Proceedings of the

FY 2004 Glass IOF Project Review

Industrial Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

In association with the Glass Manufacturing Industry Council

June 22, 2004
Arlington, Virginia

Proceedings of the

FY 2004 Glass IOF Project Review

June 22, 2004
Crystal Gateway Marriott
Arlington, Virginia

Coordinated by
Elliott Levine
U.S. Department of Energy
Energy Efficiency and Renewable Energy
Industrial Technologies Program

Prepared by
Energetics, Inc.
Columbia, Maryland

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***E**nergy-Efficient Glass Melting - The Next Generation Melter (Submerged Combustion Melting)*

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***M**onitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulates and Crown Corrosion*
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***P**rocess Optimization Strategies, Models, and Chemical Databases for On-Line Coating of Float Glass*

Appendices

A Sample Evaluation Forms and Scoring Standards

B Other Presentations

***G**PLUS Update*

Agenda

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

MATERIALS, GLASS, AND SENSORS PROJECT AND PORTFOLIO REVIEW MEETING

June 21-24, 2004 • Crystal Gateway Marriott • Arlington, Virginia

PRELIMINARY AGENDA

Monday, June 21

7:00 – 8:15	Registration and Breakfast
8:15 – 8:30	**Welcome and Overview of Sensors & Automation Sub-Program** Gideon Varga, Industrial Technologies Program
8:30 – 9:00	S&A Project: **Sensor Network for Advanced Energy Management Solutions** (14225) – José A. Gutierrez, Eaton Wireless
9:00 – 9:30	S&A Project: **Distributed Wireless Multisensor Technologies-A Novel Approach to Reducing Motor Energy Usage** (14226) – Daniel Sexton, GE Wireless
9:30 – 10:00	S&A Project: **Wireless and Sensing Solutions Advancing Industrial Efficiency** (14227) – Steve Huseth, Honeywell Wireless and Sensing
10:00 – 10:30	BREAK
10:30 – 11:00	S&A Project: **Surface Quality Assured Steel Bar Program** (14228) – Tzyy-Shuh Chang, OG Surface Quality
11:00 – 11:30	S&A Project: **Boiler and Furnace Efficiency Improvement with Low-Cost CO Sensor and Burner Control System** (14229) – Howard B. Mason, TIAX
11:30 – 12:00	S&A Project: **Remote Automatic Material On-Line Sensor** (1254) – Erik Magnuson, Quantum Magnetics, Inc.
12:00 – 1:15	LUNCH (Speaker: Buddy Garland, Industrial Technologies Program)
1:15 – 1:35	SBIR Project: **Mid-IR Hydrocarbon Sensor** (17141) – Douglas Bamford, Physical Sciences, Inc.
1:35 – 1:55	SBIR Project: **Cavity Enhanced Gas Analyzer** (17139) – Manish Gupta, Los Gatos Research
1:55 – 2:15	SBIR Project: **Tunable Diode Laser for Combustion Control** (1604) – Peter DeBarber, MetroLaser, Inc.
2:15 – 2:30	BREAK

2:30 – 3:00	Ongoing S&A Project: **Tunable Diode Laser for Harsh Combustion Environments** (1303) – William VonDrasek, American Air Liquide
3:00	Adjourn
3:30 – 5:00	BREAKOUT SESSION – Materials Review Board Meeting BREAKOUT SESSION – Glass Portfolio Presentation
6:00 – 8:00	**Reception and Poster Session**

Sensors & Automation Posters

- **Measurement of Melt Constituents with LIBS** (980) – Robert De Saro, Energy Research Company
- **In Situ Analysis for the Chemical Industry** (14211) – J. D. Tate, Dow Chemical Company
- **Thermal Imaging Control of Furnaces and Combustors** (981) – David Rue, Gas Technology Institute
- **Advanced Wireless Sensors for the Industries of the Future** (967) – Wayne Manges, Oak Ridge National Laboratory
- **Tunable Diode Laser for Combustion Control** (1604) - Peter DeBarber, MetroLaser, and John Bergmans, Bergmans Mechatronics LLC.

Materials Project Posters

- **High-Density Infrared Treatment of Refractories** (1758) – Terry Tiegs, Oak Ridge National Laboratory
- **New Class of Fe-3Cr-W(V) Ferritic Steels** (1763) – John Paules, Ellwood Materials Technologies and Vinod Sikka, Oak Ridge National Laboratory
- **Development of Cast Austenitic Stainless Steels** (1772) – Roman Pankiw, Duraloy Technologies and Govindarajan Muralidharan,, Oak Ridge National Laboratory
- **New Class of Bainitic Chromium Tungsten Steels** (1781) – Scott Mao, University of Pittsburgh and Vinod Sikka, Oak Ridge National Laboratory
- **Ultrasonic Processing of Materials** (1784) – Qingyou Han, Oak Ridge National Laboratory
- **New Class of Ultra-Hard Borides** (1789) – Bruce Cook, Ames Laboratory
- **Ultrahigh Magnetic Field Processing of Materials** (1792) – Gerry Ludtka, Oak Ridge National Laboratory
- **High-Density Infrared Transient Liquid Coatings** (1765) – Gail Ludtka, Oak Ridge National Laboratories
- **Ceramic and Refractory Components for Aluminum Melting and Casting** (1764) – Dale Brown, Pyrotek, Inc.

- **Inverse Process Analysis for the Acquisition of Thermophysical Data** (1776) – Adrian Sabu, Oak Ridge National Laboratory and George Osborne, University of Tennessee
- **Virtual Welded Joint Design** (1773) – Zhishang Yang, Caterpillar Technical Center
- **Physical and Numerical Analysis of Extrusion Process for Production of Bi-Metallic Tubes** (1782) – Wojciech Misiolek, Lehigh University
- **Novel Carbon Films for Next-Generation Rotating Equipment** (1785) – Michael McNallan, University of Illinois at Chicago
- **Oxide Dispersion Strengthened Tubes for the Production of Industrial Chemicals** (1783) – Marvin McKimpson, Michigan Technological University
- **Advanced Chlor Alkali Technology** (1797) – Jerzy Chlistunoff, Los Alamos National Laboratory
- **Advanced Composite Coatings** (1791) – Raj Bordia, University of Washington and Yigal Blum, SRI International
- **Modified Zeolites for Hydrocarbon Separations** (1779) – Tina Nenoff and Mutlu Kartin, Sandia National Laboratory

Tuesday, June 22

7:00 – 8:30	Registration and Breakfast
8:30 – 12:00	BREAKOUT SESSION – Sensors & Automation Steering Committee Meeting
8:30 – 8:50	**Welcome and Overview of Glass Sub-Program** Elliott Levine, Industrial Technologies Program Michael Greenman, Glass Manufacturing Industry Council
8:50 – 9:30	Glass Project: **High-Intensity Plasma Melter** (14232) – Ron Gonterman, Plasmelt Glass Technologies
9:30-10:10	Glass Project: **Measurement and Control of Glass Feedstocks** (1609) – Arel Weisberg, Energy Research Company
10:10 – 10:40	BREAK
10:40 – 10:55	Glass Project: **GPLUS Program** (1253) – Peter Angelini, Oak Ridge National Laboratory
10:55 – 11:35	Glass Project: **Oxy-Fuel Fired Front-End System** (14233) – Steve Mighton, Owens Corning

11:35 – 12:05	Glass Project: **Monitoring and Control of Alkali Volatilization** (1608) – Linda Blevins, Sandia National Laboratories
12:05 – 1:30	LUNCH
1:30 – 2:00	Glass Project: **Coupled Combustion Space Model** (1025) – Brian Golchert, Argonne National Laboratory
2:00 – 2:40	Glass Project: **Submerged Combustion Melting** (14231) – David Rue, Gas Technology Institute
2:40 – 3:10	Glass Project: **Improvement of Performance and Yield of Glass Fiber Drawing Technology** (no CPS number) – Phil Sanger, Cleveland State University
3:10 – 3:40	BREAK
3:40 – 4:10	Glass Project: **On-Line Coating of Float Glass** (1640) – Mark Allendorf, Sandia National Laboratories
4:10 – 4:30	Glass Presentation - TBD
4:30 – 5:00	Materials Project: **Advanced Thermoelectric Materials for Efficient Waste Heat Recovery in Process Industries** (16947) – Peter Martin, Pacific Northwest National Laboratory
5:00	Adjourn
7:00 – 9:00	Group Dinner (Speaker: Peter Garforth, Garforth International)

Wednesday, June 23

7:00 – 8:30	Registration and Breakfast
8:30 – 9:00	**Welcome and Overview of Materials Sub-Program** Sara Dillich, Industrial Technologies Program
9:00 – 9:30	Materials Project: **Thermochemical Models and Databases for High-Temperature Materials** (1788) – Mark Allendorf, Sandia National Laboratories and Ted Besmann, Oak Ridge National Laboratory
9:30-10:00	Materials Project: **Combinatorial Methods for Alloy Design and Optimization** (1778) – George Pharr, University of Tennessee, Knoxville
10:00 – 10:30	BREAK

10:00 – 12:00	BREAKOUT SESSION – Glass Review Meeting
10:30 – 11:00	Materials Project: **Ultrananocrystalline Diamond Coatings for Pump Seals** (1798) – John Hryn, Argonne National Laboratory
11:00 – 11:30	Materials Project: **Advanced Composite Coatings** (1791) – Raj Bordia, University of Washington and Yigal Blum, SRI International
11:30 – 12:00	Materials Project: **Novel Superhard Materials and Nanostructured Diamond Composites** (1795) – Yusheng Zhao, Los Alamos National Laboratory
12:00 – 1:15	LUNCH
1:00 – 3:00	BREAKOUT SESSION – Glass Site Visit (Catholic University)
1:30 – 2:00	Materials Project: **Materials for High-Temperature Black Liquor Gasification** (16540) – Jim Keiser, Oak Ridge National Laboratory
2:00 – 2:30	Materials Project: **Advanced Nanoporous Composite Materials for Industrial Heat Applications** (1796) – Arlon Hunt, Lawrence Berkeley National Laboratory
2:30 – 3:00	Materials Project: **Zeolites for Energy-Efficient Hydrocarbon Separations** (1779) – Tina Nenoff, Sandia National Laboratory
3:00 – 3:30	BREAK
3:30 – 4:00	Materials Project: **Advanced Tooling for Molds and Dies** (1790) – Kevin McHugh, Idaho National Engineering and Environmental Laboratory
4:00 – 4:30	Materials Project: **Stress-Assisted Corrosion in Boiler Tubes** (1762) – Preet Singh, Institute of Paper Science and Technology and Steve Pawel, Oak Ridge National Laboratory
4:30 – 5:00	**Overview of New Materials Projects** Mahesh Jha, DOE Golden Field Office
5:00	Adjourn (Dinner on your own)

Thursday, June 24

7:00 – 8:30 Registration and Breakfast

8:30 – 11:00 **New Materials Projects Poster Session**

- **Materials for Industrial Heat Recovery Systems** (16940) – Jim Keiser, Oak Ridge National Laboratory and Preet Singh, Institute of Paper Science and Technology
- **Development of Functionally Graded Materials for Manufacturing Tools** (16941) – Glenn Grant, Pacific Northwest National Laboratory and Lou Lherbier, Carpenter Powder Products
- **Structurally Integrated Coatings for Wear and Corrosion** (16942) – M. Brad Beardsley and D. Trent Weaver, Caterpillar
- **Multifunctional Metallic and Refractory Materials for Energy Efficient Handling of Molten Metals** (16943) – Xingbo Liu, Thomas Damiani, and Carl Irwin, West Virginia University
- **Development of Materials Resistant to Metal Dusting Degradation** (16944) – Ken Natesan, Argonne National Laboratory
- **Advanced Integration of Multi-Scale Mechanics and Welding Process Simulation in Weld Assessment** (16945) – Wentao Cheng, EMC2 AND Zhili Feng, Oak Ridge National Laboratory
- **Advanced Wear and Corrosion Resistant Systems through Laser Surface Alloying and Materials Simulation** (16946) – Richard Martukanitz, Penn State Applied Research Laboratory
- **Advanced Thermoelectric Materials for Efficient Waste Heat Recovery in Process Industries** (16947) – Peter Martin, Pacific Northwest National Laboratory
- **Low-Temperature Surface Carburizing of Stainless Steels** (16948) – Sunniva Collins, Swagelok
- **Development of Bulk, Nanocrystalline Cemented Tungsten Carbide for Industrial Applications** (16949) – Z. Zak Fang, University of Utah
- **Prediction of Corrosion of Advanced Materials and Fabricated Components** (16950) – Andre Anderko, OLI Systems and Sean Brossia, Southwest Research Institute
- **High-Strength/High Alkaline-Resistant Fe-Phosphate Glass Fibers as Concrete Reinforcement** (16951) – Ted Day, Mo-Sci Corporation

11:00 Adjourn

2

List of Reviewers

Reviewers

Glass Manufacturing Industry Council

CORE MEMBERS

CertainTeed Corporation
Terry Berg

Corning Incorporated
Fred Quan

Owens Corning
Steve Mighton

PPG Industries
David Bivins
Doug Dawson

Techneglas
Rob Adams

ASSOCIATE MEMBERS

Eclipse/Combustion Tec
Kevin Cook

Gas Technology Institute
David Rue

Savannah River National Laboratory
Ray Schumacher

Unimin Corporation
Eric Westbrook

Retired Industry Experts

John Brown
Jim Shell
Warren Wolf

3

Ongoing Project Evaluation Results and Presentations

Plasmelt Glass Technologies, LLC
High Intensity Plasma Glass Melter

- Agenda
  - Project Overview (What was planned)
  - Project Status (What we did)
  - Plasma Melting Value to the Glass Industry
    - Results of marketing
  - Initial glass quality / Next Steps
  - Summary

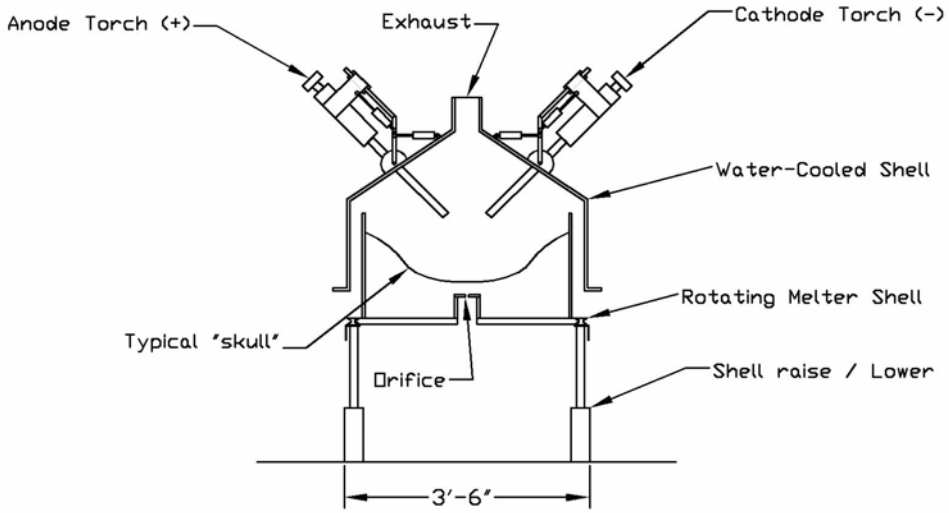
Project Overview

- Build a transferred-arc plasma melter
- Establish baseline operation at 500 lbs/hour
- Determine market requirements
- Produce marbles (or patties/lenses) & fibers / test quality at partners site
- Commercialize process

Project Overview

- History
  - JM developed technology in 90's
  - Tested with scrap and batch melting
    - *E-Glass, S-Glass, Basement Scrap, Insulation, etc.*
  - Tested and proved system works.
    Results of testing:
    - Low throughput rates / low efficiency
    - High throughput rates / high efficiency / low torch life

Project Overview – As Proposed



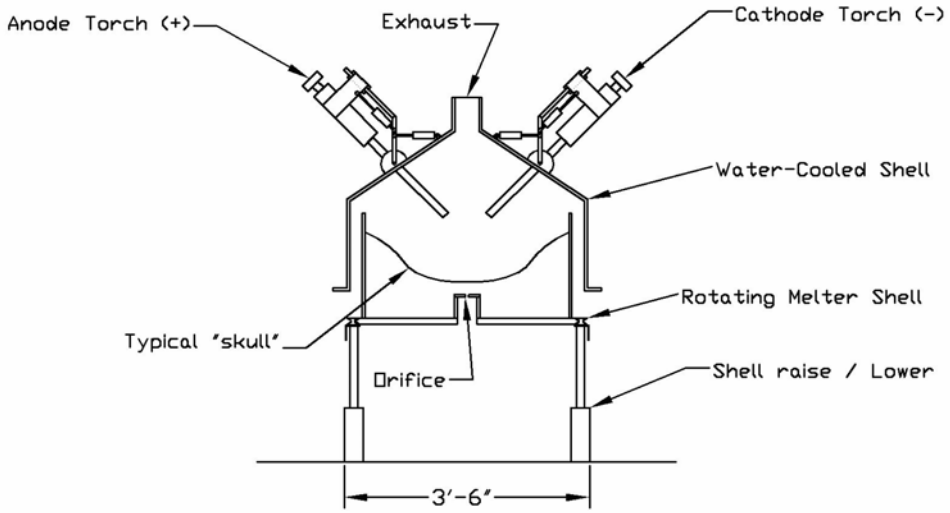
Project Status

- We designed and built research melter
  - Working on high-risk areas first
  - Robustness and looks come second
  - Rapid development cycle

Need to answer key questions:

- What is the maximum life of torches?
- Can it produce acceptable glass quality?
- Does anyone want this if we make it work?

Project Overview – As Proposed



Project Status – As built

Project Status – As built

Project Status – As built

Project Status – As built

Project Status – As built

- Built entire system
  - Upgraded power / facility
  - Installed all equipment
- Built / tested over 50+ torches
- Built / tested over 14 orifice designs

Results are:

⇨Ran melter at 200 lbs/hr for 2+ hrs with "stable" operating conditions

Project Status

- Project Plan – Year 1

	Original	Actual
Project Start	7/28/03	Complete
Facility Selection	8/21/03	Complete
Utilities / Facility Modifications	10/28/03	Complete
System Design	12/11/03	Complete
Construction	1/22/04	Complete
Initial testing	2/27/04	In Progress
Full-scale testing	5/30/04	In Progress
Market Study	5/31/04	Complete
Glass Cullet Testing	6/30/04	

Plasma Melting – Value to Glass Industry

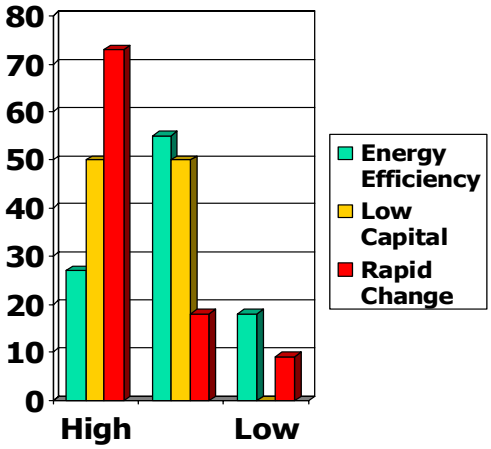
- Energy Efficiency
- Production Flexibility
  - 20 min startups / stops
  - Can melt many different materials
  - Fast process response time
- Modular / Scalable
  - Can add additional melting capacity in modular blocks
  - Provide means of matching production requirements with market demand
- Ability to Quickly Start / Stop Process
  - Better power rates
  - Improved labor utilization

Plasma Melting – Value to Glass Industry

- Scrap Processing
  - Standard technology with ability to process several types of material
  - Ability to use same melter for batch melting and scrap processing
  - Industry-proven technology for processing scrap material
  - Landfill cost was very expensive
  - Potential long-term issues with landfill of big concern
- Low-capital system
  - Small
  - Modular
  - No refractory
- Capability to process new materials
  - Unique high temperature materials
- Small exhaust stream

Plasma Melting – Value to Glass Industry

- Preliminary Market Study Results
  - Highest priority benefits of the Plasmelt Melter are its rapid changeover capability and its low initial capital and maintenance costs
  - Energy use is important. But, electric melting at 4.1 MM btu/lb is not perceived as a particularly low energy cost melting process.
  - Environmental benefits, with the exception of the elimination of refractory disposal, are low in relative value to special glass segment companies interviewed. Ability to recycle waste with a plasma melter is important to several companies.
  - New Materials / New Products / New Lines is a potential benefit of the high temperature capability of the plasma melter system.



Initial Glass Quality

Initial glass samples have not yet been sent to Integrex, but our cursory observations are:

- The glass has abundant very small seeds (as expected).
- Cordy glass and minor amounts of un melted batch.
- No evidence of Moly in glass.
- High exit orifice temperatures are promoting volatilization.
- Volatilization is occurring from the E-glass exit stream.

Baseline suite of glass samples has been collected and are being prepared for:

1. Physical property test variation over time (e.g. viscosity, refractive index)
2. Glass chemical analyses (target vs actual)
3. Fiberizing trials

Final suite of glass samples will be submitted for a more detailed analysis:

1. Fiberizing and fiber property testing
2. Homogeneity Testing: Shelyubski? Density spread? RI via Interferometry?

Known Obstacles

- Technical Obstacles:
  - Anode torch life
  - Glass Quality (mixing, refining, volatilization)
- Market Obstacle
  - No installed base in the glass industry
  - Process economics
    - Capital, abatement, power source, etc.

High Intensity Plasma Glass Melter -- GO 13093

BARRIER - PATHWAY - APPROACH

BARRIERS	PATHWAYS	APPROACHES
Torch Life	Development of Robust Torch Designs	Rapid turnaround time on torch trials and design evaluations
Process Stability	Understand the relationship between process operation and process stability	Conduct parametric trials to relate operational settings to exit temperatures and glass flow rates.
Energy Efficiency	Understand relationship between energy efficiency and process operations	Conduct parametric trials to relate process settings to transferred arc energy
Glass Quality	Understand relationship between process operation and glass quality	Conduct parametric trials to relate process settings to glass quality
Market Acceptance	Market Study & Technical Economic Analysis Tools	Conduct market study of Specialty Segment and develop a TEA tool to use for marketing efforts

Next Steps based on initial glass quality

- Goal : Achieve 500 # / hr with a stable process at efficiencies of at least 4.1 MM / BTU / ton and with improved environmental impact
- Determine the relationship of furnace operation & glass throughput to glass quality & energy efficiency
- Outline a detailed plan and engineering feasibility study of first pilot installation at AGY
- Evaluate alternate higher melting glass compositions
  (e.g. S-glass, Alumino-silicates, silica, etc.)
- Conduct fiberizing trials to establish the benefits/penalties
- Conduct energy balance of entire system
- Conduct environmental assessment

Summary—Plasmelt Year 2 Technical Efforts Being Driven by CSP's and Market Study Results

- Technical Merit:
  - Potential 25 to 40% energy savings
  - Ability to rapidly changeover a melting operation (73% High Interest)
  - Need – New technology / new markets
  - Contribution of knowledge – Will generate first-ever data to relate glass quality to plasma melting process operation
- Technical Progress:
  - Progress – On track. On Budget. From nothing to melting 200 #/hr of glass in 9 months!!!
  - Expectations for successful solution – See video

Summary

- Commercial Readiness in July, 2005:
  - Answer the three questions
  - Pilot engineering & feasibility study with AGY
  - Complete glass melting trials of various glass industry glasses
  - Demonstrate process stability, glass quality, energy and environmental
- Market Potential:
  - Broadness of application – melter design is generic
  - Adaptation potential – Low-cost / flexible solution

Summary

Programmatic Merit:

- Benefits – Lower cost of production on several fronts
- Resources - Best in industry
- Commercialization plan – Focused on profit and speed to market

Summary

Bottom Line

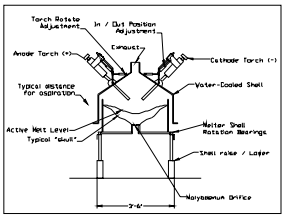
- **Proposal to glass melting in 9 months!**
- **We have completed an aggressive first year project plan.**
- **We are on budget / On schedule.**

High Intensity Plasma Glass Melter -- GO 13093

Project Goal: Develop an efficient 500 lb/hr transferred arc plasma melting process that can produce high quality glass suitable for processing into a commercial article.

Challenge: Develop a torch design that will allow a stable and efficient process producing high glass quality.

Benefits: High energy efficiency, low initial capital cost/low maintenance cost, rapid changeover design, with high temperature capability for new and novel materials.



FY 05 Activities: Develop improved torch designs, conduct parametric trials to relate melter operation to energy efficiency, glass quality, and low environmental emissions. Evaluate scrap melting for fiberglass. Conduct engineering and feasibility study for first pilot installation.

PARTICIPANTS:

1. AGY
2. JM
3. J.K. Hayward
4. LGP
5. Integrex Laboratory
6. InnovaTech

Measurement and Control of Glass Feedstocks

Arel Weisberg, Ph.D.
Robert De Saro
Joseph Craparo, Ph.D.
James Simpson, Ph.D.

Energy Research Company

2004 OIT Glass Project Review

June 22, 2004

ERCo ENERGY RESEARCH COMPANY

Batch Measurements at PPG

PPG Product Manager Kevin Streicher Operating ERCo LIBS Batch Sensor

Chester Fiber Glass Plant

Test Sample (blind)	Boron Concentration Difference
A	0.00 %
A	0.03 %
B	0.24 %
B	0.30 %

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Agenda

- Project Summary
- Project Approach
- Participants
- Brief Summary of Accomplishments
- Problem Statement
- Concept Description
- Experimental Data
- Discussion and Conclusion

Project Summary

- Goal: Develop a plant instrument for rapidly measuring oxides in batch materials
- Challenge: Bringing LIBS technology from the lab to the plant with the accompanying issues of accuracy, robustness, ease of use, and low maintenance
- Benefits: 20 percent reduction in product defects, saving the glass industry $220 to 440 million. Energy savings of 260 to 520 billion Btu per year
- FY05 Activities: Long term testing of instrument at PPG fiber glass plant while continuing to upgrade the instrument's capabilities

Barrier-Pathway Approach

- Barriers
  - Using LIBS to measure many elements rapidly and simultaneously with widely varying concentrations (fractions of % to tens of %)
  - Ruggedizing LIBS for plant environment
    - Ease of use, low maintenance
- Pathway
  - State-of-the-art LIBS hardware components
  - Innovative software algorithms
  - Complete automation
- Critical Metrics
  - 5% relative error or 0.05% absolute error in concentration measurements

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C-LESS™ LIBS Software

- ERCo has Proprietary Software Using First Principles that Translates LIBS Spectra into Concentration Measurements
- Calibration Not Required
- Method is Automatic – no user assistance necessary
- Method Applies to both Molten and Solid Data
- Method is Independent of Experimental Parameters that Can Fluctuate such as Laser Power

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Participants in Glass Project

- DOE Industrial Technologies Program – Industries of the Future: Glass
- Energy Research Company
- PPG Industries (Fiber Glass)
- Fenton Art Glass
- Oak Ridge National Laboratory

U.S. Department of Energy
Energy Efficiency and Renewable Energy

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PPG

FENTON
Handcrafted American Glass Artistry

OAK RIDGE NATIONAL LABORATORY

Accomplishments

- Built Full Scale Sensor
  - Automated & Robust LIBS Hardware
  - Developed "1-click" LIBS Software
- Installation and Testing at PPG
  - Extensive ulexite testing
  - Limestone residue testing
  - Installation for long term test scheduled
  - Upgrades for glass buttons, clay, colemanite, and silica

Accomplishments

- Applied Advanced Calibration-less (C-LESS™) LIBS Analysis to Batch Materials
- Demonstrated LIBS Utility for Cullet Sorting
- Measured Molten Glass Composition
- Related Funded Work in:
  - Coal
  - Aluminum
  - Steel
  - Alloy sorting

Problem Statement

- The Glass Industry Technology Roadmap emphasizes this need for accurate process and feedstock sensors (p. 12):

  "The lack of effective in-process sensors and control systems is the most serious barrier to better production efficiency."

Problem Statement

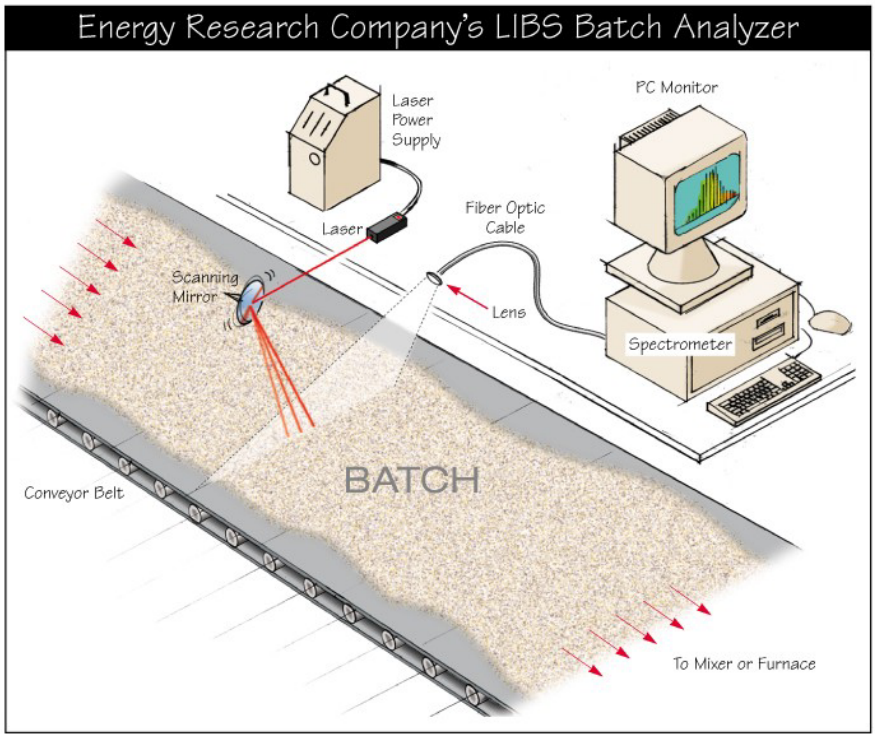
- Lack of Effective Way to Ensure Accurate Batch Oxide Concentrations
  - An indeterminate mixture of prior deliveries to a silo exits the silo
- Oxide Fluctuations Lead to
  - Wasted Feedstock
  - Quality Problems
  - Increased Energy Use and Emissions
  - Wasted Product

Benefits for PPG

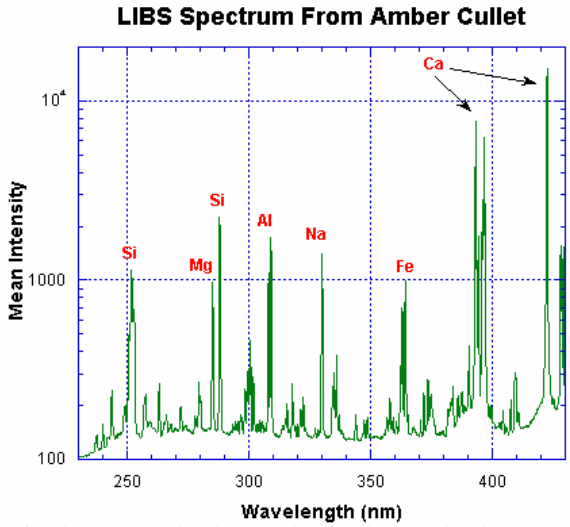
- Knowledge of batch oxides is expected to significantly improve plant efficiency leading to:
  - Energy savings
  - Material savings
  - Overall financial savings
- Result: Payback on the instrument less than 1 year

Goal

- Develop a plant instrument for rapidly measuring oxides in batch materials



LIBS Technology



Spectrometer gathers the plasma light and spreads it, like a prism, into a spectrum where the contribution of each element can be seen

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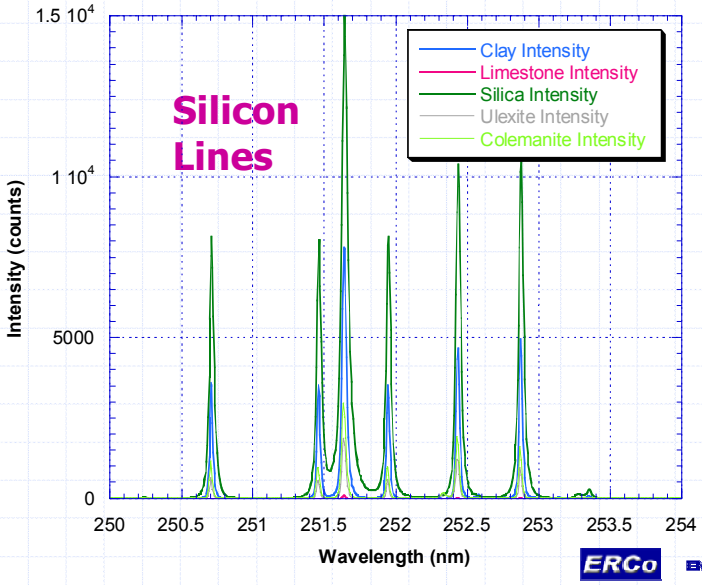
Batch Constituents

