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NATIONAL ENERGY TECHNOLOGY LABORATORY

HIGH TEMPERATURE GAS SENSOR FOR COAL COMBUSTION SYSTEM

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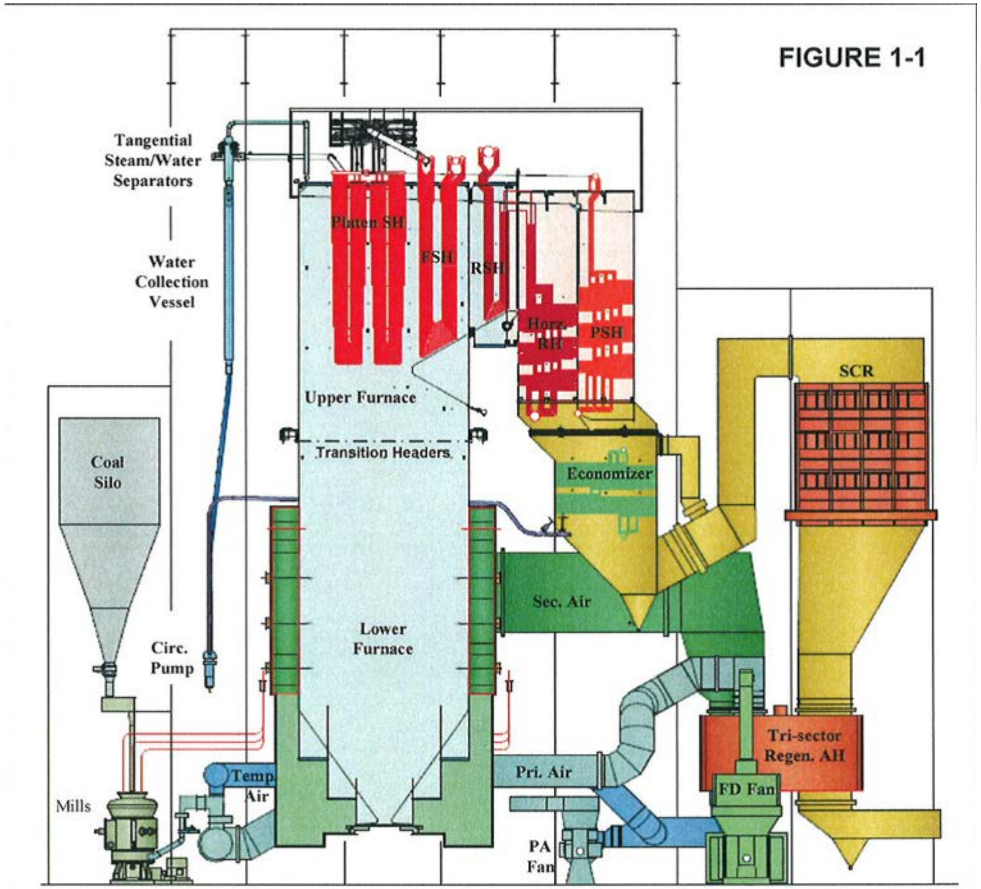
KWJ ENGINEERING INNOVATIVE SOLUTIONS FOR GAS DETECTION

