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

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RESEARCH AND DEVELOPMENT

Project Overview

- Project description
  - Develop and test an industrial multiple gas near-IR diode laser sensor for **O_2**, **CO**, **H_2O** and **T**emperature monitoring targeted for for harsh process monitoring.
- Project Partners
  - Physical Sciences, Inc. key partner in technology development, prototype construction, and characterization.
- Objectives
  - Multiple Species Monitoring
  - Calibration Free
  - Autonomous Operation
  - Low Maintenance
  - Fast-time Response (1-10 Hz)
  - Large Dynamic Range 1000<T<2000
  - Functional on High Particle Density Processes
- Overall goal
  - Technology demonstration on several IOF industries to assess and quantify the potential impact on energy efficiency, pollutant reduction, product quality.
  - Develop a commercial product offer.

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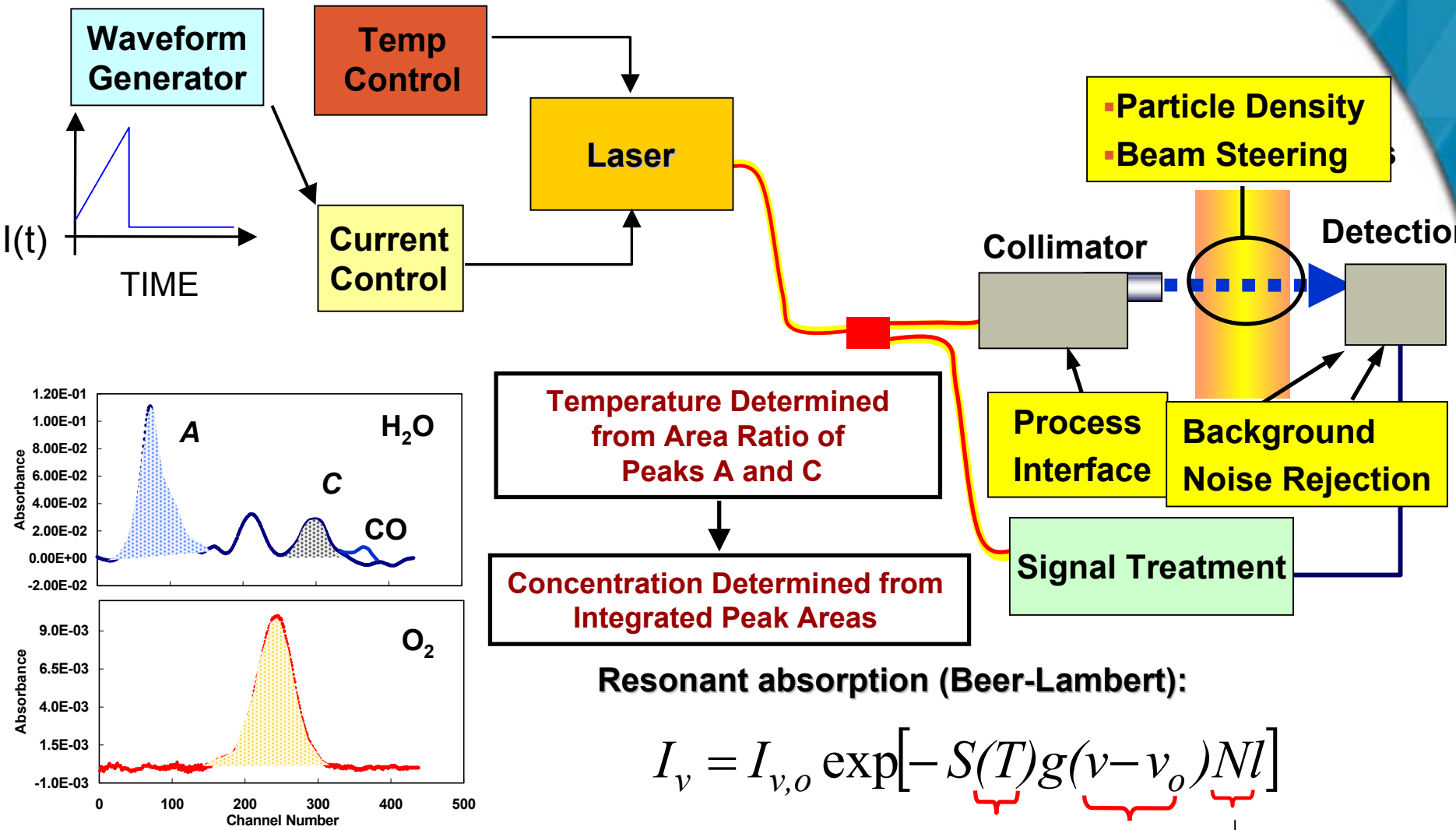
Technology Concept



