HIGH TEMPERATURE GAS SENSOR FOR COAL COMBUSTION SYSTEM

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OUTLINE

- Background & Scientific Approaches
- Project Objectives
- Project Team
- Planned Tasks & Milestones
- Research & Development Progress
- Summary
Background

Efficiency = 39%

Optimization of combustion process

Sensor
## Background

<table>
<thead>
<tr>
<th>Furnace</th>
<th>Coal flow</th>
<th>Electrostatic or microwave-based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Combustion air flow</td>
<td>Pitot tubes, Venturis, thermal mass flow meters</td>
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<tr>
<td></td>
<td>Temperature</td>
<td>Thermocouple, IR or acoustic pyrometry, TDLAS</td>
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<td></td>
<td>Oxygen</td>
<td>Electrochemical cell, paramagnetic</td>
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<td></td>
<td>CO</td>
<td>NDIR, catalytic bead, TDLAS</td>
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<td></td>
<td>Presence/quality of flame</td>
<td>UV/vis/IR detector, optical imaging</td>
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<td></td>
<td>Heat flux</td>
<td>Heat flux sensors (thermocouple or RTD-based)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Emissions monitoring and pollutant control</th>
<th>NO and NO₂</th>
<th>CLD, UV photometry, electrochemical cell</th>
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<tbody>
<tr>
<td></td>
<td>SO₂</td>
<td>NDIR, UV photometer, FTIR</td>
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<td></td>
<td>Hydrocarbons</td>
<td>Flame ionisation detector</td>
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<tr>
<td></td>
<td>CO</td>
<td>NDIR, catalytic bead</td>
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<td>Particulates</td>
<td>Optical opacity</td>
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<tr>
<td></td>
<td>NH₃ slip</td>
<td>UV photometry, diode laser/mid-IR absorption</td>
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<td></td>
<td>H₂/CO₂/CH₄</td>
<td>Thermal conductivity detector</td>
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<td>Limestone slurry pH</td>
<td>Electrochemical</td>
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<tr>
<td></td>
<td>Mercury</td>
<td>UV absorption</td>
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<td></td>
<td>Carbon-in-ash</td>
<td>Microwave-based</td>
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</table>
The variation of key combustion parameters with air/fuel ratio
**CO₂ or NOₓ sensing?**

Rate of change of CO₂ is rather small at the point of optimum excess air.

CO₂ is not a very sensitive measurement.

NO₂ and NO give opposite signal to mixed-potential type sensors.

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**CO sensing**

CO is a direct measure of the completeness of combustion, unaffected by air infiltration.

Maximum boiler efficiency when the CO is between 100 and 400 ppm.

CO is a very sensitive indicator of improperly adjusted burners.

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**O₂ sensing?**

It uses the probe should be installed close to the combustion Zone.

The flow should be turbulent probe cannot distinguish leakage from excess oxygen left over after combustion.

A relatively insensitive measurement.
High Temperature Gas Sensors

GC/MS, Infrared spectroscopy, Chemiluminescent etc.

SiC-base (Schottky diode) sensors – Silide formation

Physical properties based sensing (mass, dielectric constant, temp, surface stress etc.)

Electro-Chemical Sensors
   Potentiometric
   Amperometric

Requirements

In situ, online sensors
Accurate
Robust
Low cost
Miniature and easy for deployment

Challenges

High temperature
Corrosive conditions
Poisoning gases
Local disturbance
(1) To develop an accurate, robust, high temperature oxygen sensor based on refractory, reliable, catalytically inactive materials capable of monitoring combustion in a coal-fired plant in real time to improve combustion performance;

(2) To investigate the feasibility and sensitivity of a new catalytic/non-catalytic sensor design to detect “oxidizable” target gases at high temperatures where other electrochemical sensors have failed;

(3) To integrate and test the basic components of the proposed sensor in a commercial, 700 MW power plant consistent with TRL-5.
West Virginia University -
• In-depth understanding/modeling of electrochemical reaction – more accurate, better prediction & sensor material selection
• Characterization of electrochemical kinetics toward oxygen and target gas reactions.
• Testing in lab- and industrial environments

Los Alamos National Lab: Experimental Development of High-temperature Sensor

KWJ Engineering – High Temperature Sensor Packaging

Longview Power – Testing site for the High Temperature Gas Sensor
### Project Team Member – Longview Power

<table>
<thead>
<tr>
<th>Location</th>
<th>Monongalia County, near Maidsville, WV</th>
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<tbody>
<tr>
<td>Status</td>
<td>Operational</td>
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<tr>
<td>Commission date</td>
<td>2011</td>
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<td>Owner(s)</td>
<td>Longview Power</td>
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<tr>
<td>Primary fuel</td>
<td>Coal and natural gas</td>
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<tr>
<td>Type</td>
<td>Steam turbine</td>
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<td>Power generation</td>
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<tr>
<td>Nameplate capacity</td>
<td>700 MW</td>
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- Officially a "zero discharge" power plant in WV
- Includes a new air pollution control system that results in emissions that are Among the lowest in the nation for coal plants.
- Emits less CO₂ than most other coal plants because of its **fuel efficiency**
### PLANNED TASKS & MILESTONES

<table>
<thead>
<tr>
<th>I.D.</th>
<th>Task</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
<th>Q7</th>
<th>Q8</th>
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<td>Project Management</td>
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<td>Sensor Testing in Utility Boiler</td>
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#### Task 1.0
Quarterly, annual, and final reports

#### Task 2.0
High temperature gas sensor with the temperature capability up to 1300°C

#### Task 3.0
Packaging for the sensor developed by LANL in Task 2

#### Task 4.0
Library of performance matrix for the sensor in lab-scale power plant simulator

#### Task 5.0
Microstructures of high temperature gas sensor after lab-scale testing

#### Task 6.0
Verification of the electrochemical mechanisms of high temperature gas sensing on maximum reading and temperature-proportional signal.