LONGVIEW POWER LLC

OUTLINE

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

Background



Efficiency = 39%

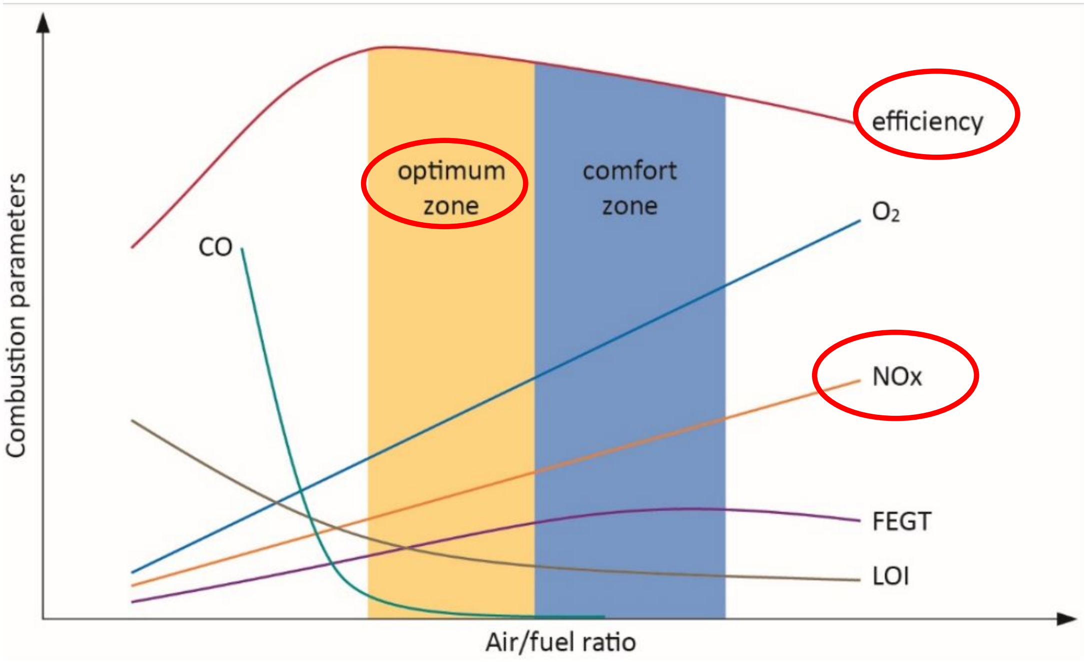
Optimization of combustion process

Sensor

Background

Furnace	Coal flow	Electrostatic or microwave-based
	Combustion air flow	Pitot tubes, Venturis, thermal mass flow meters
	Temperature	Thermocouple, IR or acoustic pyrometry, TDLAS
	Oxygen	Electrochemical cell, paramagnetic
	CO	NDIR, catalytic bead, TDLAS
	Presence/quality of flame	UV/vis/IR detector, optical imaging
	Heat flux	Heat flux sensors (thermocouple or RTD-based)
Emissions monitoring and pollutant control	NO and NO_2	CLD, UV photometry, electrochemical cell
	SO_2	NDIR, UV photometer, FTIR
	Hydrocarbons	Flame ionisation detector
	CO	NDIR, catalytic bead
	Particulates	Optical opacity
	NH_3 slip	UV photometry, diode laser/mid-IR absorption
	$H_2/CO_2/CH_4$	Thermal conductivity detector
	Limestone slurry pH	Electrochemical
	Mercury	UV absorption
	Carbon-in-ash	Microwave-based

Background



The variation of key combustion parameters with air/fuel ratio

Background

CO_2 or NO_x sensing?

Rate of change of CO_2 is rather small at the point of optimum excess air.

CO_2 is not a very sensitive measurement.

NO_2 and NO give opposite signal to mixed-potential type sensors

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.

O_2 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

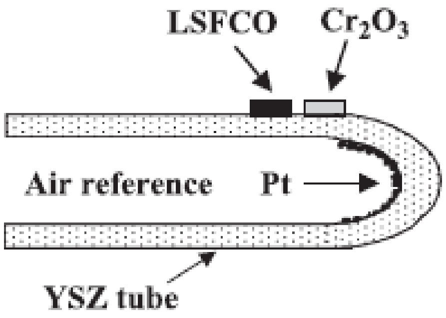
GC/MS, Infrared spectroscopy, Chemiluminescent etc.

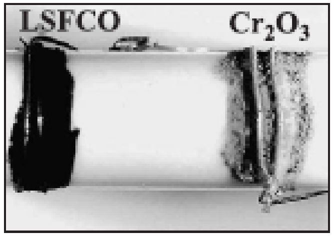
SiC-base (Schottky diode) sensors – Silide formation

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

Electro-Chemical Sensors

- Potentiometric
- Amperometric





Nicholas F. Szabo, Prabir K. Dutta: Correlation of sensing behavior of mixed potential sensors with chemical and electrochemical properties of electrodes, Solid State Ionics 171 (2004) 183–190

Background

Requirements

In situ, online sensors

Accurate

Robust

Low cost

Miniature and easy for deployment

Challenges

High temperature

Corrosive conditions

Poisoning gases

Local disturbance

PROJECT OBJECTIVES

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(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.

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PROJECT TEAM

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

Location	Monongalia County, near Maidsville, WV
Status	Operational
Commission date	2011
Owner(s)	Longview Power
Thermal power station	
Primary fuel	Coal and natural gas
Type	Steam turbine
Power generation	
Nameplate capacity	700 MW

- 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 CO_2 than most other coal plants because of its fuel efficiency

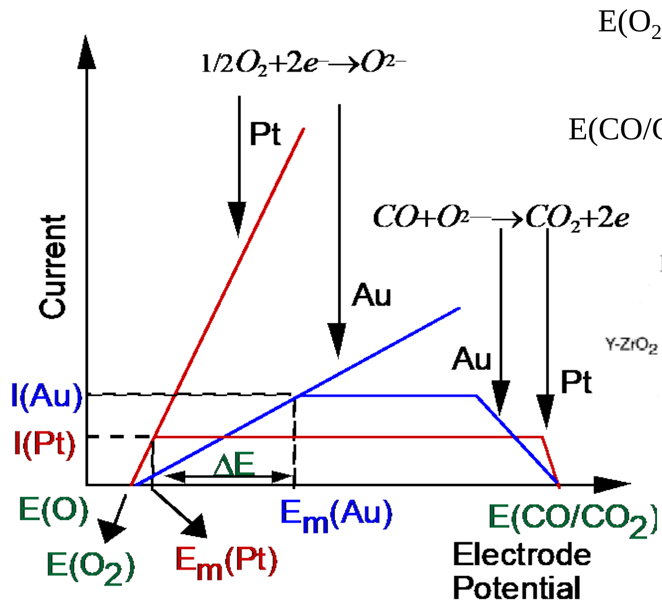
PLANNED TASKS & MILESTONES

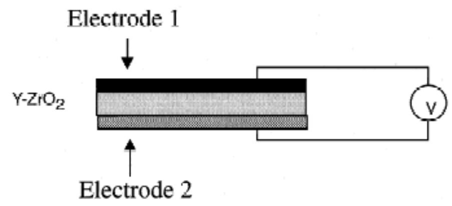
I.D.	Task								
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1.0	Project Management	■	■	■	■	■	■	■	■
2.0	Sensor Development	■	■	■		■	■		
3.0	Sensor Packaging		■	■			■		
4.0	Lab-scale Sensor Testing		■	■			■	■	
5.0	Post-mortem Characterization			■	■			■	■
6.0	Electrochemical Mechanisms Investigation	■	■	■	■	■	■		
7.0	Sensor Testing in Utility Boiler							■	■

Task 1.0 Quarterly, annual, and final reports
Task 2.0 High temperature gas sensor with the temperature capability up to 1300^{o}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

