

S&C FY02 ANNUAL REVIEW MEETING

Tunable Diode Laser Sensors for Monitoring and Control of Harsh Combustion Environments

**American Air Liquide
5230 S. East Ave.
Countryside, IL 60525**

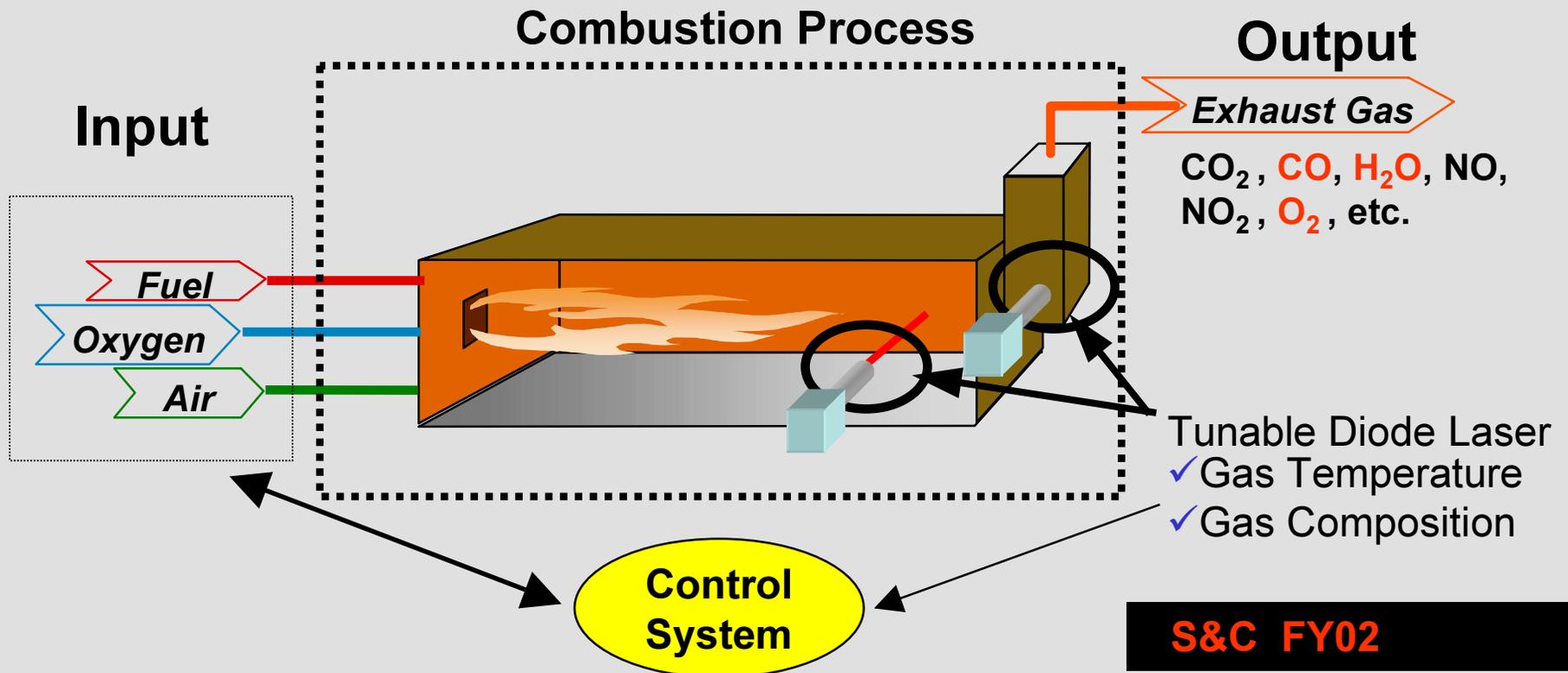
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Project Description

Objective: Fabricate and test an industrial multi-gas NIR diode laser sensor system for O_2 , CO , and Temperature monitoring applicable for high temperature harsh industrial environments.

Project Partner: Physical Sciences, Inc.



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Project Objectives/Goal

- **IOF need(s) addressed by this technology**

- Cross-Cutting technology supporting all IOF industries requiring combustion atmosphere monitoring and control

- **Objectives**

- Develop and test a multi-gas species sensor based on NIR diode lasers with the following features:

- ✓ *Harsh Environment Acceptable*

- ✧ *T > 1600 °C*

- ✧ *High Particle densities*

- ✓ *Multi-species Monitoring O₂, CO, H₂O*

- ✓ *Fast-Time Response 1-10 Hz*

- ✓ *Calibration Free*

- ✓ *Integrate with Processes Control*

- ✓ *Autonomous Operation*

- **Overall goal**

- Technology demonstration on several IOF industries to assess and quantify the potential impact on energy efficiency, pollutant reduction, product quality

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Technical Risks/Innovation

■ Technical risks

- Long-term Stability and/or Reliability
- Matching Industry Requirements

■ Innovation

- Spectral window Identified for simultaneous CO/H₂O and T monitoring
- Integrated System for Broad wavelength multiple species detection
 - O₂ @ .76 μm
 - CO/H₂O @ 1.5 μm

■ Advancement of state-of-the-art; over competition

- Scan-and-integrate measurement
 - Insensitive to line broadening
 - Reduced sensitivity to broadband absorbers and scatters
- *In-situ* simultaneous multiple species and temperature monitoring

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Task Performance

Past Technical Milestones

Milestone	Due Date	Completion Date	Comments
<i>Pilot Furnace Test Platform</i>	10/00	9/01	Testing under Simulated industrial conditions
<i>Prototype Industrial Sensor</i>	9/01	1/02	Laser Supply Issue Resulted in Program Adjustments (org. 5/01)
<i>Multi-species validation test</i>	11/01	2/02	Validation and system testing CO/H ₂ O & T only
<i>Industrial Beam Launch & Receiver Modules</i>	11/01	4/02	Adapted for Broad wavelength sources
<i>Pilot Scale Testing</i>	11/01	4/02	Partially completed will be revisited
<i>Industrial Field-testing</i>	1/02	5/02	Steel Reheat Furnace

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Prototype Industrial Sensor

● **Program Adjustment**

- ✓ *Multi-section laser not available until 2002-2003 (No Guarantees but future availability seems promising.)*
- *Suppliers are currently Interested only in large volume customers in telecom industry*

● **Action**

Assemble Multiple species monitoring systems using standard DFB lasers aligned with the ITU-GRID (Guarantee laser supply)

- ✓ *Detailed Spectral Survey Required*
- ✓ *System ready by Fall 2001 for industrial testing (stay on schedule)*
- ✓ *Test and Industrialize process interface*
- ✓ *Improve overall System robustness and portability*

● **Future Actions**

- ✓ *Multi-section laser is still an objective*
- ✓ *Identified a 3rd party for supply and support development costs*