- LIBS Spectra Collected from Each Sample



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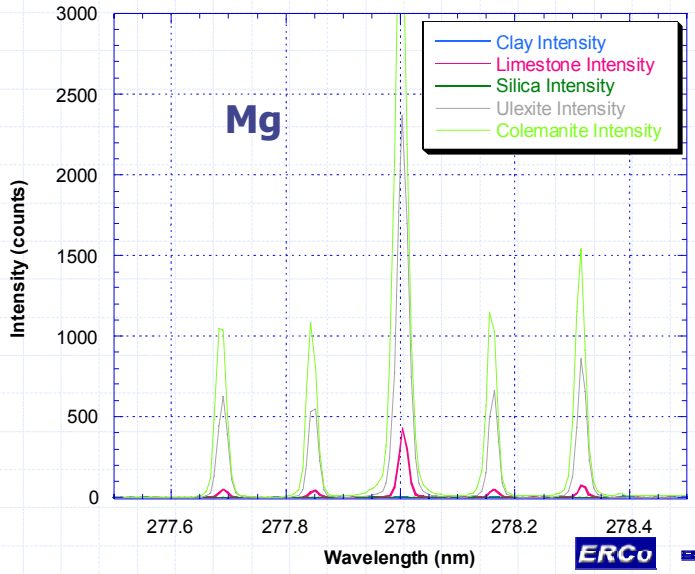
Batch Constituents

- LIBS Spectra Collected from Each Sample



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LIBS Advantages

- Fast
  - A few minutes to perform a complete elemental analysis
- Accurate
  - Fractions of a percent to ppm
- Applicable to a wide range of materials
  - Glass, Batch
  - Metals, other solids, liquids, gases
- Proven
  - Extensive literature on use of the process in lab environments
  - **ERCo's** LIBS installation in aluminum plant production line

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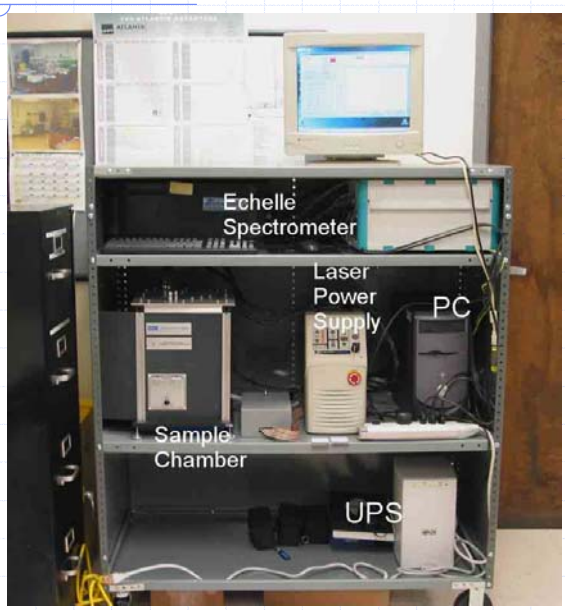
Experimental Results

- Apparatus and method
- Concentration measurements from PPG on-site test

Apparatus

- PPG requested an off-line analyzer
  - Ability to measure more than one material more important than continuous operation
    - Batch minerals such as ulexite, clay, limestone, silica
    - Limestone residue from scrubber system
    - Glass "buttons" taken from furnace
  - Batch materials likely not varying within any one 24 hour period
  - Potential for analysis of glass "buttons" in same instrument

ERCo LIBS Batch Analyzer at PPG's Chester Plant



- Laser
  - Big Sky Laser ULTRA-CFR, 1064nm
  - Up to 20 Hz , 50 mJ
  - Industrial Design
  - Low Maintenance
- Spectrometer
  - LLA ESA 3000
  - 200-850nm Echelle
  - $\lambda/\delta\lambda$=40,000 (7 pm @ 300nm)

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ERCo LIBS Batch Analyzer

- Sample Chamber
  - Contains laser head, motorized stages, and detection optics
  - Samples consist of a few grams on custom holder and placed inside the chamber door
- Completely Computer Controlled
- Laser light is contained – Eye Safe
- Low Maintenance

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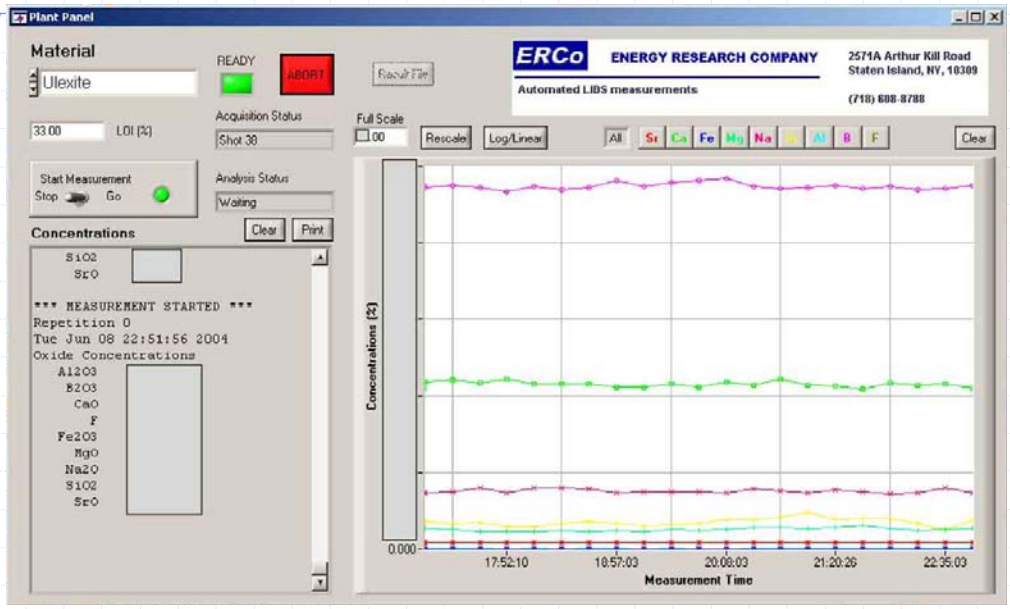
ERCo LIBS Batch Analyzer



Materials

- Materials choice determined by PPG
  - Single batch ingredient analysis more useful than mixed batch analysis
  - Ulexite is the top priority material
  - Limestone used in scrubber system is next most important

» Sensor will analyze all of PPG's materials of interest

PPG Testing Program

- Ulexite samples provided by PPG together with compositional analyses prior to testing
  - 3 different mine locations
  - Samples from same mine location illustrative of variability in shipments
  - Each delivery to PPG sampled only once by mining company

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PPG Testing Program

- Ulexite samples provided to ERCo during testing without compositional analyses for "blind" testing for boron content

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PPG Chester Test Results

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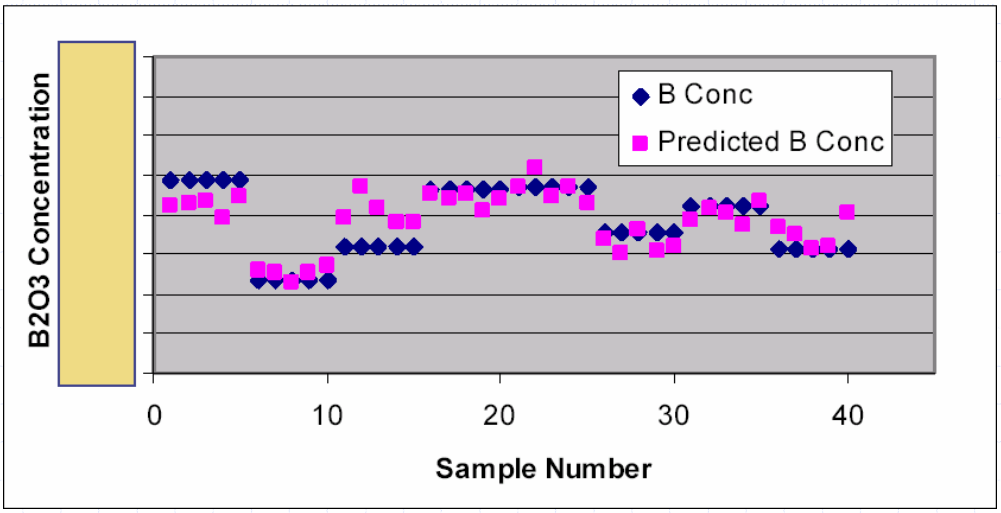
Boron



Average difference: 0.54% ± 0.43%

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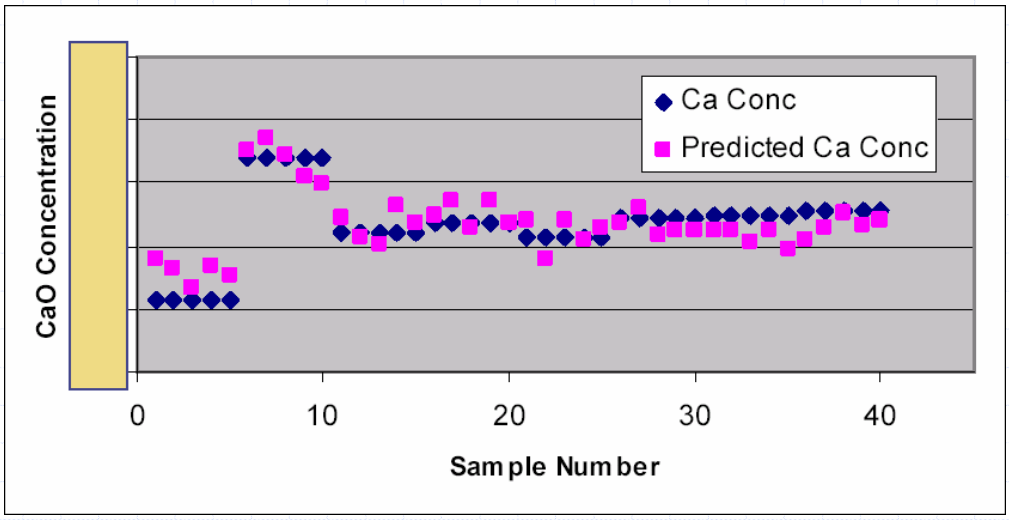
Calcium



Average difference: 1.51% ± 0.94%

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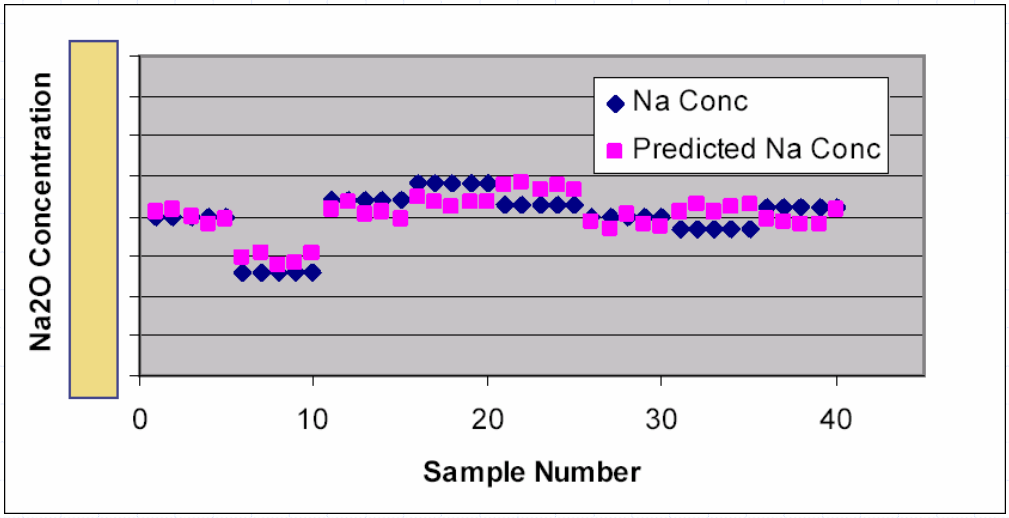
Sodium



Average difference: 2.75% ± 1.34%

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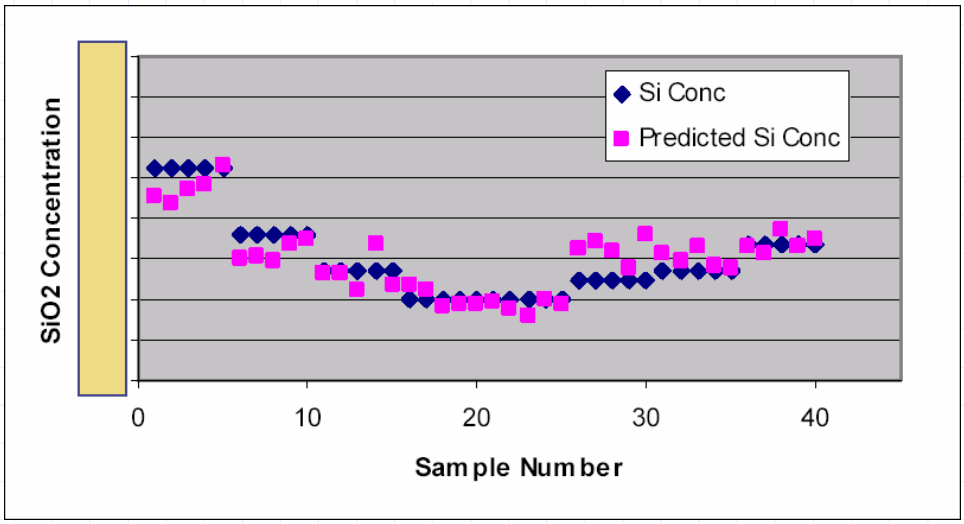
Silicon



Average difference: 4.98% ± 4.02%

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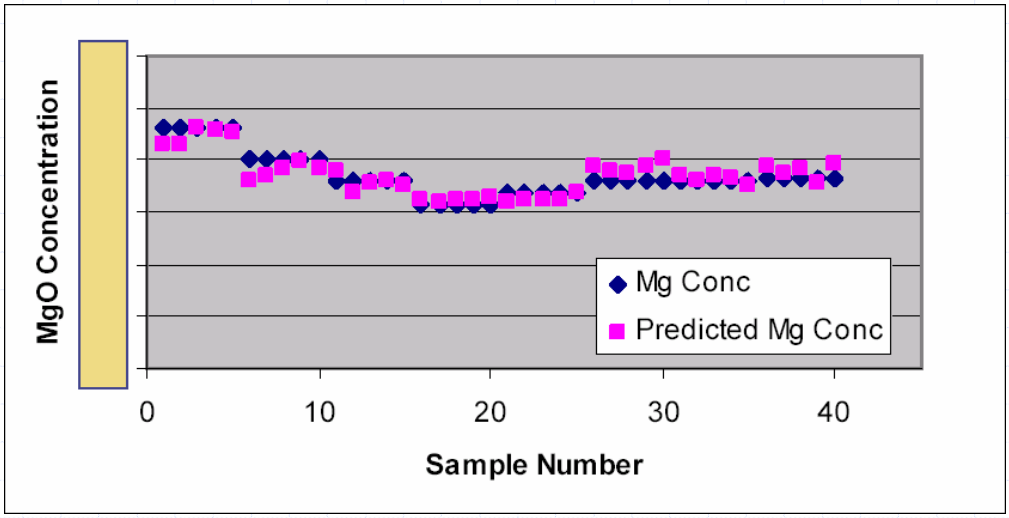
Magnesium



Average difference: 4.06% ± 2.72%

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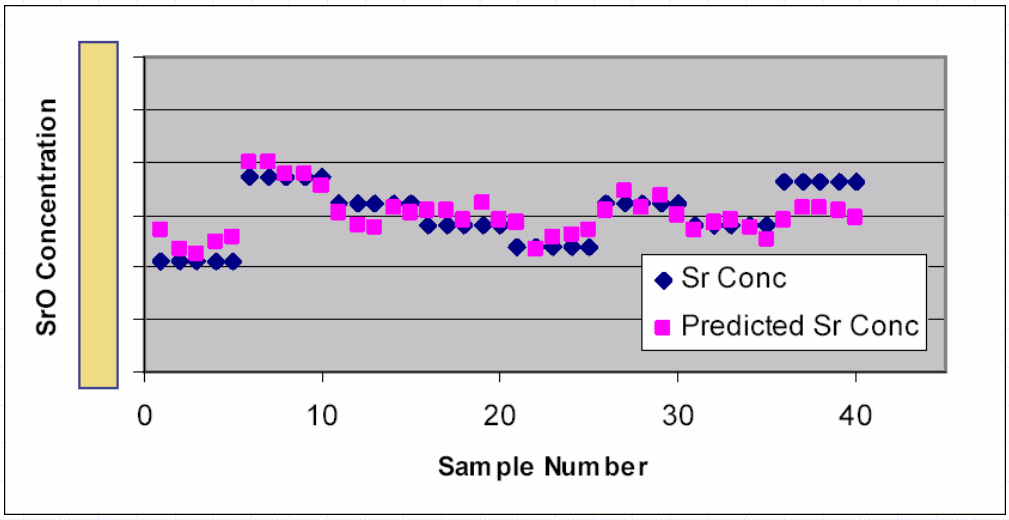
Strontium



Average difference: 0.026% ± 0.018%

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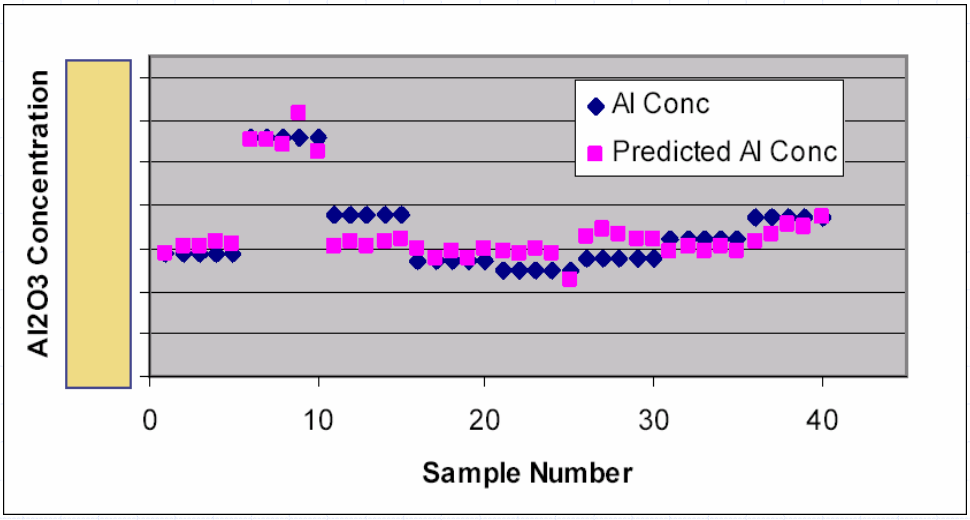
Aluminum



Average difference: 0.007% ± 0.004%

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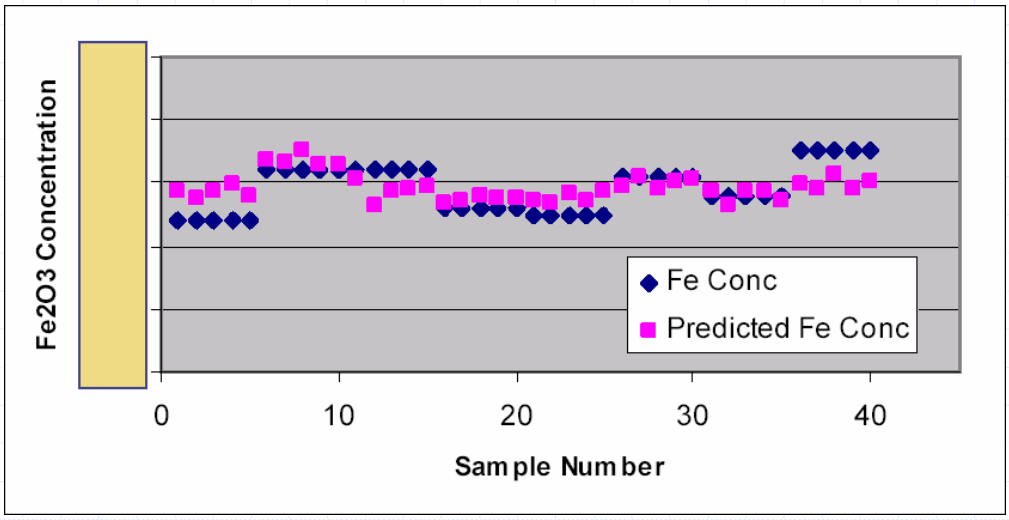
Iron



Average difference: 0.003% ± 0.002%

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"Blind" Ulexite Samples

- Samples A & B analyzed twice
- 0.3% change or variability in boron measurement not significant

Test Sample (blind)	Boron Concentration Difference
A	0.00 %
A	0.03 %
B	0.24 %
B	0.30 %

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PPG Test Summary

- Equipment successfully transported and installed
- Sensor operation is reliable
  - 20 days equivalent testing performed
- PPG personnel satisfied with accuracy, repeatability, ease of use
- "Blind" tests successful

PPG Test Follow On Program

- Return to plant in July with improved sensor for long term testing by PPG employees
- Add capability for limestone residue analysis
- Add capability for glass "button" analysis
- Add capability for other batch materials

Clay Results (% difference)

El.	A	B	C	D	E	Avg.
Si	0.21	2.64	2.64	2.16	2.37	**2.00**
Al	0.10	1.38	0.65	1.42	1.93	**1.10**
Ti	0.13	0.04	0.04	0.37	0.23	**0.16**
Fe	0.08	0.01	0.09	0.09	0.06	**0.07**
Na	0.03	0.03	0.03	0.03	0.03	**0.03**

Major Minor

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Silica Results (% difference)

El.	A	B	C	D	E	Avg.
Si	0.10	0.20	0.23	0.18	0.18	**0.18**
Al	0.05	0.02	0.04	0.01	0.01	**0.03**
Ti	0.01	0.01	0.01	0.00	0.00	**0.03**
Fe	0.01	0.02	0.02	0.00	0.00	**0.01**

Major Minor

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Limestone Results (% difference)

El.	A	B	C	D	E	Avg
C	1.28	0.62	1.54	1.59	0.09	**1.02**
Ca	0.26	0.09	0.57	0.41	0.18	**0.30**
Mg	0.00	0.00	0.01	0.01	0.00	**0.00**
Al	0.01	0.01	0.00	0.01	0.01	**0.01**
Si	0.08	0.07	0.10	0.10	0.13	**0.10**
Fe	0.00	0.00	0.01	0.04	0.02	**0.01**

Major Minor

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Future Interest

- Measure Concentrations of Molten Glass in Tank in Real-Time, In-Situ
- LIBS probe patent granted
- NYSERDA seed money received in 2nd quarter ’04 towards a furnace suitable for extensive molten glass LIBS work

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Molten Glass Data

Element	Result	% Outside Range
Si	Good	0.81
Na	Good	
Ca	Good	
Mg	Out	5.2
Ba	Out	2.8
Fe	Good	
Sr	Good	
Mn	Good	

Actual Concentrations Proprietary

Glass Analyzed Before And After Melting

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Industrial Installation

- Molten Aluminum LIBS Probe Installation at Commonwealth Aluminum Newport Rolling Mill

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LIBS Sensor for Molten Aluminum

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Commercial Installation

- Industrial Cabinet

- Sealed, Air Conditioned, EMI Shielded

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Molten Aluminum Concentrations

Aluminum Alloy 3105

	Al	Cu	Fe	Mg	Mn	Si	Cr
LIBS Average	97.87	0.17	0.65	0.47	0.52	0.28	0.04
Commonwealth Average	97.56	0.18	0.65	0.49	0.56	0.30	0.05
% Difference	0.32	5.6	0.0	4.1	7.1	6.7	20.0
LIBS RSD	0.09	5.0	4.87	11.61	4.54	6.29	5.52
Commonwealth RSD	0.03	3.51	3.65	1.53	3.57	2.25	2.17

Discussion and Conclusions

- ERCo's LIBS Batch Analyzer proven in role as rapid glass batch analysis
- Follow on testing and upgrades to continue in FY05
- Oxide concentrations in PPG batch and other materials measured using ERCo's C-LESS™ method
- Molten glass preliminary concentration measurements successful

Schedule

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
1	**Laboratory Development**			
1.1	Facility Modification	9/30/01	9/30/01	
1.2	Testing	3/31/02	2/28/02	
1.3	Initial Software Development	3/31/02	3/31/02	
1.4	Performance Evaluation	3/31/02	3/31/02	
2	**Sensor Fabrication**			
2.1	Facility Construction	9/30/02	8/31/02	
2.2	LIBS Testing	8/31/03	5/31/04	
2.3	Modifications to PPG Facility	12/31/03	3/31/04	Not necessary
2.4	Procure System	6/30/04	5/31/04	
3	**Sensor Testing**			
3.1	Testing at PPG	2/28/05		Commenced in 6/04
3.2	System Integration	12/31/04		

Commercialization Plans

- Intellectual Property Consisting of Issued Patent and Trade Secrets
- Commercialization Study Completed
- Licensee Discussions Underway
  - ERCo Fabricates, Services, and Installs
  - Licensee Sells
  - Approach Fits in with ERCo's Business Model for All of its LIBS Products

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

U.S. Department of Energy

2004 Glass Project Review

June 22 , 2004

Crystal City, Virginia

Steve Mighton

(740) 321-7633

steve.mighton@owenscorning.com

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

Presentation Outline

- Consortium Membership
- Background
  - •Modeling
  - •Advantages of oxy flame
  - •Cost Saving examples
- Project Task List
  - •Bench trials - OC Science & Technology Center, Granville, Ohio
  - •Ongoing in-plant top fire trial in OC's Guelph
  - •Side fire trial in Guelph
  - •Safety interlocks – Jackson no gas, no oxygen
- Consortium activity supporting project

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

Consortium Partners:

- Owens Corning
- Osram-Sylvania
- BOC
- CTI/Eclipse

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

Objectives:

Develop an oxy-fuel combustion system specifically for front-end systems that delivers:

- Improved energy efficiency
- Reduced operating cost
- Improved environmental performance
- More uniform glass thermal quality.

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

Major Tasks:

(1) Develop burner systems for system integration

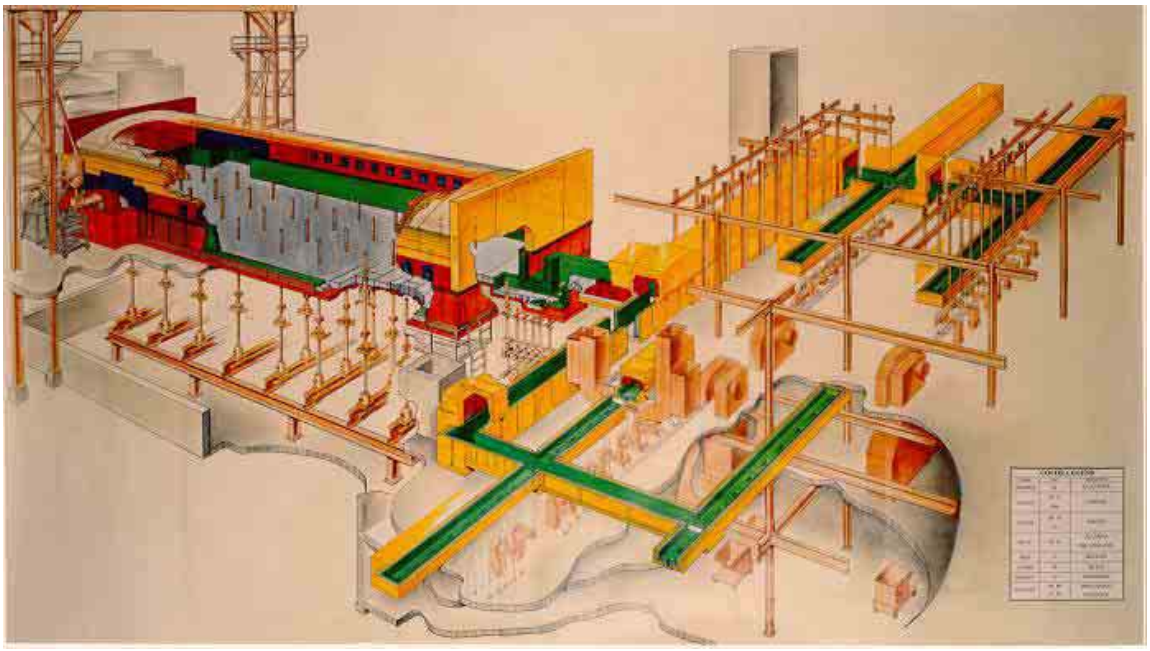
(2) Develop, test a firing system with minimum capital costs

(3) Field test the firing system(s) to obtain operational data;

(4) demonstrate the technology on a production system

(5) work with consortium to benefit other sectors of the glass industry

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System



Background

- **Energy Usage Distribution in Our Process**

  Oxyfuel Furnace = 47% Front-end System 53%

- **Current Technology: Low Energy Efficiency = ~25%**

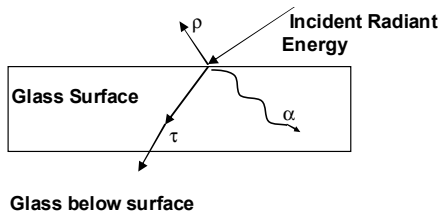
  Massive Piping & Control Systems

- **Prior attempts by the fiberglass industry to use gas/oxy combustion in a Front End have not led significant proliferation due to high cost, long payback or other reasons**
- **Premixed System Always a Safety Concern**

Why oxy firing is more efficient.

Thermal Radiation definitions

- ***Absorptivity,*** α, *the fraction of incident energy absorbed by a surface.*
- ***Reflectivity,*** ρ, *the fraction of incident energy reflected at a surface.*
- ***Transmisivity,*** τ, *the fraction of incident energy transmitted through a surface.*
- ***Emissivity***, ε, *is defined as the fraction of energy emitted by a real surface ratioed to that of an ideal surface.*



Why oxy firing is more efficient

1) Higher flame temperature – more energy radiated due to Δ T

Flame energy radiated (Q) is proportional to the 4th power of the difference in temperature between the flame and glass.

$$\dot{Q} = \varepsilon \cdot \sigma \cdot A\left(T_{\text{flame}}^4 - T_{\text{glass}}^4\right)$$

σ = ***constant***

A = ***surface area***

ε = ***thermal emissivity, fraction of energy emitted by flame***

T_{abs} = ***absolute temperature emitting surface***

Why oxy firing is more efficient

1) Higher flame temperature – more energy radiated due to Δ T

$$\dot{Q} = \varepsilon \cdot \sigma \cdot A\left(T_{\text{flame}}^4 - T_{\text{glass}}^4\right)$$

$T_{\text{oxy flame}}$ = ~ 2973 K (4900 F or 2700 C)

$T_{\text{gas flame}}$ = ~ 2255 K (3600 F or 2000 C)

T_{glass} = ~ 1643 K (2500 F or 1370 C)

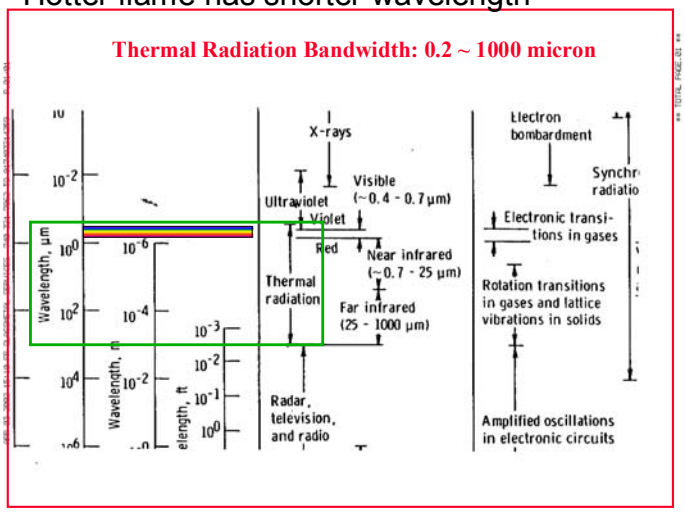
Ratio of (T^4 -T^4) term using: a) **$T_{\text{oxy flame}}$**

b) **$T_{\text{gas flame}}$**

Why oxy firing is more efficient

2) Higher flame temperature – more energy transmitted through the glass

- Hotter flame has shorter wavelength

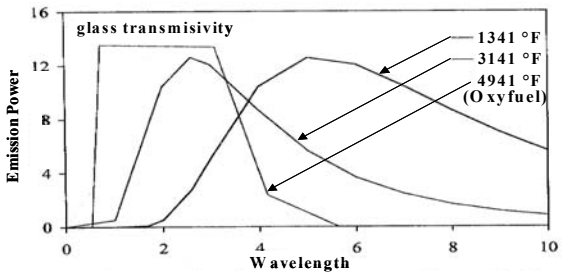


Why oxy firing is more efficient

2) Higher flame temperature – more energy transmitted through the glass

- shorter wavelength radiation enters glass more readily

Spectral Radiation Emission Power



Radiation from combustion can penetrate glass melt.

Why oxy firing is more efficient

3) Oxy/gas flame does not have to heat up N2 in air

- Air is 78% nitrogen, 21% oxygen
- eliminating nitrogen component reduces amount of gas that has to be heated

Why oxy firing is more efficient

Gas savings with oxy firing:

Melter: ~40% savings

- Front End: ~65-70% energy savings (before oxygen cost)

Why the difference?