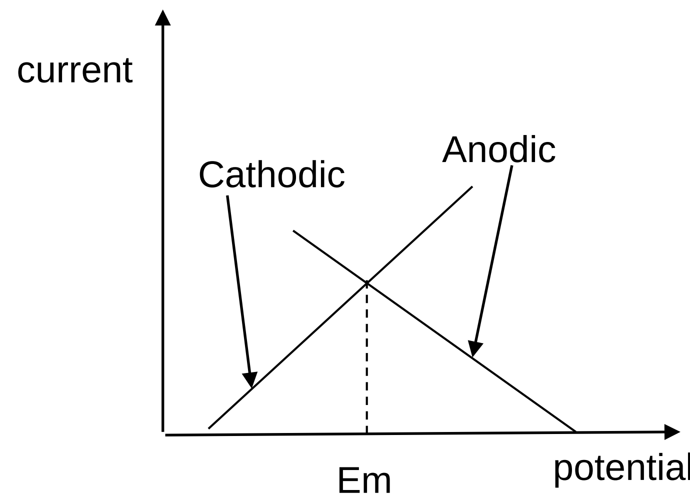
DECISION POINTS:
1.Q1 – Finish PMP
2.Q3 - Sensing ability (lab) <=800ppm CO concentration in a Po_2 range of 0.5-2% @ 1000C
3.Q7 – Sensing ability (lab) <=400 ppm CO concentration in a Po_2 range of 1-3% @ 1000 C

Current Mixed Potential Sensors





Mixed Potential Theory

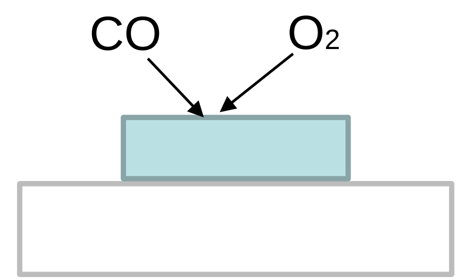


CO electrochemical oxidation kinetics

$$i_{CO} = 2FAD_{CO}\frac{C_{CO}}{\delta}$$

Oxygen reduction kinetics

$$i_{O_2} = i^{o}_{O_2}\frac{4F}{RT}(Em - E_{O_2})$$



Heterogeneous catalysis decrease CO available for electrochemical oxidation

Fernando H. Garzon, ***Rangachary Mukundan***, Eric L. Brosha: Solid-state mixed potential gas sensors: theory, experiments and challenges, Solid State Ionics 136–137 (2000) 633–638

High Temperature Electrochemical Gas Sensors

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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 ºC
- High sensitivity to CO/HCs/NOx
- High durability
- Dense electrodes/Porous electrolyte

Proposed HT sensors

- Oxygen (Free vs Equilibrium)
- T_{op} up to 1500 ºC
- Higher sensitivity as T↑ and P_{O2}↓
- High durability
- One dense and one porous electrode