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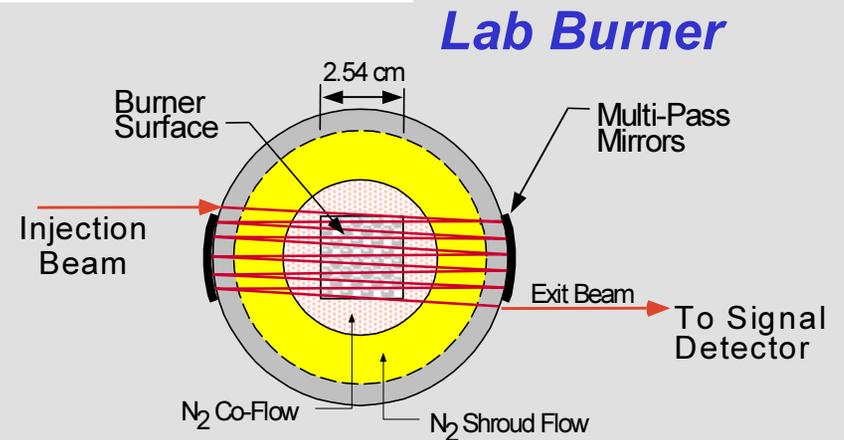
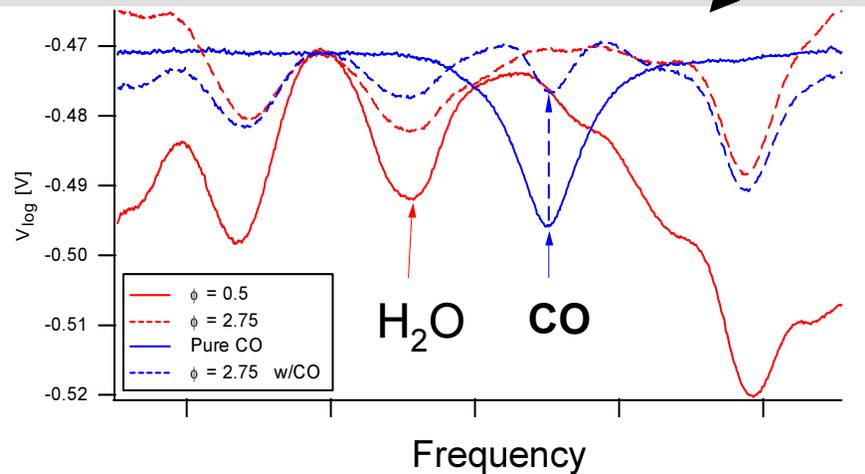
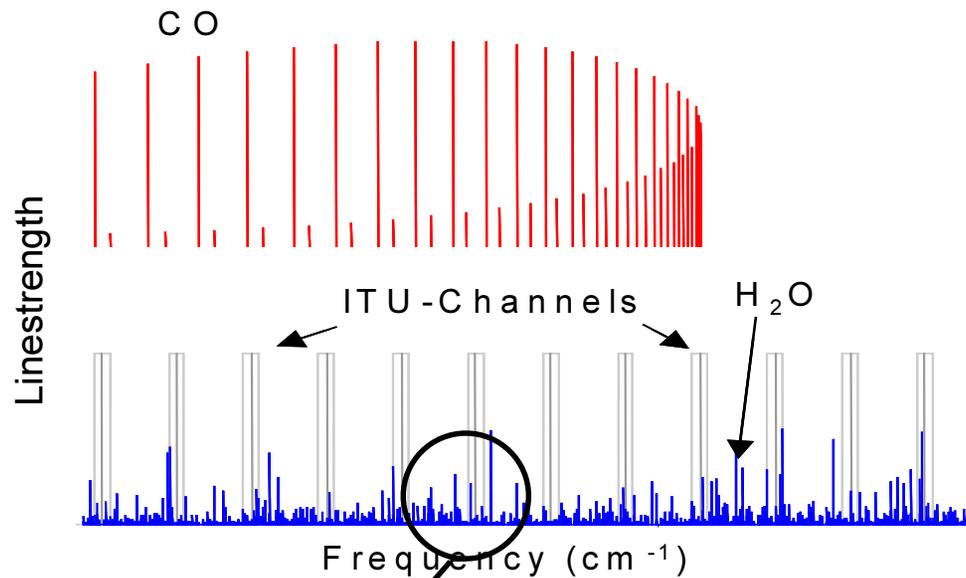
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Detailed Spectral Survey

Identify Spectral Window for CO and multiple H₂O lines

- *Line Selection Process (HITRAN+Experimental)*
 - ✓ *Optimum Energy Separation*
 - ✓ *Minimum Linestrength Required, S_{min}*
 - ✓ *Spectrally Isolated*
 - ✓ *Spectrally accessible (1.5 μm)*
 - ✓ *Validation Required (Experimental)*
 - ✓ *Empirical Calibration (Experimental)*