Why oxy firing is more efficient

Gas savings with oxy firing:

Melter: ~40% savings

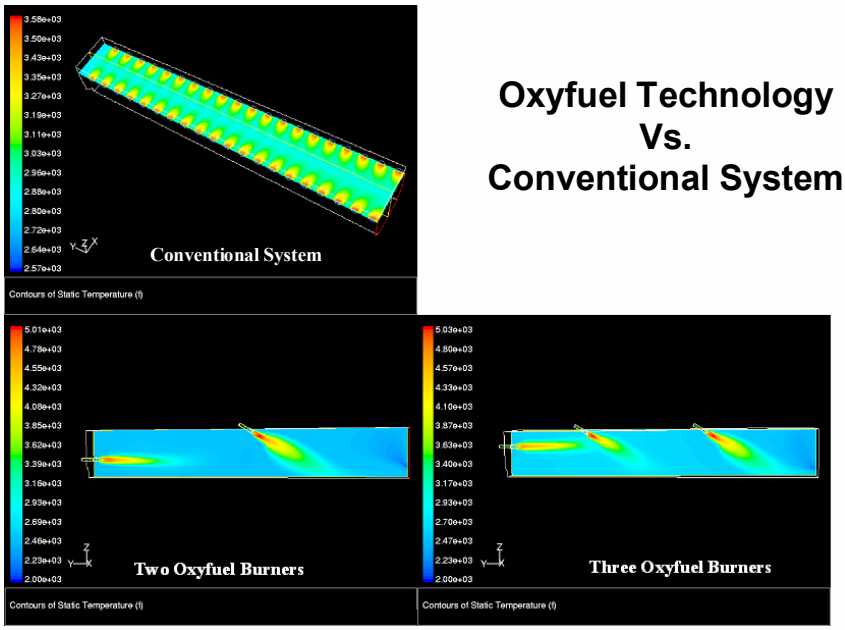
Front End: ~65-70% savings

Why the difference?

Melter combustion air is preheated in a recuperator

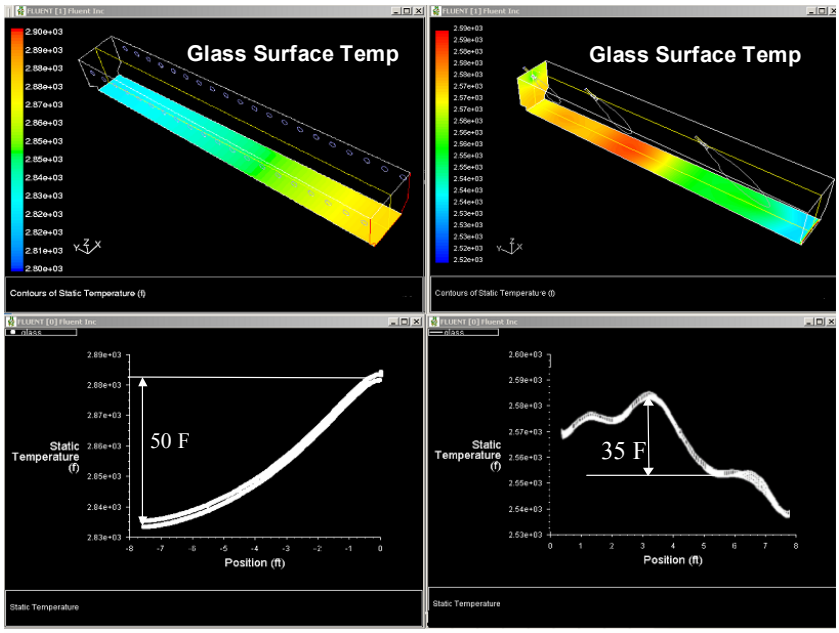
Front End - no recuperator

Technical Approach – The Technology



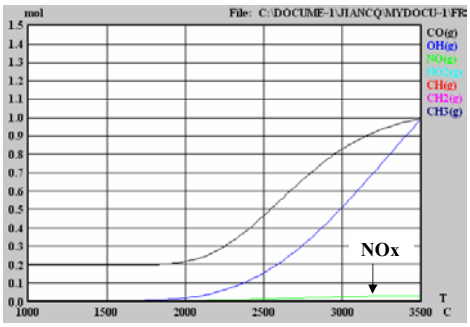
Oxyfuel Technology
Vs.
Conventional System

Technical Approach – Temperatures

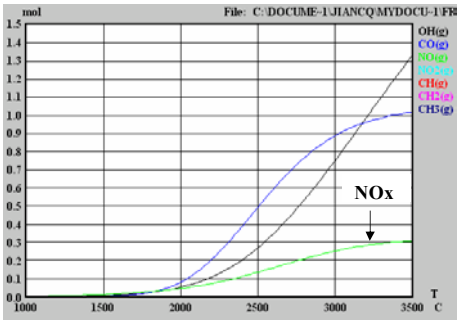


Emissions Reduction

- **Carbon Dioxide Reduction: 65 -70%**
- **Nitrogen Oxides Reduction: 90%**

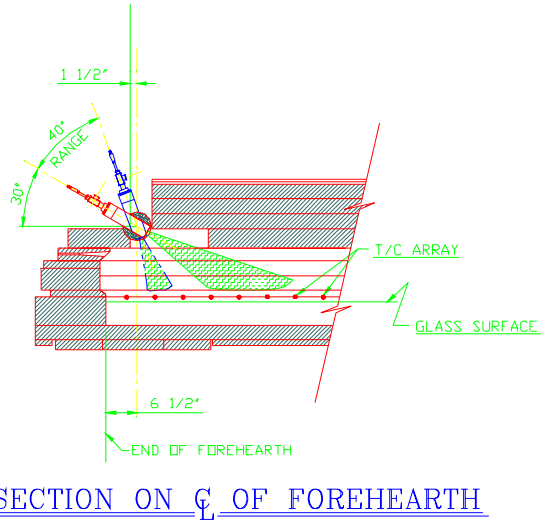


Oxyfuel

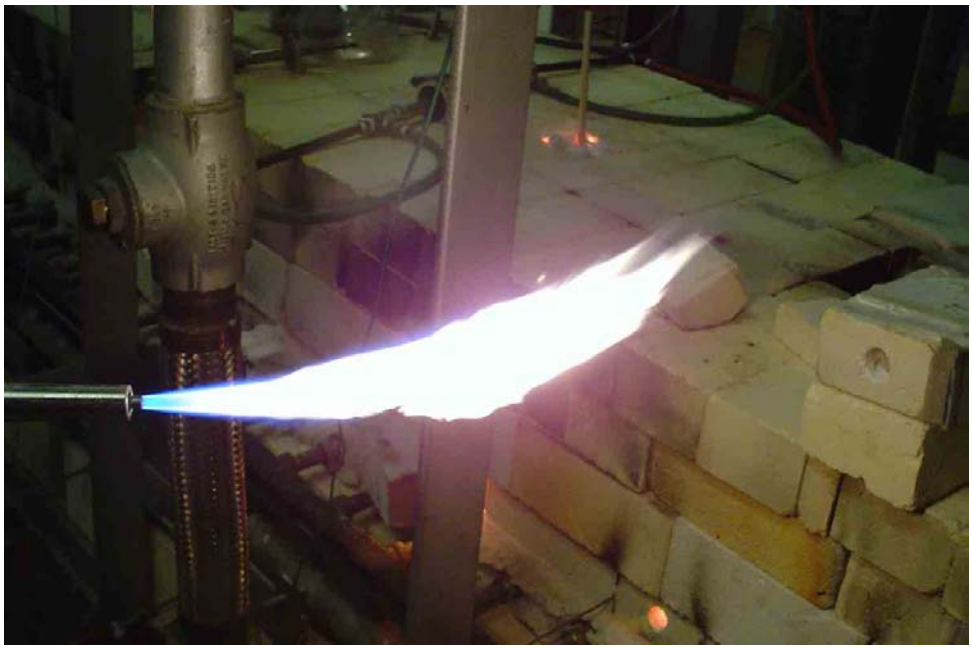


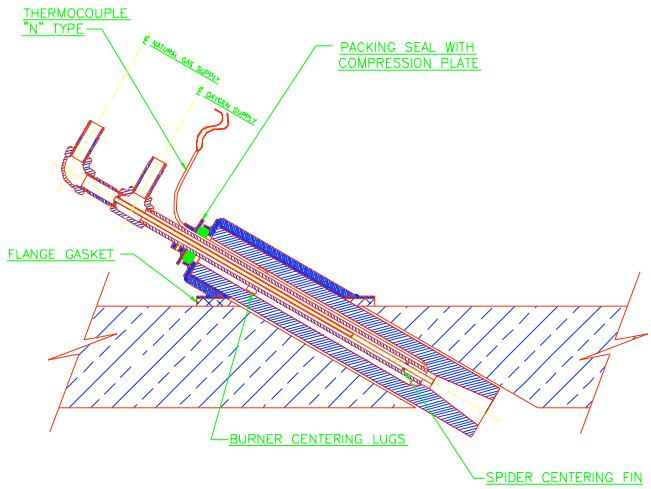
Air/gas

Bench Trials – top fire configuration

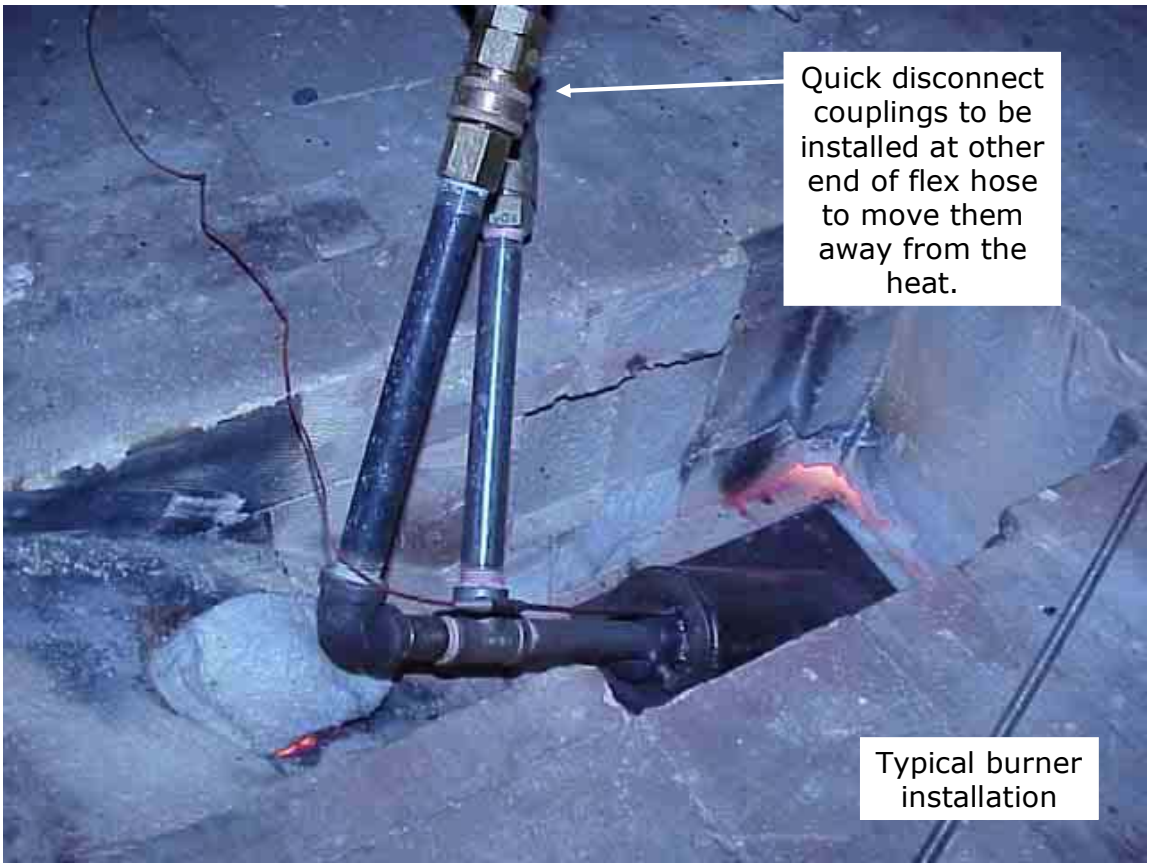


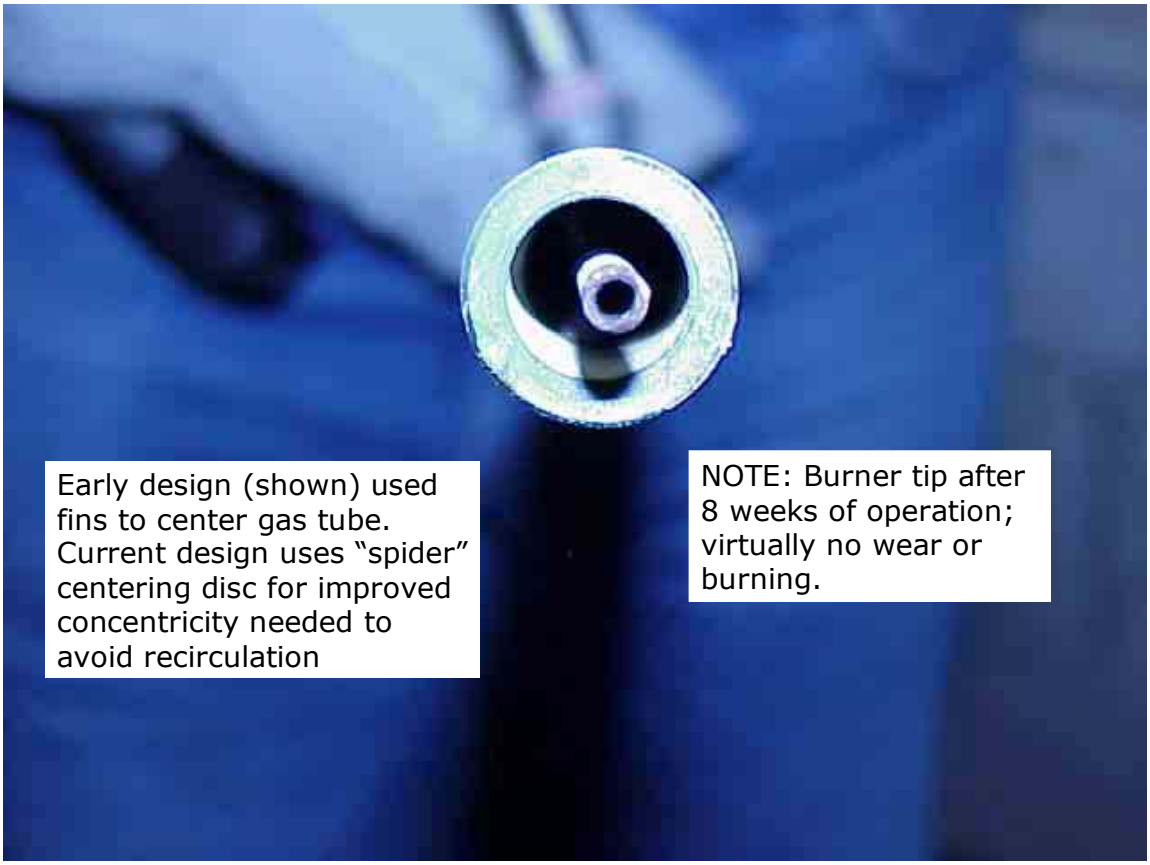
Equal Velocity Burner Trial



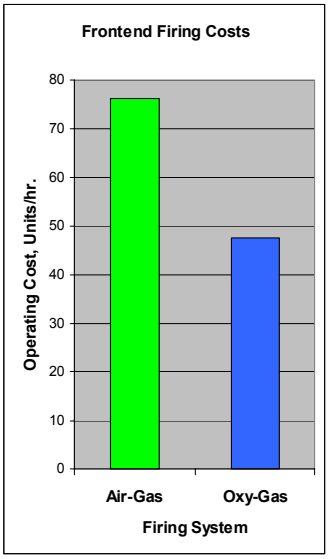

THERMOCOUPLE
"N" TYPE
℄ NATURAL GAS SUPPLY
℄ OXYGEN SUPPLY
PACKING SEAL WITH
COMPRESSION PLATE
FLANGE GASKET
BURNER CENTERING LUGS
SPIDER CENTERING FIN

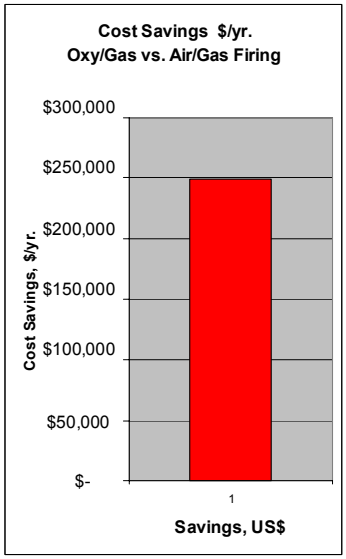
Dave Baker changing
out the oxy-gas burner


Quick disconnect couplings to be installed at other end of flex hose to move them away from the heat.
Typical burner installation


Early design (shown) used fins to center gas tube. Current design uses "spider" centering disc for improved concentricity needed to avoid recirculation
NOTE: Burner tip after 8 weeks of operation; virtually no wear or burning.

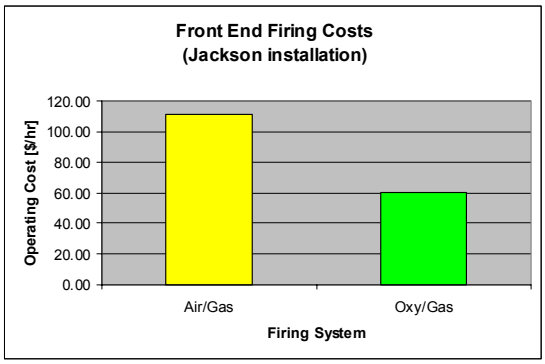
Economics for mid size melter





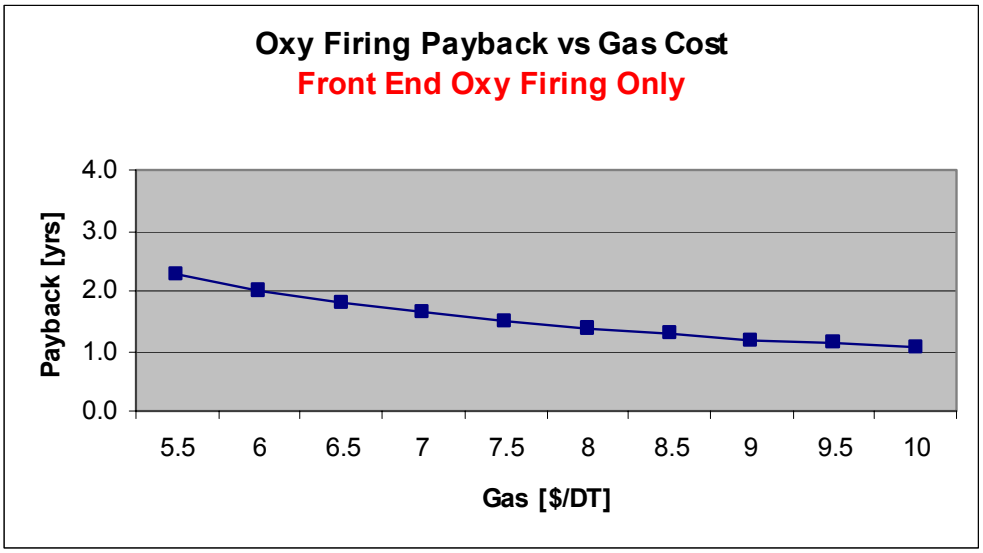
Total Percent Savings w/oxy-gas firing 37

Economics for Jackson front end



- Gas $6.75/DT
- Energy Input before conversion 16 DT/hr
- Operating Savings $440,000 – 470,000/yr
- Payback (excluding one time R&D development) = 1.85 yrs

Payback vs Gas Cost

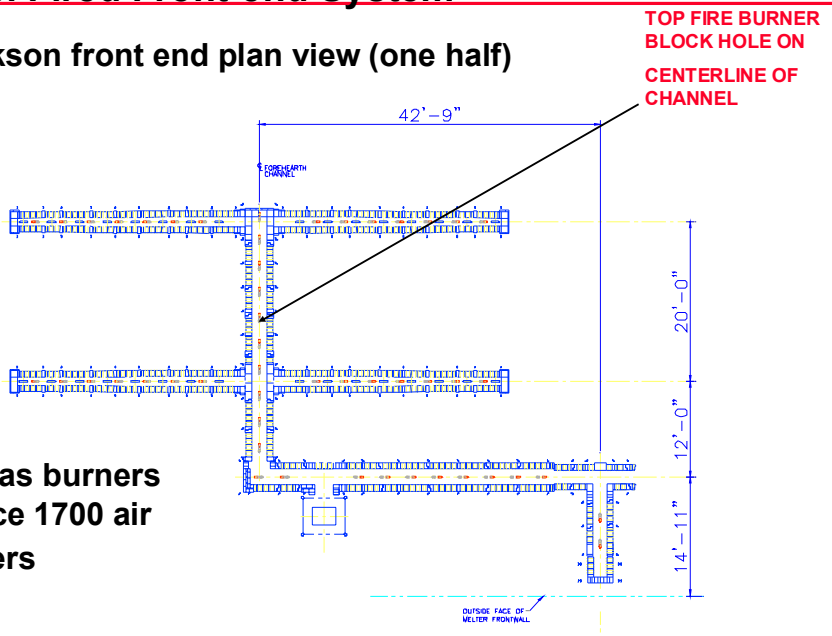


Goals – Jackson Installation

- Assessment of equipment improvements for reliability
  - Burner block, check valve, burner packing, manifold design
- Demonstrate "green" melting technology
- Demonstrate cost savings

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

Jackson front end plan view (one half)



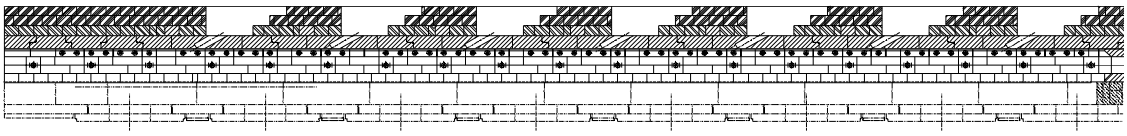
108 oxy gas burners will replace 1700 air gas burners

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

Jackson forehearth: 1 burner, 1 bushing

Profiling: potential for improved profiling

Transmissivity: reduced vertical thermal gradient

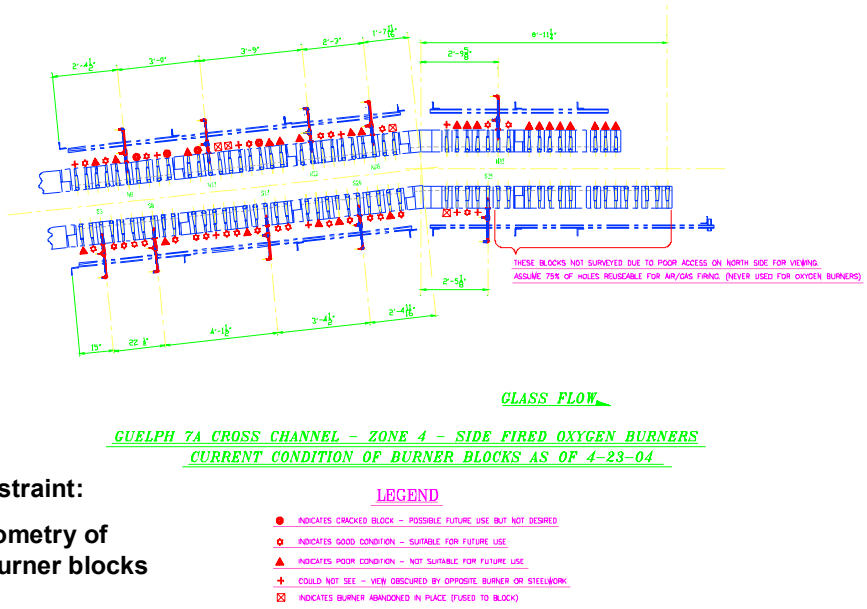


Trial Risks – Oxy Fired Burners

- Higher flame temp: risk of melting block
  - 4 top fired burner blocks destroyed in Guelph
    - 1 - fh 7A4: checkvalve, low O2 flow
    - 1 - CFM MC Zone2, #4: trial block design
    - 1 - (CFM MC Zone 2), high temp. oxidation of s/s burner or off ratio flow of gas& O2
    - 1 - CFM MC Zone 2, #5: Feb 18, 04 (cast block material sagging??/gas tube sagging??)
- Degradation of cast (not fired) mullite blocks due to minor melting of burner block bore is a concern in Guelph

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

Retrofit Side fire burner and block failures



Major constraint:

Using geometry of existing burner blocks

Equipment Improvements

- Zone control skid linkage geometry
- Increased size of zone control skid valves
- Increase supply and manifold piping dia.
- Low pressure drop (springless check valve)
- Burner gas tube concentricity (lower gas tube temp)
- Burner material
- Burner block material and internal design

Safety Considerations

Safety Interlocks:

•Minimum temperature for auto ignition

•If oxygen is lost: gas off – per existing safety skid interlocks

•When gas is lost: oxygen for 15 minutes

O2/N2 mix after 15 minutes

•Check valves upstream of flex hoses

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

Consortium activities for Jackson Trial:

CTI/Eclipse: CTI burner in top fired configuration for comparison of two burner technologies

BOC: exhaust gas sampling support

O2/N2 mixing station

Osram: monitoring progress for applicability

Concluding Remarks

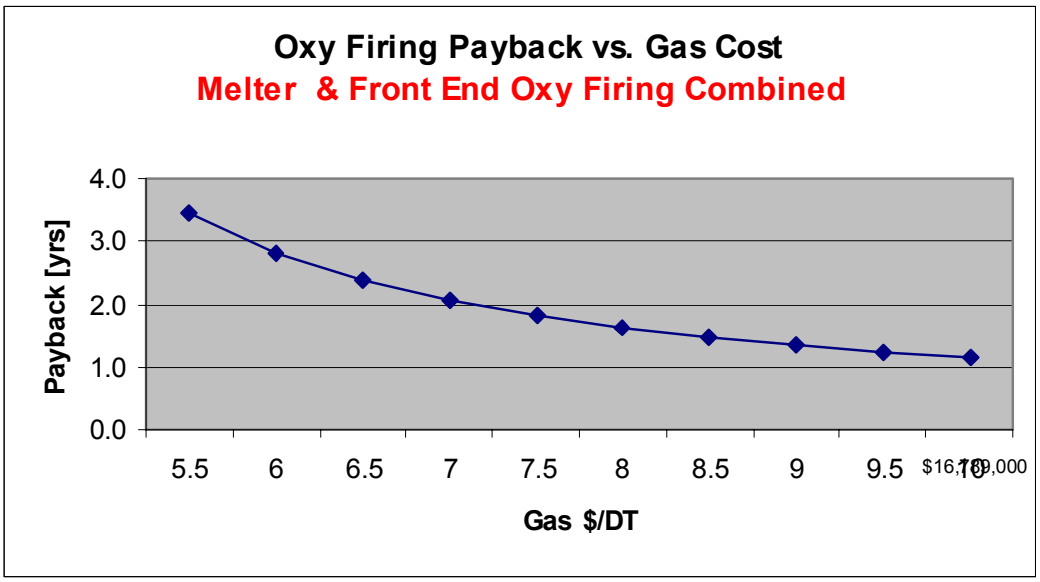
- Significant Energy Conservation
- Significant Environmental Benefit (less CO2 & NOx)
- Risks: technology still being developed
  - – months not years of run time: potential for equipment failure due to high temperature flame (burner & block)
  - Impact on fine fiber process is not known

Questions & comments are welcomed!

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

- Supplemental Slides follow

Melting Energy Reduction



Energy-Efficient Glass Melting - The Next Generation Melter

David Rue
Gas Technology Institute

DOE Industrial Technology Program

2004 Project-Industry Review
June 22, 2004

The Next Generation Melter

- **Goal** - to demonstrate the melting and homogenization stage of a low capital cost, energy efficient Next Generation Glass Melting System
- **Challenge** – to fabricate a 1 ton/h pilot scale melter based on the submerged combustion melting technology and generate homogeneous glass without stones
- **Benefit** – Energy savings, emissions reductions, using a significantly less expensive and more flexible melter
- **FY2005 Activities** –
  - Complete pilot melter, first tests and glass analyses
  - Cold flow model tests to optimize melter flow patterns
  - Working CFD model to assess parameter changes and scale up
  - Lab tests to acquire glass behavior data

Project Sponsors

- U.S. Department of Energy – OIT
- Gas Industry
  - GTI Sustaining Membership Program (SMP)
  - Gas Research Institute FERC funds
- New York State Energy Research and Development Authority (NYSERDA)
- Glass companies each providing cash and technical support
  - CertainTeed Corp.
  - Corning Incorporated
  - Johns Manville
  - Owens Corning
  - PPG Industries, Inc.
  - Schott North America

Project Participants

- GTI
- Glass company consortium (6 glass companies)
- Fluent, Inc.
- A.C. Leadbetter and Son, Inc.
- Praxair, Inc.
- Combustion Tec / Eclipse
- Consultants
  - Leonard S. Pioro - SCM developer
  - Vladimir Olabin – Gas Institute, Ukraine
  - John Brown – glass technology and GMIC contact
- GMIC - monitoring

Barriers, Pathway, Metrics, Benefits

Barriers
- Technical (meeting industry needs)
- Financial (providing large cost savings)
- Organizational (affecting a change in approach to melting practice)

Pathway
- Build and operate 1 ton/h pilot SCM
- Sample and analyze product glass
- Provide cold flow and CFD models supporting SCM approach

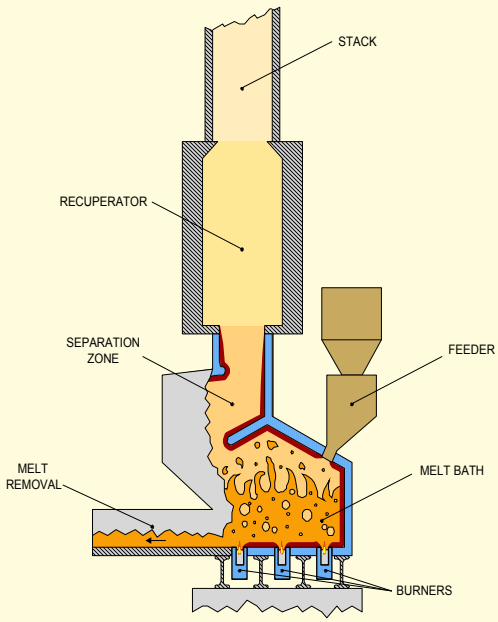
Critical Metrics
- Material / energy balances (with OTM)
- Glass quality analyses
- Working and validated CFD model

Benefit	
Energy Savings	26 TCF
Capital Savings	$73 million
Carbon Reduction	0.3 MMTCe
Refractory Reduction	80 %

Requirements for NGMS Melting Step

- Melt all glass compositions
- Scalable from 25 to 500+ tons/day
- Rapid melting (high heat transfer)
- Low capital cost (small size, minimal refractory)
- Long furnace life
- High thermal efficiency
- Homogeneous product (needed for rapid fining)
- Low emissions (CO, NO_x, particulates)
- Stable operation over wide range of pull rates
- Low volatilization of alkalis, borates, etc.
- Reliable, low-cost batch handling and charging
- Foam management
- Redox control
- Physically compatible with rapid fining step of NGMS

SCM Technology



- Oxy-gas firing into the melt bath
  - Intense combustion
  - Direct contact heat transfer - products of combustion bubble through the melt
    - reduced NO_x formation
    - reduced CO and unburned hydrocarbon emissions
  - High rate of heat transfer and rapid mass transfer
    - High thermal efficiency
    - Reduced melter size
- Melter is reliable and robust
  - Low capital cost
  - Externally cooled walls
  - Can be stopped and started easily
- Melting and mixing in one step
- Compatible with other NGMS operations
  - Charging
  - Rapid fining
  - heat recovery

SCM Saves Energy

Melter		Tank	SCM	SCM
Wall Heat Rec., %		0	0	20
Res. Time, h	Melter	--	4.5	4.5
	Fining	--	3.25	3.25
	Total	30	7.75	7.75
Pull Rate, ft2/ton/day	Melter	--	0.63	0.63
	Fining	--	0.47	0.47
	Total	4.2	1.1	1.1
Surface Area,	Melter	--	15	15
% of tank melter	Fining	--	11	11
	Total	100	--	--
Wall Loss,	Melter	--	0.48	0.39
MMBtu/ton	Fining	--	0.07	0.07
	Total	0.73	0.55	0.46
Total Energy, MMBtu/ton		3.64	3.46	3.37
Energy Savings, %		0	5	7.5

Assuming SCM wall losses of 3 times tank wall losses in Btu/ft^2.h

Project Schedule

Task		Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Modeling												
2	Melter Design												
3	Procurment												
4	Physical Modeling												
5	Fabrication												
6	Shakedown												
7	Test Planning												
8	Testing - Parametric												
9	Melter Modification												
10	Second Test Series												
11	Analysis												
12	Toward Commercialization												

Progress to Date (first 9 months)