Resonant absorption (Beer-Lambert):

$$I_v = I_{v,o} \exp\left[-S(T)g(v-v_o)Nl\right]$$

Linestrength **Lineshape** **Number Density X Pathlength**

Technical Merit

- IOF needs addressed by this technology
  - **Cross-cutting technology** supporting all IOF industries requiring combustion atmosphere monitoring and control

Multiple Gas Sensor Matches IOF Needs

- Aluminum Melting
  - *Fuel efficiency in melting and holding furnaces*
  - *Reduce emissions*
  - *Minimize melt loss*
- Steel Making
  - *EAF Off-gas chemistry for feedback control*
    - Post combustion of CO and H2 for energy recovery
  - *NOx Reduction*
    - Sensors for continuous control of pollutants
- Glass Melting
  - *Robust Atmospheric Gas Sensors*
    - Durable long-life Sensors for combustion gas species analysis above the glass bath

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Technical Merit

- Relevant Technology Innovations developed
  - Spectral window identified for simultaneous CO/H_2O and T monitoring from a single DFB laser
    - Large dynamic range (1000<T<2000)
    - Reduced complexity
  - Integrated system for multiple wavelength (multiple species) detection
    - O_2 @ .76 μm
    - CO/H_2O @ 1.5 μm
  - Scan-and-Integrate Measurement
    - Insensitive to line broadening
    - Reduced sensitivity to broadband absorbers and scatters
    - Absolute measurement reducing computation overhead and complexity
- New Innovations In-progress
  - Multi-section laser
  - Fiber amplifier

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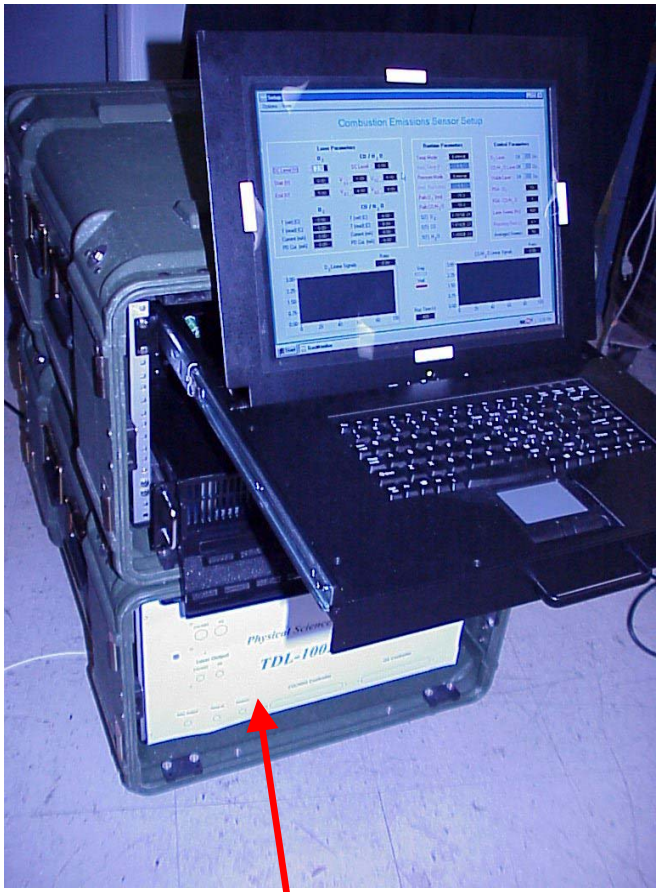
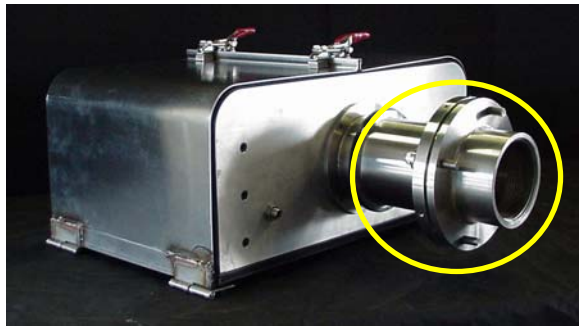
Industrial Prototype System