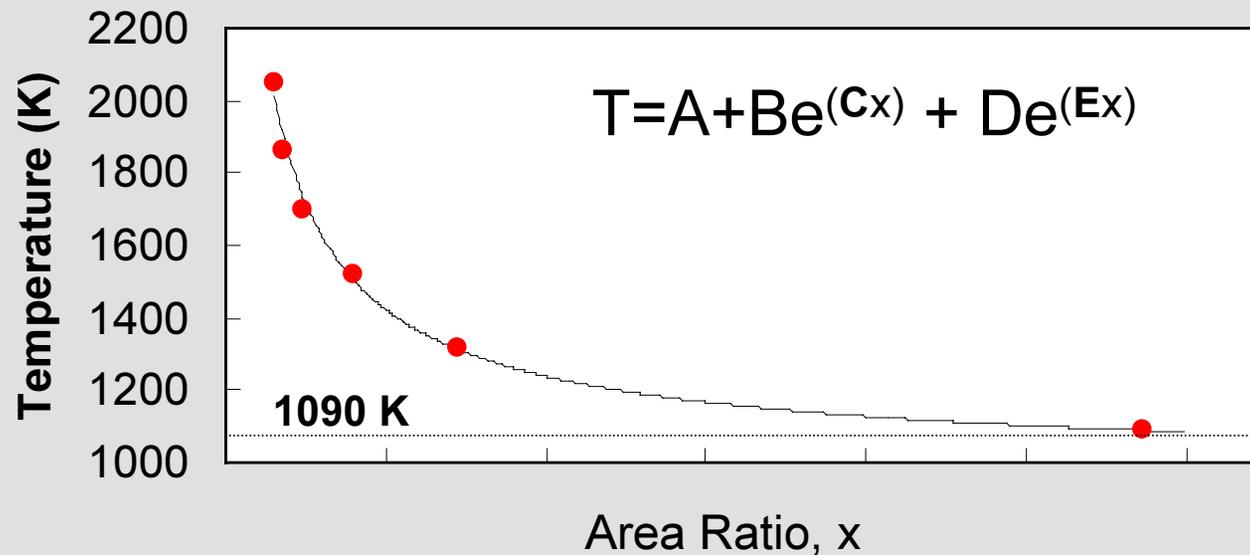
Detailed Spectral Survey



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Empirical Calibration

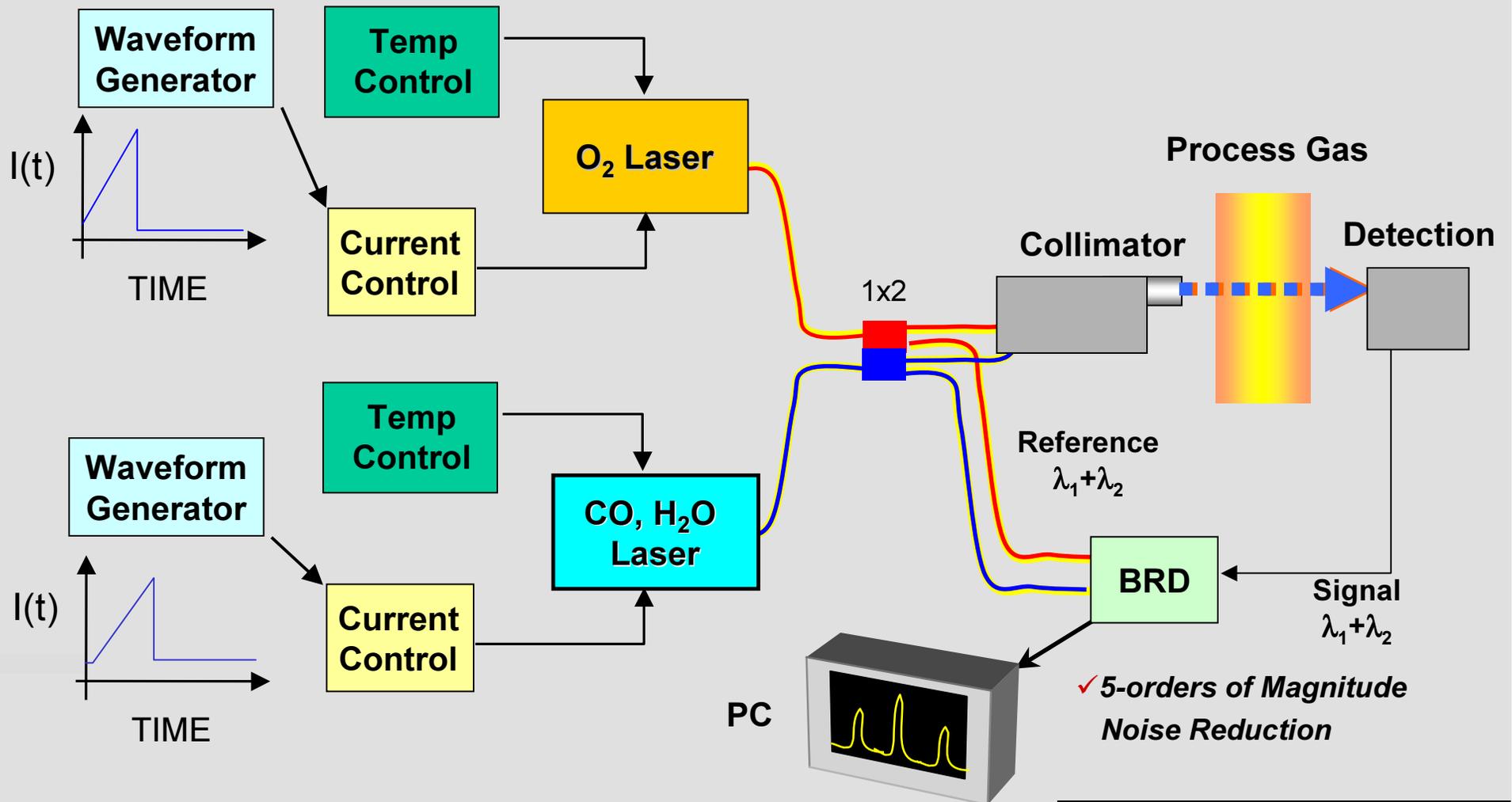
- Temperature



- H₂O Concentration

- Based on Equilibrium

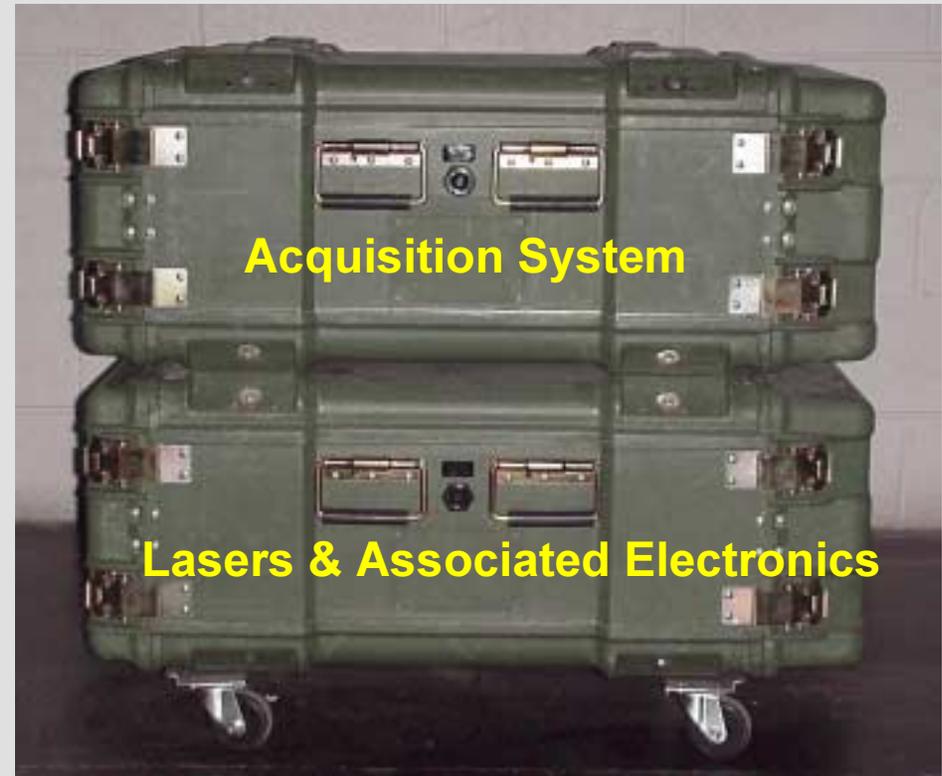
Multi-species Measurement Strategy



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Multiple Gas Sensor

- **Robust**
- **Modular Design**
 - Size: 37" x 23" x 15"
 - Wt.: ~120 lb



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Multiple Gas Sensor

Front View



Laser Output & Signal Input
Internal Visible Alignment Laser

Interlocking Modular Design

Industrial PC with
LCD Screen &
Key Board
Drawer

