



# Probe Operation at Plant



View Port

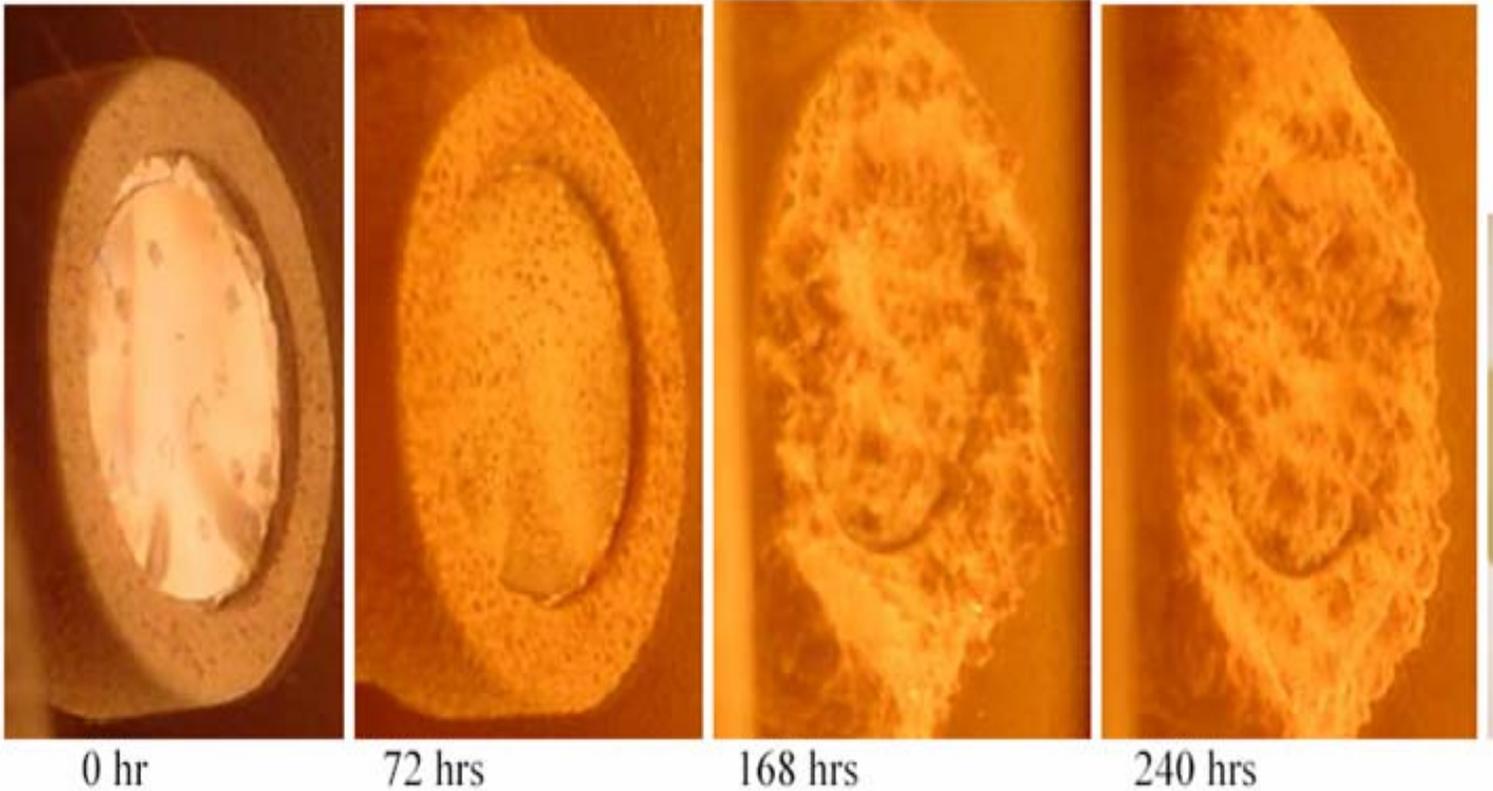


Viewing with a mirror

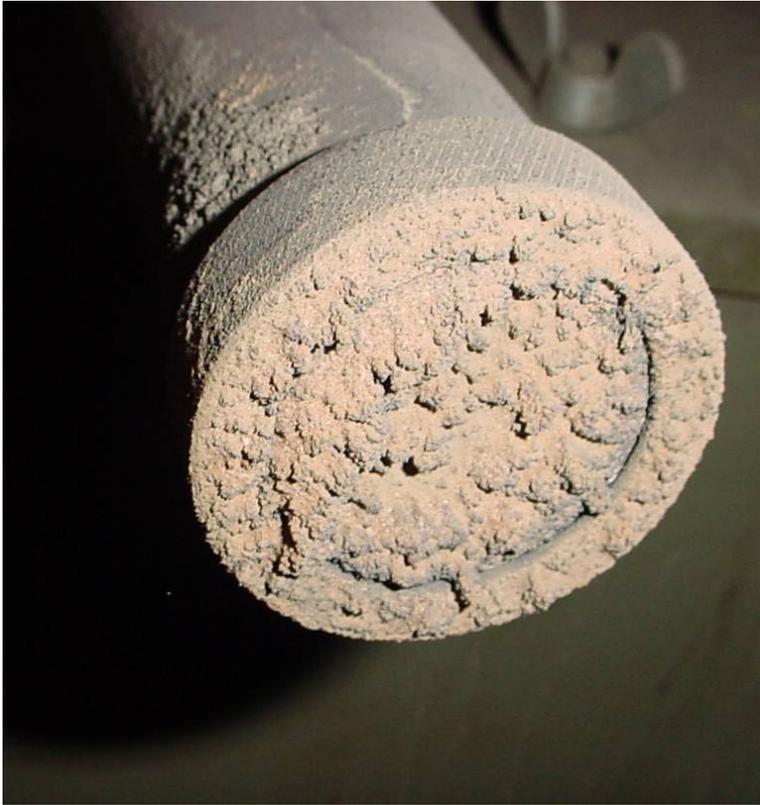
# Control and Measurement Unit



# Ash Deposition on the Coupon



# Coupon after experiment



# Work Completed

---

- Assemble the corrosion sensor and the measurement system.
- Conduct laboratory muffle furnace tests to obtain data on system performance.

# Future Work

---

- Conduct tests at SRI pilot coal combustion furnace ( $1 \text{ MW}_{\text{th}}$ ).
- Improve the system design and test it at a coal-fired power plant.

# Acknowledgement

---

- Financial support from DOE UCR
- Susan Maley (DOE NETL)
- Participants
  - Dr. Bochuan Lin (UAB)
  - Zhuorui Song (UAB)