Multiple Gas Sensor (MGS) System (CO,O_2, H_2O & Gas Temperature)

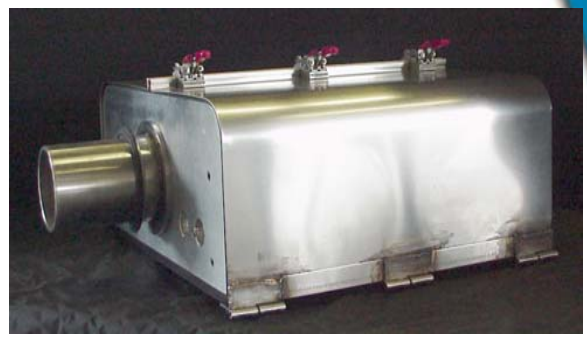


Lasers & Associated Electronics

Launch Module



Receiver Module



Features

Lasers & associated electronics

- Modular Design
- Multiple Laser System
- Fiber optic Beam Transport

Process interface modules

- Multiple Wavelengths Launched and Received { ***.76 μm*** ***1.5 μm*** }
- Alignment Hub Process Interface
- Background Radiation Rejection
- Gas Purged

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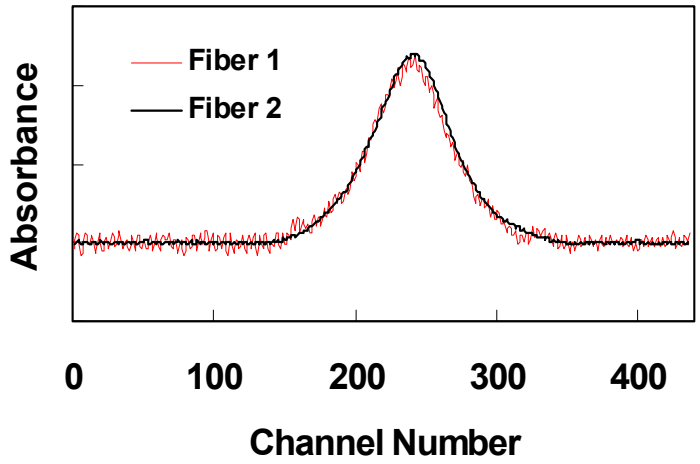
Technical Progress and Outlook

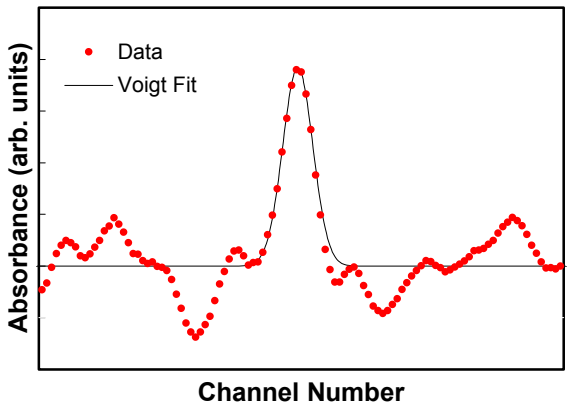
- Major progress/accomplishments to date

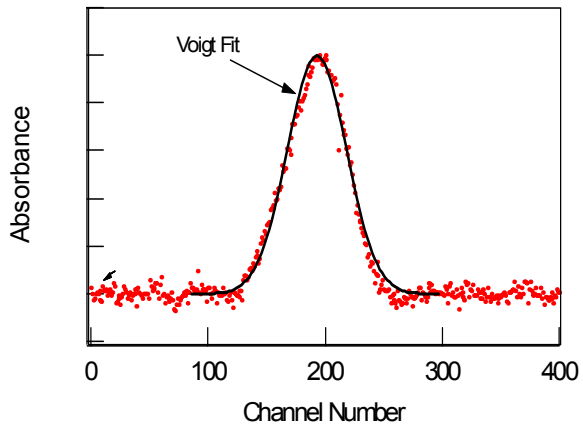
Milestone	Due Date	Completion Date	Comments
Pilot Furnace Test Platform	**10/00**	**9/01**	Testing under Simulated industrial conditions
Prototype Industrial Sensor	**9/01**	**1/02**	Laser Supply Issue Resulted in Program Adjustments (org. 5/01)
Multi-species validation test	**11/01**	**2/02**	Validation and system testing CO/H_2O & T only
Industrial Beam Launch & Receiver Modules	**11/01**	**4/02**	Broad wavelength sources
Pilot Scale Testing	**11/01**	**4/02**	Partially completed will be revisited
1st Industrial Field-testing	**1/02**	**5/02**	Steel Reheat Furnace
Pilot Furnace Evaluation & Refinement	**9/02**	**1/03**	Characterization & Calibration
2nd Industrial Test Campaign	**10/02**	**3/03**	Secondary Aluminum Melter
3rd Industrial Test Campaign	**2/03**		EAF (Planning in-progress)
Long-term testing low level process control	**3/03**		Quantify Performance Merit