- Completed design and specification of glass batch feed and exhaust gas systems, purchase orders placed
- Space prepared, layout designed, permit in place, steel, electrical, and mechanical bids received
- Equipment for physical Cold Flow Modeling designed and equipment ordering begun
- Critical parameters identified for Fluent CFD modeling
- Subcontracts established with SCM technology experts
- Literature searches continued and translations completed
- Website established to facilitate communications
  - www.glassmelting.com

Pilot-Scale SCM Tests

- Preparations underway for Year 1 tests in batch SCM unit (at right)
  - Tests to evaluate glass melting conditions
  - Feed, exhaust, and sampling systems will be commissioned
  - Samples acquired and analyzed
- Year 2 and 3 tests with new 1 ton/h continuous SCM pilot unit
  - Range of compositions and operating parameters evaluated
  - Comparison with cold flow and CFD modeling predictions
  - Full sample analysis

Major Pilot SCM Components

Vacuum unloading system	Pilot SCM melter
Loss in weight system	Roura hoppers (4)
Screw charger	Gas/oxy burners
Vibratory conveyor	Melter control system
Gas/Oxy/Nitrogen control and safety trains	Glass discharge channel with sampling orifice
Baghouse	Sample molds (annealing)
Dilution air fan	Hoists (2)
Exhaust fan	Steel structure
Cooling tower	Misc. chutes and hoppers

Existing Lab Melter

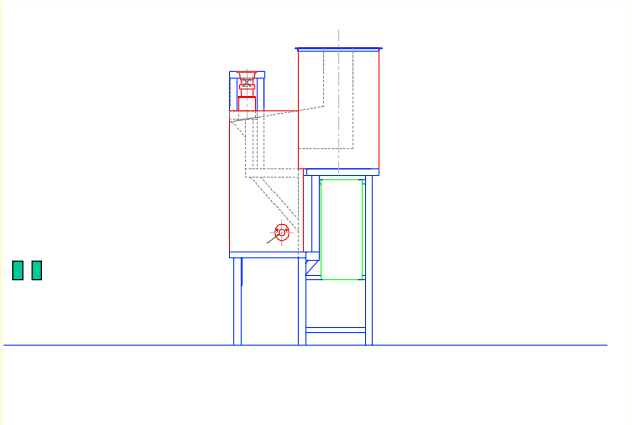
Raw Material Feed
Location

Exhaust Gas Location

Glass Discharge

Submerged Combustion
Burners

Control Panel



Glass Batch Unloading System

Bulk Bag Discharge Frame and Hopper

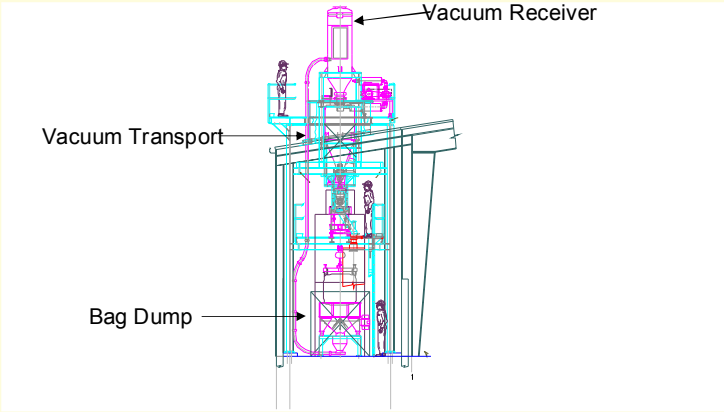
Accepts "super sacks" of premixed glass batch raw materials

Vacuum Transport and Elevation System

Blower creates vacuum in delivery pipe to transport raw material

Vacuum Receiver Chamber

Hopper receives raw material and completes unloading cycle



Glass Batch Weigh and Feed System

Loss In Weight Bin

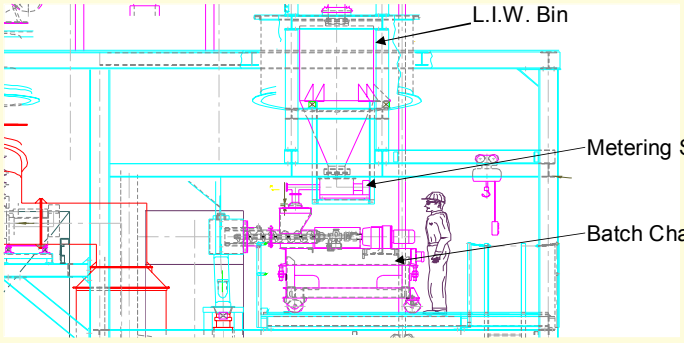
Cone shaped hopper mounted on load cells

Metering Screw Auger

Variable speed auguring screw controls raw material discharge

Screw Feeder Batch Charger

Main auguring screw to convey raw materials into melter



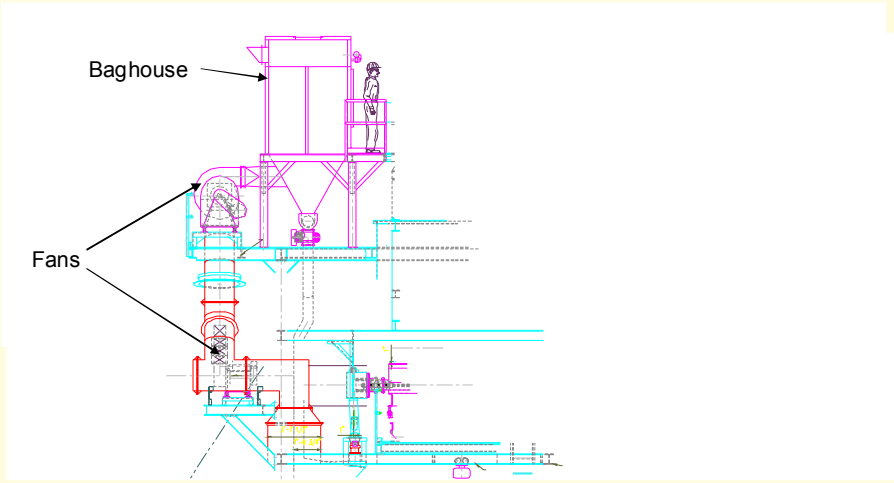
Melter Exhaust and Dust Collector

Exhaust Fan/ Dilution Air Fan

Draws gaseous products of combustion from melter

Baghouse/Dust Collector

Filters exhaust gas to remove solid particulate



Melter, Feed, and Exhaust Controls

Control Equipment	Power Supply	Field Devices
8 channel analog input card	RSLogic 5000 PLC	Furnace transmitters
6 channel T/C card	RSView software	Actuators
8 channel output card 4-20 mA	Dedicated PC	T/Cs – duplex
16 channel 120VAC digital input card	PLC panel	T/Cs - triplex
16 channel 120VAC digital output card		WFD for furnace pressure
DH + R10 adapter module		Combination starters
Ethernet communication module		Scale interface logic
10 slot control logix chassis		
Control Logix PLC IM memory		

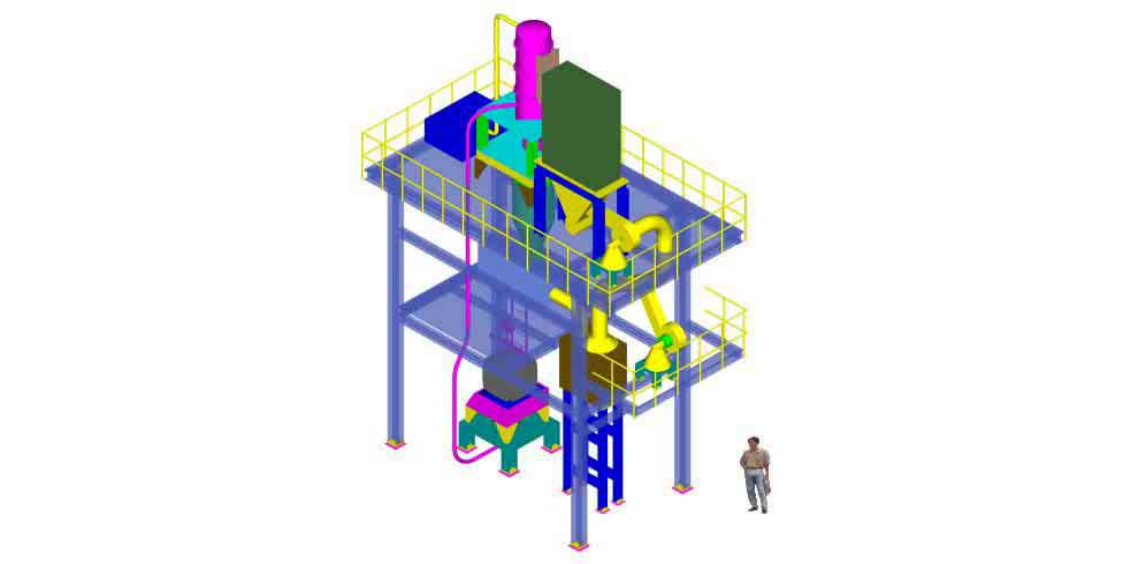
Melting Tests for FY2004

- Batch tests in existing melter before 9/30/2004
- First test will be with a soda-lime batch
  - Feed and exhaust systems will be commissioned
  - Glass sample collection and analysis
- Second test will be with e glass batch
  - Glass sample collection and analysis
  - Results used for pilot melter design and input into modeling

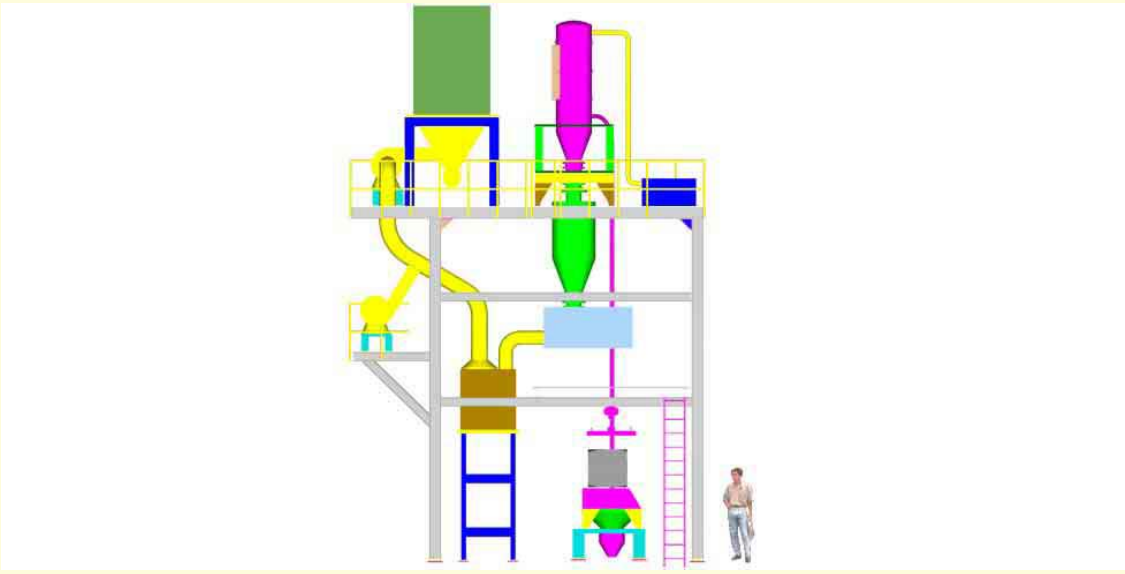
Glass Sample Lab Analyses

- Glass Devitrification Analysis
- Glass Metal Contamination Analysis
- Glass Homogeneity Analysis
- Seed Quantity and Size Distribution Evaluation
- Unmelted Batch/ Stone Evaluation
- Glass Batch Volatilization Evaluation

NGMS Pilot Melter Installation



NGMS Pilot Melter Installation



Differences Between SCM and Traditional Glass Melting

- Combustion and flame formation radically different
- Gas flow through burners must overcome hydrostatic head of molten glass
- High speed shear flow and bubble formation/break-up with gas diffusion
- Forced convection heat transfer vs. buoyancy driven flow in a traditional glass furnace
- Presence of highly turbulent flow (gas) in the vicinity of low Re laminar, viscous flow (glass)
- Presence of cold walls and formation of a semi-solid glass layer (due to cooling water flow)

Modeling of SCM Furnace

Complete modeling of SCM will require:

- ✓ CFD model for molten glass flow and heat transfer
- ✓ Gas bubble formation and reaction/diffusion in bubbles
- ✓ Multiphase model for gas/liquid/solid flows
- ✓ Combustion/reacting species transport model with multiphase flow
- ✓ Turbulence modeling with multiphase flow
- • Granular multiphase model for batch feeding
- • Batch melting model with reaction kinetics and multiphase flow
- ✓ Conduction, convection, and radiation heat transfer model
- ✓ Couple radiation from the gas phase to molten glass
- ✓ Ability to model gray-band radiation with variable absorption coefficients
- • Mass transfer from bubble surface to glass melt and vice-versa
- • Gaseous reaction/diffusion in bubbles and dissolution in molten glass

- • Needs model enhancement or development
- ✓ Currently available in FLUENT

SCM Modeling Approach in FLUENT

- First task will be to model bubble formation and convective flow/heat transfer w/o combustion →this will give overall furnace flow and temperature distribution
- Next, combustion and gas diffusion in bubbles will be modeled →this will provide information about flame shape and heat transfer to the glass melt
- Next, Eulerian multiphase model will be used with chemical reactions (more rigorous approach) →solves Navier-Stokes eqn. for each phase
- Radiation from gas bubbles to glass melt and internal radiation within glass will be modeled
- Next, mass transfer and diffusion from one phase to another will be modeled
- Batch melting model added for complete SCM modeling

Developments Needed in FLUENT

- Coupling of Discrete Ordinate (DO) radiation model with Volume Of Fluid and Eulerian multiphase models
- Batch melting model implementation with Granular multiphase model
- Implementation of mass transfer model for gas diffusion and dissolution in molten glass (currently done via User Defined Function)
- Improvements in coupling of turbulent flow with multiphase models for strong secondary phase turbulence
- GUI development for ease of problem set-up

Suitability of FLUENT for SCM Model

- Unique combination of reacting Volume of Fluid (VOF) model and reacting Eulerian multiphase model
- Availability of state-of-the-art Discrete Ordinate (DO) radiation with gray-band model and variable absorption coefficients
- Ability to model internal radiation in glass with semi-transparent interface
- Existing expertise using FLUENT within team (GTI and glass companies)
- Fluent's infrastructure and commitment for long-term support of glass melting CFD, including new enhancements for SCM

Why Physical Modeling

- Provides insights to full scale melter
  - Faster turn around.
    - Reduce scale (physical dimension, temperature, velocity, viscosity..etc.)
  - Low initial and running cost.
  - Easily accessible for quantitative data.
  - Flexibility of evaluating different design concepts and parameters.
  - Validation of numerical models.

NGMS Physical Modeling Objective

- Model molten glass flow patterns in SCM.
- Investigate design parameter effects on the response time/curve
  - Burner positions and operating parameters
  - Height/width/depth of melt
  - Feed and discharge positions
  - Temperature effects on mixing patterns
- Temperature mapping

Dimensionless Groups 1

- Grashof and Reynolds numbers
  - Grashof # $\equiv \frac{l^3}{\nu^2}\beta\Delta T \frac{(inertia)(buoyant)}{(viscous)}$
  - Reynolds # $\equiv \frac{Vl}{\nu}\frac{(inertia)}{(viscous)}$
- Advantage:
  - Match viscosity-temperature curve.
  - Model flow patterns well in traditional glass furnace.
- Disadvantage:
  - Does not take heat transfer into consideration.

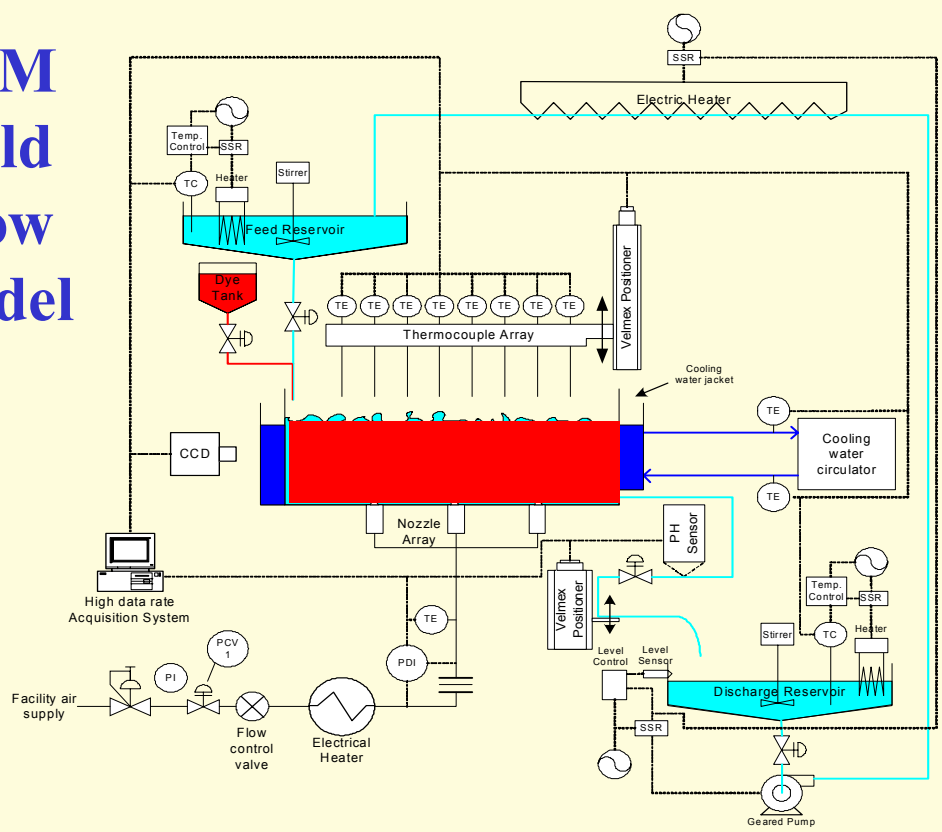
Dimensionless Groups 2

- Raleigh, Peclet, and Power numbers
  - Raleigh # $\equiv \frac{C_P\rho^2 l^3}{\mu k}\beta\Delta T \frac{(gravity)}{(therma-diffusivity)}$
  - Peclet # $\equiv \frac{\rho C_P V l}{k}\frac{(heat-conduction)}{(heat-convection)}$
  - Power # $\equiv \frac{P}{kl\Delta T}$
- Advantage:
  - Match heat transfer characteristics.
- Disadvantage:
  - Does not match the viscosity-temperature curves between molten glass and model liquid.

Physical Modeling Limitations

- Molten glass surface tension effect.
- Devitrification.
- Melter wall interaction

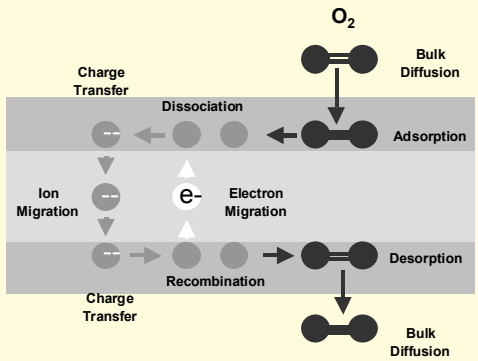
SCM Cold Flow Model



Physical Modeling Status

- A cause-and-effect analysis was conducted
- Two sets of dimensionless groups were identified as potential candidates for physical modeling
- Potential model liquids were identified; their viscosity and temperature ranges were calculated
- Experimental apparatus was laid out. Components were sized, specified and currently under purchase process
- Assembly will commence as soon as the equipment arrives

Praxair Mixed Conductor Transport Mechanism for OTM



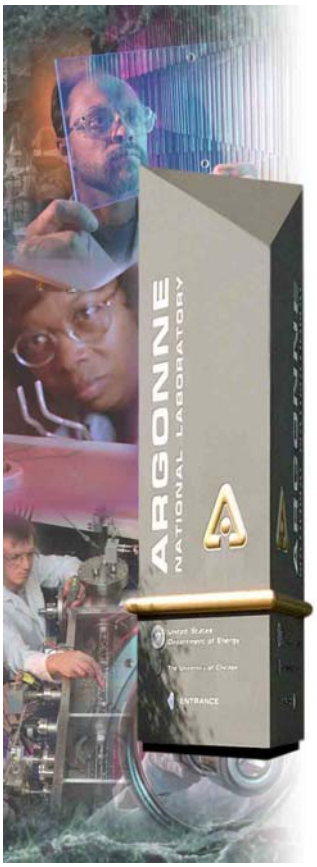
- Praxair to evaluate OTM for oxygen production from SCM exhaust gases (+1000°C)
- Subcontract ready for signing – work ready to start
- Praxair work funded by NYSERDA

Consortium Activities

- Meeting Dec. 10, 2003
  - Project planning, assignment of focus areas
- Trip to Europe – GTI, Corning, Owens Corning, GMIC
  - Tours of Sorg and Wiegand Glass
  - HVG/DGG meeting
  - Tour working SCM units in Belarus
- Meeting June 29, 2004
  - Planning for initial batch SCM tests, focus activity initiation
- Lawyers working to finalize consortium agreement

4

Final Project Evaluation Results and Presentations



Development and Validation of an Advanced Multiphase Glass Furnace Model

Presenter: Brian Golchert – ANL

Argonne National Laboratory

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Presentation Outline

- **Program Overview**
  - Goals, Technical Approach, Program Description
  - Program Status
    - *Program 'completed' on 12/31/03 as scheduled*
- **Technical Progress/Accomplishments**
  - Brief Overview of Program Accomplishments
  - Continued application of GFM to industrial furnaces
- **Technology Transfer of GFM Code to Industry**
  - Initiated in FY04
  - Initial Technology Transfer Results
- **Broadened the 'Vision' of GFM**

Program Overview

and

Status

Program Goals

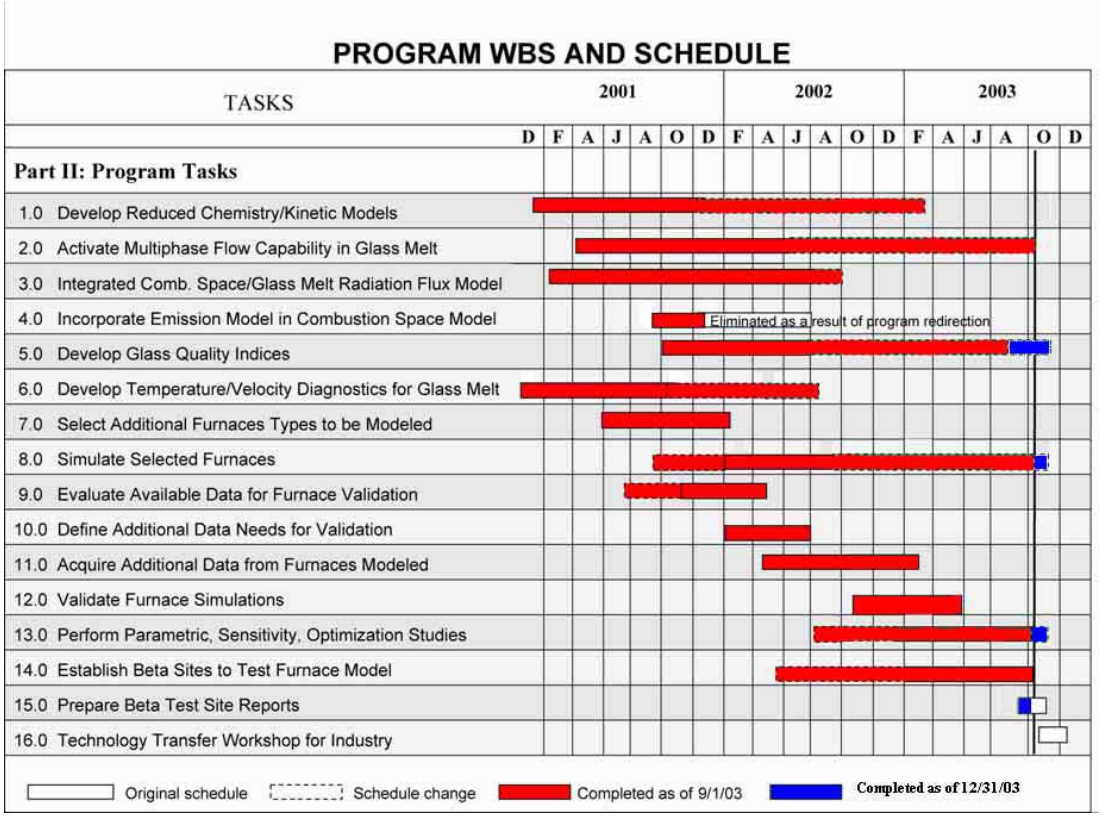
- **Advance the "State of the Art" in Glass Furnace Modeling/Simulation**
- **Provide Industry with a Validated Furnace Model that Can be used to Analyze Different Types of Furnaces**
- **Create a Code that can be Used by Engineers, not Only Computational Experts**
- **Make the Validated Code (Executable and Source Codes) Readily Available to Industrial Users.**

Program Description

- **Two Part Program Initiated in 1998**
- **Supported by Industrial Consortium**
  - Techneglas, Inc. Libbey, Inc. Visteon
  - Owens Corning Osram Sylvania
- **University Participants**
  - Purdue University Mississippi State University
- **Five-Year Program Schedule**
  - Part I Program completed
  - Part II Program completed at end of CY 03
- **Deliverable: User Friendly, Validated, Glass Furnace Model for Use by Engineers**
  - A step change in modeling capability
  - Technical Support is Being Provided via a Follow-On Tech Transfer Program

Technical Approach for Achieving Program Goals

- **ANL's Multiphase Reacting Flow CFD Codes (ICOMFLO, ICRKFLO) used to Develop a Coupled Glass Furnace Model (GFM)**
  - Incorporated advanced phenomenological models for spectral radiation heat transfer, batch melting, foam layer formation, etc.
- **Construct Simulations of Selected Furnaces**
- **Develop/Install Diagnostics in Selected (3) Furnaces to Acquire Data for Code Validation**
- **Validate Furnace Models with Data Acquired**
- **Demonstrate the Utility and Benefits That Can Be Derived From the Use of GFM Code**
  - Conduct extensive parametric, sensitivity and optimization studies to identify opportunities to improve furnace performance



Technical Progress

and

Accomplishments

Accomplishments During Program

- **Developed a Coupled Glass Furnace Model (GFM)**
  - Incorporated advanced phenomenological models for spectral radiation heat transfer, batch melting, pollutant formation, etc.
- **Initial Workshop Held at OSU to Introduce GFM to the Industry**
  - Demo code given to 32 attendees
- **Code Validation Data Obtained from Three Furnaces with Different Operation and Design Characteristics**
  - Cross fired oxy-fuel furnace, a regenerative end port fired furnace, and a recuperative fiberglass furnace
- **Advanced Version of GFM 2.0 Developed and Validated with in situ Data from Three Furnaces**
  - Robust pre and post-processor
  - Spectral radiation computed throughout furnace volume

Accomplishments During Program (cont'd)

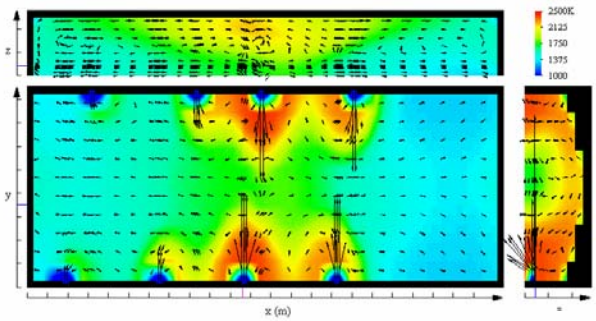
- **GFM 2.0 Beta Tested by Industrial Participants (IP)**
- **IP's Built Simulations and Used Them to Conduct Parametric, Sensitivity, & Optimization Studies**
  - Parameters varied specified by IPs
  - Studies conducted jointly by IPs and ANL
- **Multiphase Analytical Capabilities of GFM 3.0 (Final Version of Code)**
  - Transport and reaction of solid, gas, and liquid species is computed throughout glass melt
  - Chemical reactions in melt and batch incorporated
  - Foam formation/thickness calculated
  - Quality indices incorporated
  - Gas release from melt to combustion space
  - GFM3.0 to be released to licensees of GFM2.0

Continued Application of GFM by Industry

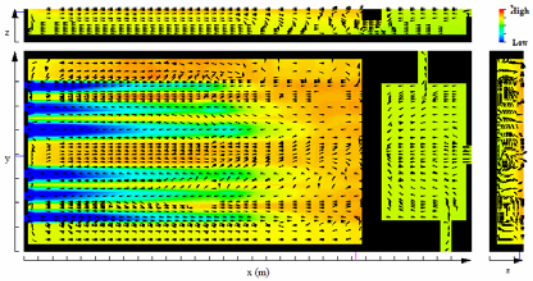
- **A Techneglas melter developed an operational problem as a result of an obstruction that led to a significant decrease in quality thus causing the operators to reduce the pull**

- **Parametric studies were/are being conducted to help:**
  - Identify the cause of the reduction in quality
  - Determination if operational parameters can be adjusted to allow increasing the pull without sacrificing quality

Computational Results



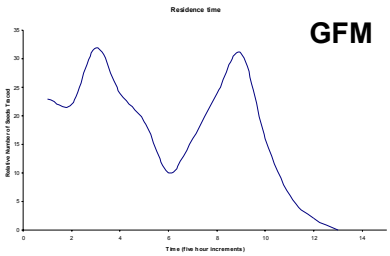
Combustion Space

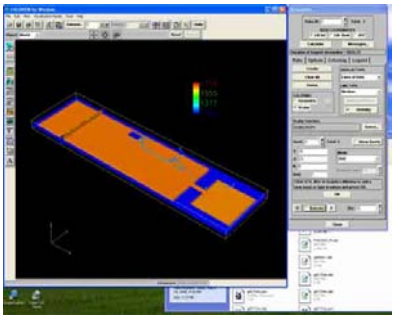


MELT

Quality Issues in Techneglas Furnace

- **Two methods are available to investigate quality issues with the GFM**
  - 'Traditional' quality indices as an output of the GFM
  - Particle tracing through a commercial visualization code FIELDVIEW
- **'Traditional' residence time quality indices indicate a bi-model distribution**
  - Shows possible reason for quality problems. Shortest residence time in the region of the obstruction

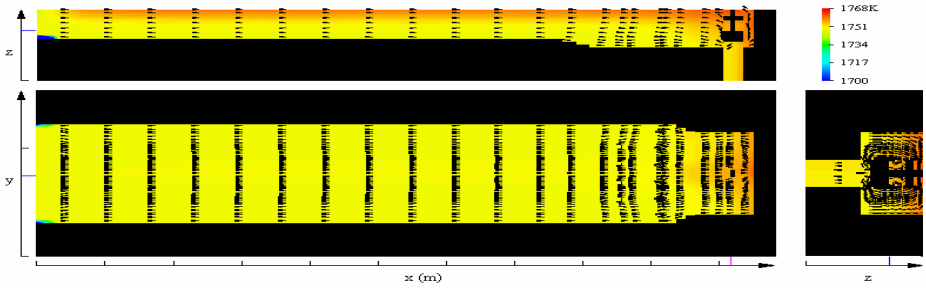




Fieldview

Techneglas Furnace Forehearth

- **John Chumley of Techneglas has extended the model for the melt and the combustion space to model the Pittston B forehearth**
- **Preliminary melt calculations are shown below.**



The Glass Furnace Model Technology Transfer (GFM-TT) Program

GFM-Technical Transfer Objective

- **Disseminate and Promote Widespread Use of the GFM Code Throughout the Glass Industry**

The GFM-TT Objective Will be Achieved By

- **Widely Disseminating Information on GFM Code to Industry**
  - Collaborating with GMIC
  - Brochure developed describing code capabilities and availability
    - *Broad mailing by GMIC to Industry*
- **Making GFM Code Readily Available to Interested Users**
  - Free trial license available for six to nine month period
- **Providing Technical Support for the GFM Code Users during the Free Trial Period**
- **Promoting Development and Implementation of Long Term Technical Support Mechanism for the GFM Code User**

Dissemination of Information on the GFM Code and Response from Industry

- **A Brochure has been prepared and sent to over 90 glass company contacts. This brochure describes:**
  - Code and its capabilities
  - How interested users can license code
  - How technical support will be provided
  - Availability of a **FREE trial license!**
- **Brochure Mailing Handled by GMIC**
  - Cover letter urges interested users to obtain a trial license
- **A Follow-up Electronic Mailing was Made Last Week**

Mechanism for Licensing GFM Code to Interested Users

- **GFM2.0 Code is available at the ANL Software Shop**
  - Accessible via internet htttp://softwareshop.anl.gov/
  - Site maintained by ANL Office of Technology Transfer
    - *Handles all licensing for ANL*
  - Allows interested users opportunity to license code online
  - Terms, conditions, and procedures for licensing code clearly outlined
- **After receiving trial license, user contacts ANL to arrange for free training on the use of the code**
  - Training is usually done during one afternoon and the following morning
  - Begin working with ANL staff on your furnace of interest and learn how to use the code at the same time
- **At the end of the free trial period, users will be required to pay a ONE TIME nominal licensing fee to continue using the code**

Technical Transfer Status as of 16 June 2004

- **Six Trial Licenses have been Signed**
  - PPG (2)
  - St. Gobain
  - Guardian
  - St. George Crystal
  - Anchor Hocking Glass
- **Additional companies have indicated they will likely apply for trial licenses**
- **Training has been conducted for three licensees**

Mechanism for Providing Technical Support to GFM Code Users

- **An Attempt will be made to Establish a GFM Code User Group (CUG)**
  - Each licensee will automatically become a member
  - Each member entitled to technical support services
- **Technical Support Services That Will Be Available to CUG Members**
  - Individual instruction on use of code at ANL
    - *Expect average user will require 2 days*
    - *User will create and run furnace simulations*
  - Additional support provided on an as needed basis
    - *Hours available will depend on number of users (CUG members)*
    - *Estimated minimum of 40 hours/year*
  - Customization services will be provided within allowable hour limits
    - *Modification of code when applied to unique/unusual geometries*
    - *Source code expected to evolve & be improved*
- **Ideally, the CUG Members will be Issued Improved Versions of GFM as the Code Evolves**
- **Technical Support will be Provided at No Cost Over 6-9 Month Period**
  - Levels to be compatible with resources provided by DOE

Long Term Technical Support

- **Need and Mechanism for Continuing Support to Be Determined by CUG Membership**
  - At conclusion of 9 month DOE Support Period
- **CUG Would Ideally Evolve into an Industry Organization that**
  - Supports continued development/improvement of the GFM codes
    - *Funding provided by membership dues and possibly DOE*
  - Ensures that technical support for the GFM is available
  - Continues to maintain a “state of the art” modeling capability for the industry

Going beyond the original frontier…..

