Proceedings of the

FY 2002 Glass Industry Project Review

Industrial Technologies
Glass Research Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

In association with the Glass Manufacturing Industry Council

September 9-10, 2002
Livermore, California

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FY 2002 Glass Industry Project Review

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Sandia National Laboratories
Livermore, California

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

Prepared by
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Columbia, Maryland

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***A**dvanced Process Control System for Glass Production*

***A**uto Glass Process Control*

***E**lectrostatic Batch Preheater System*

***H**igh-Heat Transfer Low-NOx Natural Gas Combustion*

***M**odeling of Glass Processes*

***E**nhanced Cutting and Finishing of Handglass Using a Carbon Dioxide Laser*

***G**lass Furnace Combustion and Melting Research Facility*

Appendices

A Sample Evaluation Forms

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***G**PLUS Update*

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***I**mprovement of Performance and Yield of Continuous Glass Fiber Drawing Technology*

***N**ext Generation Melting System Technical and Economic Evaluation Results*

C Attendees

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E EERE Program Posters

Agenda

FINAL AGENDA

DOE GLASS PROJECT REVIEW

September 9, 2002

6:30 - 9:00 pm	**WELCOMING RECEPTION at Mudds Restaurant**

September 10, 2002

Sandia National Laboratories
Livermore, California

Time	Activity	Speaker(s)
7:00 - 8:00 am	**REGISTRATION and CONTINENTAL BREAKFAST**	
8:00 - 8:20 am	Welcome and Introduction	Elliott Levine Department of Energy Michael Greenman Glass Manufacturing Industry Council
8:20 - 8:35 am	*GPLUS Update*	Peter Angelini Oak Ridge National Laboratory
8:35 - 9:10 am	*Diagnostics and Modeling of High-Temperature Corrosion of Superstructure Refractories in Oxy-Fuel Glass Furnaces* Questions and Answers	Mark Allendorf Sandia National Laboratories George Pecoraro PPG Industries
9:10 - 9:45 am	*Development and Validation of a Coupled Combustion Space/Glass Batch Furnace Simulation* Questions and Answers	Mike Petrick Argonne National Laboratory Shen-Lin Chang Argonne National Laboratory
9:45 - 10:00 am	**BREAK**	
10:00 - 10:35 am	*Measurement and Control of Glass Feedstocks* Questions and Answers	Robert De Saro Energy Research Company Arel Weisberg Energy Research Company
10:35 - 10:55 am	*Advanced Process Control for Glass Fabrication* Questions and Answers	Chester Shepard Pacific Northwest National Laboratory
10:55 - 11:15 am	*Auto Glass Process Control* Questions and Answers	Moe Khaleel Pacific Northwest National Laboratory
11:15 - 11:50 am	*Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulates and Crown Corrosion* Questions and Answers	Pete Walsh Sandia National Laboratories John Neufeld Gallo Glass
11:50 am - 12:55 pm	**LUNCH**	

September 10, 2002 (Continued)

12:50 - 1:10 pm	DOE Reorganization Update	Elliott Levine Department of Energy
1:10 - 1:30 pm	*Electrostatic Batch Preheater System* Questions and Answers	Neil Simpson BOC Gases
1:30 - 1:50 pm	*High-Heat Transfer Low-NOx Natural Gas Combustion* Questions and Answers	David Rue Gas Technology Institute
1:50 - 2:10 pm	*Modeling of Glass Processes* Questions and Answers	Tom Seward Center for Glass Research
2:10 - 2:30 pm	*Enhanced Cutting and Finishing of Handglass Using a Carbon Dioxide Laser* Questions and Answers	Steve Woodruff National Energy Technology Laboratory
2:30 - 3:05 pm	*In-House Recovery and Recycling of Glass from Glass-Manufacturing Waste* Questions and Answers	Bassam Jody Argonne National Laboratory
3:05 - 3:25 pm	*Glass Furnace Combustion and Melting Research Facility* Questions and Answers	Pete Walsh Sandia National Laboratories John Connors PPG Industries
3:25 - 3:35 pm	**BREAK**	
3:35 - 3:45 pm	OIT Clearinghouse	Gil McCoy Washington State University
3:45 - 4:00 pm	*Improvement of Performance and Yield of Continuous Glass Fiber Drawing Technology*	Phil Sanger Advanced Manufacturing Center Simon Rekhson Cleveland State University
4:00 - 4:35 pm	*Process Optimization Strategies, Models and Chemical Databases for On-Line Coating of Float Glass* Questions and Answers	Mark Allendorf Sandia National Laboratories Jill Aaron PPG Industries
4:35 - 4:50 pm	*Optimization of Oxy-Fuel Furnaces*	John Plodinec Mississippi State University (DIAL) Cheryl Richards PPG Industries
4:50 - 5:05 pm	*Next Generation Melting System Technical and Economic Evaluation Results*	Phil Ross Glass Industry Consulting
5:05 - 5:10 pm	Wrap-Up: Comments and Recommendations	Elliott Levine Department of Energy
6:45 pm	**RECEPTION and DINNER at Black Hawk Museum**	