MGS Measurement Improvement

- Noise Source Identified and fixed
  - Observed for both O_2 and CO
  - Factor of 6 SNR improvement
- CO calibration refinement
  - Correction for background H_2O
  - Parameters used in 2nd Industrial test
- High particle density monitoring
  - Enhanced radiation rejection

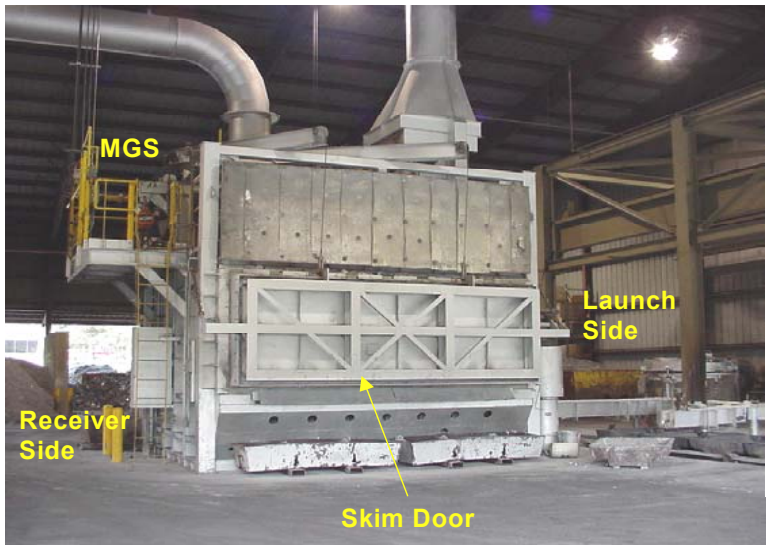


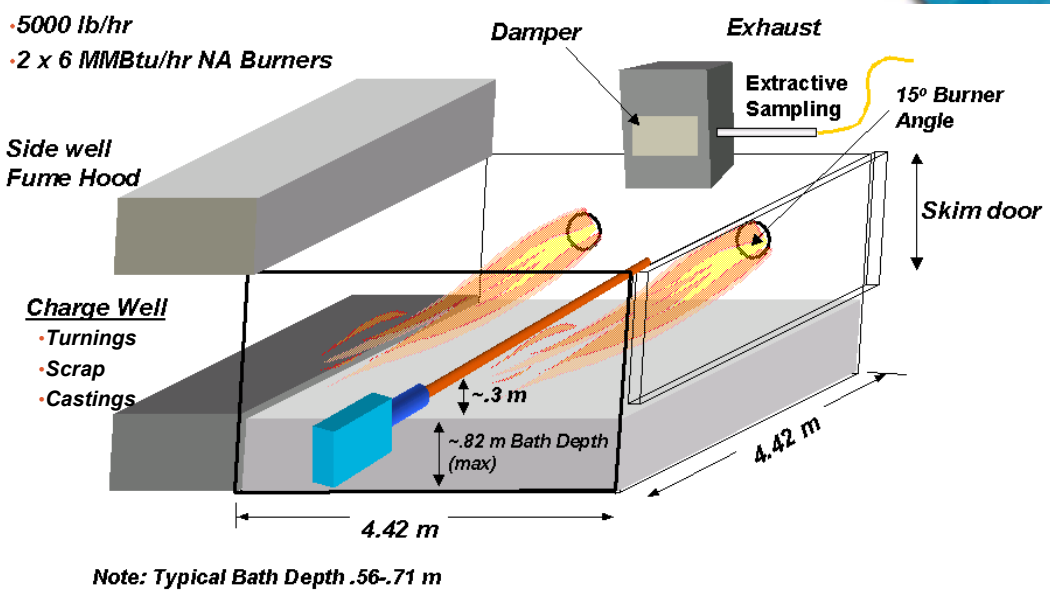


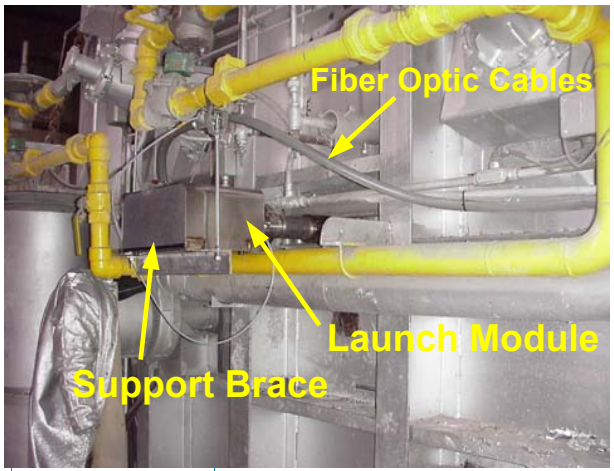


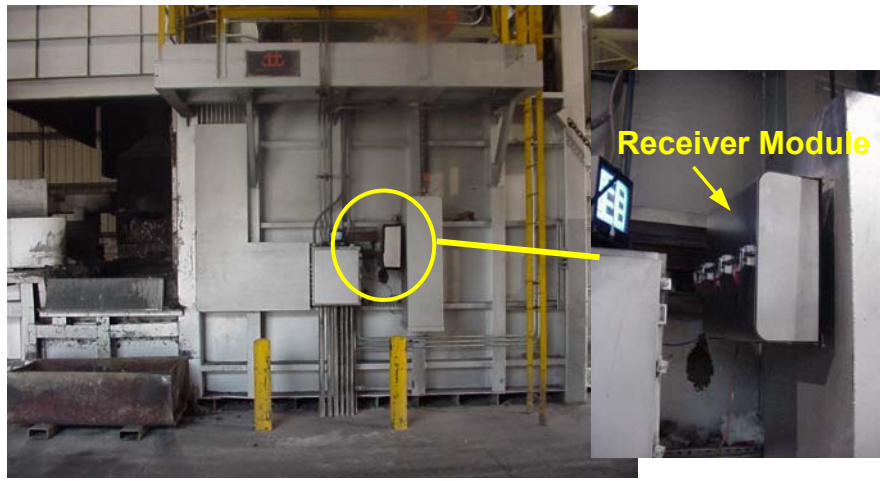
Secondary Aluminum Melting (2nd Industrial Test)