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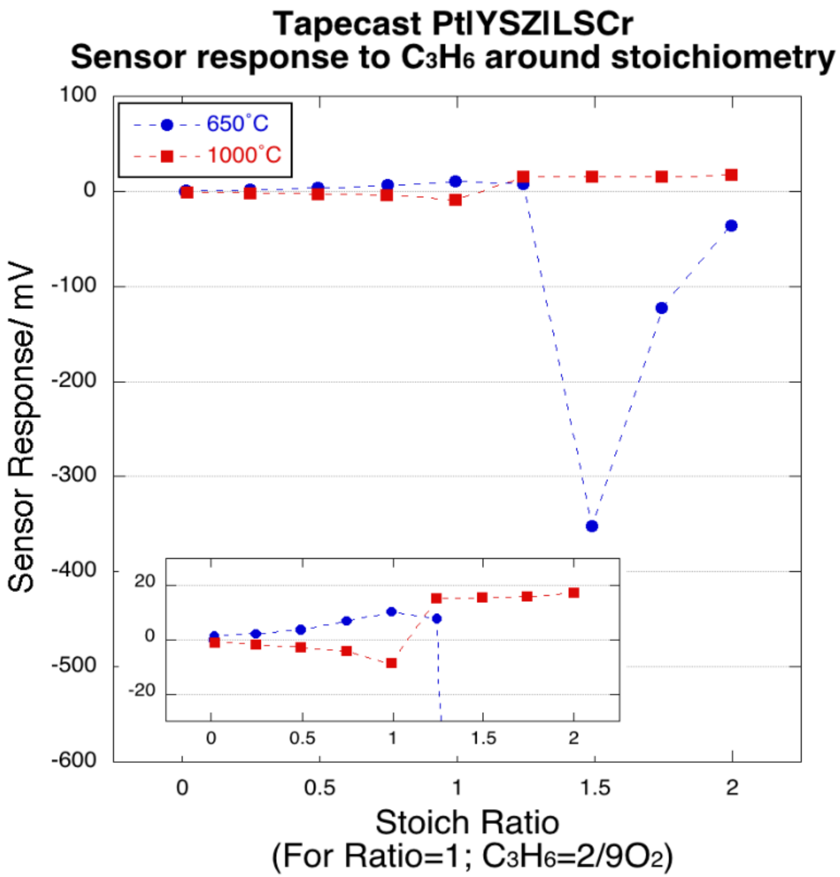
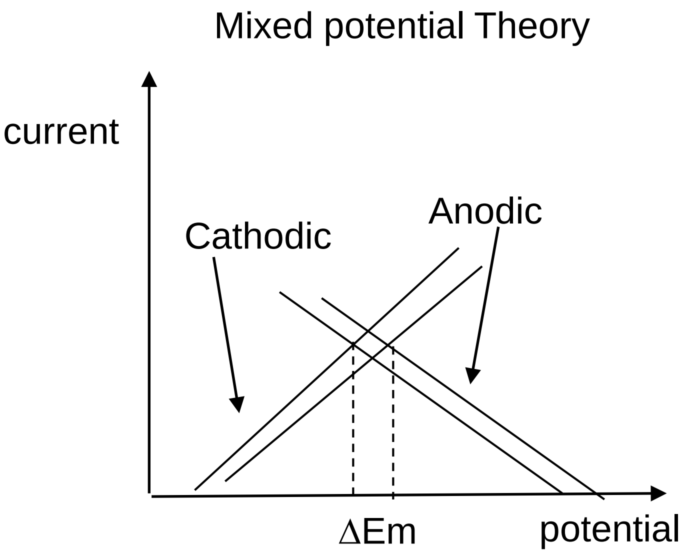
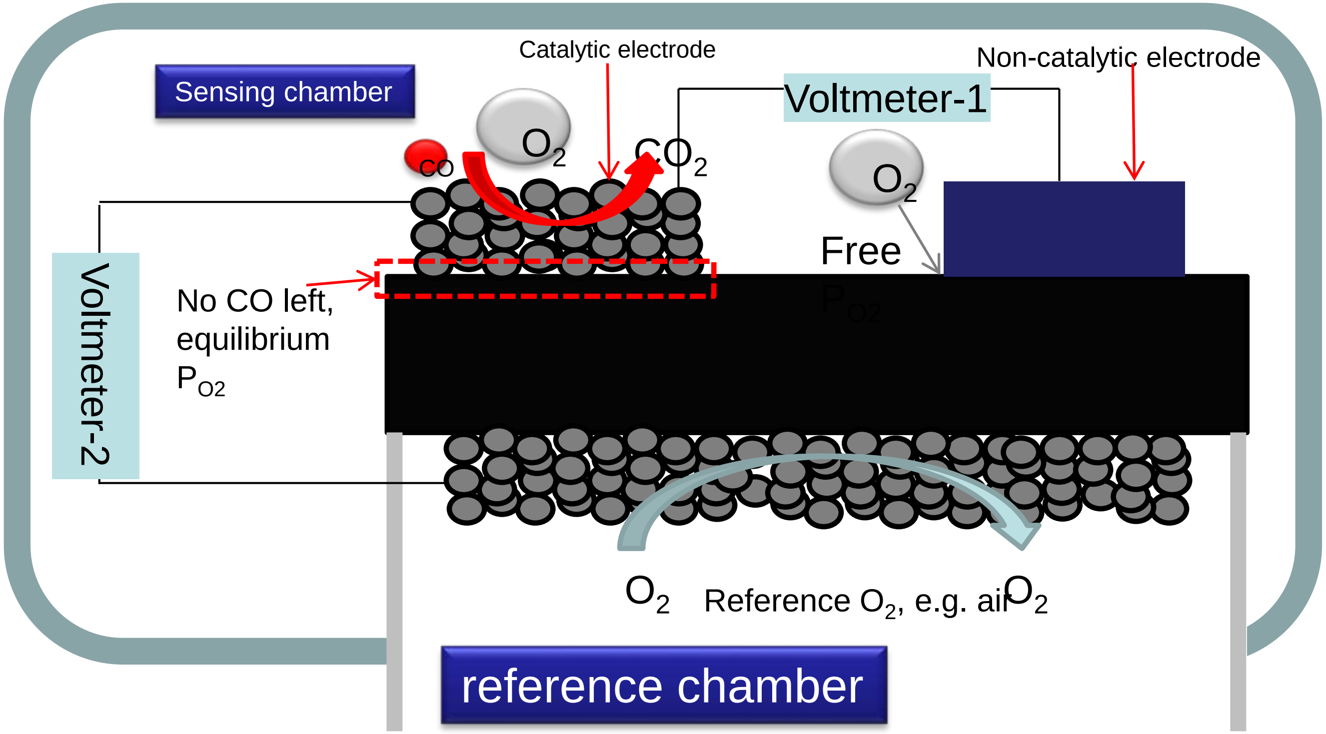
Sensor Development