X_{O_2} , X_{CO} , X_{H_2O} & T
Outputs

Lasers & Associated
Electronics

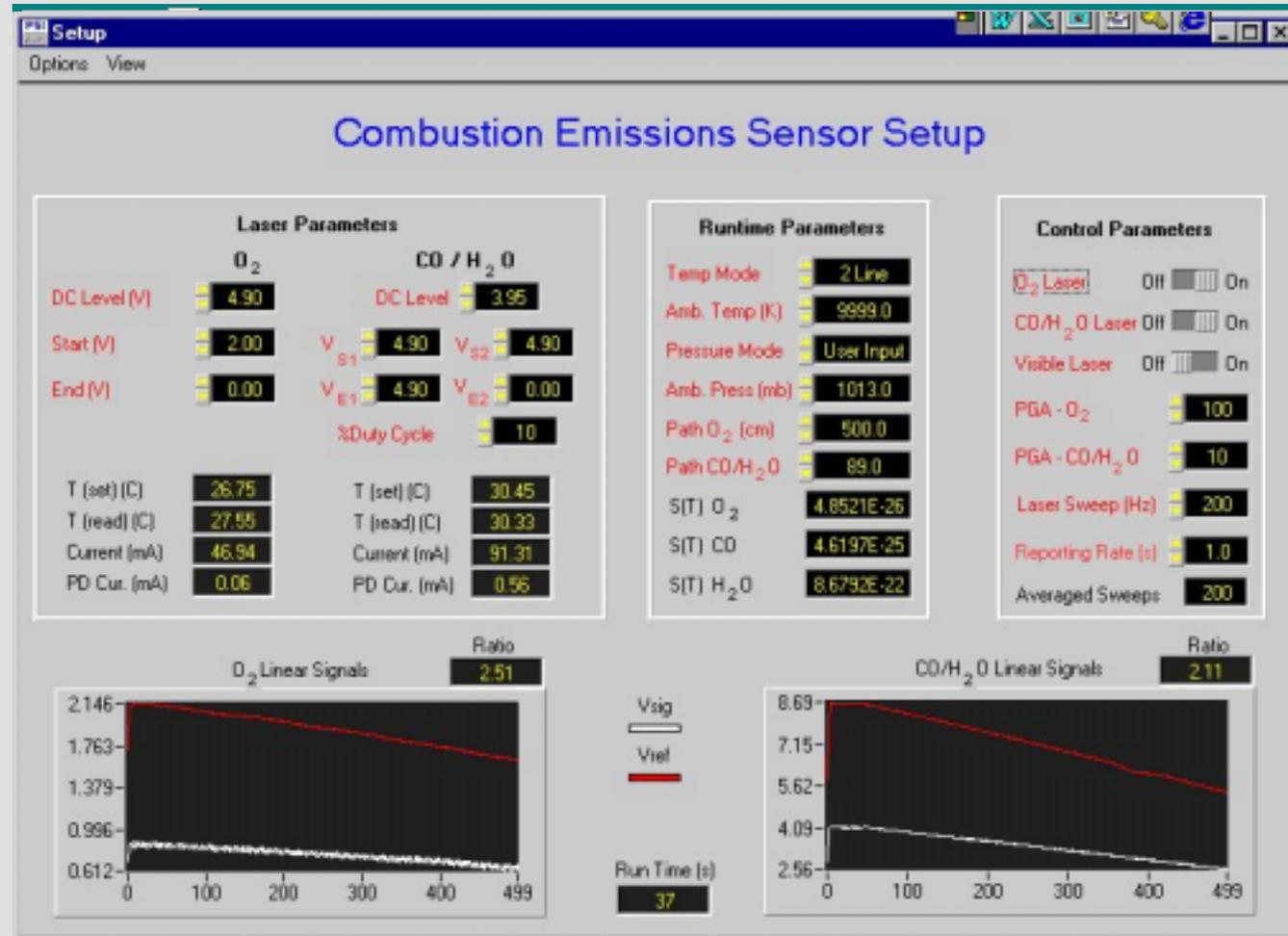
Rear View



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Sensor Data Acquisition and Control System

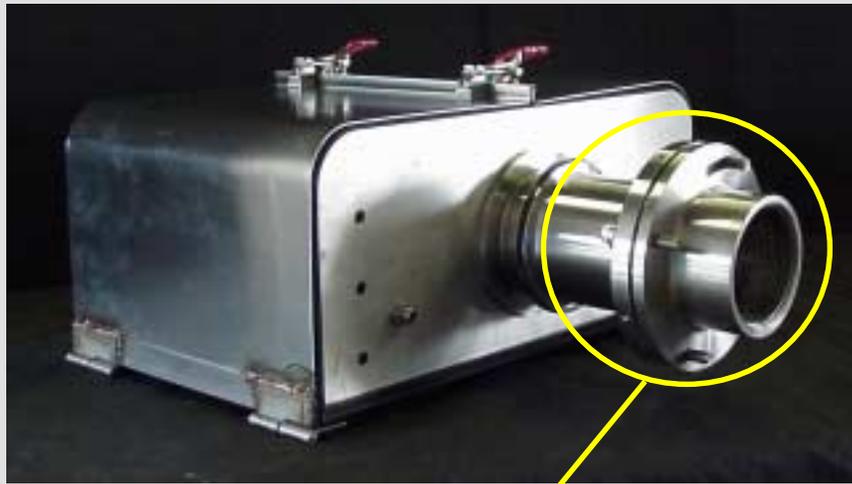


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Beam Launch & Receiver Modules

Launch Module



12" x 18" x 8"
wt. ~ 50 lb.

Alignment Hub

Receiver Module



18" x 18" x 8"
wt. ~65 lb.

Features

- Multiple wavelength launch and receive
- Alignment hub process interface
- Single purge inlet
- Latched and removable covers

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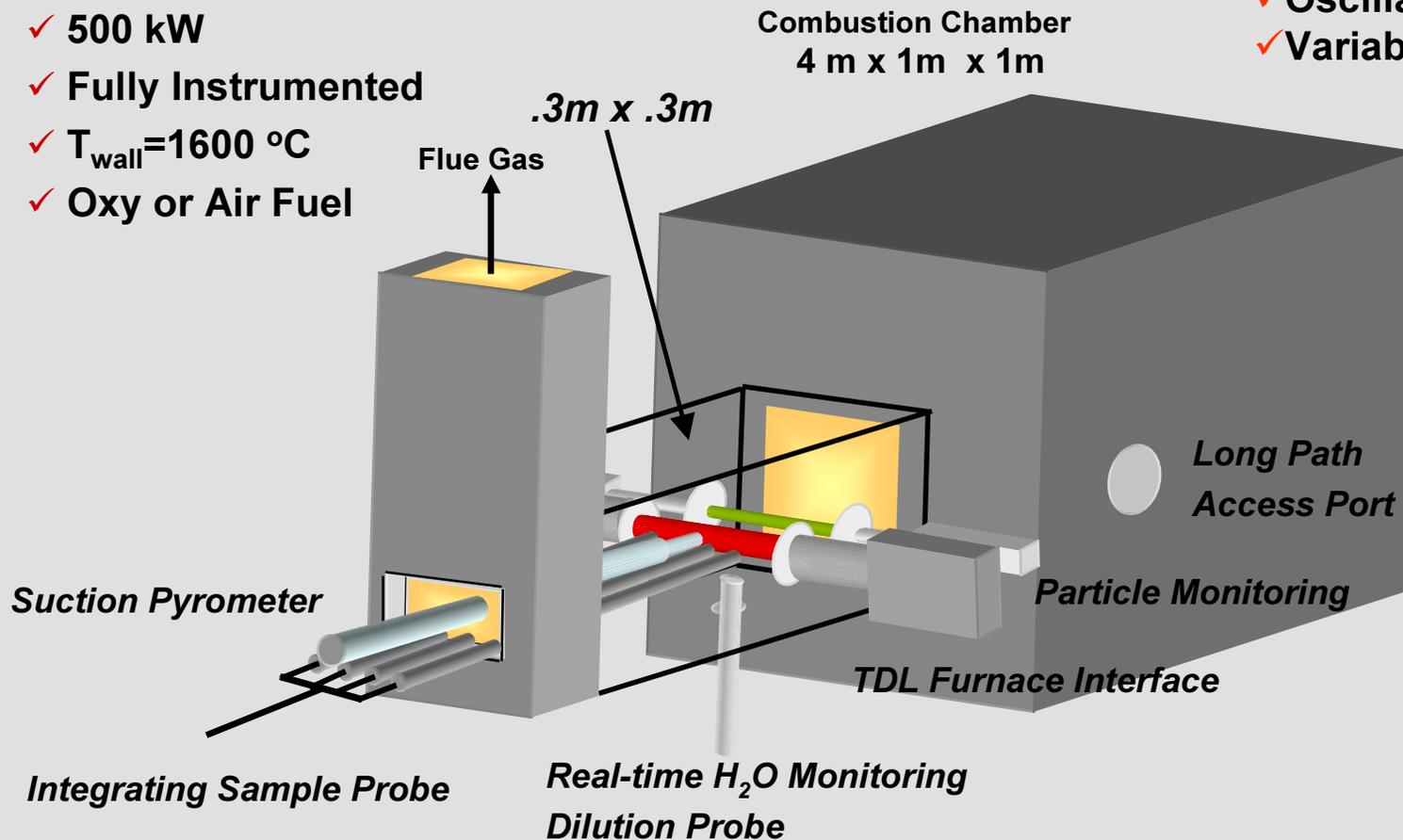
Pilot Furnace Test Platform