Expanded 'Vision' for the Glass Furnace Model

- **GFM can be the 'repository' of many of the advances achieved in the DOE Glass projects such as**
  - Alfred's material property database
  - Sandia's crown corrosion work
  - BOC's batch preheat work
- **Incorporation of the results from these projects into the GFM achieves the following:**
  - Enhanced modeling capabilities
  - Creates a commercialization vehicle for these DOE projects
  - Increased likelihood that the results from all of these projects will culminate in energy savings to the industry

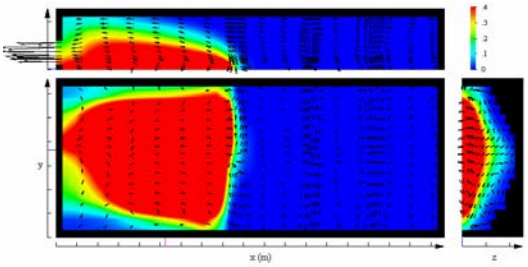
Center for Glass Research Database

- **A significant effort has been expended by the DOE and by Alfred University (CGR) to develop a high temperature materials database specifically for computational modeling**
- **CGR has completed their database and it covers the majority of glasses found in industry**
- **CGR, ANL, and DOE are discussing the incorporation of the CGR database into the GFM. This would allow the user to 'point and click' on a particular glass composition in order to obtain the required thermophysical properties needed**
  - Using the database in the GFM would provide the user ready access to hard-to-find thermophysical data

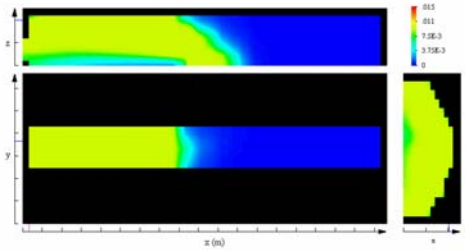
Corrosion Modeling in Glass Furnaces

- **The DOE funded Sandia project on crown corrosion has developed models and chemical reactions to determine the likely locations of corrosion based on species concentration and temperature**
  - All variables available from the GFM calculations
- **Based on observations in furnaces and the results from several modeling efforts, a crude, first order corrosion model in the melt has been developed.**

Implementing Sandia's Model into the GFM



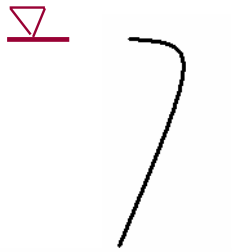
OH concentration



Estimate of corrosion

- The Sandia model indicates that the OH concentration and the temperature are key components to crown corrosion
- A crude model similar to Sandia's model has been incorporated into the GFM
- Gaseous OH from the batch reactions is transported throughout the combustion space
- OH concentration and wall temperature give indications of locations of high crown corrosion

Using Results from GFM to 'Predict' Corrosion/Erosion in the Melt Refractory



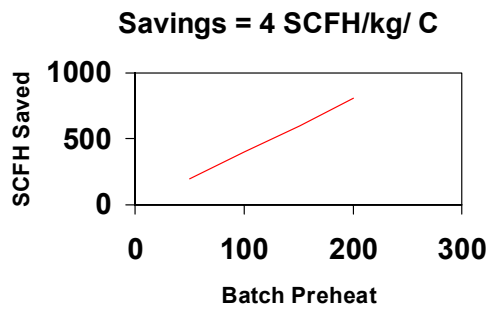
Approximate wear shape in melter back wall

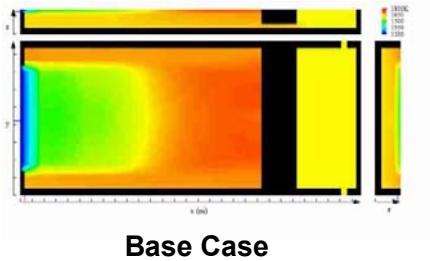
Computed velocity field near back wall

- After several visits and talks with plant personnel, it became apparent that there was a relationship between liquid glass velocity and corrosion/erosion of refractory material.
- The computed velocity field is in very good agreement with the observed wear pattern
- GFM can be used to estimate locations of high refractory wear caused by high melt velocities

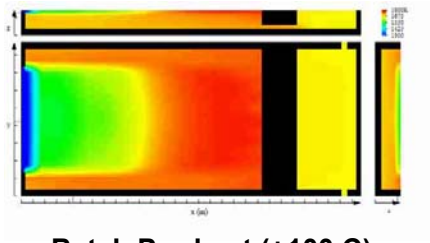
Effect of Batch Pre-heating

- The DOE funded a program to investigate the effects of pre-heating the batch using the exhaust heat from the combustion space
- The GFM can model the effects of batch pre-heating on the temperature and flow field in the melter.





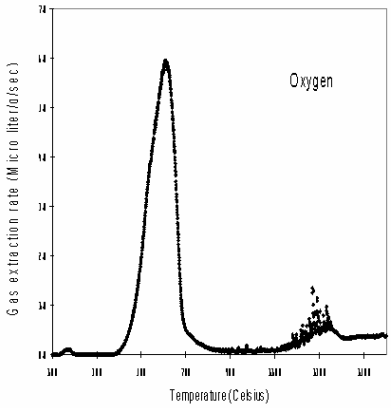
Base Case



Batch Pre-heat (+100 C)

Additional Work Needed for Batch Pre-Heating

- There are two main components for modeling batch preheating
  - Thermal effects (easy)
  - Gas release effects
- Thermal effects of batch preheating already in the GFM
- Work is being done to incorporate the effect of preheating on the gas release using models/data derived by Purdue University.



Improvement of Performance and Yield of Continuous Glass Fiber Drawing Technology

Phillip A. Sanger and Simon Rekhson
Cleveland State University
Cleveland, OH

Outline
Project Overview and Summary
Barrier-Pathway-Metrics
Progress to Date
Future Plans
Commercialization Plans

High Performance Glass Forming Technology Consortium

Acknowledgements

- Our industrial partners at JM, PPG, US Borax and Schott Glas patiently explained the intricacies of glass fiber drawing process and offered critical inputs at every stage of the project
- Dr. James Leonard and his NSF REU students, Rick Bartel and Ryan Burson, adopted the PPG drawing tower, conceptualized GEN 2 bushing, set up instrumentation and ran tests
- Our graduate students - Uma Sistu and Zhongzhou Chen - made excellent contributions to developing our computer model
- Dr. Paul Lin and his students developed the cone image analysis system

High Performance Glass Forming Technology Consortium

Goal,Challenge,Benefits, FY04 Activities and Participants

•*A Initiative on Cooperative Programs with States for Research, Development and Demonstration*

Goal: Demonstrate a four-fold break reduction and four hours of run time on a continuous glass fiber drawing tower

Challenge: Requires a comprehensive process design and validation effort on a better than 6 σ level

Benefits: Eliminates unrecyclable waste (more on the next slide)

FY04 Activities: Finish process design and validation; demonstrate 0.25 breaks/hour

Prime: Ohio Department of Development Office of Energy Efficiency
Lead Organization: Cleveland State University, The High Performance Glass Forming Consortium
Participating Industrial Partners: PPG Industries, Johns Manville, U.S. Borax
Supporting Companies: Schott Glas

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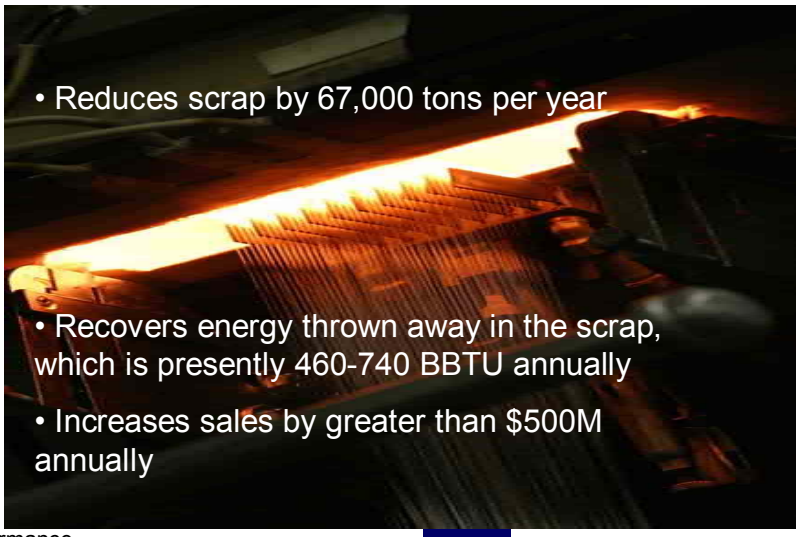
When implemented industry-wide



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Validated process models and industrially representative platforms are key pathways

Barrier-Pathway Approach

Barriers

- Key quantitative insights into breakage drivers
- A single fiber drawing rig does not exhibit some of the *key* phenomena driving breakage

Pathways

- Efficient and quantitative computer model that integrates physics and statistics into a capable process design tool
- Construction of an industrially representative platform for further model validation and developing breakage reduction techniques

Critical Metrics

- The model is validated and its fidelity established using break rate data
- Demonstration of reducing breakage from one break per hour to less than 0.25 breaks per hour

A theoretical model of jet attenuation is adopted from Glicksman, J. of Basic Eng'g, 1968

$$\frac{\partial(VS)}{\partial z} = 0 \;\heartsuit\; W = \rho VS = \text{const} \qquad \text{- mass}$$

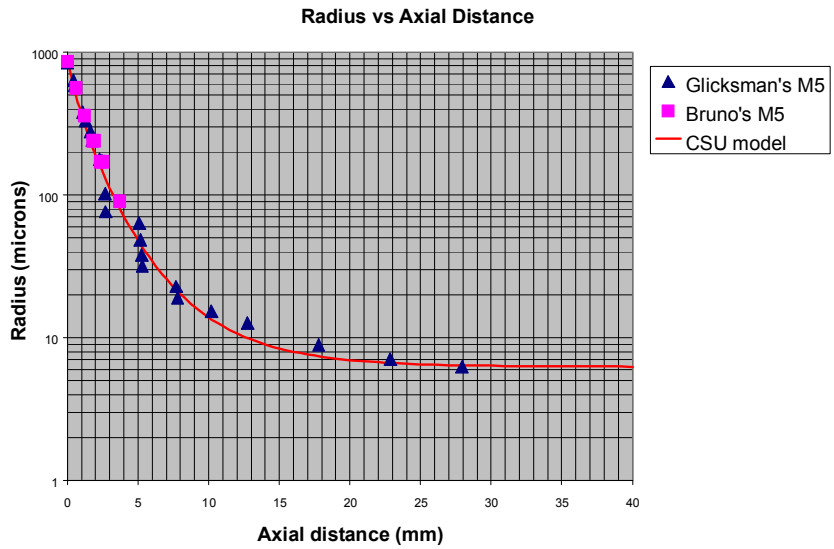
$$\underbrace{\rho VS\frac{\partial V}{\partial z}}_{\text{inertial}} = \underbrace{\frac{\partial}{\partial z}\left(3\eta S\frac{\partial V}{\partial z}\right)}_{\text{viscous}} + \underbrace{\frac{\partial\left(\sigma(\pi S)^{1/2}\right)}{\partial z}}_{\text{surface tension}} + \underbrace{gS}_{\text{gravitational}} - \underbrace{2\tau_\infty(\pi S)^{1/2}}_{\text{airdrag}} \qquad \text{- momentum}$$

$$WC_p\frac{\partial T}{\partial z} = \underbrace{k\frac{\partial}{\partial z}\left(\frac{\partial T}{\partial z}\right)}_{\text{axial heat conduction}} - \underbrace{\pi D\left[h(T - T_{air}) + \sigma\varepsilon\left(T - T_{fin}^4\right)\right]}_{\text{heat loss}} \qquad \text{- energy}$$

Glicksman's initial conditions of $T = T_E$ and $dr_0/dz = -0.1$ at $z = 0$ were after much testing replaced by $T = T_{tip}$ and $r_0 = r_{tip}$

- ✓ Hagen-Poiseuille law to calculate tip throughput
- ✓ Air drag, surface tension, gravitational and inertial forces included
- ✓ Axial heat conduction neglected
- ✓ Convection and surface radiation heat transfer
- ✓ Kase - Matsuo empirical relation for convective heat transfer
- ✓ Ambient and fin temperatures are independent process variables

Our modification of Glicksman's model is validated against data and Purnode's 2D FEM model (Polyflow)



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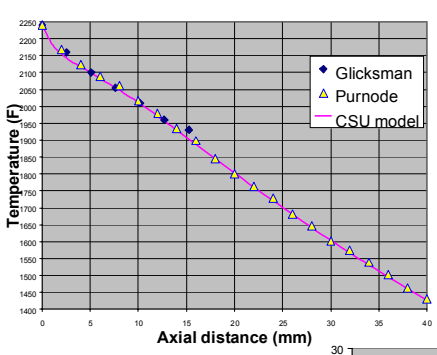
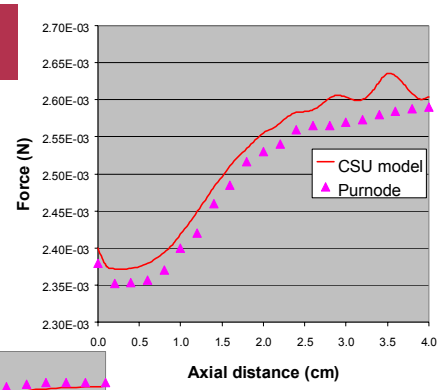
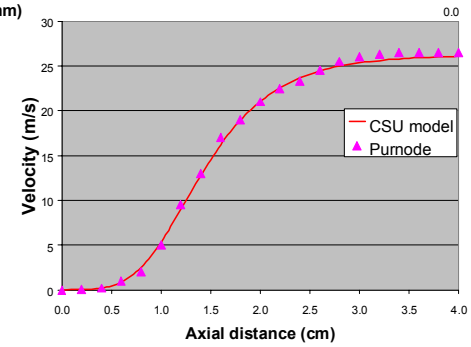
Validation cont'd







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Transfer function from first principles

KPIV

Head Set Point ⇨ **KPOV** Filament diameter

Winder speed ⇨ **KPOV** Filament diameter

Fins ⇨ **KPOV** Cone length and viscosity, breakage

⇨ $$\sigma(L) = 3V_L \ln\left(\frac{V_L}{V_0}\right)\frac{\langle\eta\rangle}{L}$$ ⇨ $$\left[\sigma \frac{d\sigma'}{\beta(\sigma)}\right]^{\alpha}$$ ⇨ Frequency of breakage and runtime

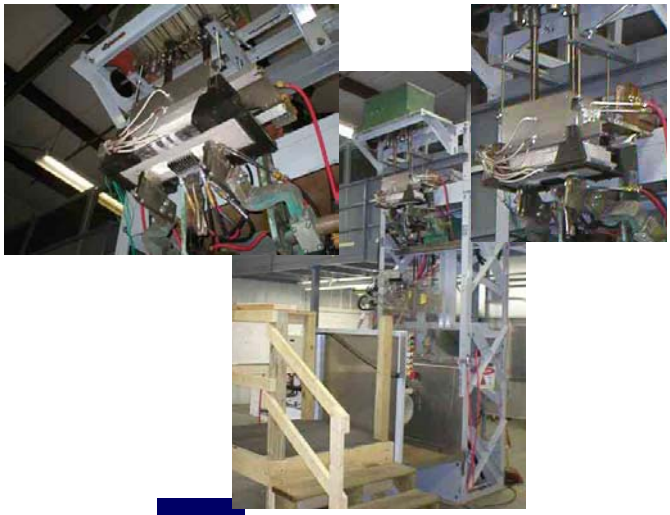
σ = stress in the filament
V_L and V_o = final and initial velocities
L = length of cone
$\langle\eta\rangle$ = average viscosity of cone
β = Weibull strength of the fiber
α = glass quality factor (Weibull modulus)

Goal: define KPIV's to achieve a specified filament diameter (customer) and low breakage level (manufacturer)

High Performance Glass Forming Technology Consortium

Dr. Jim Leonard and his team transferred from PPG a 40 lbs per hour glass drawing tower, brought it to full operation to run tests and validate our process models

- >500 operational hours
- >5000 lbs of glass drawn
- Instrumentation is up and running
- Independent control over melting and bushing temperatures



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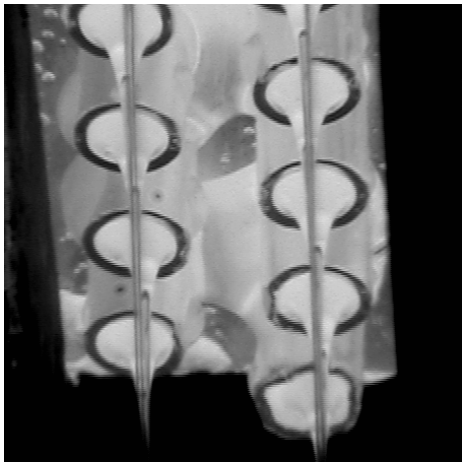
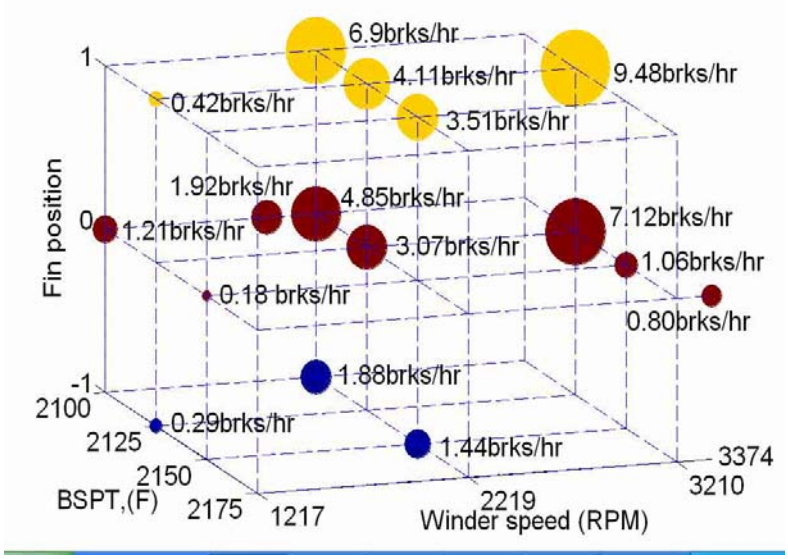
Diagnostic instrumentation collects data needed to estimate breakage probability

- **Tension** - manual, three wheel
- **Speed** - laser doppler on the bundle continuous
- **Simultaneous cone shape and cone temperature measurement** – both looking up at 45° into the bushing face
- **Cone Imaging** – photography with 1 D traverse limited to cones on the end of the bushing
- **Temperature Profile** – pyrometer at 45°, 2D scan on tip and plate, semi continuous scanning
- **Nuclear Level Gauge** – continuous, feedback to melter

Dimensional monitoring of cone size plus temperature – key parameters in determining breakage



We map the process variable space to bracket desired range and achieve target break rates



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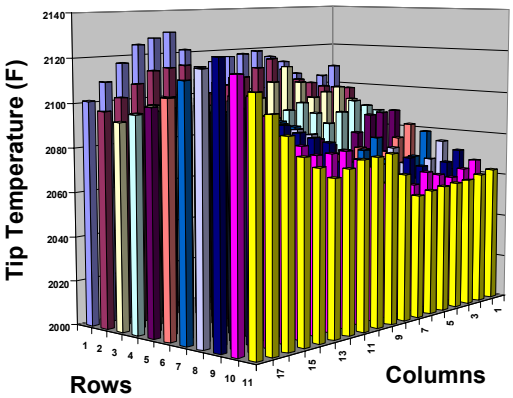
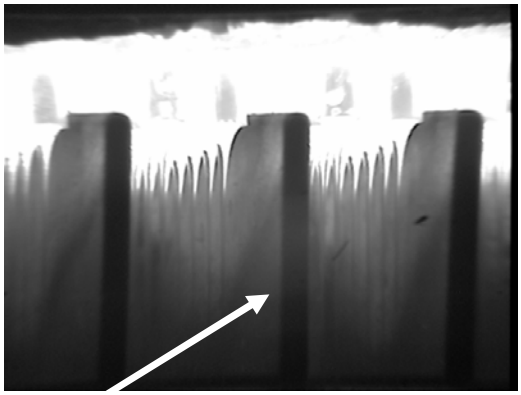
In systematic study and model validation we control incoming glass temperature, airflow and cooling fins location

Tip Temperatures vs. location on CSU Bushing

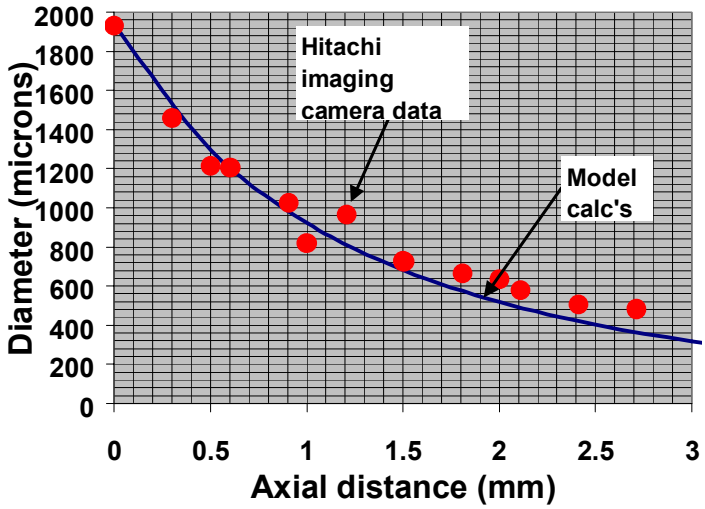




Cooling fins

High Performance Glass Forming Technology Consortium

Model validation, cont'd: agreement of observed cone shape with model prediction



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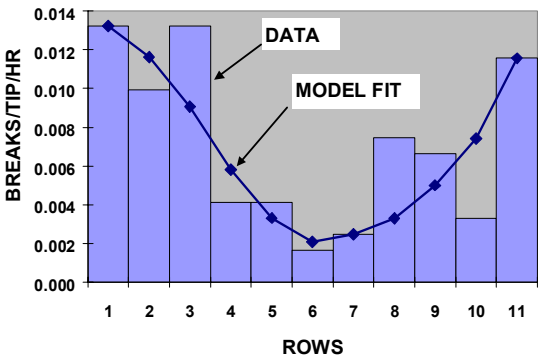
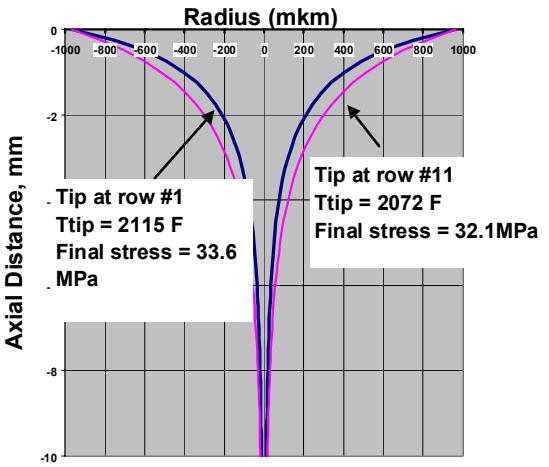
Main effects: Hotter tip with harsher cone cooling yields same stress and break rate as colder tip with gentle cooling

Breaks in 11 rows: data vs calc's



Cones Shapes for tips in row #1 and row #11



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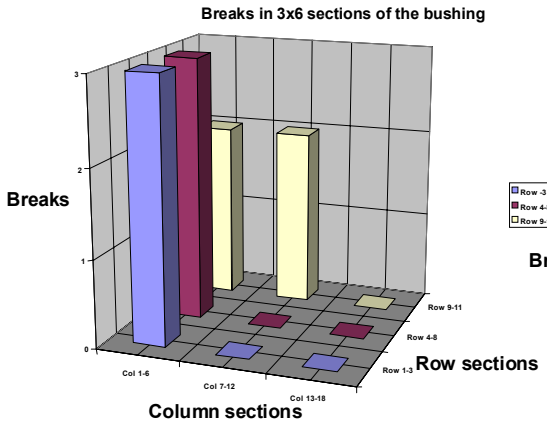
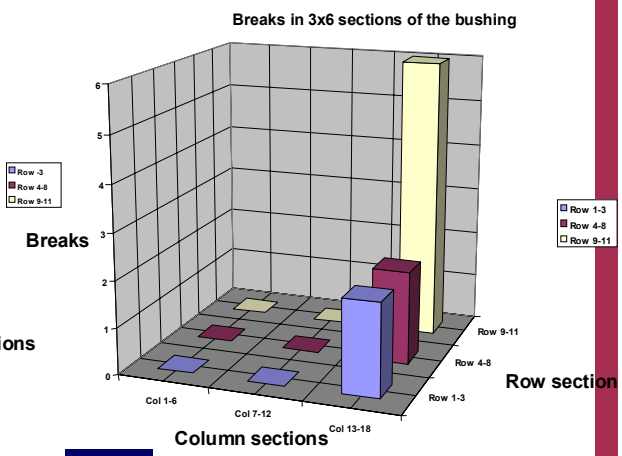
A key "knob" to control breaks location: fins orientation

Fins overlap tips by +1/16" on the left side of the bushing



Fins overlap tips by +1/16" on the right side of the bushing



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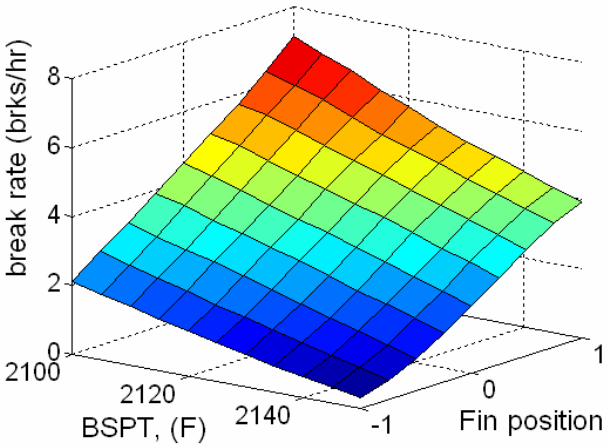
Key knobs to control breakage level: set point temperature and fins translation

Transfer function calculation for 10 mkm fiber:



Validation:

Fin position wrt tip, inches	Breaks/hr data	Breaks/hr model
+ 1/16	5.5	6.9
0	2.12	1.7
- 1/16	2.7	0.1

High Performance Glass Forming Technology Consortium

Toward successful completion by January '05

- Complete model validation
- Optimize set point/winder speed and fins/air to minimize break rate
- Demonstrate a less than 0.25 breaks/hr process

Commercial readiness and market potential

- Conducted tri-weekly conference calls and visits with JM and PPG, achieved correct focus and developed customers "pull"
- Conducted data collection and analysis in production facilities
- Demonstrated use of instrumentation
- Joint plans are being developed to achieve full-scale factory implementation and continue toward a new target of one break per 24 hours
- Reducing break rate by 0.1 br/hr yields ~$2 M/year savings in the glass fiber industry we target

Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulate Emissions and Crown Refractory Corrosion in Glass Melting Furnaces

Linda G. Blevins, Alejandro Molina, Shane M. Sickafoose, and Douglas D. Scott
Sandia National Laboratories
Livermore, CA

Peter M. Walsh
University of Alabama Birmingham
Birmingham, AL

John W. Neufeld
Gallo Glass Company
Modesto, CA

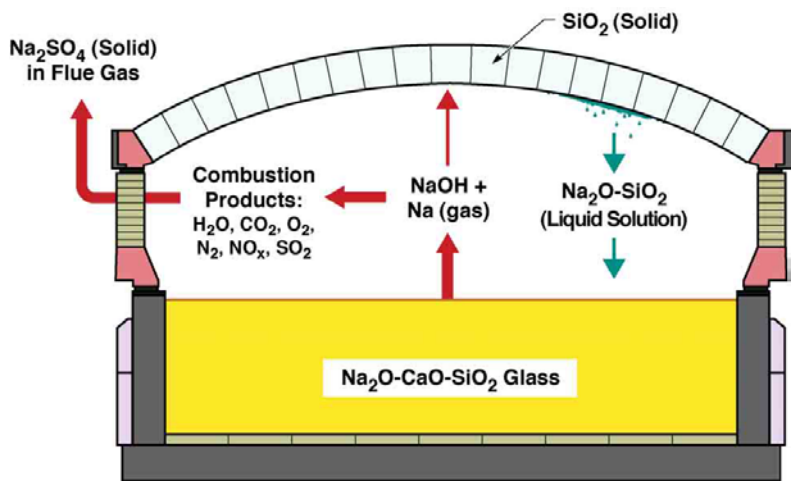
DOE Materials, Glass and Sensors Portfolio and Project Review
June 2004

Introduction

- Many glass furnaces are oxygen/natural gas fueled
- Typical raw materials (batch) for container glass
  - Sand (SiO_2)
  - Soda ash (Na_2CO_3)
  - Limestone ($CaCO_3$)
  - Salt cake (Na_2SO_4)
  - Recycled glass
  - K, Al, Mg, Fe, Ti, etc.
- Inorganics can enter the combustion space
  - Volatilization
  - Batch carryover
- Problems with inorganics
  - Crown and superstructure corrosion
  - Particulate matter emissions

Example

Crown corrosion more problematic in oxy-fuel furnaces



Background

- **Volatilization depends on**
  - **Temperature of the furnace**
  - **Velocity of gases across the melt**
  - **Composition of gases above the melt**
  - **Diffusion in the melt**
  - **Mass transfer at the melt/gas interface**
- **Batch carryover depends on**
  - **Composition of the batch**
  - **Particle size of the batch**
  - **Velocity across the batch**
- **Simultaneous optimization is difficult – especially in oxy-fuel furnaces**

Reactive volatilization sample reactions

- $Na_2O\ (l) \Leftrightarrow 2\ Na\ (g) + \frac{1}{2}\ O_2\ (g)$
- $Na_2O\ (l) + H_2O\ (g) \Leftrightarrow 2NaOH\ (g)$
- $Na_2O\ (l) + CO\ (g) \Leftrightarrow Na\ (g) + CO_2\ (g)$

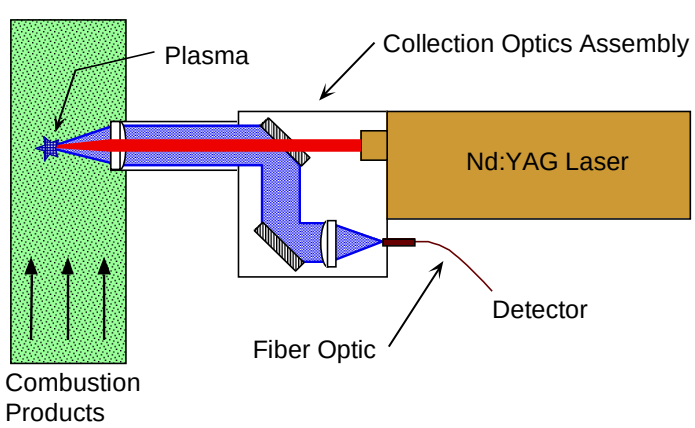
Motivation

- Oxy-fuel furnaces relatively new so not understood
- Methods outdated for analyzing volatilization and carryover
  - Collection on cooled targets
  - Extractive sampling
- Difficult to correlate with changes in furnace conditions
- In-situ technique would allow more thorough study

Objectives

- Use laser-induced breakdown spectroscopy (LIBS) to examine Na, K, Ca, Mg, Si, and Al *in-situ* in the flue of an operating glass furnace
- Use gas analysis to determine furnace stoichiometry
- Determine effect of furnace operating conditions on volatilization and batch carryover
  - Temperature
  - Stoichiometry
  - Pressure