Sensor Development

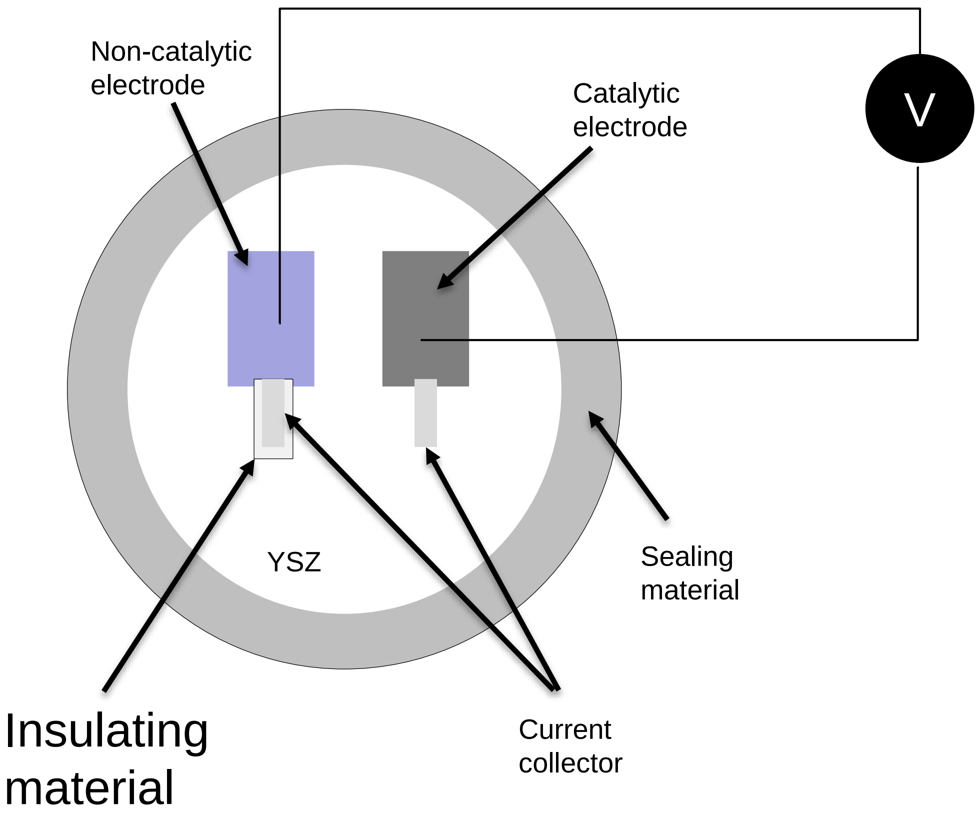


$$\Delta E_1 = \frac{RT}{nF}\ln\left(\frac{P_{O2,Free}}{P_{O2,Eq}}\right)$$

$$\Delta E_2 = \frac{RT}{nF}\ln\left(\frac{P_{O2,Eq}}{P_{O2,\ ref}}\right)$$

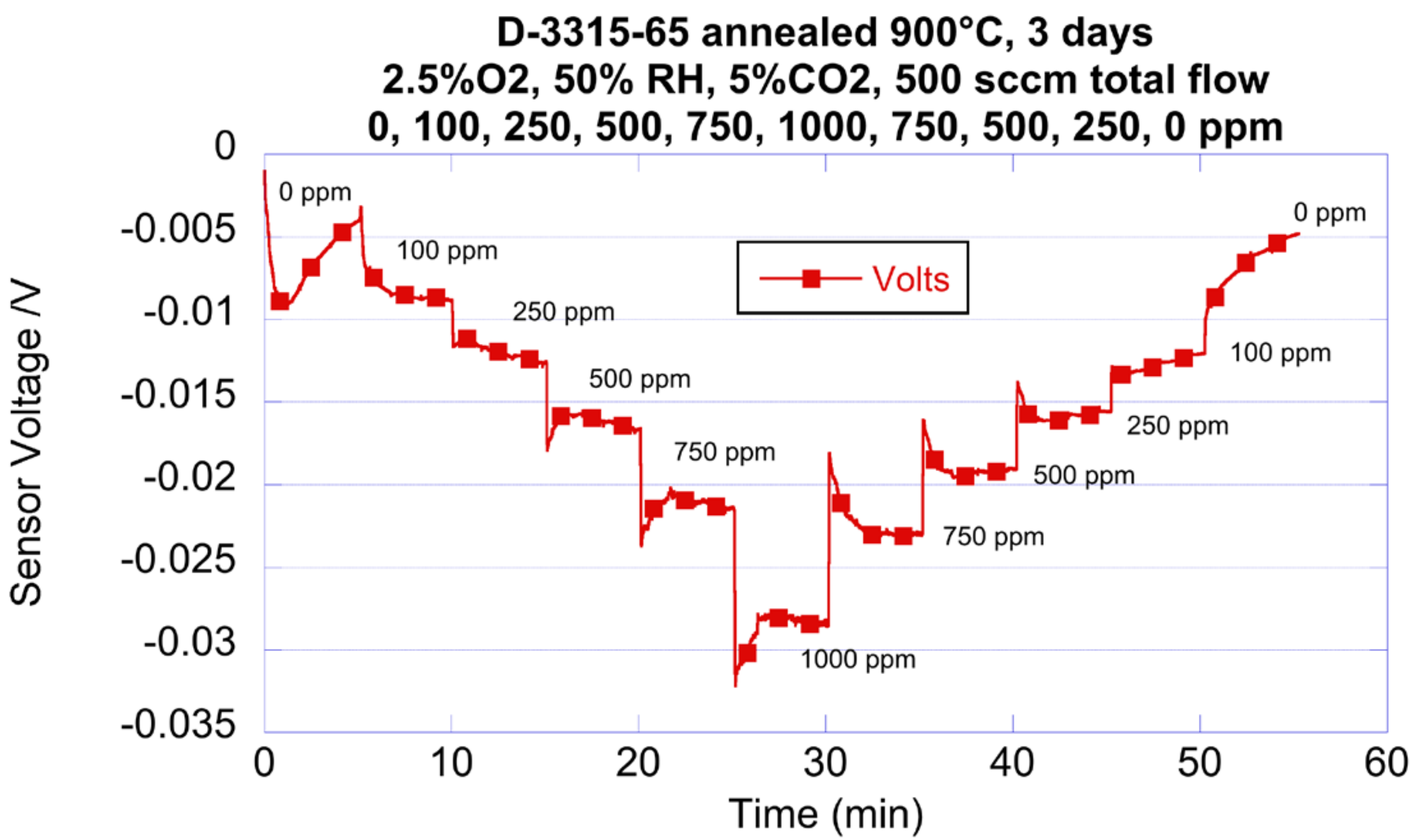
Sensor Development