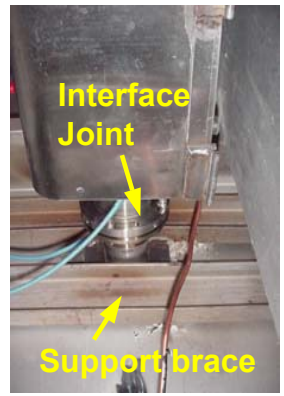
IMCO RECYCLING REVERBERATORY FURNACE TRIALS





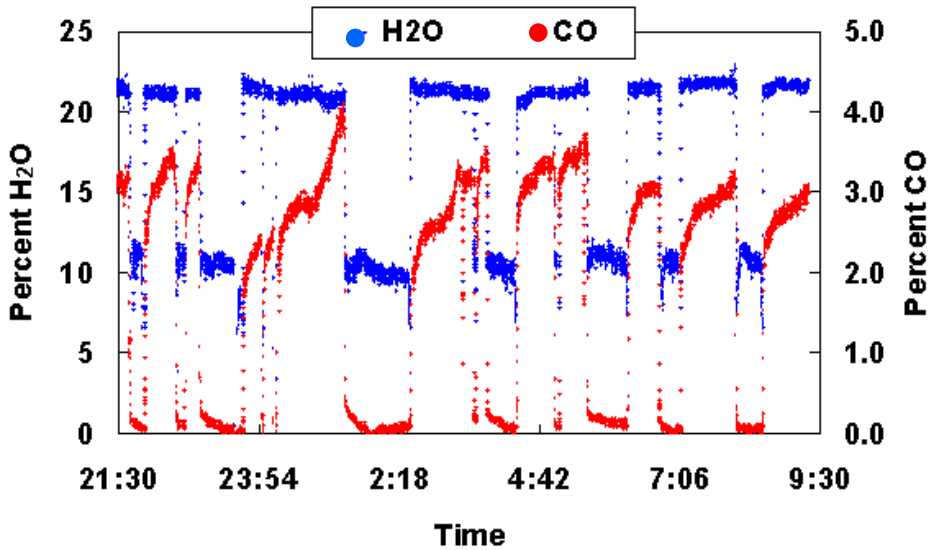


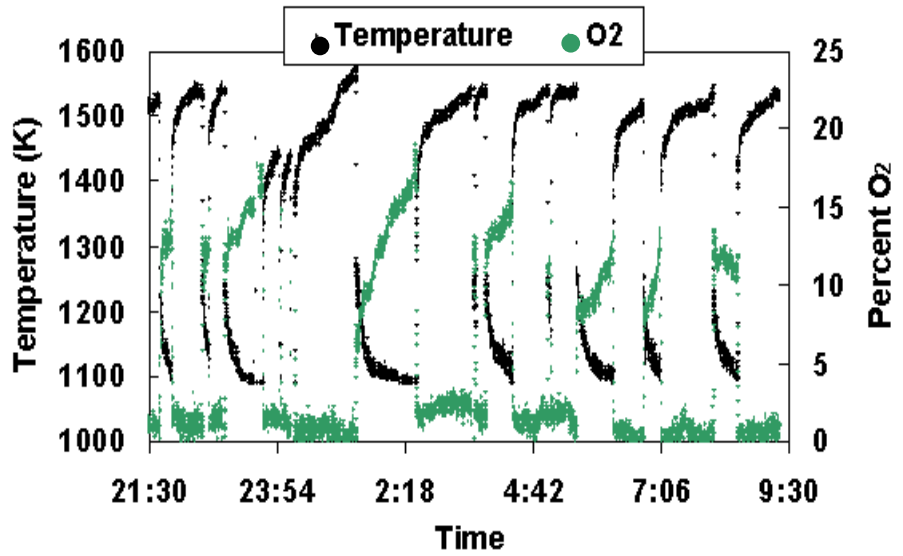




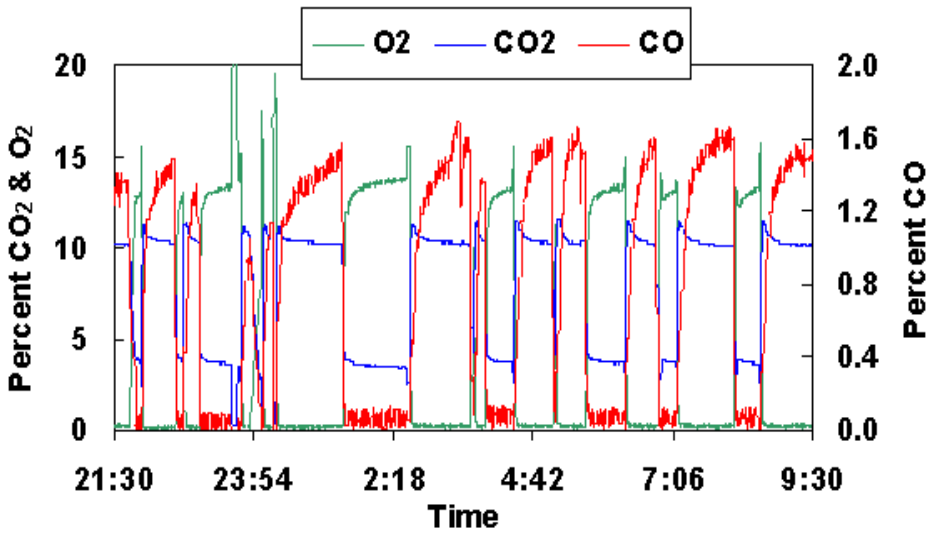
Reverberatory Furnace Monitoring Results