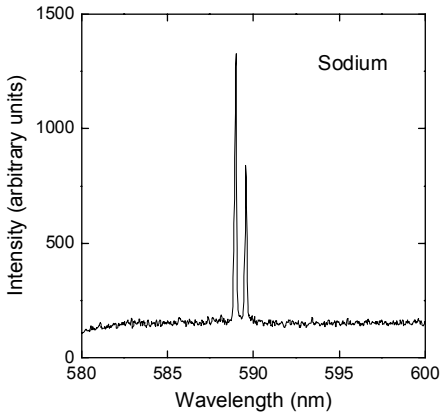
LIBS

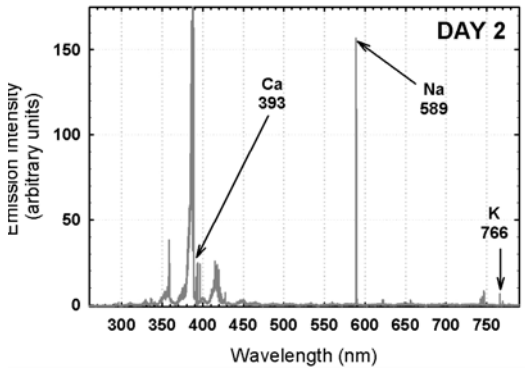


- Particles + gases
- ND:Yag Laser
  - 400 mJ, 5 Hz
- 1064 nm, 10 ns
- Delay time 10 μs or 20 μs
- Gate width 50 μs

Two LIBS detection schemes

- Linear spectrometer
  - Single shots at 5 Hz
  - Narrow spectral windows
    - 20 nm at 0.05 nm resolution
  - Can see Ca & Al, Si & Mg, Na, or K depending on window
- Echelle spectrometer
  - 1600, 800, or 500 shot averages
  - Broadband
    - 300 nm – 900 nm
    - Resolution 0.1 nm at 400 nm
  - Multiple elements

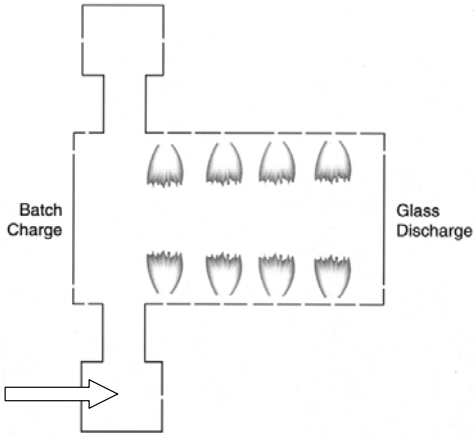




LIBS has been applied in two areas of a container glass furnace

- Exhaust duct
  - Dilution ~2.5-3.5
  - Low temperature
    - 620 K – 720 K (650 ° F - 840 ° F)
  - High velocity
    - 29 m/s (95 ft/s)
- Vertical flue
  - Little dilution
  - High temperature
    - 1450 K (2150 ° F)
  - Low velocity
    - 0.5 m/s (1.6 ft/s)

Gallo Glass Company
Tank #1



Field Tests to Date

Date	Pull Rate (t/day)	O/G	Heat Release Rate (MW)	% Boost	
Dec 2001	430	2.16	15.2	14.6	Exhaust
June 2002	336 435	2.12	12.0 14.9	13.2	Vertical Flue
May 2003	322 405	1.98 - 2.18	11.3 - 13.9	13.7 - 15.6	Vertical Flue
June 2004	325 270 375	2.00 - 2.13	13.1 - 14.8	12.6 - 14.6	Both

(40-50 MMBtu/hr)

Highlights of Previous Findings

- Combustion products depend on O_2/NG
- Ambient temperature affects in-leakage and NO
- Rich conditions alter SO_2 release

- Sodium correlates with potassium
- Other metals do not correlate with alkali but intercorrelate
- Alkali release depends on temperature & maybe stoichiometry
- Rich conditions may affect alkali release

- Batch particles
  - can be detected
  - size distributions can be calculated
  - depend on pressure

FY04 Results

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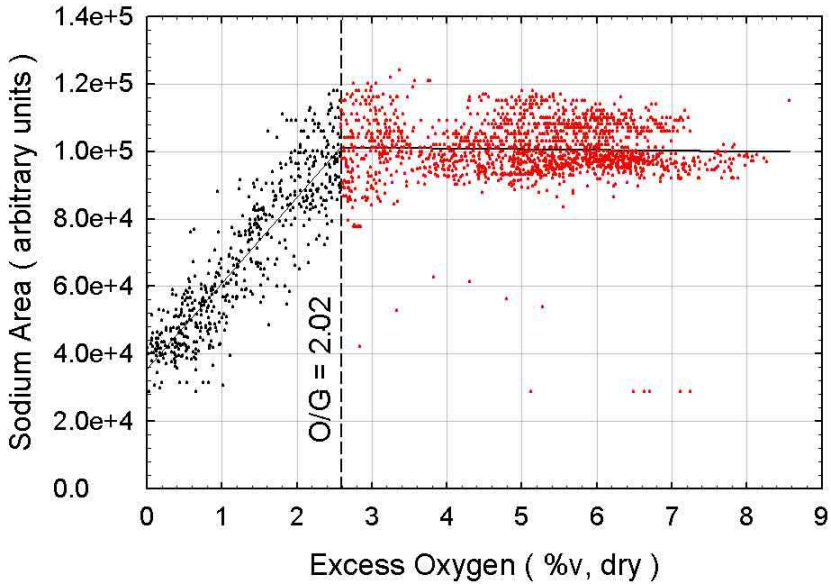
FY03 mystery solved



May 2003

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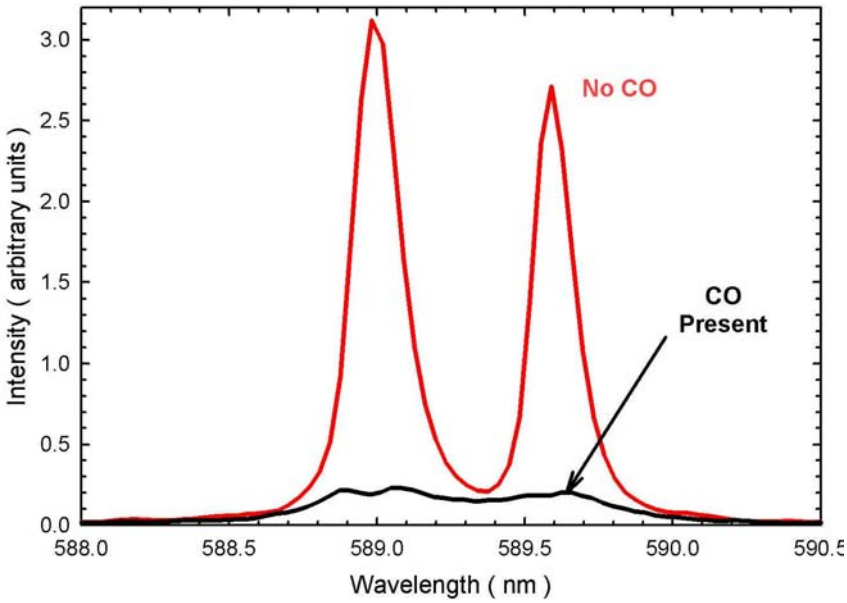
Spectra in presence and absence of CO



May 2003

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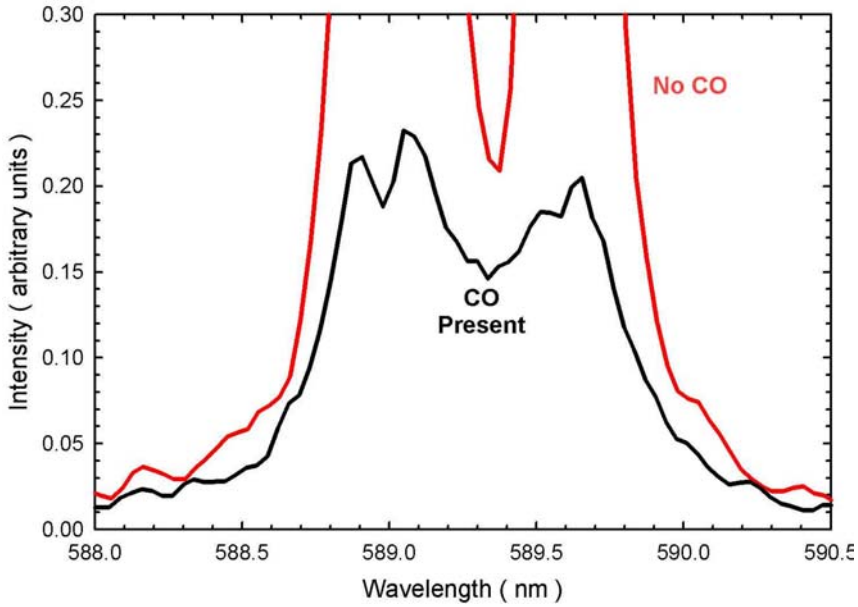
Na atoms absorb signal when CO is present



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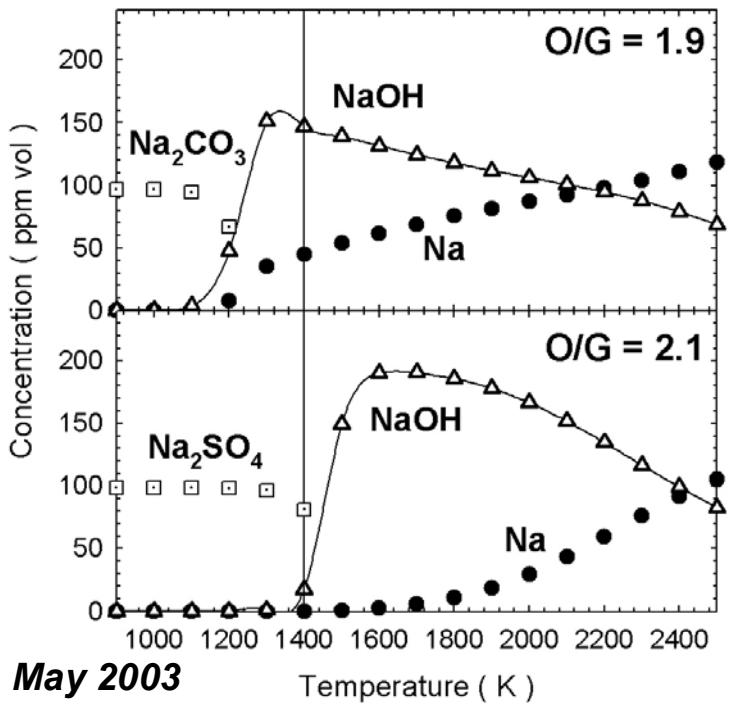
Equilibrium shows Na when fuel-rich



Rich (CO Present)

Lean (No CO)

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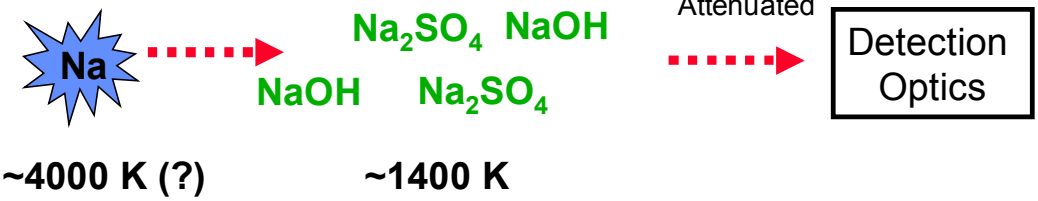
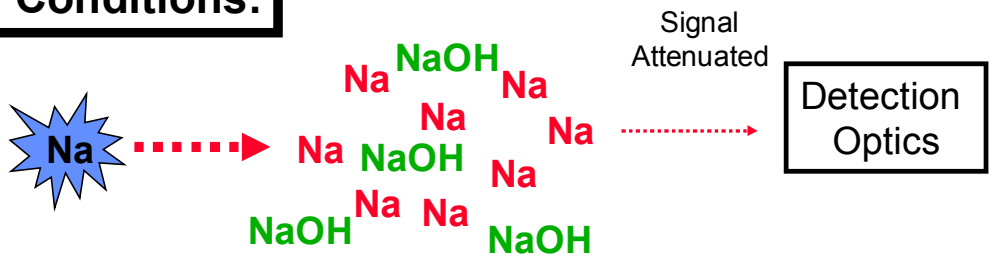
Scenario in glass furnace

Lean Conditions:



~4000 K (?) **~1400 K**

Rich Conditions:



~4000 K (?) **~1400 K**

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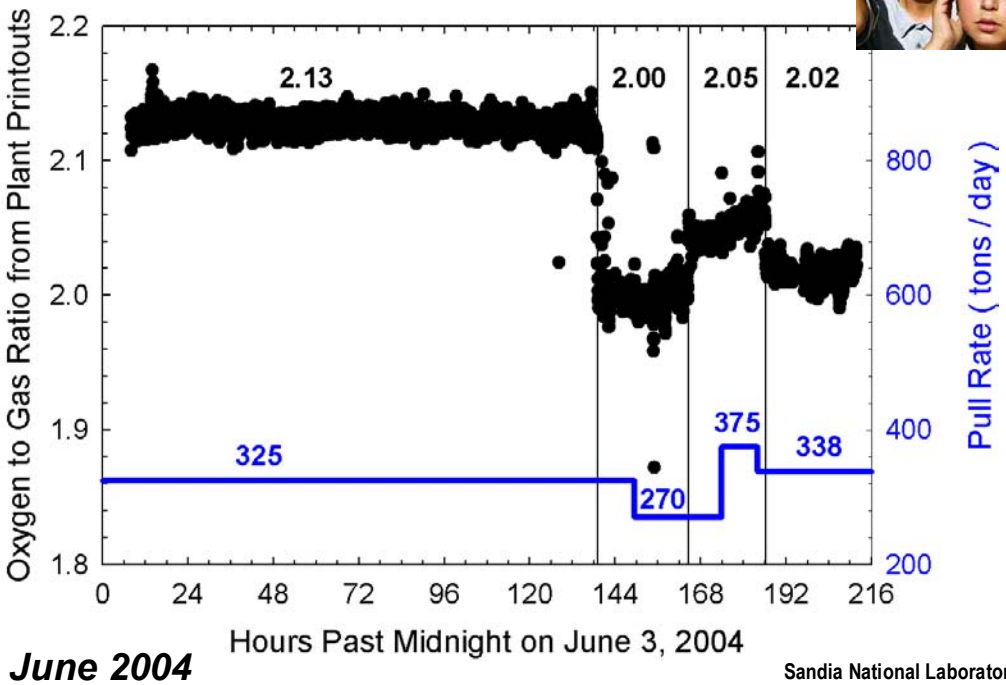
June 2004 tests



June 2004

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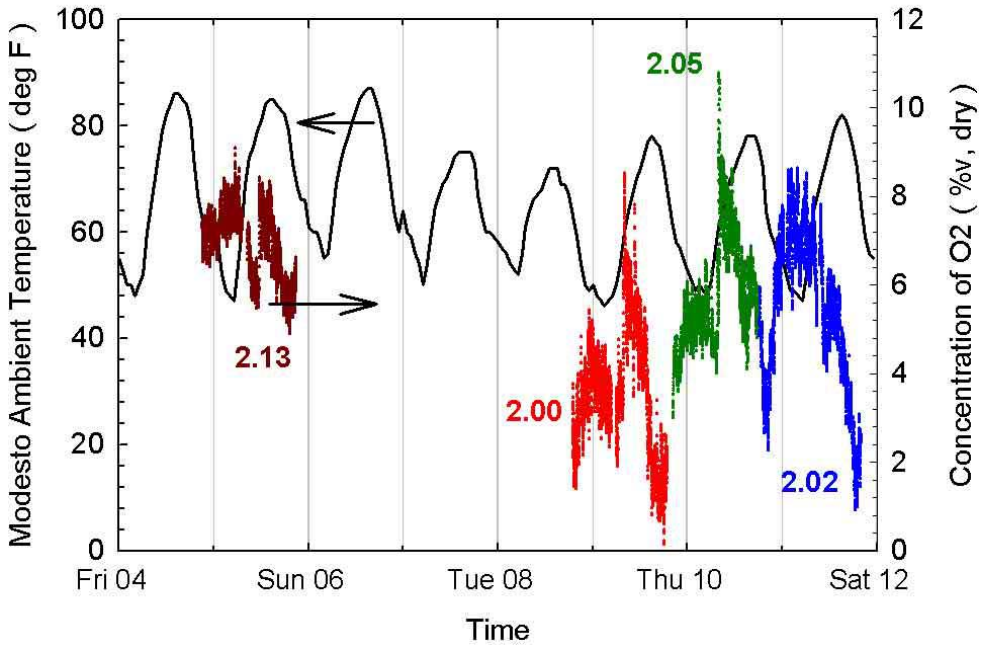
Ambient T still affects inleakage



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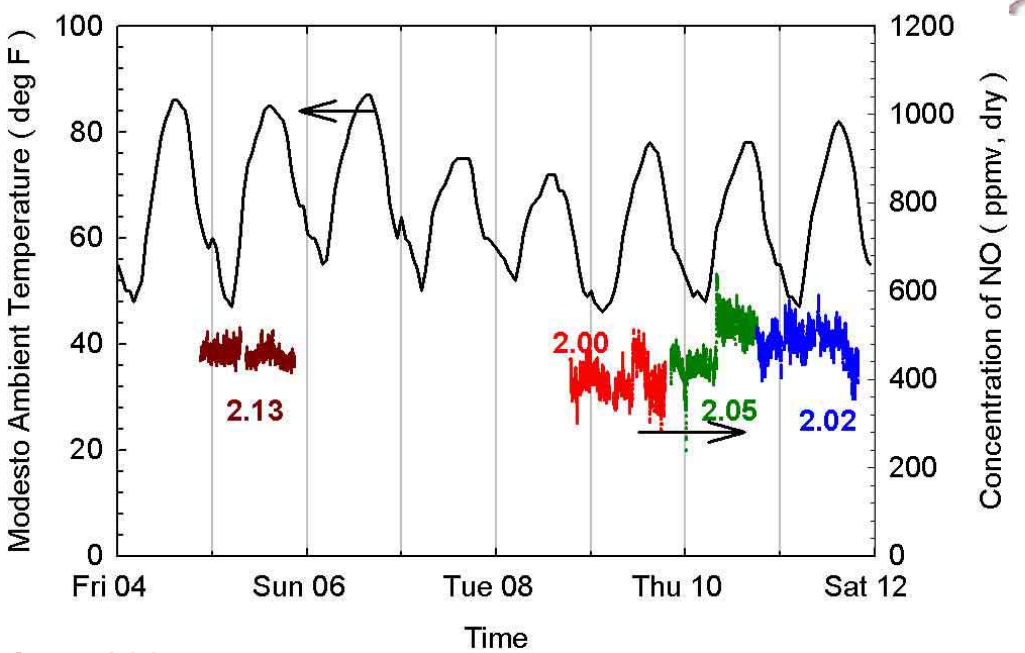
NO also affected by inleakage



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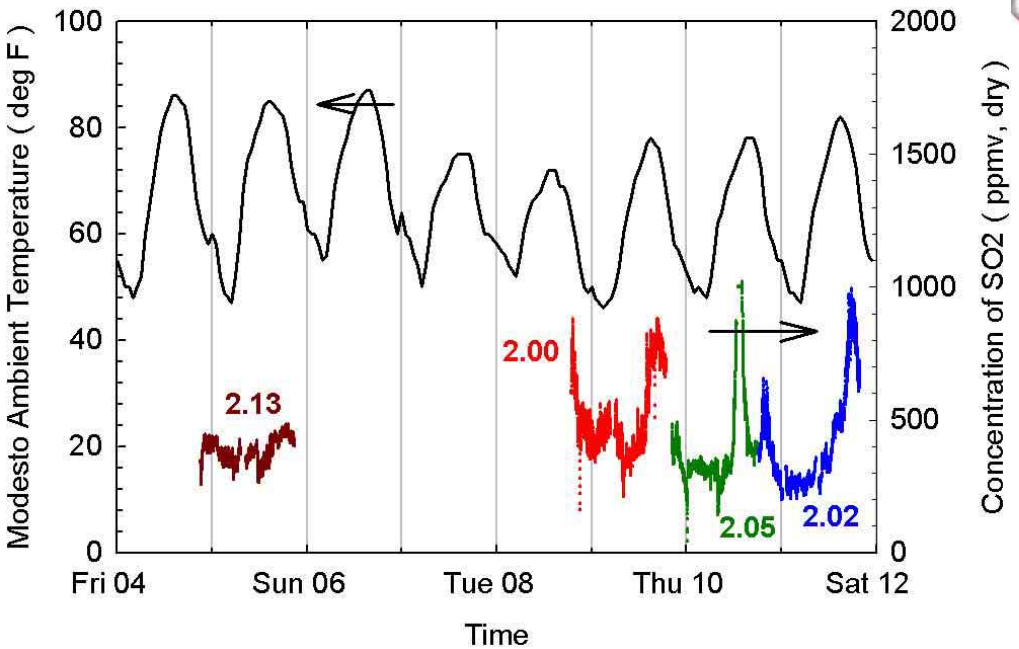
Rich conditions still alter SO_2 release



June 2004

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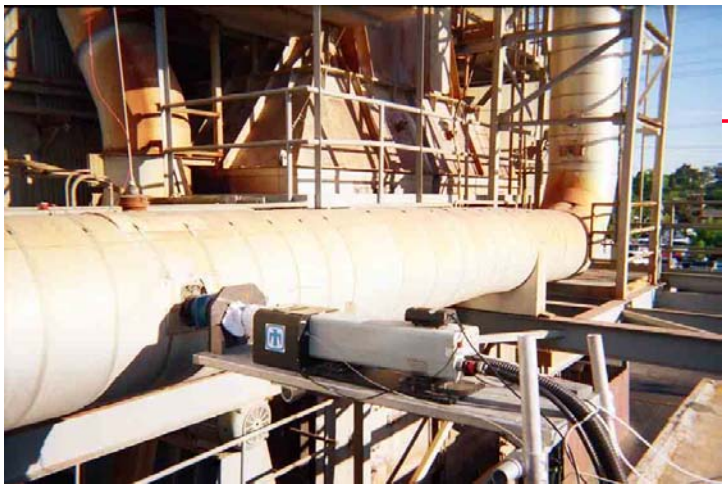
June 2004 Field Test Objectives

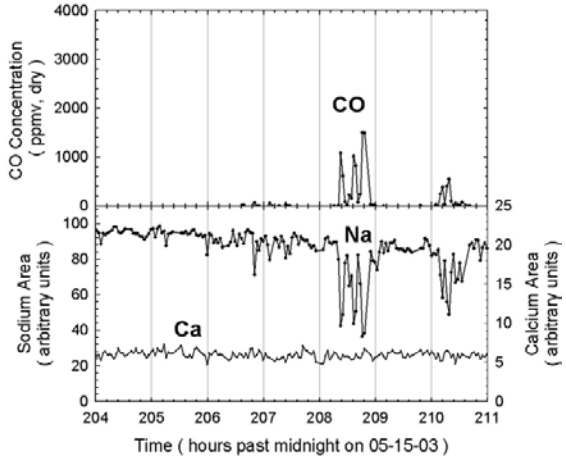
1. Measure Na at a cooler location to avoid interference
2. Quantify and determine source of air inleakage
3. Examine effect of furnace pressure on batch particles
4. Expand energy analysis to include inleakage



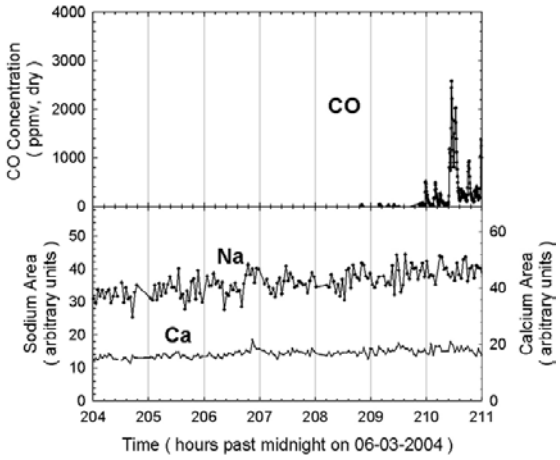
1. Measure Na at a cooler location to avoid interference

Upstairs Na signal not affected by CO

May 2003 – Vertical Flue ~1400 K (2100 °F)

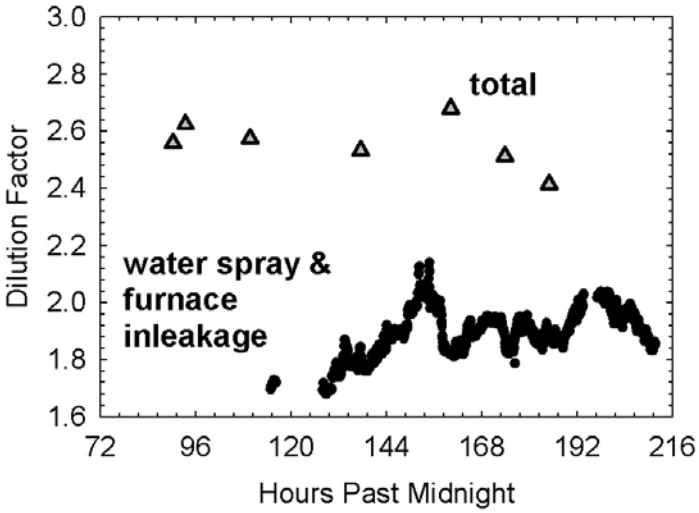


June 2004 – Exhaust Duct ~700 K (900 °F)



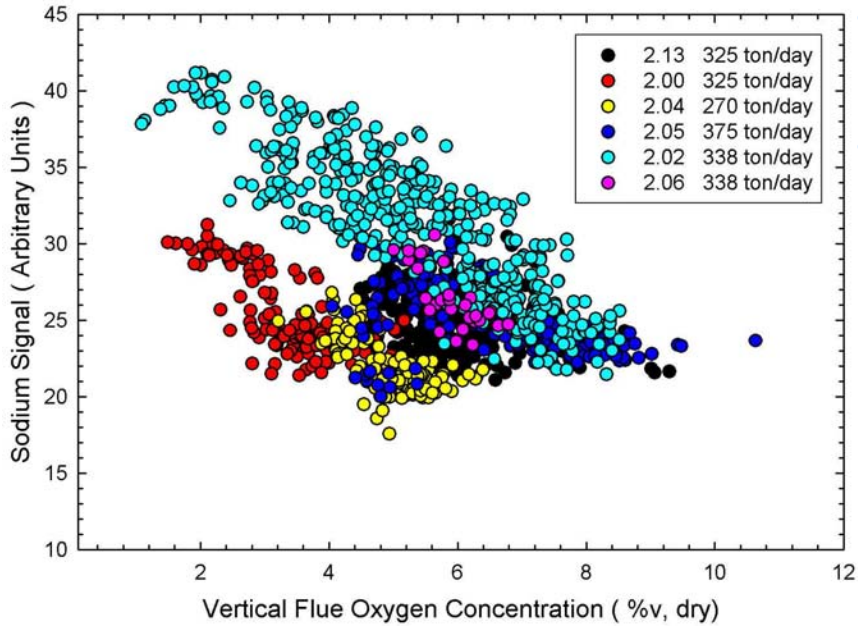
Upstairs location diluted

- Cooling water nozzles
  - 7-9 gal/min
  - 70 scfm atomizing air
  - Water contains metals
- Furnace air inleakage
  - Measured in vertical flue using GC
  - Dilution factor 1.7-2.0 including water nozzles
- Duct air inleakage
  - Deduced from gas analyzer O2 down- and up-stairs
  - Overall dilution ~2.5



June 2004

Sodium varies inversely with excess O_2



- Appears to be dilution related
- Samples extracted from furnace show little effect of stoichiometry ~120 ppmv Na ~20 ppmv K

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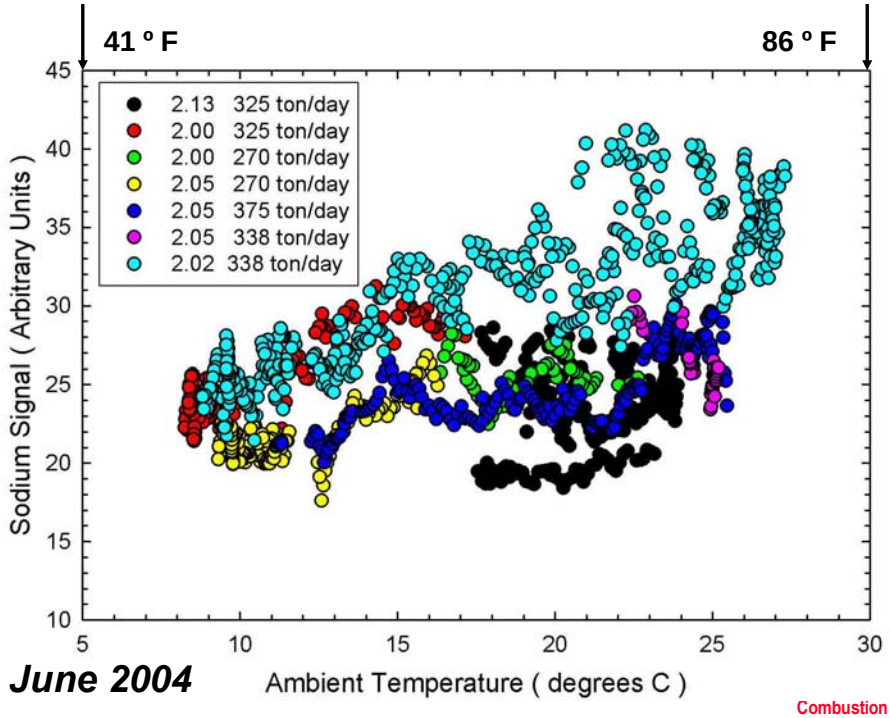
Sodium correlates with ambient T



- Must be inleakage

June 2004

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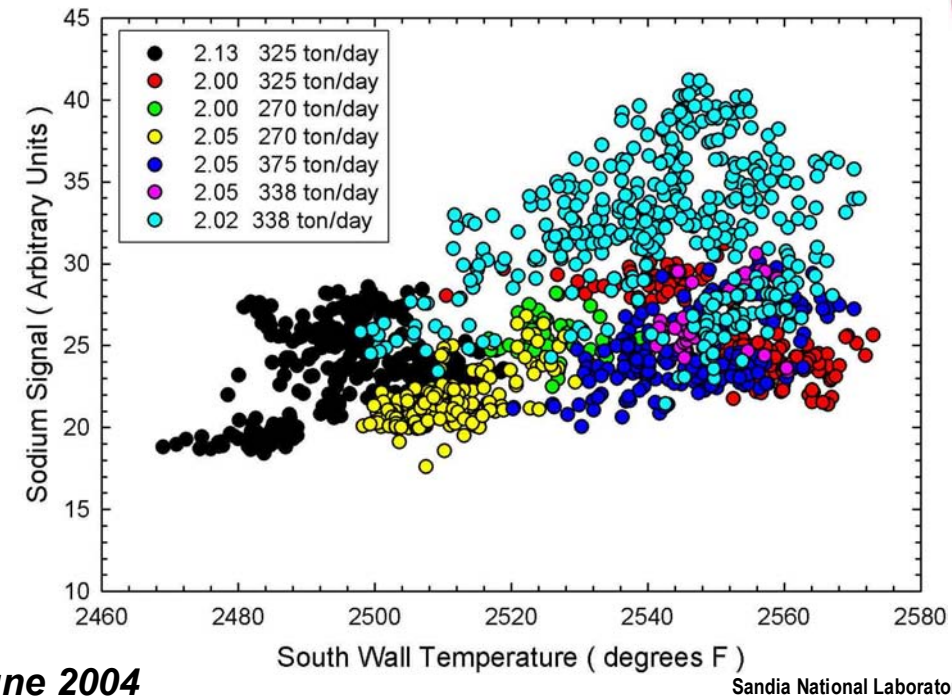
Sodium vaporization depends on furnace T



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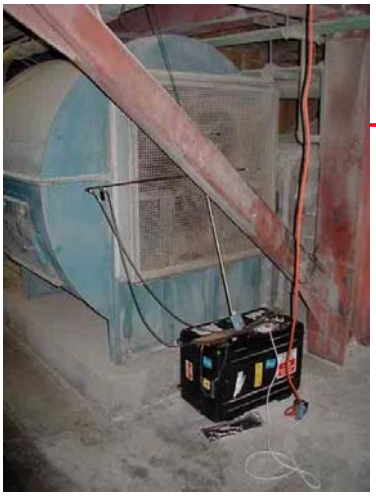
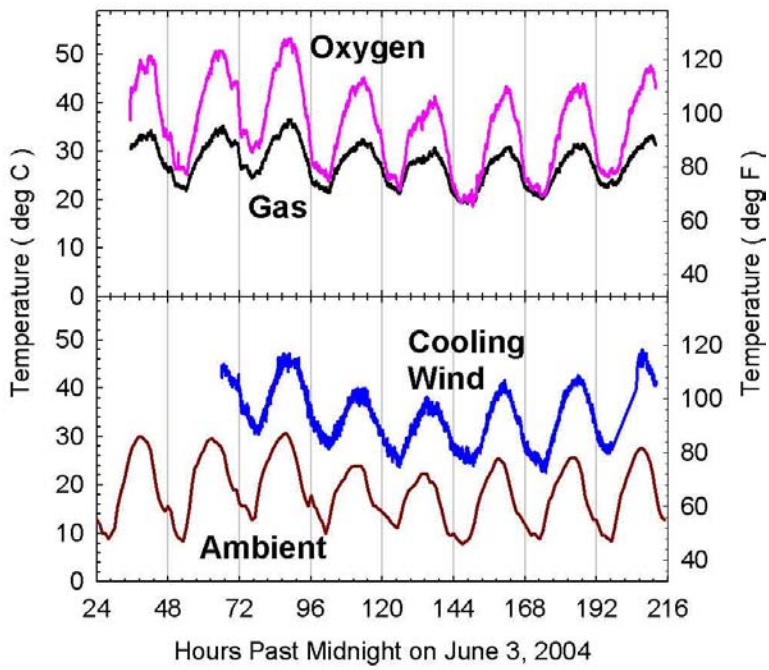