One-chamber design



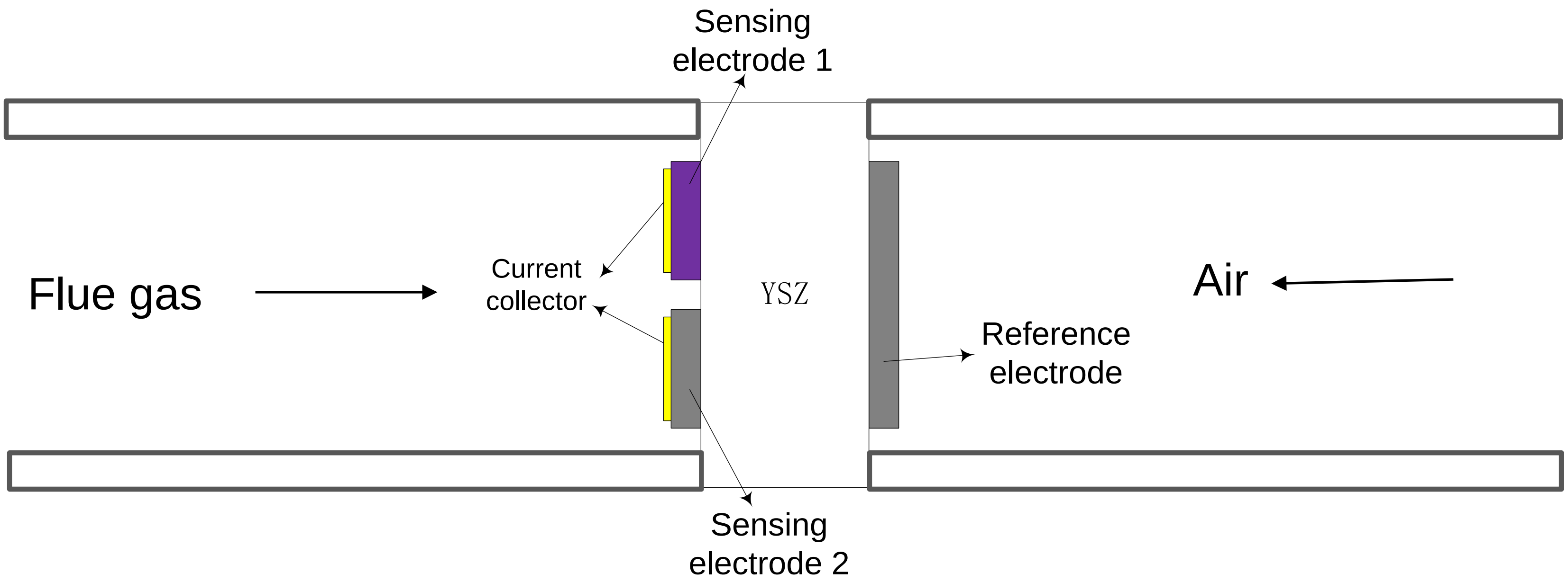
Sensor Testing – Lab-Scale

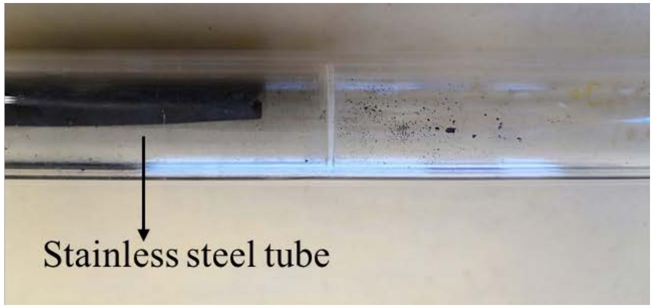
One-chamber design sensor



Sensor Development

Two-chamber design





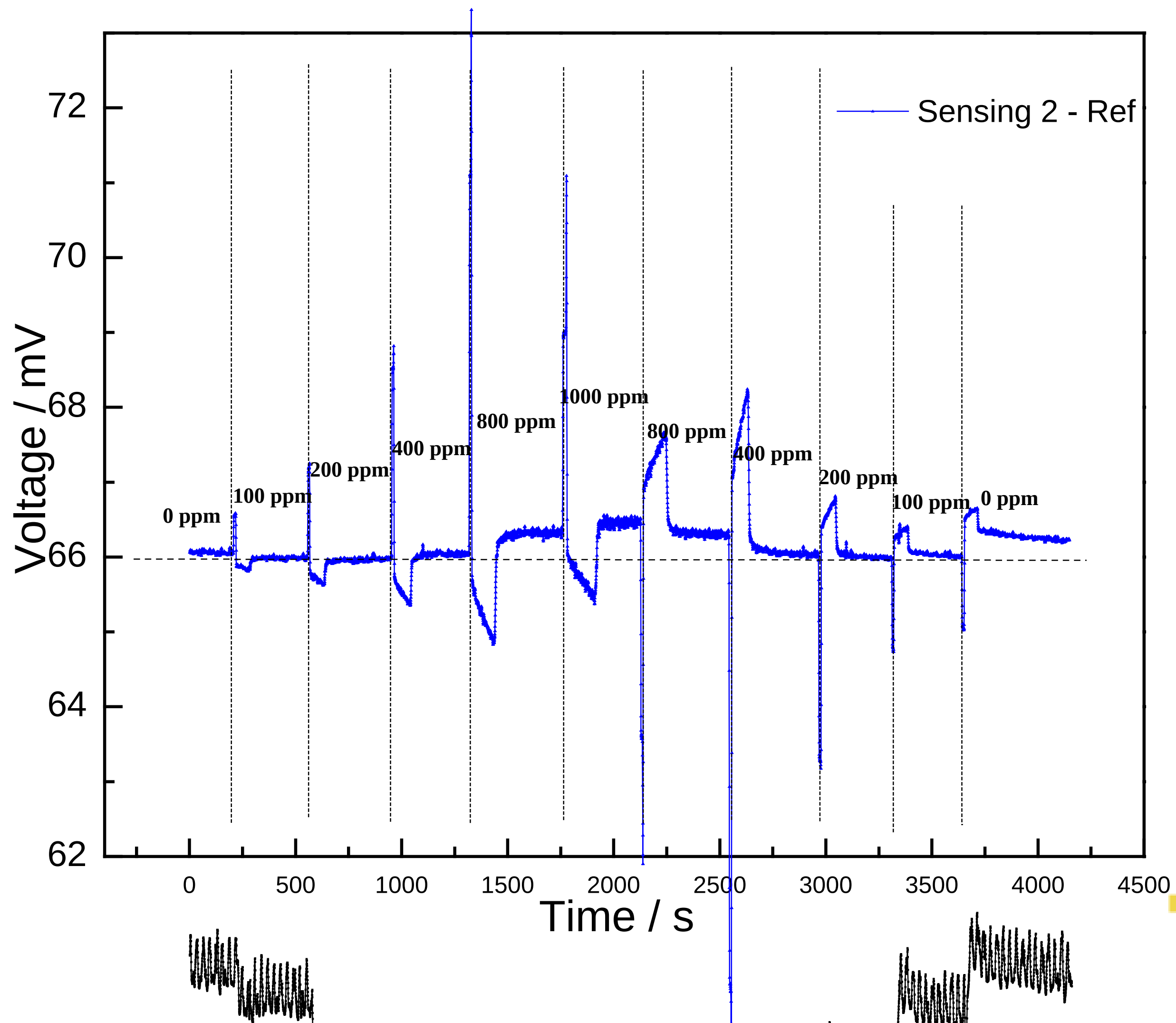
Sensor Testing – Lab-Scale