#### Task 7.0
Library of performance matrix for the sensor in utility boiler & microstructures of high temperature gas sensor after testing

### DECISION POINTS:
1. Q1 – Finish PMP
2. Q3 - Sensing ability (lab) <=800ppm CO concentration in a Po2 range of 0.5-2% @ 1000°C
3. Q7 – Sensing ability (lab) <=400 ppm CO concentration in a Po2 range of 1-3% @ 1000 C
Current Mixed Potential Sensors

\[ E(O_2) \approx -57 \text{mV} \]

\[ E(\text{CO}/\text{CO}_2) \approx -850 \text{mV} \]

**CO electrochemical oxidation kinetics**

\[ i_{CO} = 2FAD_{CO} \frac{C_{CO}}{\delta} \]

**Oxygen reduction kinetics**

\[ i_{O_2} = i_{O_2}^0 \frac{AF}{RT} (E_m - E_{O_2}) \]

Heterogeneous catalysis decrease CO available for electrochemical oxidation

High Temperature Electrochemical Gas Sensors

Determine reducing gas composition in a background of oxygen

Working principle

\[ O_2' + 4e^- \Leftrightarrow 2O^- \] (1) Oxygen reduction

\[ CO' + O^- \Leftrightarrow CO_2' + 2e^- \] (2) CO electrochemical oxidation

\[ CO' + \frac{1}{2}O_2 \Leftrightarrow CO_2' \] (3) CO heterogeneous oxidation

Current Mixed-potential sensors

- Mixed potential sensors
- \( T_{op} < 600 \, ^\circ C \)
- High sensitivity to CO/HCs/NOx
- High durability
- Dense electrodes/Porous electrolyte

Proposed HT sensors

- Oxygen (Free vs Equilibrium)
- \( T_{op} \) up to 1500 \( ^\circ C \)
- Higher sensitivity as \( T \uparrow \) and \( P_{O2} \downarrow \)
- High durability
- One dense and one porous electrode
Sensor Development

**Tapecast Pt/YSZILSCr**

Sensor response to $\text{C}_3\text{H}_6$ around stoichiometry

![Graph showing sensor response to $\text{C}_3\text{H}_6$ around stoichiometry with plots for 650°C and 1000°C.](image)

Mixed potential Theory

- **Cathodic**
- **Anodic**

$$\Delta E_m$$

potential

current

**Stoich Ratio**

(For Ratio=1; $\text{C}_3\text{H}_6=2/\text{9O}_2$)
Sensor Development

\[ \Delta E_1 = \frac{RT}{nF} \ln\left(\frac{P_{O_2,\text{Free}}}{P_{O_2,\text{Eq}}}ight) \]

\[ \Delta E_2 = \frac{RT}{nF} \ln\left(\frac{P_{O_2,\text{Eq}}}{P_{O_2,\text{ref}}}ight) \]
One-chamber design

- Non-catalytic electrode
- YSZ
- Insulating material
- Sealing material
- Current collector
- Catalytic electrode
- V (Voltage)
Sensor Testing – Lab-Scale

One-chamber design sensor

D-3315-65 annealed 900°C, 3 days
2.5%O2, 50% RH, 5%CO2, 500 sccm total flow
0, 100, 250, 500, 750, 1000, 750, 500, 250, 0 ppm
Sensor Development

Two-chamber design

Flue gas → YSZ → Air

- Sensing electrode 1
- Sensing electrode 2
- Current collector
- Reference electrode

Stainless steel tube
Sensor Testing – Lab-Scale

- 1000 °C

- Sensing side:
  - CO/N₂ Bal. || N₂ || air
  - 200 sccm Total
  - P₀₂ = 2.1%

- Ref side:
  - Air
  - 100 sccm

Two-chamber design sensor

Voltage / mV

Time / s

0 ppm 100 ppm 200 ppm 400 ppm 800 ppm 1000 ppm

0 ppm 100 ppm 200 ppm 400 ppm 800 ppm 1000 ppm

0 ppm 100 ppm 200 ppm 400 ppm 800 ppm 1000 ppm

0 ppm 100 ppm 200 ppm 400 ppm 800 ppm 1000 ppm
Sensing Testing – Lab-Scale

- 1000 °C

- Sensing side:
  - CO/N$_2$Bal. || N$_2$ || air
  - 200 sccm$_{Total}$
  - PO$_2$ = 2.1%

- Ref side:
  - Air
  - 100 sccm

Two-chamber design sensor

![Graph showing sensor testing results](chart.png)
- 1000 °C

- Sensing side:
  - CO/N$_2$Bal. || N$_2$
  - 200 sccm$_{Total}$
  - P$_{O2}$ = 2.1%

- Ref side:
  - Air
  - 100 sccm
SUMMARY & FUTURE WORK

Major Progress To-Date

• Two complementary approaches have been developed
• Clearly met the 1st Go/No-Go Target

Future Work

• Continue R&D to meet the 2nd Go/No-Go Target
• Mechanisms Investigations
• Packaging Development
• Prepare for Installation in Longview Boiler
ACKNOWLEDGEMENT

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Technology Manager – Dr. Briggs White
Project Managers – Dr. Sydni Credle, Dr. Barbara Carney
Thanks