- MGS Measurement





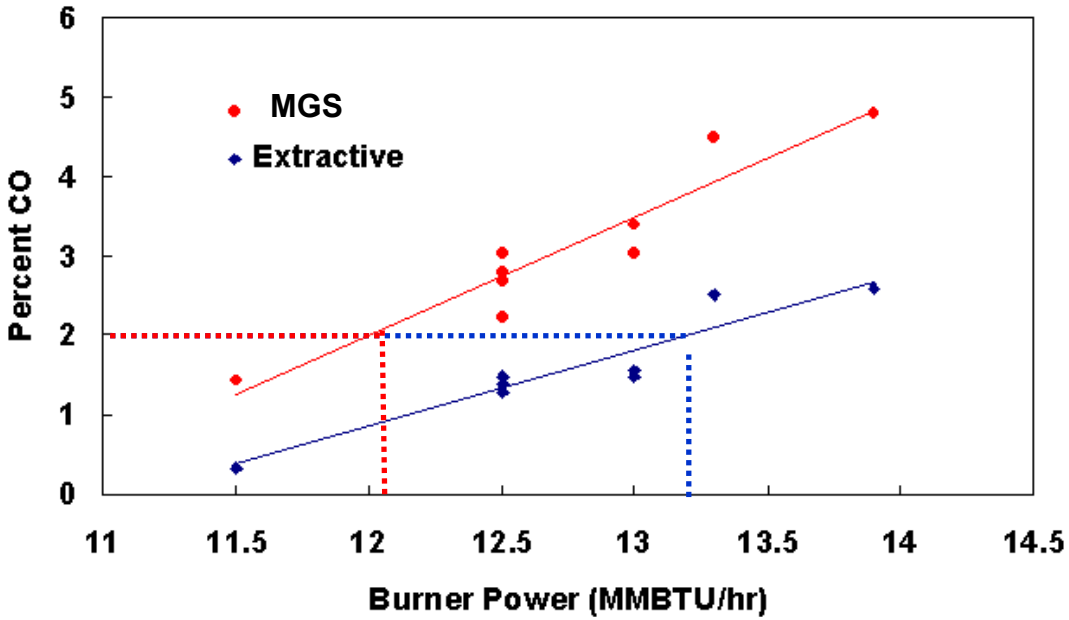
- Extractive Sampling



- Key Results
  - 8-days Continuous Operation
  - No Maintenance
  - Process Dynamics Captured
  - Efficiency Improvements

Low-Level Process Adjustments

- High-fire Average CO Concentration



	MMBTU/hr	MMBTU/yr	Energy Reduction (MMBtu/yr)	Percent Fuel Savings	Savings (HF100%)	Savings (HF 51%)
Baseline Conditions →	13.7	119782	0	0.0%	$0	$0
	13.3	116899	2883	2.5%	$14,319	$7,303
Long-term Setting →	13.0	113948	5834	5.1%	$28,976	$14,778
	12.5	109202	10580	9.7%	$52,546	$26,798
	11.5	100417	19366	19.3%	$96,179	$49,051

- Combustion Air Fixed

Technical Progress and Outlook

- Future Technical Milestones/Goals

Milestone/Goal	Projected Completion Date	Comments
MGS System Upgrades	**9/03**	Requirements for EAF
EAF Phase I Testing	**10/03**	Establish baseline performance
MGS controlled amplification	**12/03**	EDFA implementation
Multi-section laser	**12/03**	Controller Development
EAF Phase II Testing	**12/03**	EDFA & Multi-section Laser and other modifications
EAF PHASE III Testing	**4/03**	Long-term testing in best system configuration
Project Completion	**4/30/03 (?)**	no-cost extension (?)

Phase I Technical Progress and Outlook

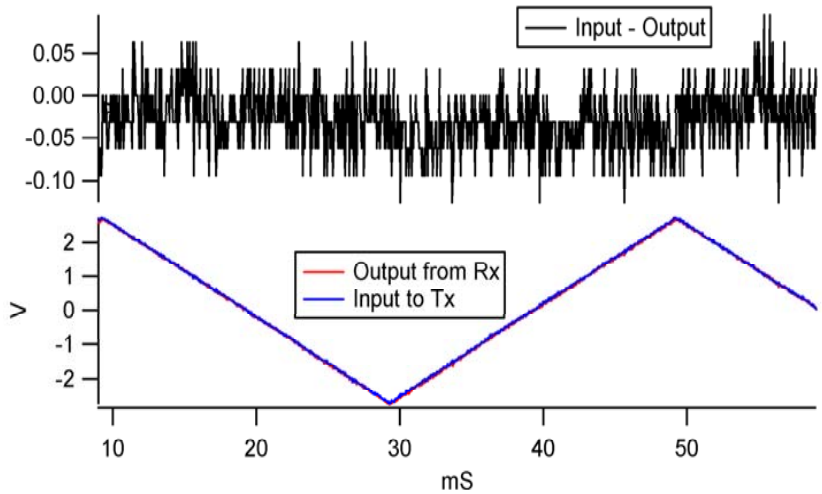
Sensor Requirements for EAF Application

- Overall System Hardening
  - Process Interface
  - Process Modifications
  - Water-Cooling