- 1000 ℃

- Sensing side:
  - $CO/N_{2\ Bal.}$ || N_2 || air
  - 200 $sccm_{Total}$
  - P_{O2} = 2.1%

- Ref side:
  - Air
  - 100 sccm

Two-chamber design sensor



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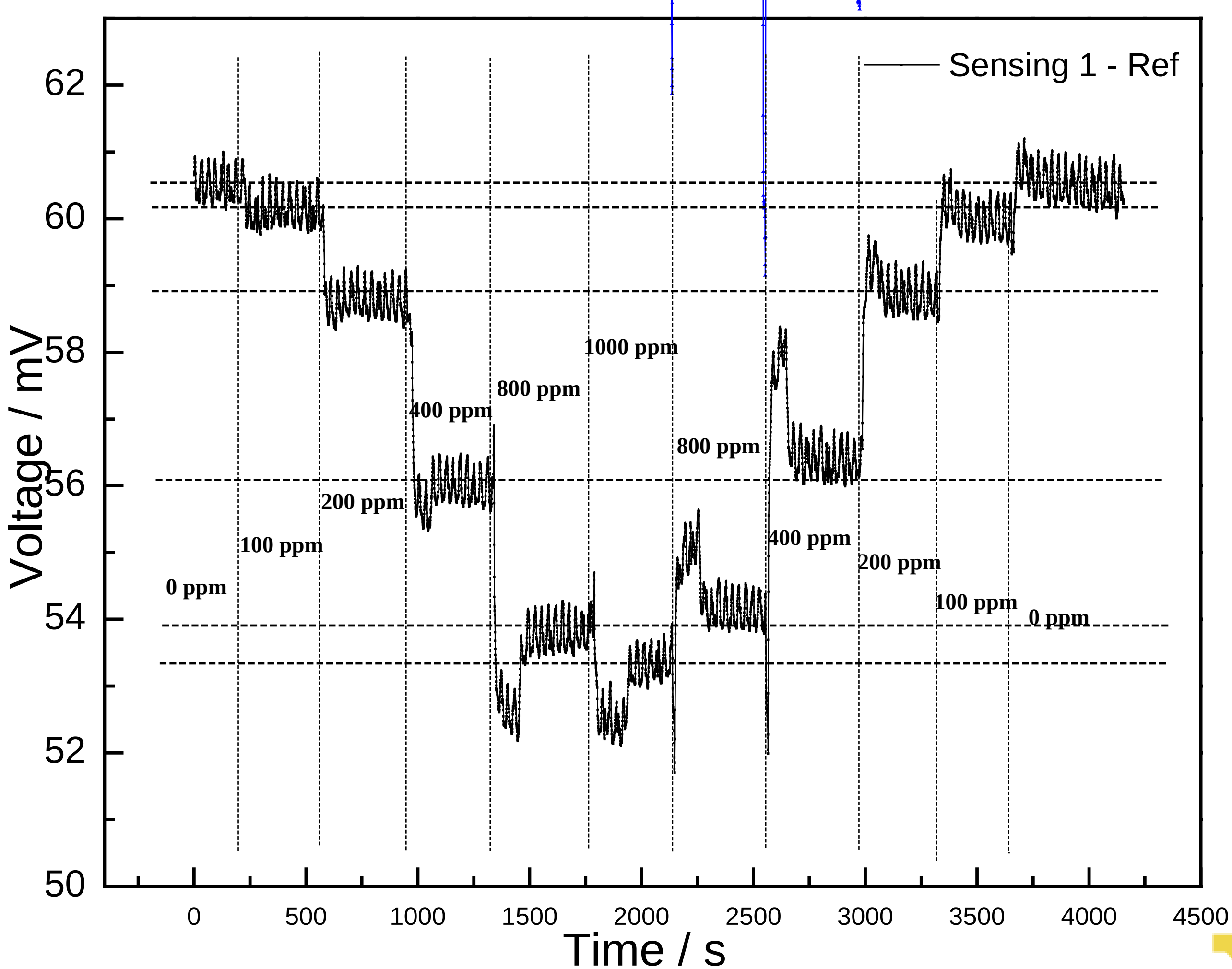