Furnace Features

- ✓ 500 kW
- ✓ Fully Instrumented
- ✓ $T_{\text{wall}} = 1600\text{ }^{\circ}\text{C}$
- ✓ Oxy or Air Fuel

Dynamic Monitoring

- ✓ Oscillating combustion
- ✓ Variable Frequency

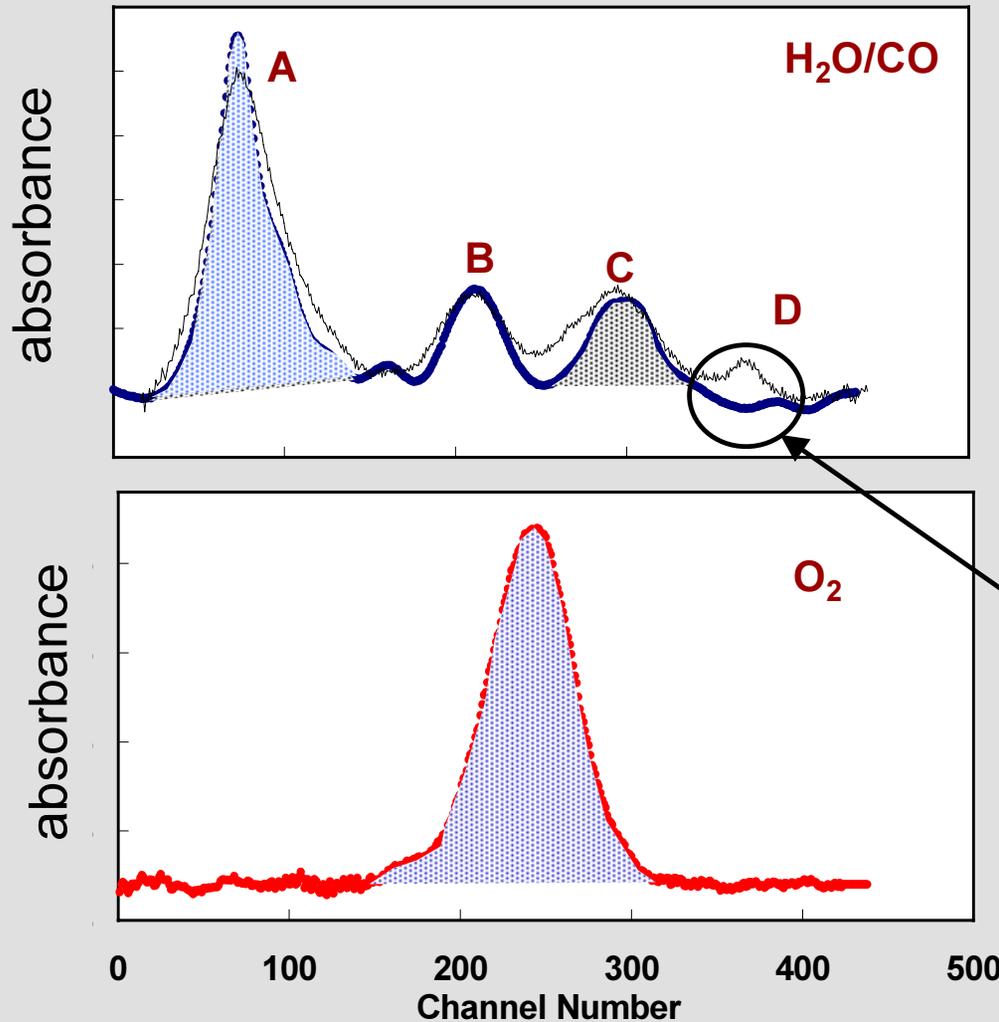


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Raw Data Collection and Analysis

T=1557 K, O₂=5.95%, H₂O=7.8%



Temperature Determined from
Area Ratio of Peaks A and C

Concentration Determined from
Integrated Peak Areas

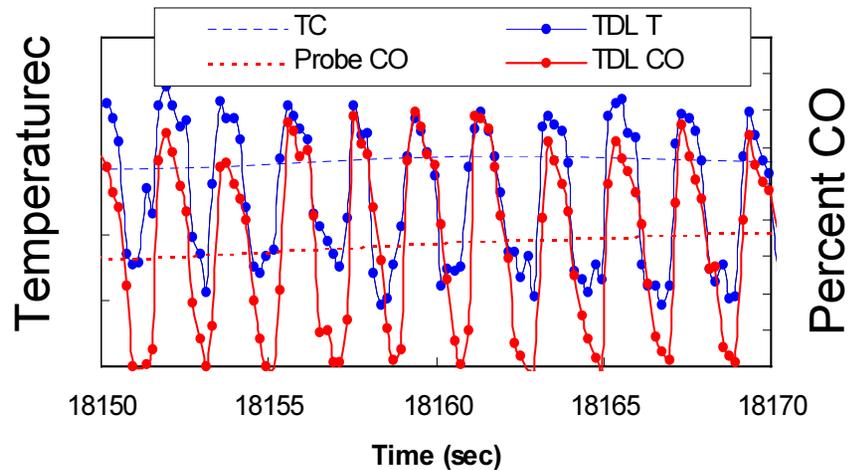
CO is superimposed on
H₂O Background

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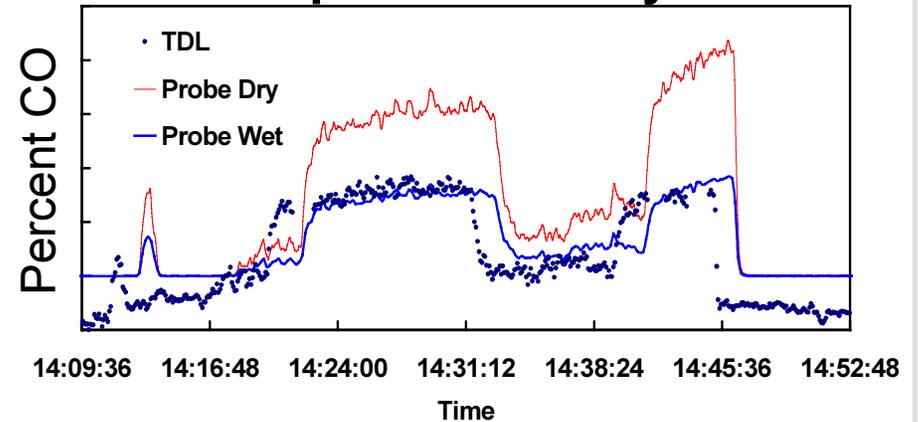
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Simulated Industrial Testing