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List of Reviewers

Reviewers
Glass Manufacturing Industry Council

CORE MEMBERS

CertainTeed Corporation
Terry Berg
Robert Butler

Corning Incorporated
Fred Quan

Johns Manville
Gerald DeMott

Owens Corning
Manoj Choudhary
Tom Huff

PPG Industries
Jill Aaron
Cheryl Richards
John Sopko

Saint-Gobain Containers
Marvin Gridley
Erik Helin

Society for Glass Science and Practices
Tom Fenton (Fenton Art Glass Company)

Schott Glass Technologies
Carsten Weinhold

Techneglas
Jim Williams

Visteon
Ed Boulos

ASSOCIATE MEMBERS

Advanced Manufacturing Center
Philip Sanger

BOC Gases
Neil Simpson

Center for Glass Research
Thomas Seward

Diagnostic Instrumentation and Analysis Laboratory
John Plodinec

Eclipse/Combustion Tec
Dan Wishnick

Gas Technology Institute
David Rue

Praxair
Frank Dumoulin

Siemens Energy and Automation
Robert Newell

U.S. Borax
Bob Smith

3

Ongoing Project Evaluation Results and Presentations

Development of Models and On-Line Diagnostic Monitors of the High-Temperature Corrosion of Refractories in Oxy/Fuel Glass Furnaces

Mark Allendorf
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George Pecoraro
Principal Investigator
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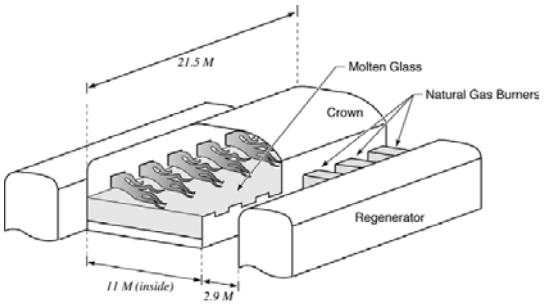
A project conducted with support from the
U.S. DOE/Office of Industrial Technologies
and
American Air Liquide, BOC Gases, PPG Industries, Inc., Gallo Glass, RHI Refractories, Monofrax Inc., Pennsylvania State University, and University of Missouri-Rolla

The need to understand corrosion processes in oxy/fuel furnaces has several major drivers

- **Melting furnaces represent major capital investments for glass manufacturers**
  - **Example: $10 M to rebuild a float-glass furnace**
- **Highly competitive industry, so reducing manufacturing costs and increasing productivity are important objectives**
- **Federal air-quality regulations are tightening, esp. with regard to NOx**
- **Some refractories used contain hazardous materials (e.g., chromium)**



This Project Has Three Major Objectives

- Identify factors controlling corrosion of refractories
- Develop models to predict corrosion rates based on these factors
- Develop *in-situ* optical techniques to monitor gas-phase alkali concentrations:
  - — Process optimization
  - — On-line monitoring

As of this date (year 4 of 5 in the project), all three of these objectives have been met or addressed

Sandia, Glass Manufacturers, Gas Suppliers, Refractory Manufacturers And Universities Are Working Together

- **Current consortium members (includes both direct and in-kind cost sharing):**
- **PPG Industries, Inc. (Project PI; furnace gas analysis; direct funding support)**
  - **American Air Liquide (CFD modeling; direct funding support)**
  - **BOC Gases (direct funding support)**
  - **Gallo Glass Co. (corrosion data)**
  - **NARCO/Harbison-Walker Refractories (refractory samples; post-mortem analysis)**
  - **Monofrax Corp. (refractory samples; corrosion tests; post-mortem analysis)**
  - **University of Missouri, Rolla Dept. of Ceramics (corrosion tests; post-mortem analysis; pilot-scale diagnostic tests)**

  - **Thermodynamic data were obtained through a subcontract:**
  - **Prof. Karl Spear, Pennsylvania State University Dept. of Materials Science and Engineering**