2. **Quantify and determine source of air inleakage**

Temperatures can affect inleakage



- Single flow meter T compensation may not apply for every point
- Cooling wind temperature varies with ambient

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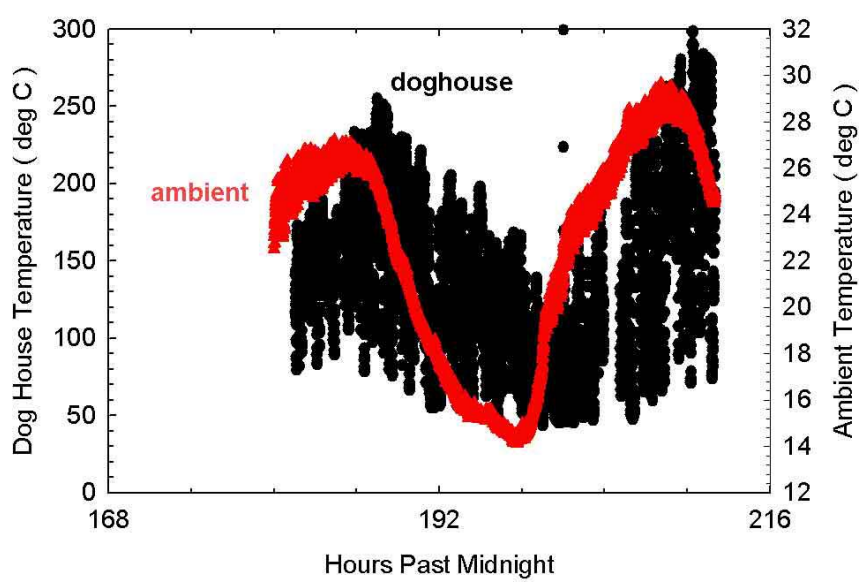
Air can enter through the doghouse, too



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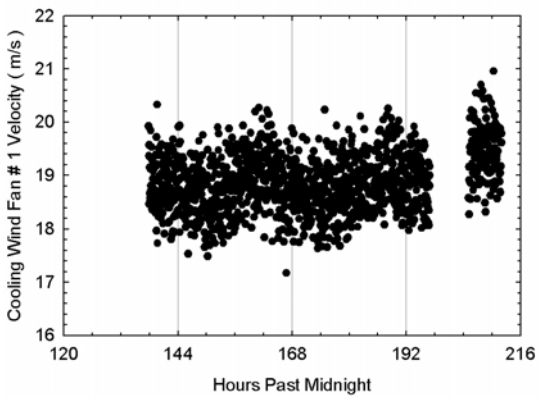
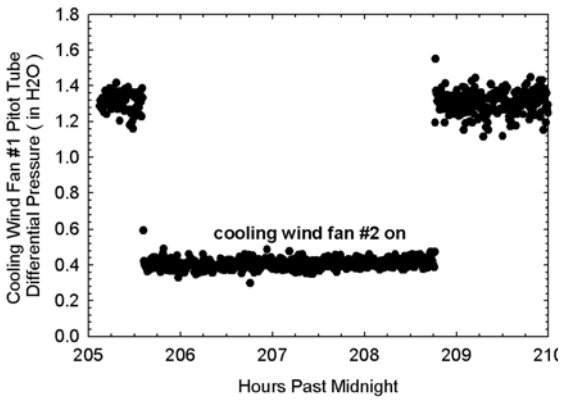
Cooling wind fan(s) moves constant volume





So rate of mass flow varies with ambient

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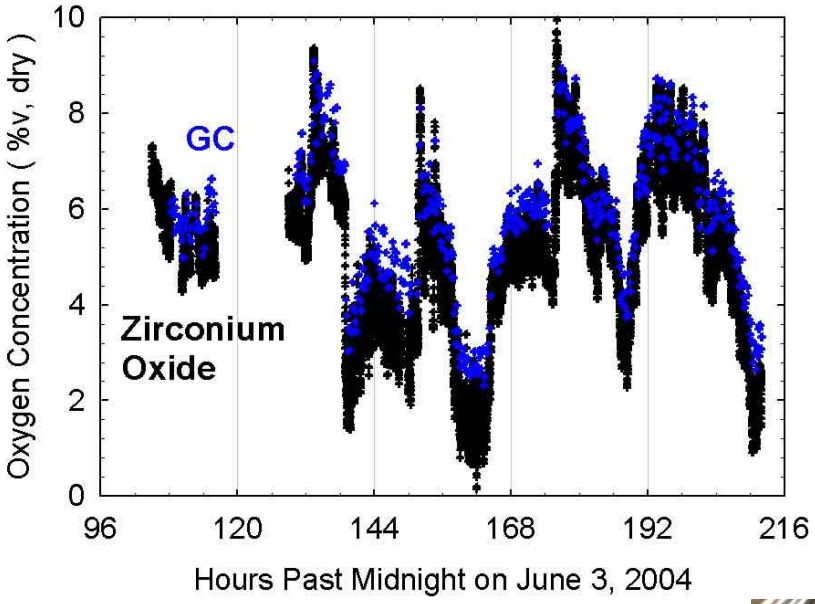
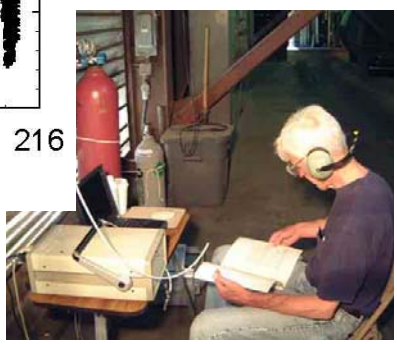
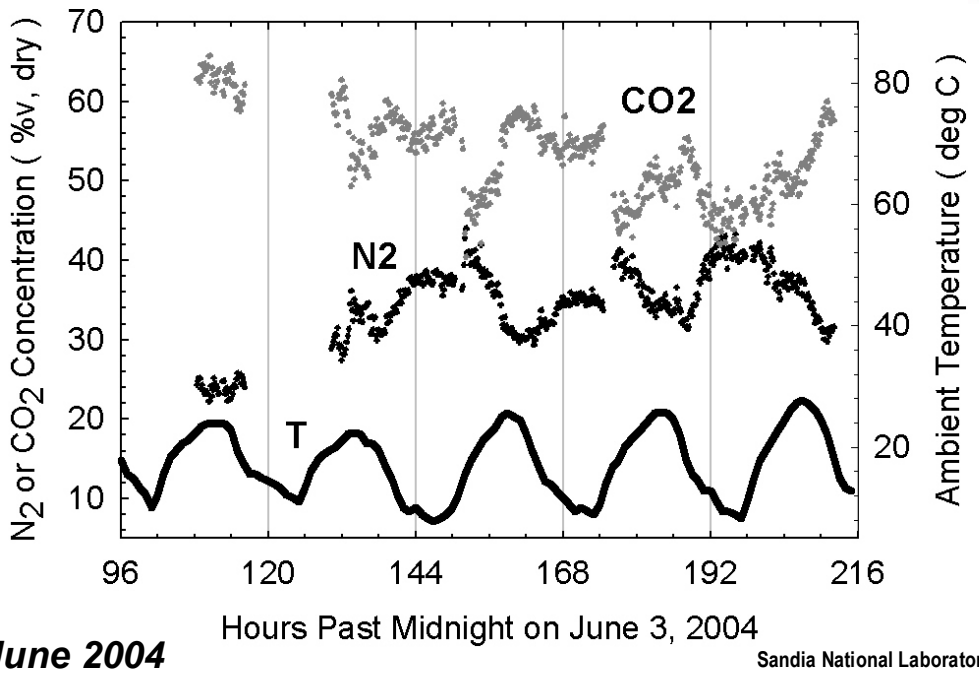
GC and gas analyzer agree for O2





June 2004

N_2 and CO_2 track ambient T

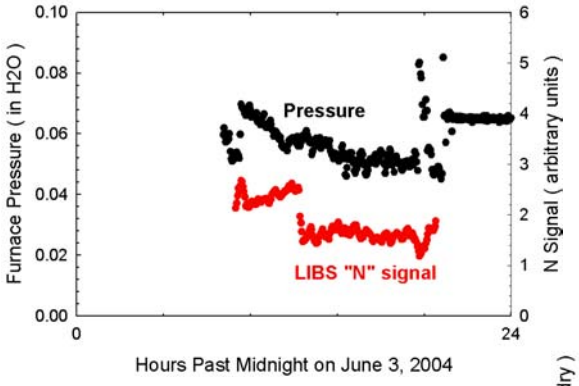


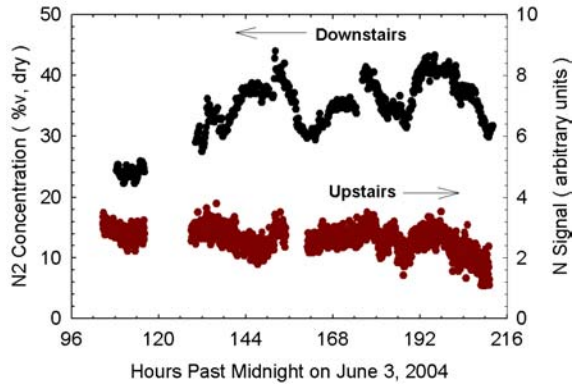
June 2004

Estimated* contributions to inleakage

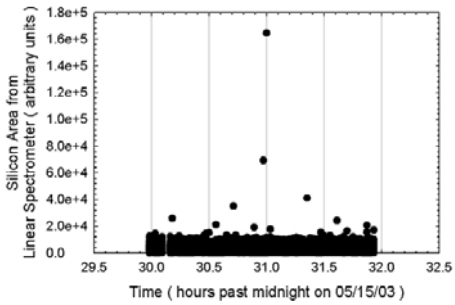
Exhaust flow	**~140,000 scfh**	
Inleakage measured with GC	**~40,000 scfh**	**25 % of total flow**
Flow into doghouse	**~5,000 scfh (80% in, 20% out)**	**2 % of total flow**

LIBS may be useful for inleakage, too

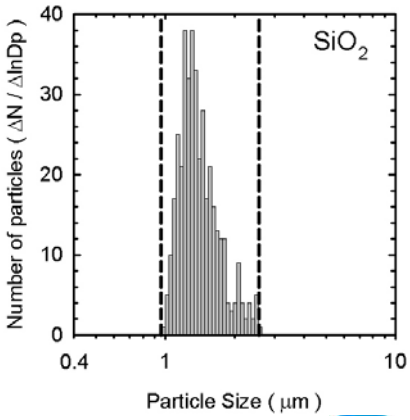




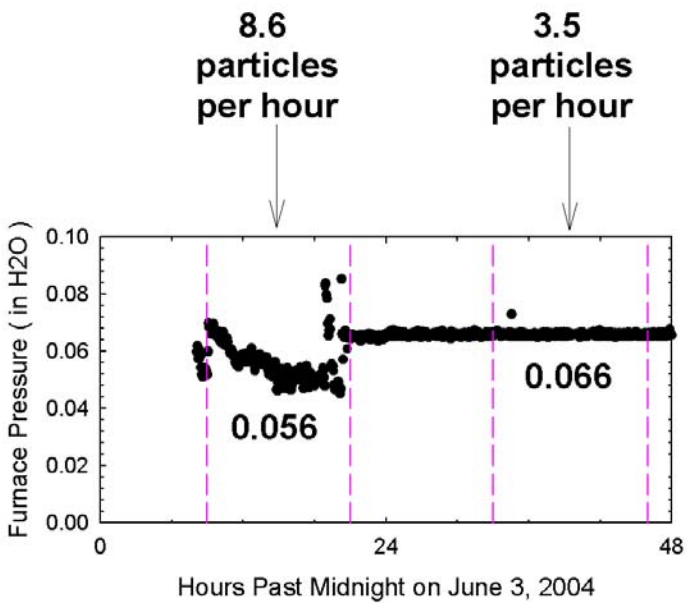
June 2004



3. Examine effect of furnace pressure on batch particles



Batch particles high under manual control



- Furnace pressure under manual control for a few hours
- More than twice as many batch particles counted
- About half of hits are Mg & half are Si

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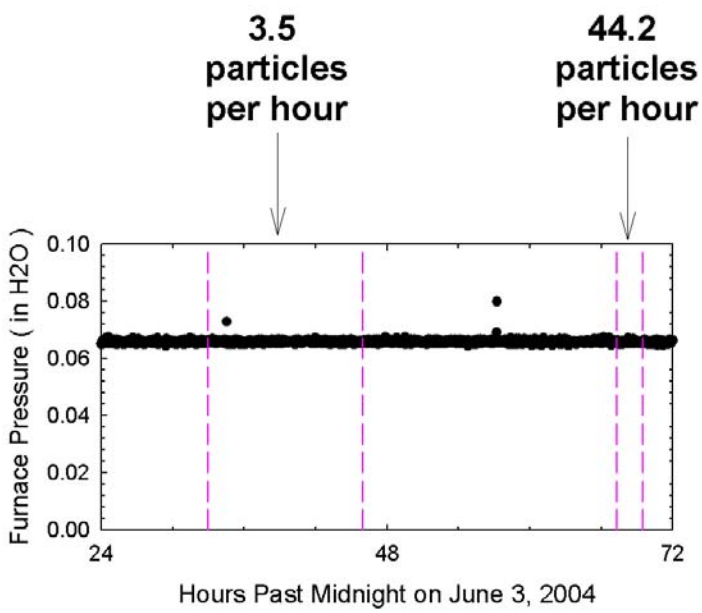
Improved LIBS detection parameters found



- Delay time shortened from 10 us to 1 us
- Gate width shortened from 150 us to 50 us
- Particle detection frequency improved 10X

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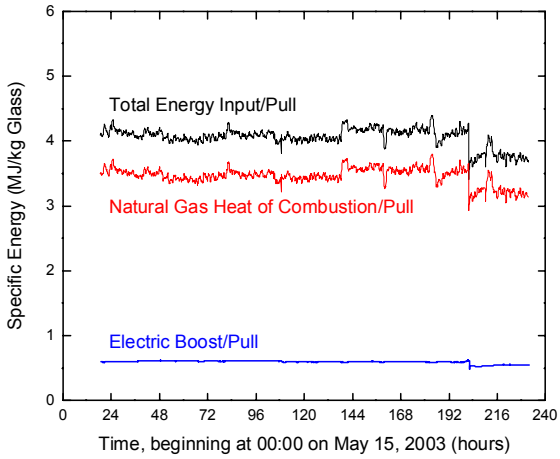
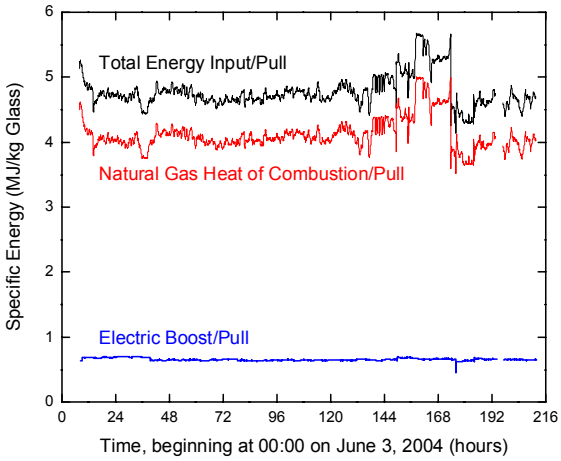
4. Expand energy analysis to include inleakage

Specific energy inputs

May 2003



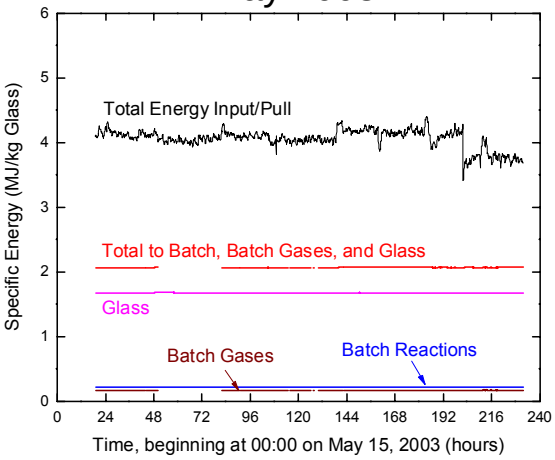
June 2004



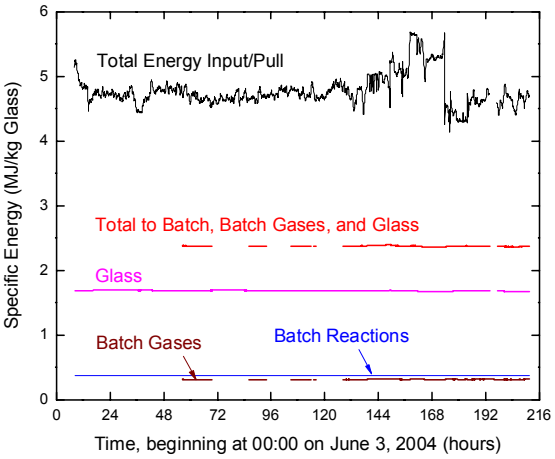
(6 MJ/kg = ~2580 BTU/lb = 5.2MMBTU/ton)

Specific energy uses

May 2003

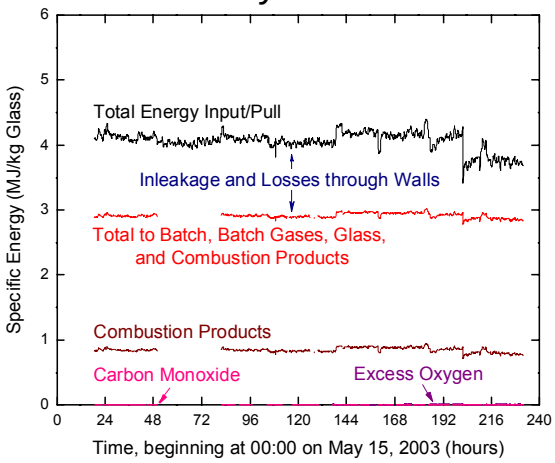


June 2004

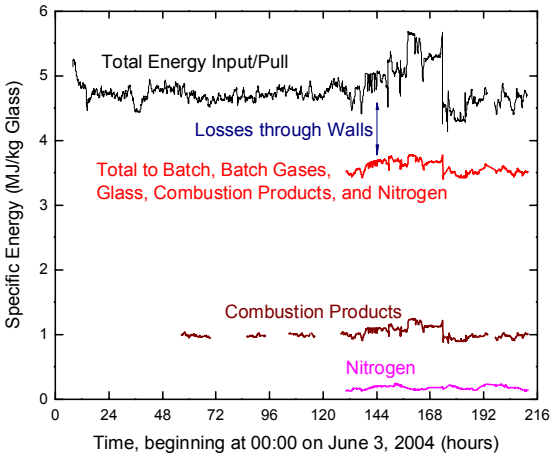


Specific energy losses

May 2003

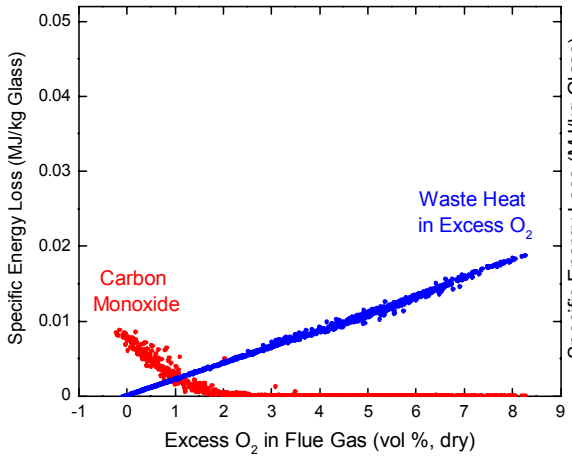


June 2004



Losses to excess O_2 and CO

May 2003



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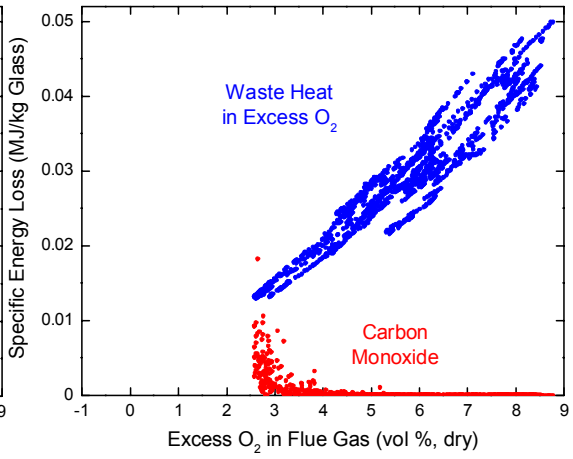
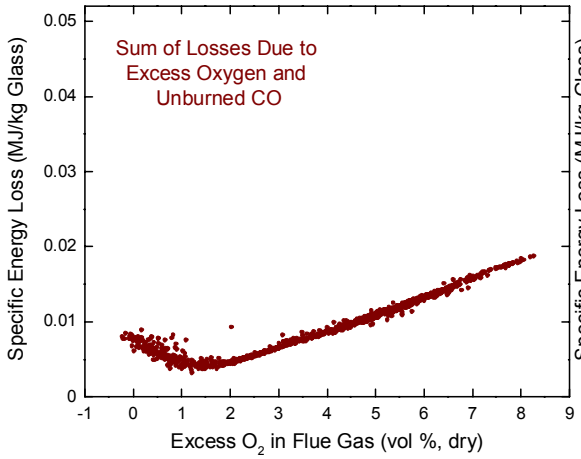
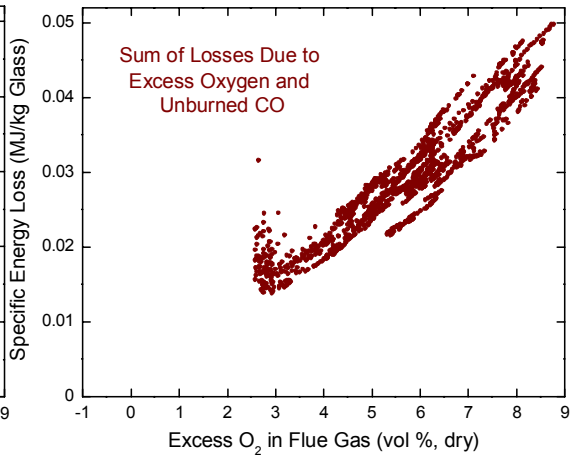


Optimum excess oxygen

May 2003



June 2004



Improvements to LIBS diagnostic

- New method for baseline normalization
- Power meter pick-off installed
- Improved settings for batch particle detection
- Elimination of first-shot artifact for batch detection
- Single-shot broadband spectra detected multi-element batch particles for the first time
- Calibration issues for Na and K being examined
  - Using controlled burner and high temperature cell
- May be able to use LIBS to determine inleakage

Tasks/Milestones

No.	Task / Milestone Description	Planned Completion	Actual Completion
1	Data acquisition system	7/31/01	6/20/02
2	CO and O_2 monitors	9/30/01	12/14/01
3	Furnace exit gas temperature	10/31/01	6/20/02
4	Flame and refractory radiation	11/30/01	6/20/02
5	Synchronized records	12/31/01	6/20/02
6	Measurements of sodium	2/28/02	12/14/01
7	Sources of sodium	3/31/02	8/31/02
8	Conditions influencing sodium	4/30/02	8/31/02
9	Maximum furnace efficiency	5/31/02	6/30/04

Tasks/Milestones

No.	Task / Milestone Description	Planned Completion	Actual Completion
10	Measurements of silicon	7/31/02	12/14/01
11	Measurements of calcium	9/30/02	12/14/01
12	Correlations for metals	11/30/02	6/20/04
13	Broad-band LIBS instrument	3/31/03	10/31/01
14	Software for LIBS instrument	5/31/03	10/31/01
15	Simultaneous measurements of Na, K, Ca, and Si	7/31/03	12/14/01
16	Relationship between Na and K	8/31/03	06/01/03
17	Optimum stoichiometry	9/30/03	06/01/03
18	Sodium and calcium monitor	1/31/04	
19	Control strategy	3/31/04	
20	Demo in melting research facility	4/30/04	
21	Method for monitoring and control of volatilization and carryover	5/31/04	

Plan for the rest of FY04

- **Examine temperature effects on calibration**
- **Further analyze furnace data**
- **Recommend data-based control strategy to improve efficiency and minimize alkali release**
- **Compile "best practices" for using LIBS to monitor particulates and corrosion in container glass furnaces**
- **Write final report**

Budget

Estimated Budget Data as of June 2004**:**

			Approved Spending Plan ($000)			Actual Spent to Date ($000)		
Phase / Budget Period			DOE Amount	Cost Share	Total	DOE Amount	Cost Share	Total
	From	To						
Year 1	6/01	5/02	350	350	700	350	350	700
Year 2	6/02	5/03	350	350	700	350	350	700
Year 3	6/03	5/04	350	350	700	275	275	550
Totals			1,050	1,050	2,100	975	975	1,950

Publications and Presentations

- **Seven papers and presentations**
  - **List available on request**
- **Further dissemination of information planned**
  - **Air in-leakage causes and effects**
  - **Alkali devolatilization and batch carryover**
  - **Furnace energy balance**
- **Best practices recommendation to be written**
- **Final report to be written**

Findings

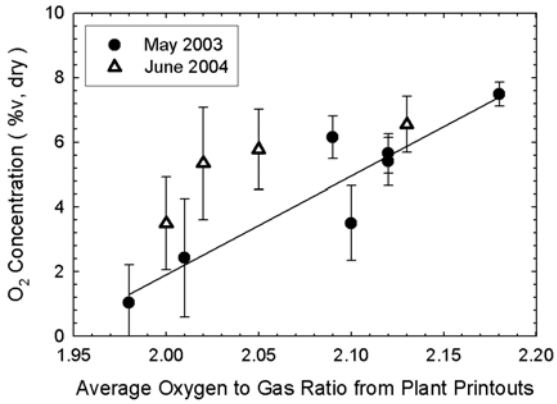
- As O_2/NG increases, O_2 and NO increase, SO_2 decreases
- Ambient temperature affects actual oxygen to gas ratio
- Na and K correlate with each other; Al, Ca, and Mg correlate with each other; no inter-correlation
  - Suggests different release mechanism for these metals
- Alkali release depends on furnace temperature
- Alkali release seems insensitive to furnace stoichiometry
- Decreasing furnace pressure encourages batch carryover
- Optimum excess oxygen for best efficiency

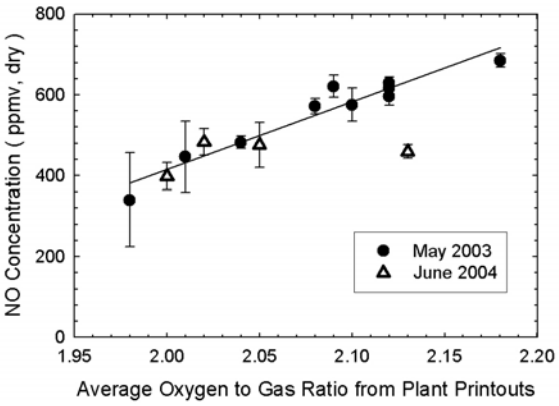
Acknowledgments

- Department of Energy
  - Elliot Levine
- Gallo Glass Company
  - Doug Moore, Plant Technical Staff
- Sandia National Laboratories
  - Jay Keller, Bob Gallagher, Jim Wang, Mark Allendorf, Steve Rice, Gary Hubbard, Howard Johnsen, Bob Steinhaus, Chris Shaddix

Extras

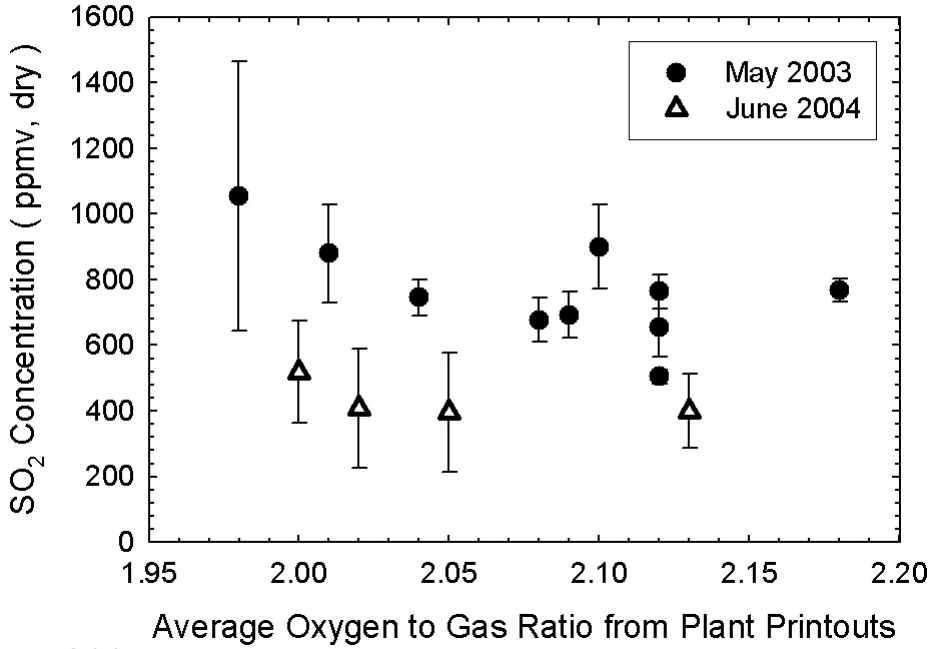
2004 compares with 2003





June 2004

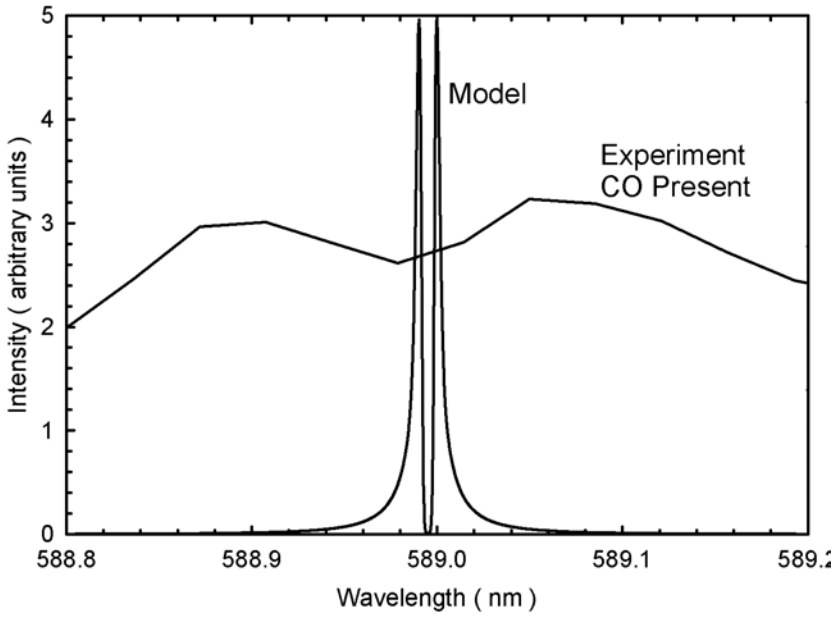
SO_2 concentrations repeat trend



June 2004

Sandia National Laboratories
Combustion Research Facility

Self-reversal can be modeled



More work to do on calculating broadening

May 2003

Sandia National Laboratories
Combustion Research Facility

Development of Process Optimization Strategies, Models, and Chemical Databases for On-Line Coating of Float Glass

Douglas Dauson
PPG Industries, Inc.

Mark D. Allendorf
Sandia National Laboratories
Livermore, California

Glass Industry of the Future Team
Program review meeting
Washington, D. C.
June 22, 2004

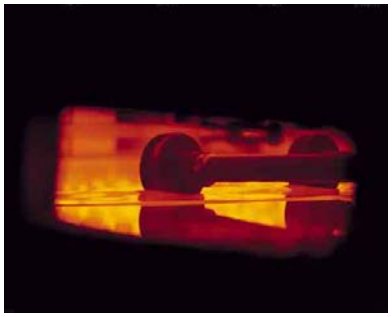
Atmospheric Pressure Chemical Vapor Deposition (APCVD) In The Glass Industry

Goals: Double the efficiency of tin precursor utilization and reduce coating defects related to thickness

Challenges:
- Very complex process
- High process development costs
- Knowledge base required to develop process models is absent

Benefits: Doubling efficiency of precursor use will save $13 M/year in waste disposal costs, while reductions in coating defects could save 4.5 x 10^{10} BTU/year to remelt glass

FY05 Activities: CRADA with PPG extended to 12/04 to evaluate production and licensing potential of IP.