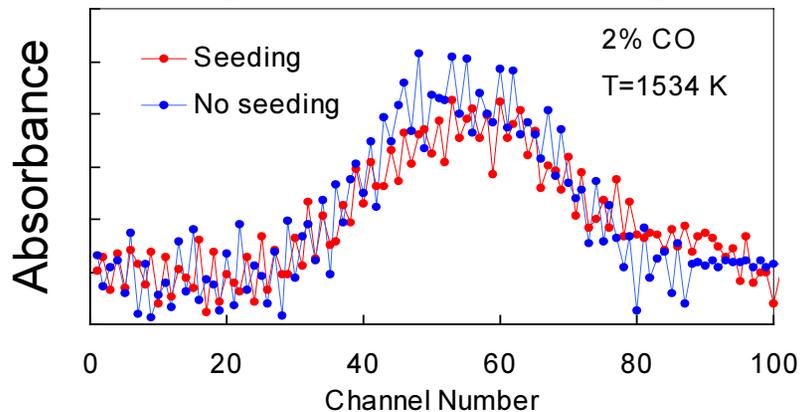
Dynamic Monitoring



Comparative Analysis



Dirty Flow Monitoring



Summary

- Fast-time Response
- Comparable measurement quality under dirty flow conditions
- Calibration refinement needed

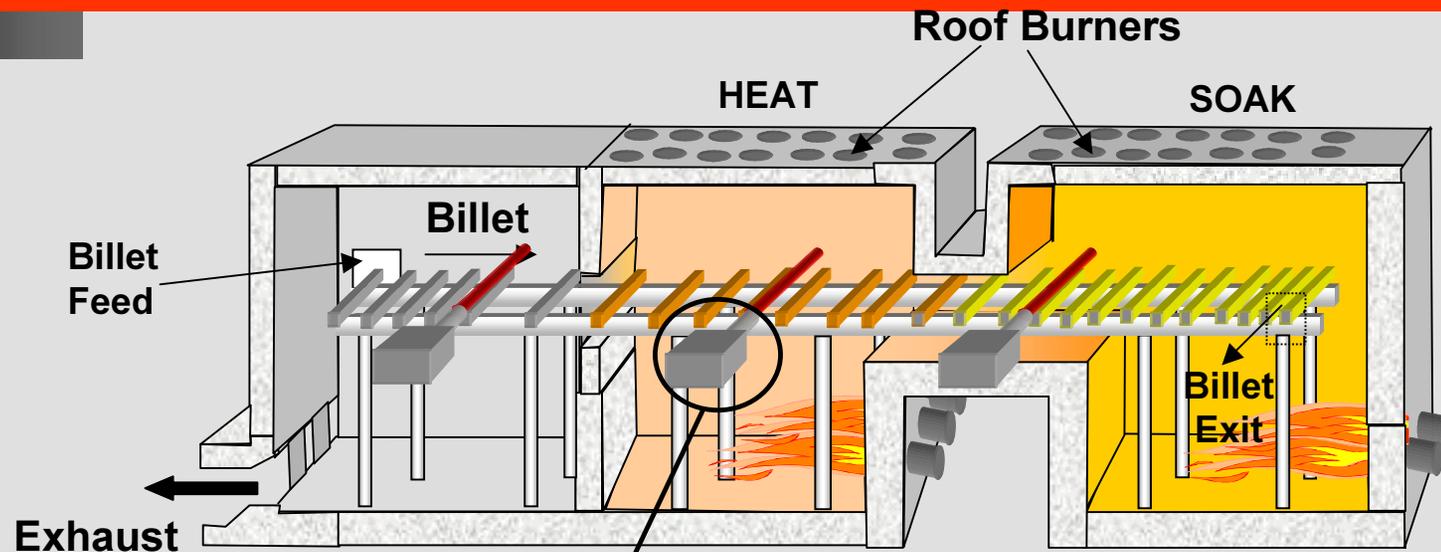
Next-steps

- O₂ monitoring added

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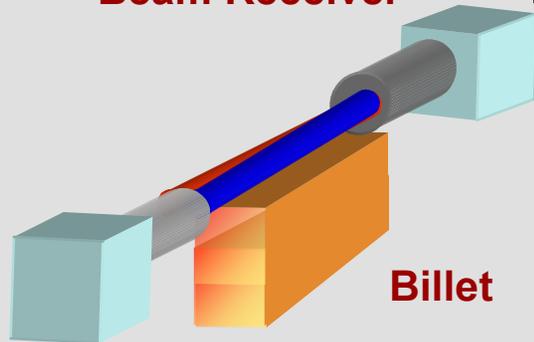
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Reheat Furnace Monitoring Locations



Temperature

Beam Receiver



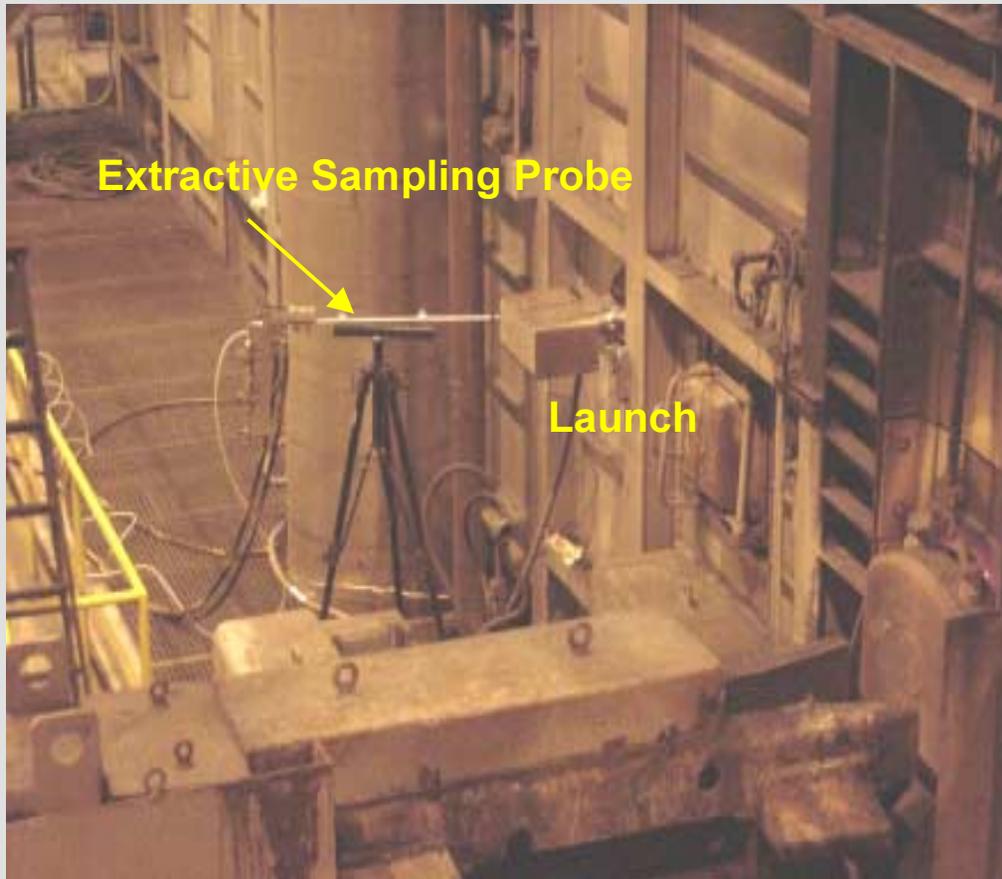
Beam Launch

- ✓ Integrated Measurement
- ✓ Near Billet Surface
- ✓ Multiple Species
 - O₂, CO, and H₂O
- ✓ Gas Temperature