Project Tasks

- Task 1: Experimental characterization of the corrosion process
  - Simulate corrosion process in controlled laboratory environment
  - Measure furnace concentrations using conventional methods
  - Characterize samples of corroded furnace brick
- Task 2: Corrosion modeling
  - Compile thermodynamic database for predicting corrosion chemistry
  - Construct models describing corrosion phenomena
  - Evaluate competition between transport and chemistry
  - Verify model predictions
- Task 3: On-line monitors for gas-phase alkali detection
  - Laboratory development/evaluation
  - *In-situ* furnace testing
  - Commercialization

Major Accomplishments Have Been Achieved In FY02

- Completed database of thermodynamic properties relevant to silica and alumina corrosion now available on the web
- Factors contributing to and controlling refractory corrosion have been thoroughly analyzed
  - Results submitted to *Glass Science and Technology* for publication
  - Subroutines delivered to *American Air Liquide* for incorporation into *Athena* furnace code
- Two field tests completed:
  - University of MO, Rolla, pilot-scale melter
  - PPG, Fresno oxy/fuel float-glass facility (in progress)

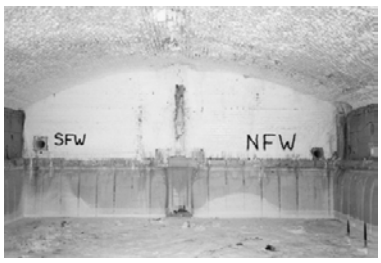
LIFF Sensor installed at UMo, Rolla

Task 1. Experimental Characterization. *This Task Is Complete*

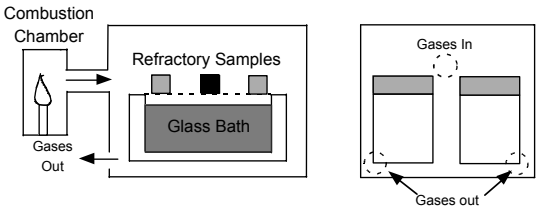
- **Industry partners have made major in-kind contributions:**
  - **Praxair: oxy-fuel burners**
  - **Monofrax, HW, UMR: sample characterization**
  - **PPG: measurements of furnace gas composition; batch/cullet for tests**
  - **BOC: oxygen system for UMR tests**
  - **Gallo Glass Co.: corrosion data and furnace operating information**
- **Corrosion tests conducted to provide data for model development**
  - **Monofrax:**
    - **2 Air/fuel tests complete; 1 oxy/fuel scheduled**
    - **Samples: NARCO/HW Vega, Vega O2, Visil, Crownseal I**
    - **Postmortem analysis by Monofrax and NARCO/HW**
    - **Air-sampling equipment purchased to enable gas analysis**
    - **Additional tests were planned, but could not be performed due to personnel reductions at Monofrax**
  - **University of Missouri/Rolla:**
    - **2 oxy/fuel tests complete**
    - **Samples: Vega 1, Vega 2, Gensil**
    - **Post-mortem analysis complete**

Corrosion Data From Laboratory Tests, Furnace Post-Mortem Analysis, And The Literature Are Being Used

- **Monofrax tests (oxy/fuel and air/fuel)**
- **Gallo Tank #1 post mortem**
  - **operated oxy/fuel for 7 years**
  - **Furnace rebuild in 1998**
  - **Gallo provided:**
    - **Furnace operating conditions**
    - **Furnace dimensions**
    - **Photographs and video**
    - **Harbison-Walker post-mortem analysis of Gen-Sil brick**
    - **Corrosion rates**
- **Other data**
  - **PPG (air-fired)**
  - **TNO experiments air (1997) and oxy (1998)**
  - **Corning experiments**
  - **Paskocimas et al. (1998)**



Interior of Gallo Tank 1



Schematic of Monofrax test facility

Task 2. Corrosion Modeling. Data And Results Are Now Being Widely Distributed To Assist Glass Manufacturers

- Equilibrium predictions of corrosion chemistry. *Thermodynamic data now on a web site*
- Detailed analysis of possible rate-limiting corrosion mechanisms: complete. *Manuscript submitted to Glass Science and Technology*