- ***Designs Developed***
- ***Partial Construction***
- ***Key Contractors Identified***

- Signal Transmission
  - Convert to optical fiber

- Remote Alignment
  - Limited access
  - Utilize fiber transmission system



Phase II Technical Progress and Outlook

- On demand laser power control
  - Erbium doped fiber amplifier + feed back control
  - Evaluation in-progress
  - Use with current system or multi-section laser
- Multi-section laser
  - Expanded tuning range (10's nm)
  - Controller development in-progress
  - Vendor Identified
- Phase II EAF testing
  - Use existing process interface hardware
  - Multi-section laser with EDFA
  - Compare performance against Phase I test

Characterization

- ✓***Linewidth***
- ✓***Wavelength***
- ✓***Repeatability***
- ✓***Stability***

PHASE III Technical Progress Outlook

- Long-term Performance Evaluation
  - Measurement reliability
    - Percent time acquiring data
  - Measurement accuracy
    - Valid data
    - Comparative analysis with conventional extractive measurement
  - Level of Maintenance
    - Frequency
    - Classify
      - *Low-level skill*
      - *High-level skill*

Technical Progress and Outlook

- Industrial end-user involvement
  - CHARTER STEEL
    - Provide access to process
    - Involvement in monitoring locations
    - Interest for other processes
  - IMCO RECYCLING
    - Provide access to process
    - Supported 2nd test campaign
      - *Interest in Rotary Furnace Monitoring*
    - Process adjustments based on measurement
    - Process conditions maintained for an extended period
    - Follow-up evaluation
  - North Star Steel (EAF In-progress)
    - Provide access to process
    - Coordinated work effort for process modifications and installation

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Market Potential

- Commercialization plan
  - Identified Instrument manufacturing partner
    - Well established industrial instrument manufacturer
    - Experience in TDL systems
    - Technology transfer initiated
  - Develop Commercial Offer
    - 2004 time horizon
    - Sensor technology/process control
    - Selected markets
    - System tailored to process needs
- Continued Development Post-OIT
  - Synergy with manufacturing partner
  - Technology evaluation and integration
    - **Multiplexed systems**
    - **Emerging laser technology**
  - Explore new applications

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Market Potential: Why EAF?

- Coupling Measurement with Post-combustion Control
  - Potential low maintenance alternative
  - Targets Key chemical species (CO & O2)
  - Temperature (Improved energy balance)
  - Fast-Time response

	Theoretical real time oxygen injection	Control by set-points	Extractive Sampling	Real-time MGS
Savings	**9.5-12.7 kWh/t**	**50-80 %**	**60-70 %**	**100 %**

Potential US EAF Energy Savings → 640,000,000 KWh

$19M

Programmatic Merit

- Improving energy efficiency
  - Monitoring and controlling global or local combustion atmosphere to optimize O_2 and CO levels
  - Controlled oxidant injection to optimize chemical energy usage
- Reduce emissions
  - Control of excess O_2 → Control of NOx
  - Control of CO emission
- Minimizing waste and quality improvements
  - Combustion atmosphere control
    - Scale formation in reheat furnaces
    - Dross formation from aluminum melter

  } Quantifying impact is process and plant dependent
- Improving productivity
  - Productivity increases through improved energy efficiency
    - Post-combustion control for EAF

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Summary

- Industrial Prototype Development
  - Thorough testing on pilot furnace
  - Identify & address technical issues
- Industrial Process Monitoring
  - Steel reheat furnace monitoring (01-02)
    - Detected dynamic process conditions
    - Measurements near billet surface
  - Reverberatory aluminum melter (02-03)
    - Performed low-level process adjustments
- Intellectual Property
  - 6 patent applications filed
- Program extension
  - Innovative sensor upgrades
  - EAF industrial monitoring

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