Correlate to Product Quality and/or Efficiency

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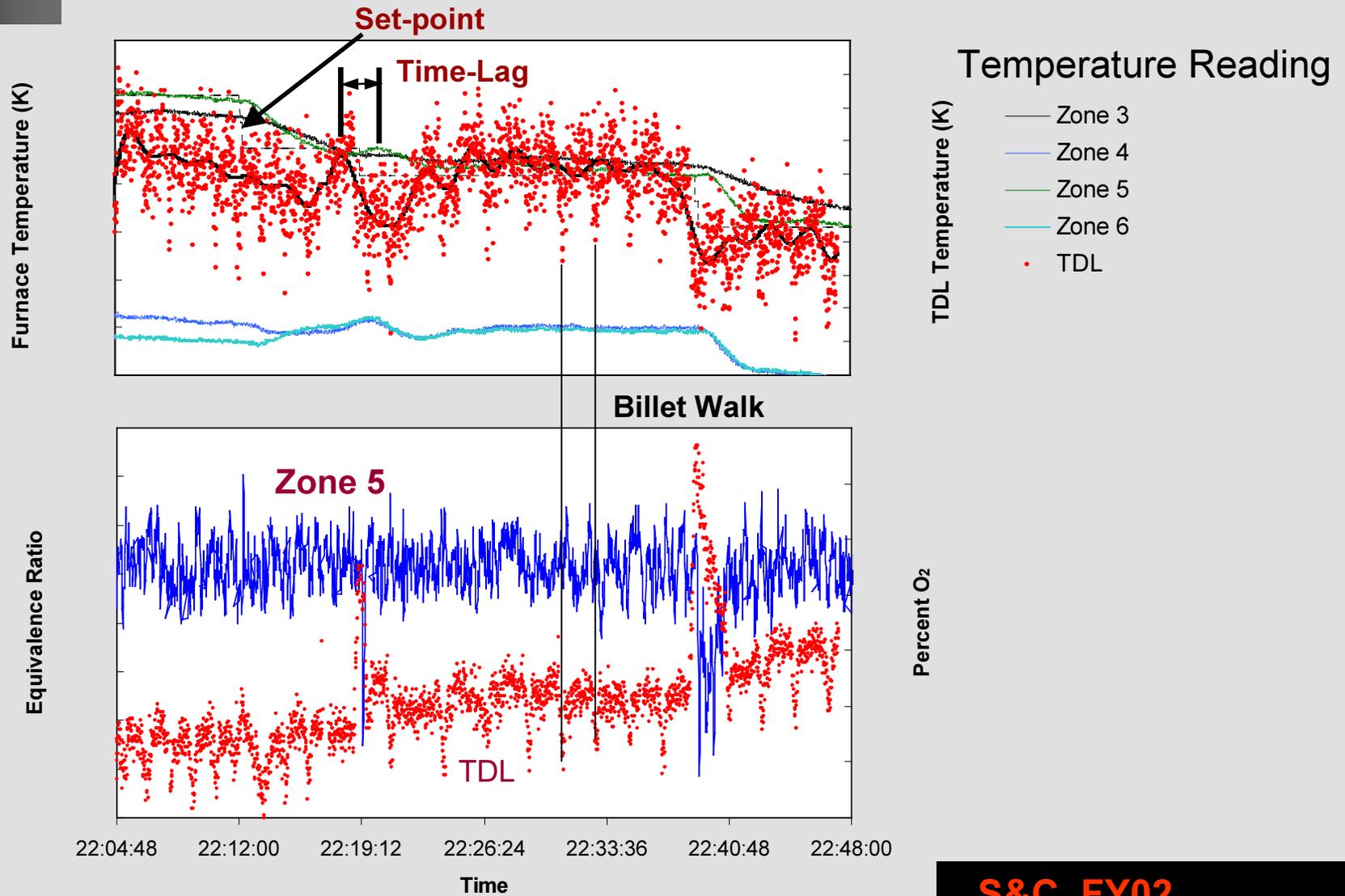
Module Installation on Reheat Furnace



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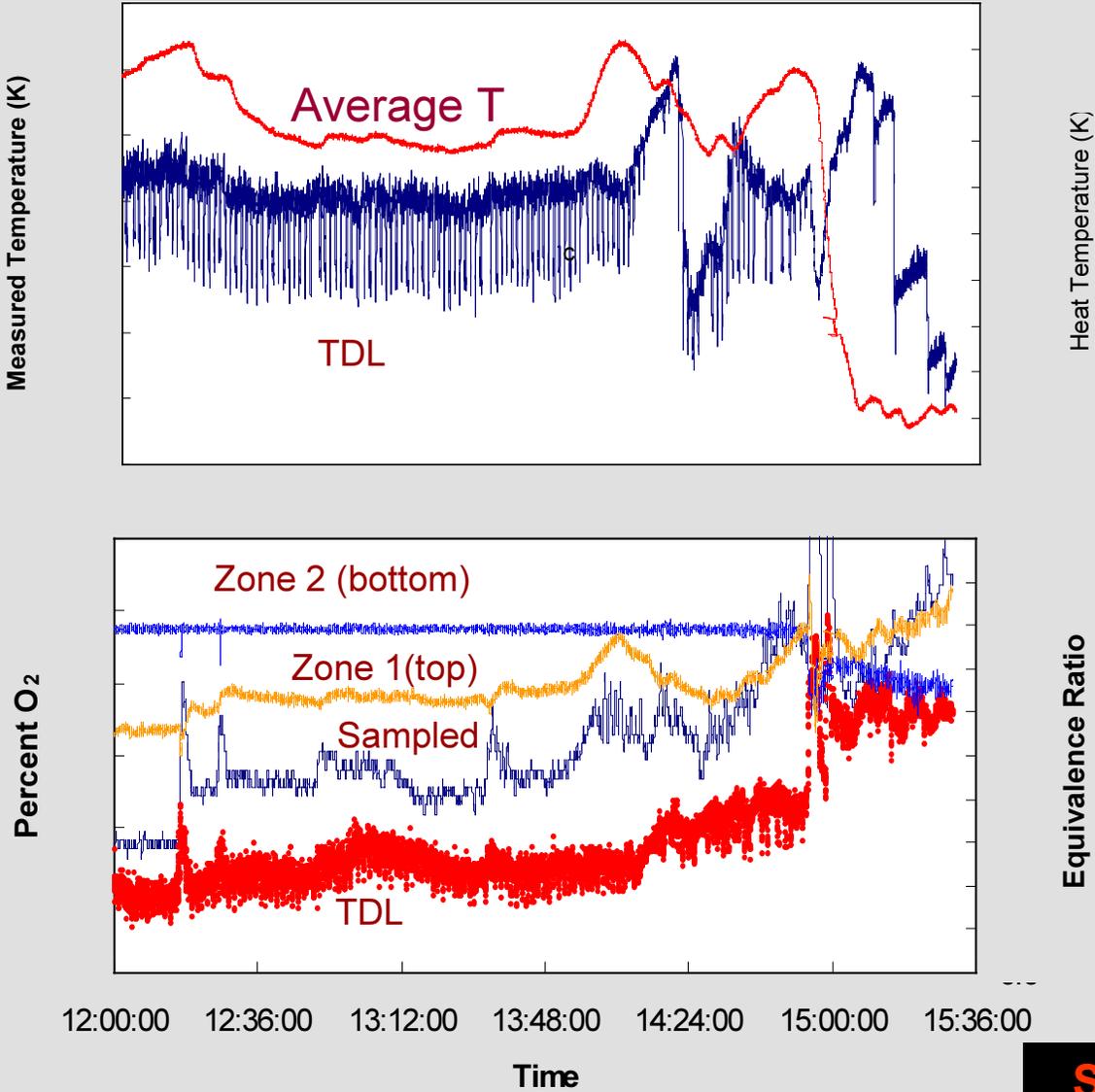
Real-Time Soak Zone Monitoring