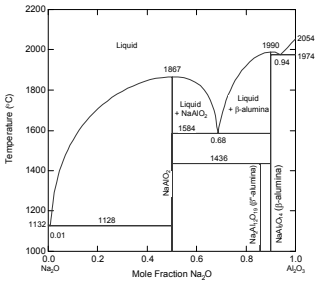
To be published:
  - Gas-phase mass-transport limited corrosion at refractory hot face
  - NaOH(gas) diffusion through pores ("In-depth" corrosion)
  - Na_2O diffusion through liquid corrosion-product layer
  - Chemical-kinetic limited reaction at SiO_2/liquid interface
  - Analysis of capillary suction mechanism completed this year

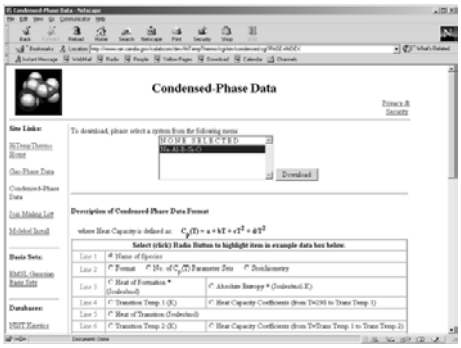
- Subroutines for modeling corrosion:
  - *Prototypes given to* American Air Liquide *for incorporation in* Athena *furnace code*
  - Model will provide crown corrosion rates via 3D CFD modeling of the furnace atmosphere

Thermodynamic for several refractory systems are now available on the web

- SiO_2/NaOH
- SiO_2/KOH
- Al_2O_3/NaOH
- Al_2O_3/KOH
- Data can be downloaded in a form compatible with the FactSage program
- Additional data for systems containing Fe-O and Ca-O species are also available
  - Data generated by ORNL (Dr. Ted Besmann)
  - Funded by OIT Industrial Materials for the Future Program (Charles Sorrell, program manager)

www.ca.sandia.gov/HiTempThermo/index.html



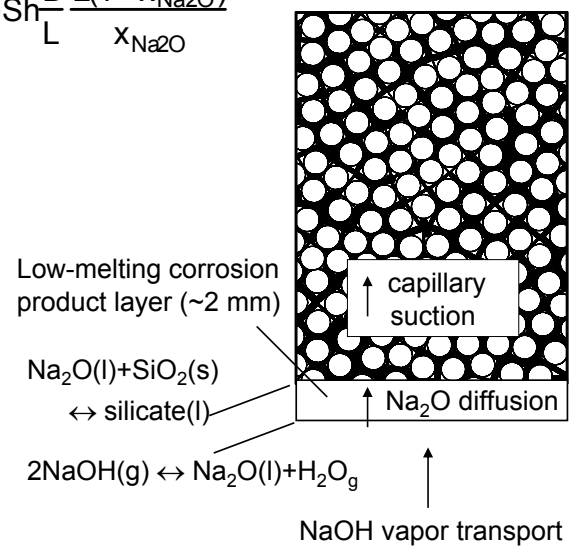


At Least Five Separate Processes May Be Occurring During Corrosion Of Porous Silica Refractories

$$\frac{dl}{dt} \approx \frac{\rho_{gas}}{\rho_{liq}}\left(X_{NaOH,\infty} - X_{NaOH,0}\right) Sh \frac{D}{L} \frac{2(1-x_{Na2O})}{x_{Na2O}}$$

Possible rate-limiting mechanisms:

- ***Gas Phase Transport:*** **NaOH(g) is transported from melt surface to crown surface and reacts there**
- ***Liquid-Phase Diffusion:*** **Na_2O diffuses through melt layer and reacts with silica to form liquid glass**
- ***NaOH transport through pores:*** **reaction occurs in-depth via gas-phase diffusion**
- ***Kinetic limitations:*** **recession is limited by chemical reaction**
- ***Capillary Suction:*** **removes liquid-phase reactants from the crown surface by withdrawl to the interior**

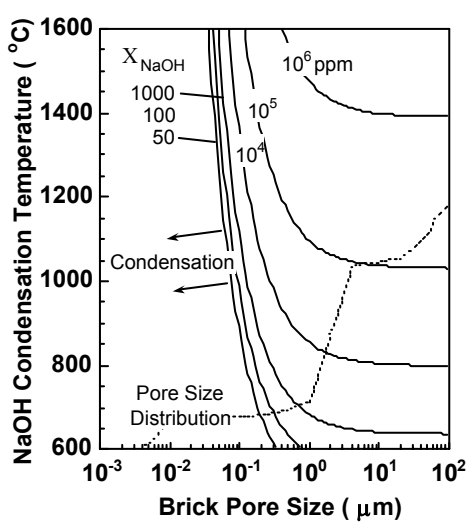


Internal Corrosion Rates May Be Enhanced By Condensation Of NaOH Gas In Small Pores