Participants: Sandia National Laboratories, PPG Industries, TNO

Barrier-Pathway Approach

Barriers

- Lack of chemical data needed for process models
- No reliable measurements of film growth kinetics
- Testbed needed to validate models and evaluate optimization strategies

Pathways

- Theory, modeling, and experiments (SNL, TNO)
- Lab reactor constructed to provide required data
- Pilot-scale experiments and full-scale plant trials conducted by PPG

Critical Metrics

- Model predictions validated by experiment
- Successful plant trials
- 2X increase in precursor utilization efficiency
- 2X reduction in waste glass due to coating defects

Benefits (est.)*	2020
Energy Savings	**350 billion Btu**
Savings due to reduced solid waste	**$200 million**

*2005 – 2020 est. cumulative total

Project Tasks

- **Task 1: Deposition Mechanism Development (SNL)**
  - Thermodynamic Data
  - Gas-Phase Chemistry
  - Surface Mechanism
  - Defect Formation
- **Task 2: Reaction Rate Measurements (SNL, TNO)**
  - Gas Phase Reactions
  - Surface Reactions
- **Task 3: On-line Coater Effluent Analysis (SNL, PPG)**
- **Task 4: CFD Modeling of Coating Reactors (SNL, PPG)**
- **Task 5: Deposition Experiments (SNL, PPG)**
  - Model Validation
  - Defect Analysis
- **Task 6: Validation of Optimization Strategies (SNL, PPG)**

This project successfully met its original goals set out in the original proposal

- Identify process modifications that will double the efficiency of reactant use to reduce waste emissions and purchases of raw materials
  - Strategies identified through modeling now undergoing full-scale testing
- Develop computational models to predict defects due to thickness nonuniformity and haze
  - Models transferred to PPG for use in full-scale simulation of coating operations; models available for use by the industry
- Generate a database of fundamental thermodynamic and kinetic information for APCVD
  - Thermodynamic data now available on the web: www.ca.sandia.gov/HiTempThermo/index.html
- Provide enhanced understanding of the underlying chemical reactions that control APCVD to enable development of coatings for other glass types, such as containers
  - 8 Publications in reviewed journals or proceedings, 12 presentations

Tin Oxide Deposition Kinetics and Model Development

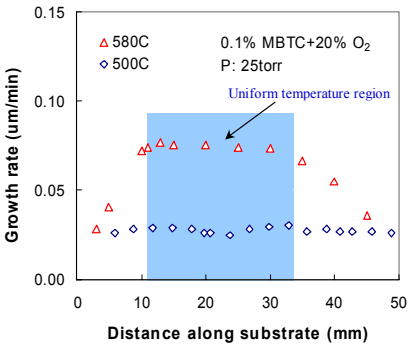
(Tasks 1, 2, & 5)

Objectives:

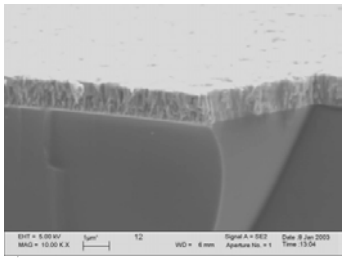
- Develop validated process model
- Generate thermodynamic and kinetic data for chemical precursors needed for modeling
- Provide enhanced understanding of underlying chemistry and physics of APCVD

New Sandia reactor provides the flexible testbed required to develop useful models of on-line coating

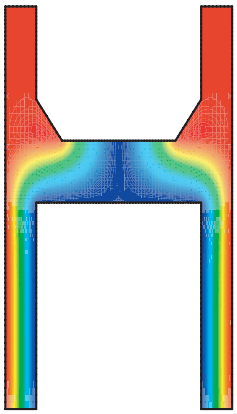
- **Broad range of accessible deposition conditions**
- **Uniform deposition due to is well behaved flow**
- **Simplified modeling due to 1-D flow environment**



Temperature: ± 8 K
Growth rate variation:
- 500 ° C: ± 5.8%
- 580 ° C: ± 3.8%



Streamlines



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PPG's pilot-scale coater provides a realistic environment for model testing and validation

- **Pilot scale coater has been modified to coat stationary substrates**
  - **Allows steady-state deposition and analysis of exhaust gases**
  - **Stationary heater installed directly under coater face**
  - **New coater face for heat transfer fluid channels for temperature control**
  - **Heat transfer fluid circulation system installed**

Side view of pilot-scale coater interior

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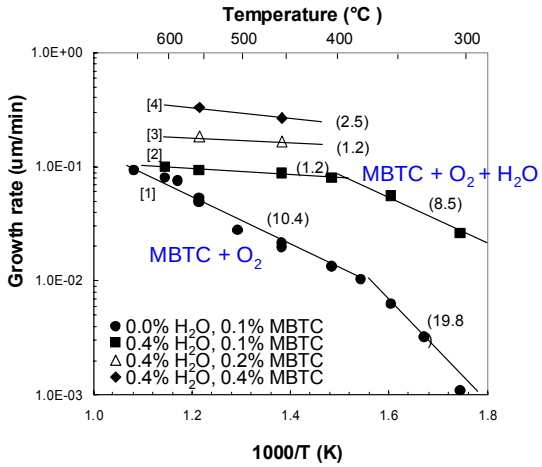
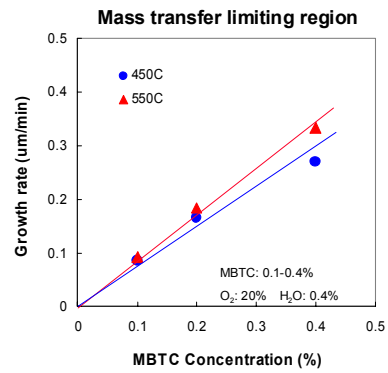
Combustion Research Facility

The kinetics of tin oxide deposition were fully characterized as part of this project

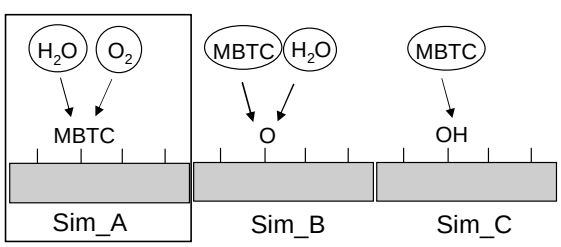


- **Effect of H_2O addition**
  - Decreases the activation energy
  - Changes the rate-controlling step:
    T > 400 °C : Mass transfer
    T < 400 °C : Kinetic
- **Which species govern the mass transfer? Two possibilities:**
  1) MBTC itself to the surface
  2) Intermediates produced by rapid MBTC reaction in the gas phase (MBTC:H_2O complex)

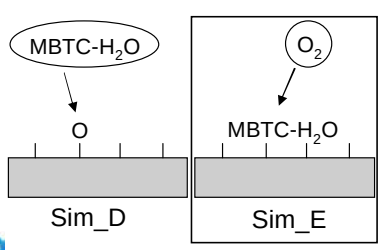


Several possible mechanisms exist for deposition from MBTC + O_2 + H_2O mixtures

No gas-phase reactions

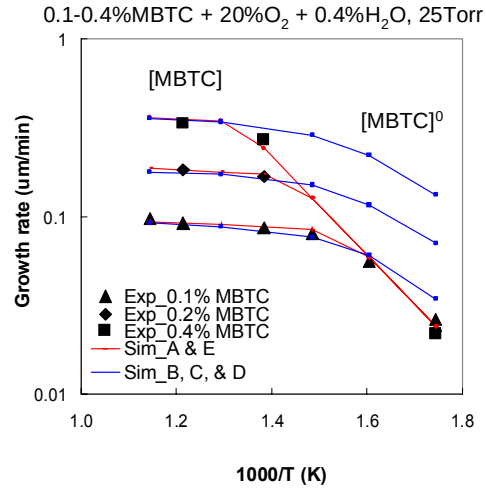


Gas phase reactions



SPIN simulation

0.1-0.4%MBTC + 20%O_2 + 0.4%H_2O, 25Torr



Sim_A and E are in good agreement with experimental data.

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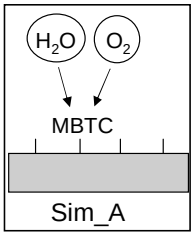
Comparison of Sim_A & Sim_E for MBTC + O_2 + H_2O reaction



$C_4H_9SnCl_3$ + _(s) → $C_4H_9SnCl_3$(s) st. coef.=1

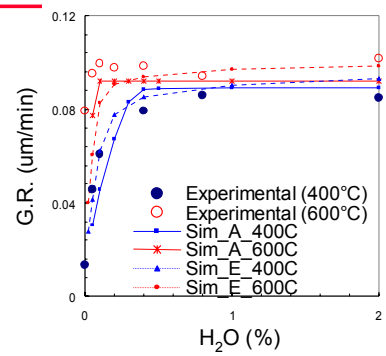
_(s): open site on surface

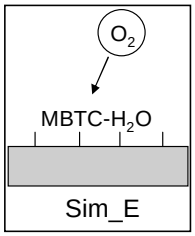
$C_4H_9SnCl_3(s) + 1/2O_2 + H_2O \xrightarrow{k_s}$

$SnO_2(B) + 3HCl + 2C_2H_4 + OS(s)$

k_s=1.5E16 Exp(-12000 / RT)

$GR \propto k_s [MBTC][O_2]^{1.12}[H_2O]^{0.5}$





$C_4H_9SnCl_3 + H_2O \xrightarrow{k_g} [C_4H_9SnCl_3:H_2O]$

k_g=4E14 Exp(-10000 / RT)

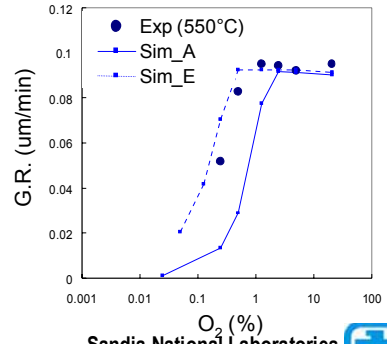
$[C_4H_9SnCl_3:H_2O]$ + _(s) $\xrightarrow{k_s}$ $[C_4H_9SnCl_3:H_2O](s)$

$[C_4H_9SnCl_3:H_2O](s) + 1/2O_2$ →

$SnO_2(B) + 3HCl + 2C_2H_4 + OS(s)$

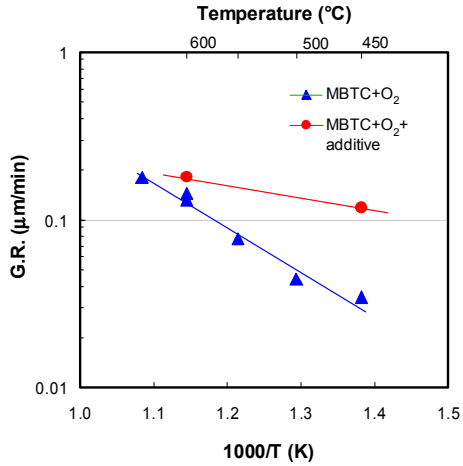
k_s=1E10 Exp(-13700 / RT)

$GR \propto k_s [MBTC][O_2]^{0.76}$



Preliminary experiments suggest that certain additives can accelerate tin oxide growth rates

- **Experiments in SNL reactor shows significant increases in growth rate**
- **MBTC conversion efficiency also increases**
- **Confirms predictions of kinetic model of MBTC oxidation**
- **SNL and PPG extended their CRADA to 12/04 to explore this further**
- **We are requesting additional funds from OIT to pursue this aspect of the project**



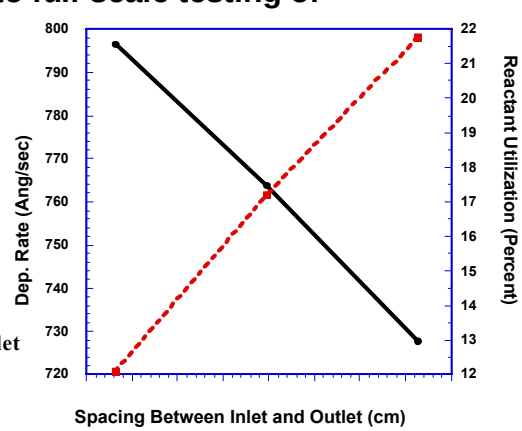
CFD Modeling of Pilot-Scale Coater Deposition Experiments (Task 4)

Objective:

Develop validated process model effective for realistic coater designs

Task 4 FY03-04 accomplishments

- **Transferred two deposition models to PPG for their use**
  - **Surface-only mechanism for MBTC + O_2 + H_2O**
  - **Surface + Gas-phase MBTC + O_2 + H_2O**
- **Advised PPG on selection of CFD modeling package**
- **Simulated PPG pilot-scale reactor to full-scale testing of optimization strategies**
  - **Inlet/Outlet spacing**
  - **Water concentration**



Effect of Spacing between Coater Inlet and Outlet On Deposition Rate and Utilization

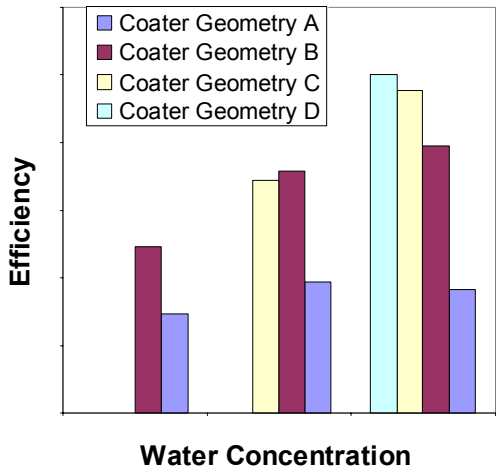
Optimization Strategies
(Task 6)

Objectives:

- **Identify modified/new APCVD coater designs that double the efficiency of reactant utilization**
- **Develop strategies to reduce coating defects, particularly non-uniform coating thickness**

Full Scale Plant Trials Conducted to Explore Maximum Efficiency of Precursor Utilization

- **Full scale plant trials were completed in October 2003 varying:**
  - **coater geometry**
  - **water concentration**
- **Under the most extreme conditions tested, the efficiency was > 3X the efficiency under standard conditions.**
- **Although the most extreme conditions are not feasible for PPG manufacturing, practical manufacturing conditions are projected to have an efficiency range of 1.5X to 2.5X the efficiency at standard conditions. Actual efficiencies will be determined after product qualification.**
- **The projected results are expected to meet the primary objective of the project (2X increase in efficiency of precursor usage)**



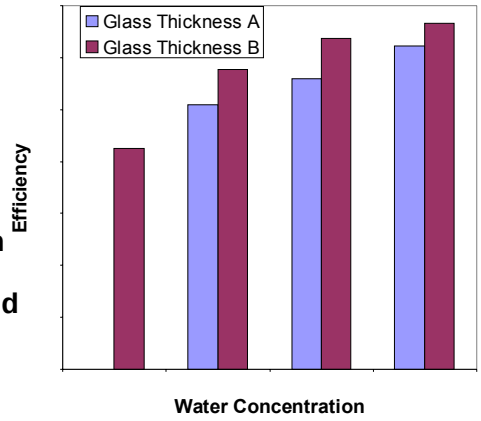
PPG Product Qualification

- Before new coating conditions are implemented during production, experiments simulating production must be conducted and samples must be analyzed and tested to assure coating quality.
- Coating qualities analyzed and tested
  - Sheet Resistance
  - Haze
  - Color Uniformity
  - Durability
- Product Qualification may limit the achievable coating efficiency

Full Scale Plant Trials Conducted to Verify Coating Quality for Implementation

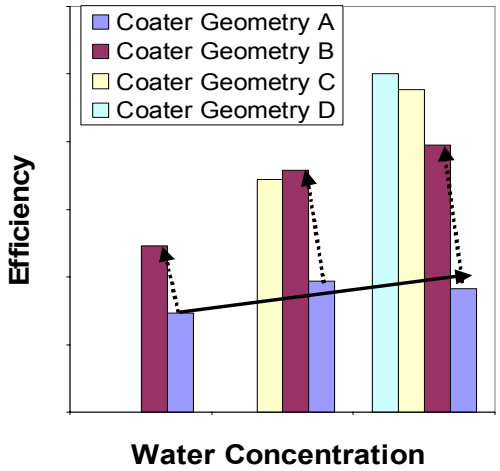
- Full scale plant trials were conducted in April 2004 on one glass thickness using increased water concentration and full coating stack
- Increasing water concentration increased efficiency by 20% over standard conditions
- Analysis and testing of samples is underway, but not yet complete

- Full scale plant trials were conducted in June 2004 on a second glass thickness using increased water concentration and full coating stack
- Increasing water concentration increased efficiency by 50% over standard conditions
- Analysis and testing of samples is just starting.



Future Trials and Implementation

- Additional trials are on-going to verify the quality of coating using increased water concentration on all glass thicknesses.
- Trials will vary:
  - coater geometry with and without increased water
  - all glass thicknesses to verify coating quality with these conditions
- Implementation of new coating conditions will occur on each glass thickness as soon as coating quality has been ascertained to be good.



Significance to glass industry

- Optimization strategies are being tested on a full-scale manufacturing line to determine achievable efficiencies based on product qualification
- MBTC is a commonly used precursor in flat- and container-glass production
  - Film growth models developed here can easily be extended to other manufacturing processes using this precursor
  - Models are sufficiently robust to cover a wide range of process conditions
- Flow modeling demonstrates that useful insight can be obtained without the need for full-scale CFD.
  - Process engineers using cost-effective, lower-dimensional modeling software can identify strategies to improve efficiency; full-scale CFD model is probably not necessary in most cases
- The use of additives to accelerate conversion and growth rates can be extended across the industry
  - Concept has commercialization potential
  - CRADA extended to explore this

Appendix A

Sample Evaluation Forms and Scoring Standards

PROJECT:

Project Title Here

(Principal Investigator, Organization)

Reviewer:_____

I. Technical Merit **Rating** **1** **2** **3** **4** **5**

A. Technical Need (Does the project address an important technical need of the glass industry?)

Comments: _____

_____

B. Contribution of Knowledge (Will this project contribute new information or technology to the knowledge base of the glass industry?)

Comments: _____

_____

II. Technical Progress **Rating** **1** **2** **3** **4** **5**

A. Adequacy of Progress (Is the research being performed competently and proceeding at a reasonable pace? Are project objectives being addressed as planned?)

Comments: _____

_____

B. Expectations for Successful Completion (How appropriate is the planned technical approach and schedule for completion? What is the likelihood that the project will meet its technical objectives as scheduled?)

Comments: _____

_____

III. Commercial Readiness **Rating** **1** **2** **3** **4** **5**

(Note: This section for ending projects only)

A. Ready for Commercial Use (Is the technology/information ready for commercial use, or is further development needed?)

Comments: _____

_____

B. End-User Commitment (Are potential end-users committed to implementing the technology/information?)

Comments: _____

_____

Please turn to reverse side ---------->

IV. Market Potential **Rating** **1** **2** **3** **4** **5**

A. Broadness of Application (If successful, will results be applied in the entire industry, or narrowly applied to a particular segment? Will results be applicable to other industries?)

Comments: _____

_____

B. Commercialization Plan (Has the project team developed a reasonable commercialization plan?

Comments: _____

_____

C. Adoption Potential (If successful, will the technology/information achieve widespread adoption? Will adoption be achieved in the near-term, or not until the long-term?)

Comments: _____

_____

V. Programmatic Merit **Rating** **1** **2** **3** **4** **5**

A. Energy, Economic, and Environmental Benefits (If successful, will the research results provide tangible energy, economic, and environmental benefits to the glass industry?)

Comments: _____

_____

B. Project Resources (Does this project have adequate resources (funding, equipment, expertise, etc.) to accomplish its objectives?)

Comments: _____

_____

C. Project Value (In your opinion, is the cost of the project in line with the anticipated value of the results?)

Comments: _____

_____

VI. Other Comments

Please comment on the project's strengths and weaknesses:

Please comment on whether there are potential barriers to successful completion and, if so, has the project team addressed these barriers:

Please provide additional comments or suggested changes that could be made to improve this project:

GLASS PROJECT EVALUATION SCORING STANDARDS

Reviewers should use the following numerical scale in rating the projects:

Technical Merit

5 **Outstanding**: The project's technical merits are exceptional and directly relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project represents a critical, significant advancement over current technical capabilities.

4 **Very Good**: The project's technical merits are very good and directly relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project will substantially supplement existing knowledge and/or offer an entirely new technology to the U.S. glass industry.

3 **Satisfactory**: The project's technical merits are sound and relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project will supplement existing knowledge and/or offer a modification on existing technology.

2 **Marginal**: The project's technical merits are marginal and somewhat relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project will produce a new application of existing technology but will not supplement existing knowledge or offer new technology.

1 **Unsatisfactory**: The project has few technical merits and is a repetition of existing work.

Technical Progress

5 **Outstanding**: The research is being performed expertly and is proceeding at an impressive rate. The overall project schedule is appropriate. Project objectives are being met at or ahead of schedule, and the project team is almost assured of meeting the remainder of its technical objectives on or ahead of schedule. The project team includes direct involvement in planning, guidance, and conducting the research from multiple industrial partners.

4 **Very Good**: The research is being performed expertly and is proceeding at a reasonable rate. The overall project schedule is appropriate. Project objectives are being met on schedule, and the project team is highly likely to meet the remainder of its technical objectives on schedule. The project team includes direct involvement in planning, guidance, and conducting the research from at least one industrial partner.

3 **Satisfactory**: The research is being performed competently and is proceeding at a reasonable rate. The overall project schedule is appropriate. Project objectives are being met on or slightly (less than 60 days) behind schedule, and the project team is likely to meet most of its remaining technical objectives on schedule. The project team includes direct involvement in planning and guidance, but no direct R&D involvement, from at least one industrial partner.

2 **Marginal**: The research is being performed competently in most aspects, but there are areas where improvement is needed. The overall project schedule is unnecessarily lengthy. Progress is slow; the project team is behind schedule in meeting most objectives. The project team is likely to meet some of its remaining technical objectives but not meet others. The project team has had moderate communication with industry on planning and guidance, but limited direct industry involvement.

1 **Unsatisfactory**: The research is not being performed competently, and significant improvement is needed. The overall project schedule is unnecessarily lengthy. Progress is slow; the project team is far behind schedule in meeting its objectives, and the team is unlikely to meet its remaining technical objectives. The team has demonstrated little interaction or involvement with industry.

Commercial Readiness (for Ending Projects Only)

5 **Outstanding**: The results from this project are more than sufficient to make an informed decision on commercial application. The project team included direct involvement in planning, guidance, and conducting the research from multiple industrial partners that intend to implement the technology as soon as possible.

4 **Very Good**: The results from this project are sufficient to make an informed decision on commercial application. The project team included direct involvement in planning, guidance, and conducting the research from at least one industrial partner that intends to implement the technology as soon as possible.

Commercial Readiness (continued)

3 **Satisfactory**: The results from this project are sufficient to make an informed decision on commercial application. The project team included direct involvement in planning and guidance from at least one industrial partner that is evaluating implementation of the technology.

2 **Marginal**: The results from this project are insufficient to make an informed decision on commercial application. The project team included direct involvement in planning and guidance from at least one industrial partner that may decide to implement the technology at a later date. It is likely additional development will be required before end-users will commit to using the technology.

1 **Unsatisfactory**: The results from this project are insufficient to make an informed decision on commercial application. The project team included direct involvement in planning and guidance from at least one industrial partner that may decide to implement the technology at a later date. It is highly likely additional development will be required before end-users will commit to using the technology.

Market Potential

5 **Outstanding**: The technology or knowledge being developed by this project is broadly applicable across multiple segments of the U.S. glass industry. The project team has developed a detailed, realistic written commercialization plan, and, if successful, the potential for application of the project results is highly likely.

4 **Very Good**: The technology or knowledge being developed by this project is broadly applicable across more than one segments of the U.S. glass industry. The project team has completely and accurately considered commercialization, and a cursory written plan is in place. If successfully concluded, continued development and application is highly likely.

3 **Satisfactory**: The technology or knowledge being developed by this project is broadly applicable across more than one segment of the U.S. glass industry. The project team has considered and recorded preliminary commercialization plans. If successfully concluded, continued development and application is likely.

2 **Marginal**: The technology or knowledge being developed by this project is applicable across a single segment of the U.S. glass industry. The project team has considered a commercialization plan on a cursory basis, but no written plan exists. If successfully concluded, continued development and application is unlikely.

1 **Unsatisfactory**: The technology or knowledge being developed by this project is applicable to only a single company in the glass industry. The project team has not considered a commercialization plan. If successfully concluded, continued development and application is highly unlikely.

Programmatic Merit

5 **Outstanding**: The project, if successfully developed and implemented, will offer significant energy savings, environmental benefits, and economic benefits in multiple segments of the U.S. glass industry. The project has outstanding technical, financial, and human resources assigned to it.

4 **Very Good**: The project, if successfully developed and implemented, will offer significant energy savings, environmental benefits, and economic benefits in more than one segment of the U.S. glass industry. The project has strong technical, financial, and human resources assigned to it.

3 **Satisfactory**: The project, if successfully developed and implemented, will offer significant energy savings, environmental benefits, and economic benefits in at least one segment of the U.S. glass industry. The project has appropriate technical, financial, and human resources assigned to it.

2 **Marginal**: The project, if successfully developed and implemented, will offer moderate energy savings, environmental benefits, and economic benefits at least one segment of the U.S. glass industry. The project has inadequate technical, financial, or human resources assigned to it.

1 **Unsatisfactory**: The project, if successfully developed and implemented, will offer minor energy savings, environmental benefits, and economic benefits to only participating firms. The project has inadequate technical, financial, and human resources assigned to it.

Appendix B

Other Presentations

GPLUS

Status of GPLUS Efforts - FY 2004

Peter Angelini
Oak Ridge National Laboratory

June 22, 2004

Research & Development Funded By:
DOE
EERE
Industrial Technologies Program
Glass Industry of the Future

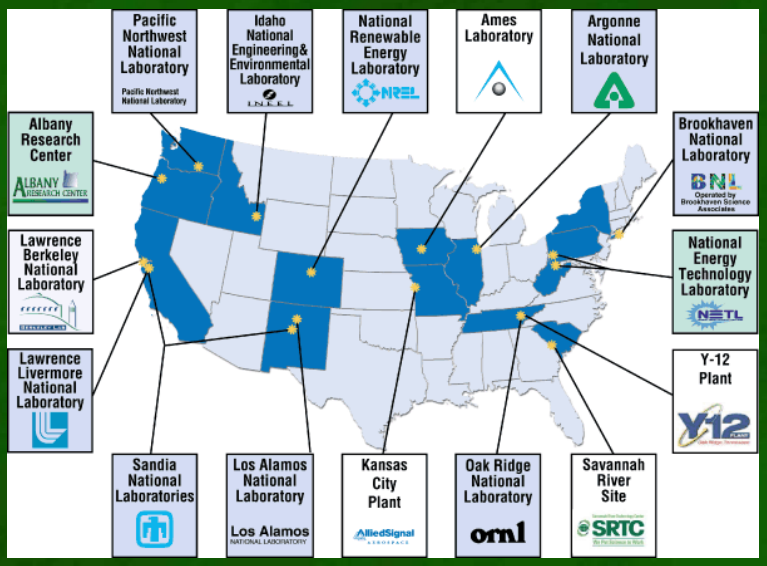
Topics

- Background
- FY 2004 Status
- Summary

Background

- **GPLUS - (Glass - Project Laboratory User Services) project**
  - Provides GMIC members access to unique capabilities of DOE National Laboratories
  - Industry/laboratory defined projects
    - $25K per project (one per member)
    - funding to participating national laboratory/ies
  - Projects - involve one or more core members, and associate members
  - Project descriptions submittal by GMIC core and associate members

DOE National Laboratory Participants



Projects Have Addressed Various Areas of Glass Processing

- Properties
  - High Temp
    - Viscosity, Thermal Conductivity
- Modeling
  - Thermodynamic
  - Furnace modeling
  - Fracture strength
- Sensing
  - Laser Breakdown Spectroscopy
    - Flue gas, batch
  - Thermocouple degr.
- Melting
  - Furnace components
    - Refractory Metal degr.
  - Batch and Cullett
  - Encapsulants
- Process/Glass Behavior
  - Surface
    - Blisters, optical defects
    - Coatings
  - Bulk
    - Combustion atm. on glass oxidation
    - Foaming

Completed Projects in FY 2004

Foaming of E-glass

- Participants: PPG; PNNL
- Issue: Foaming of E-glass is severe during processing especially in oxy-fuel fired furnaces.
- Objective: Study the effect of furnace atmosphere and water content on E-glass foaming and recommend solutions.
- *Benefits: Ability to control or reduce foaming would enable melter energy reductions as foam acts as thermal insulator in the glass melt.*

mm Wave Diagnostics for Glass Fiber Drawing

- Participants: Cleveland State Univ., Johns Manville; PNNL
- Issue: Bushing temperature and glass level are critical in fiber glass processing.
- Objective: Set up a mm wave system at Cleveland State and determine feasibility of using mm waves for measuring bushing temperature; glass liquid level; and glass viscosity.
- *Benefits: Temperature of Bushing is a key parameter affecting breakage which controls production yield and efficiency.*

Measurement of High Temperature Glass Melting Process/Property Data

- Participants: Owens Corning., ORNL
- Issue: High temperature thermophysical properties of glass are required for optimizing glass making process.
- Objective: Determine thermophysical properties of glass including thermal conductivity and thermal expansion.
- *Benefits: Data will enable optimal modeling and engineering analysis of glass making process*

Ongoing Projects in FY 2004

High Temperature Thermocouple Study

- Participants: Schott Glass Technologies; INEEL
- Issue: Precious metal thermocouples used throughout the glass making process can drift over time resulting in incorrect temperature measurements.
- Objective: Increase the understanding of how and why thermocouples degrade in use.
- Benefits: Improved understanding of the impact of furnace and other process conditions on the stability of thermocouples will lead to improved glass yields and efficient control of the furnace and other processes.

Improvement of Oxy Fuel Burner Design/Operations

- Participants: Owens Corning; SNL
- Issue: In order to maximize the benefits of oxy fuel technology improvements in burner designs, serviceability, performance, and flexibility are needed
- Objective: Determine key parameters leading to improved oxy fuel burner design and operations
- *Benefits: Increased acceptance and use of oxy fuel process can lead to improved energy, production efficiencies and environmental benefits.*

Strength Data and Design Method for Tempered Automotive Glazing which is Subject to Stress Corrosion Cracking

- Participants: Visteon; PNNL
- Issue: Stress concentrations near holes in glass can cause cracking.
- Objective: Develop a design procedure, including recommendations for limits on design stresses, for tempered automotive glazing subject to strength reductions caused by hole penetrations.
- *Benefits: Generalized data can lead to recommendations for increasing production efficiency and enable new glazing designs.*

TV Glass Surface Problems

- Participants: Techneglass; ORNL
- Issue: Various types of surface contamination can cause loss of tube/glass in later manufacturing steps (seals and inner surface issues).
- Objective: Improve understand of the composition of contaminants on glass surfaces and identify mechanisms that lead to the contamination.
- *Benefits: Reducing glass defects can result in increased yield and energy efficiency.*

Study of Sulfate Fining Chemistry in Oxidized and Reduced Soda-Lime- Silica Glasses

- Participants: Visteon; PNNL
- Issue: Sulfate fining in soda-lime-silica glasses can lead to relatively stable defects in glass
- Objective: Determine sulfate decomposition kinetics; Fe(II) content; and concentration/ distribution of silica phases
- *Benefits: Reducing glass defects increases yield and overall energy efficiency; minimizes SO_2 emissions*

Laser Induced Laser Breakdown Spectroscopy (LIBS) as a Glass Melt Monitor

- Partners: Corning; SNL
- Issue: The harsh environment of molten glass makes it difficult to probe the chemistry of glass components as the melt progresses to completion.
- Objective: Determine the feasibility of focusing a LIBS plasma above the glass melt and collect emission from the elements that are in the glass phase directly above.
- Benefits: A method of monitoring the glass composition during the glass making process can result in improved efficiencies.

Application of Furnace Model to Longhorn Glass Corp. Oxy-Fuel Furnace for the Production of Amber Glass

- Participants: Metal Container Corp.; ANL
- Issue: Oxy fuel firing in glass furnaces can lead to refractory issues and energy inefficiencies.
- Objective: Investigate gaseous species and the transport of gases released during batch/melting both in the furnace and in the exhaust.
- *Benefits: Modeling may lead to indication of possible location of corrosion in furnace crowns; more efficient firing of the furnace; and decreased costs.*

Spectral Analysis and Imaging of Colored Glasses

- Participants: Society for Glass Science Practices, Judel Products; ORNL
- Issue: Spectral characteristics of various glasses as related to glass composition and processing conditions are not currently known.
- Objective: Determine the feasibility of non-contact spectral imaging as a method to evaluate the redox state and homogeneity of glass.
- *Benefits: Real-time non-contact analysis of spectral properties at temperature can result in efficient processing and improved yield.*

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