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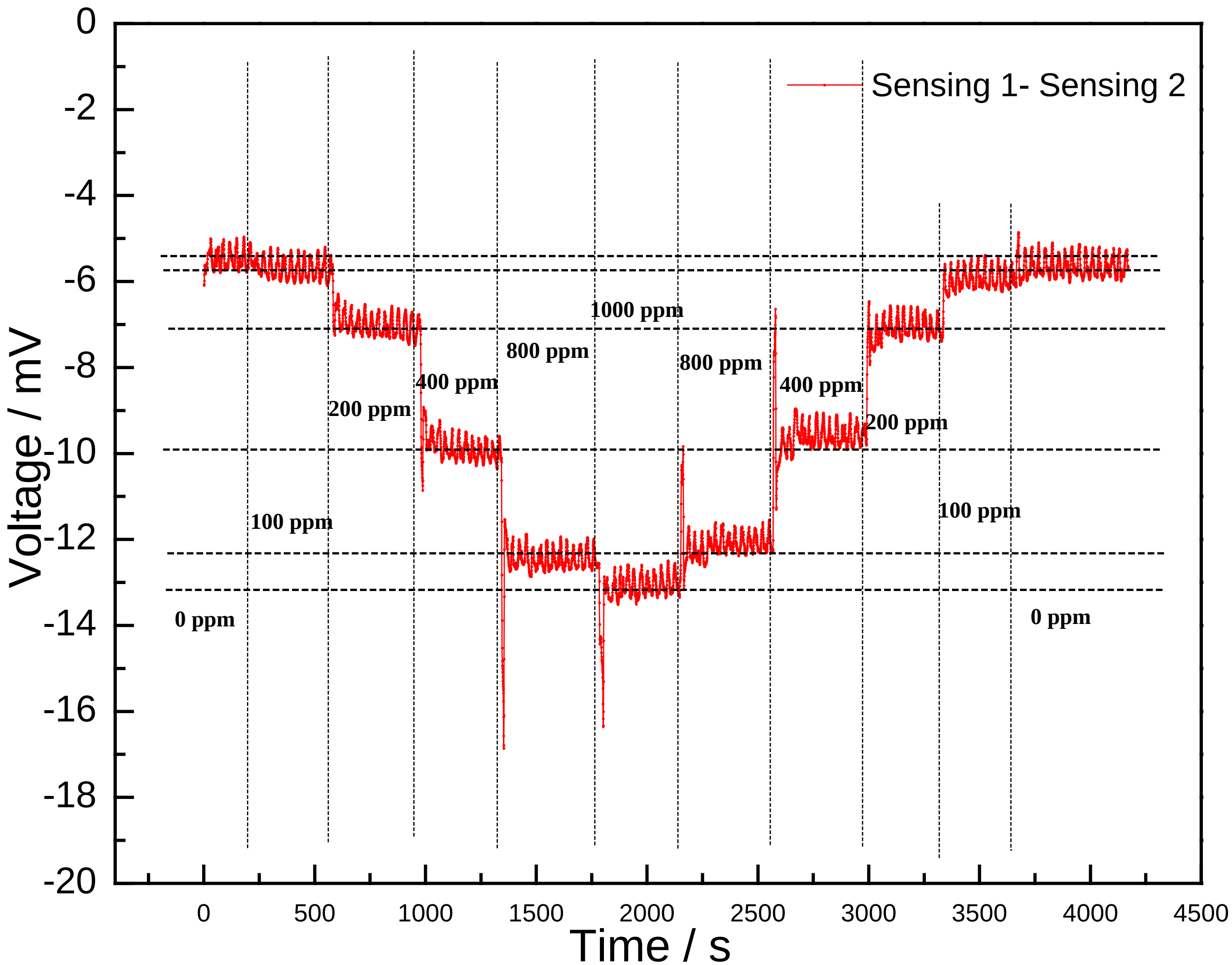
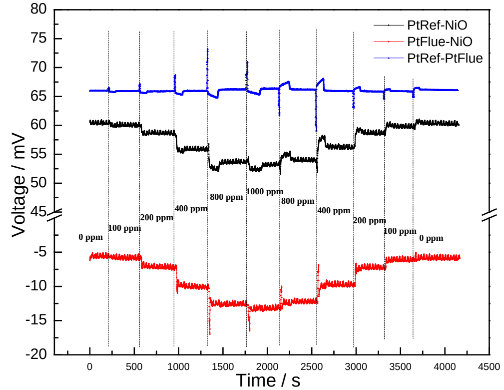


SUMMARY & FUTURE WORK

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