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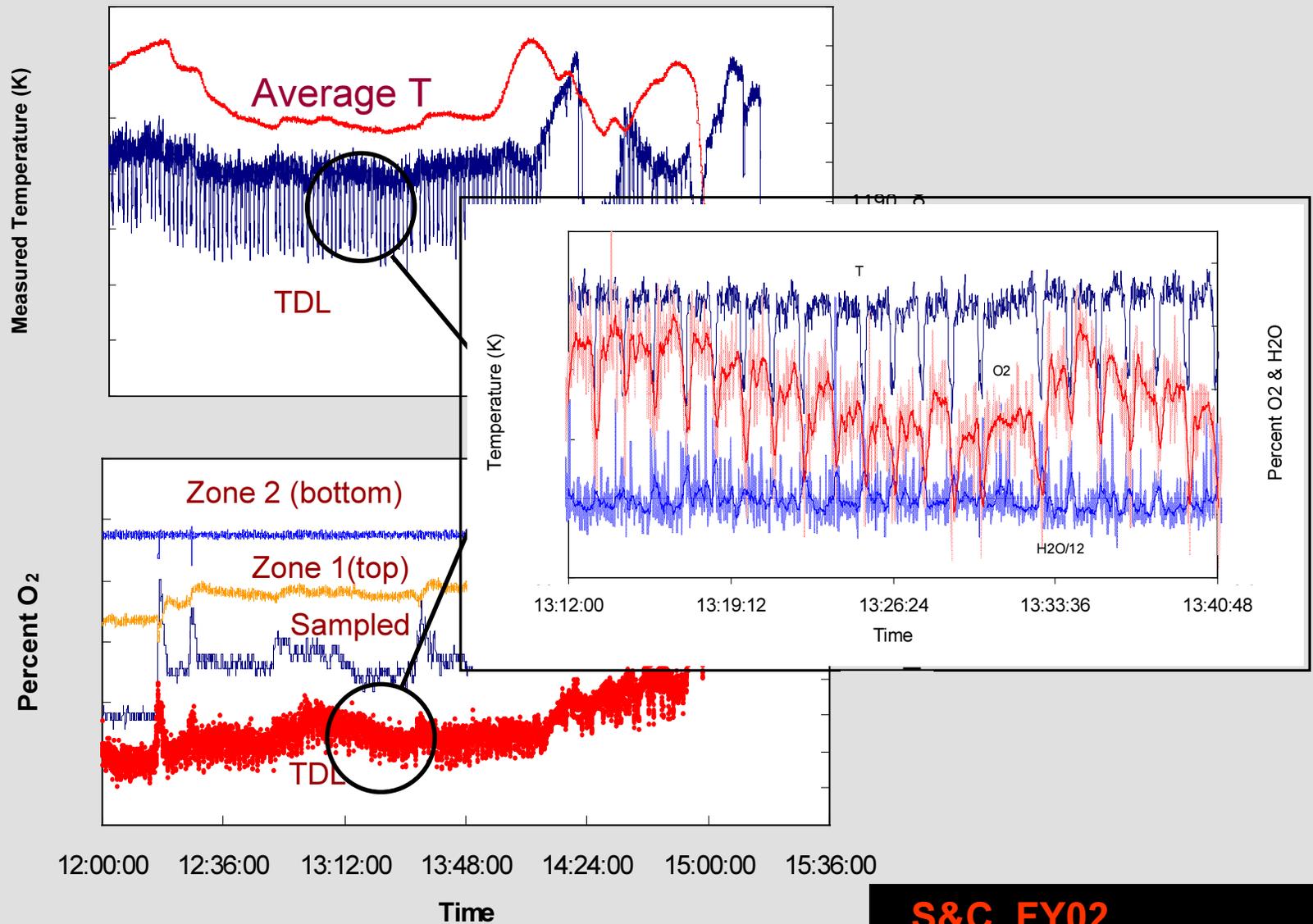
Real-Time Heat Zone Monitoring



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Real-Time Heat Zone Monitoring



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Industrial Test

- **Test Summary**

- Demonstrated hot installation & alignment on 50 ft. pathlength process
- Industrial Evaluation of beam launch and receiver module
- Agreement with conventional extractive sampling
- Correlations in O_2 and T observed for furnace operating conditions
- Observed variation in O_2 and T near billet surface

- **Next-steps**

- Complete data reduction to assess potential impact on process

Commercialization

- **Proposed plant tests/deployments, and planned use in IOF manufacturing plant(s)**
 - Steel Reheat Furnace (*1st Trial Completed*)
 - Secondary Aluminum Melter
 - Electric Arc Furnace
- **Commercialization path & partners**
 - Potential manufacturing partner has been identified
 - Well established industrial instrument manufacturer
 - Experience in TDL systems

Performance Merits

- **Improving energy efficiency**
 - Monitoring and controlling global or local combustion atmosphere to optimize O₂ and CO levels
 - Controlled oxidant injection to optimize chemical energy usage
 - **Reducing emissions**
 - Control of excess O₂ to Reduce NO_x
 - Control of CO emission
 - **Minimizing waste & quality improvements**
 - Improvements on Processes where the combustion Atmosphere has an Impact.
 - Scale formation in reheat furnace
 - Dross formation in Aluminum Melter
- } Quantifying impact is process and plant dependent
- **Improving productivity**
 - Productivity Increases through improved energy efficiency
 - Recovering lost chemical energy from EAF

Path Forward

Future Technical Milestones

Milestone	Due Date	Completion Date	Comments
<i>Pilot Furnace Evaluation & System refinement</i>	9/02		characterization & calibration improvement
<i>Data reduction from reheat furnace testing</i>	9/02		Quantify potential benefits
<i>2nd Industrial Test Campaign</i>	10/02		Secondary Aluminum Melter
<i>3rd Industrial Test Campaign</i>	2/03		EAF
<i>Long-term testing low level process control</i>	3/03		Quantify Performance Merit

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Path Forward

- **Next steps**

- Calibration refinement
- Performance Characterization (Pilot Furnace)
- Industrial Trails
- Quantify Performance Merits
- Transfer Technology to Manufacturing Partner

- **Go/no-go consideration(s)**

- Process considerations
 - Particulate levels
 - Measurement stability and reliability
 - Maintenance