- **In small pores, overlapping attractive fields of pore walls --**
  - **promote condensation**
  - **reduce condensation pressure**
  - **increase condensation temp**
- **Kelvin equation describes reduction in condensation pressure**

$$\frac{P_{cond,pore}}{P_{cond,nom}} \approx \exp\left[-\frac{\sigma}{d_{pore}\rho_{liq}RT}\right]$$

- **NaOH condensation is expected only in pores smaller than 0.1 micron for temperatures from 800 to 1600 °C.**
  - **about 10% of total pore volume**
  - **rate is limited by inward gas-phase diffusion**



Work Is In Progress To Model In-depth Corrosion In Cases Where Surface Corrosion Is Excluded

- NaOH vapor diffuses into cooler region of brick
- NaOH reaction rate, R, is non-zero only when $P_{NaOH} > P_{NaOH,eq}(T)$
- SiO_2 reaction consumes silica skeleton
- Liquid product flows to dryer regions by capillary suction
- This model allows ratholing to be predicted:
  - Gives depth, Temp at which corrosion starts
  - Pore condensation model can predict how tight joints must be

$$\frac{d}{dt}\left(\rho_g \phi (1-S) X_g\right) + \frac{d}{dz}\left(\rho_g u_g X_g\right) = \frac{d}{dz}\left(r_g D \frac{dX_g}{dz}\right) - R$$

$$R = s_v \Gamma \left(P_{NaOH} - P_{NaOH,eq}\right)$$

$$\frac{d}{dt}\left(\rho_{SiO_2}(1-\phi)\right) = -R\frac{1-x_{l,eq}}{2x_{l,eq}}$$

$$\frac{d}{dt}\left(\rho_l \phi S x_l\right) + \frac{d}{dz}\left(\rho_l u_l x_l\right) = \frac{d}{dz}\left(\rho_l D \frac{dx_l}{dz}\right) + \frac{R}{2}$$

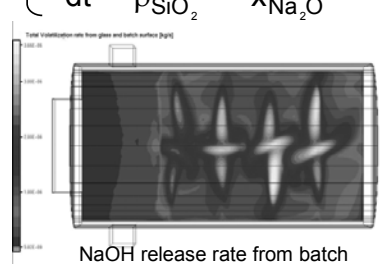
$$u_l = -\frac{\kappa}{\mu}\frac{dp_l}{dz} = -\frac{\kappa}{\mu}\frac{dp_{cap}}{dS}\frac{dS}{dz}$$

Air Liquide *Athena* CFD Model Will Compute Crown Recession Rates Using Sandia Surface Corrosion Model

- $P_{NaOH}(T) < P(T)_{NaOH,\ equil}$ at crown surface: <u>No corrosion</u>
  - surface flux of NaOH, *F*, and local recession rate, *dL/dt*, set to zero
- $P_{NaOH}(T) > P(T)_{NaOH,\ equil}$ at crown surface: <u>Corrosion</u>
  - Athena determines local NaOH flux to match the $P(T)_{NaOH,equil}$
  - Recession rate computed from this flux
- Surface corrosion model now incorporated into *Athena* and trial simulation is complete
- Future subroutines will include new in-depth corrosion model

$$\begin{cases} P_{NaOH} < P_{NaOH,eq}(T_{crown}) \\ F = 0 \quad \text{and} \quad \dfrac{dL}{dt} = 0 \end{cases}$$

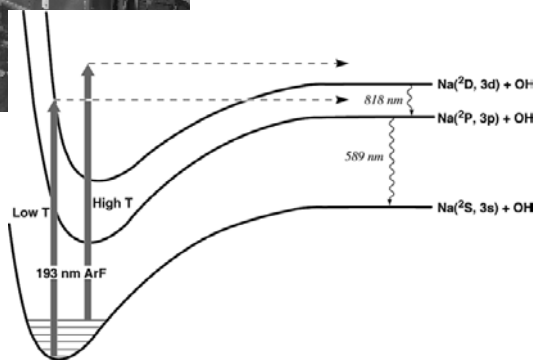
$$\begin{cases} P_{NaOH} = P_{NaOH,eq}(T_{crown}) \\ \dfrac{dL}{dt} = \dfrac{F}{\rho_{SiO_2}} \dfrac{2(1-x_{Na_2O})}{x_{Na_2O}} \end{cases}$$



NaOH release rate from batch predicted by *Athena*

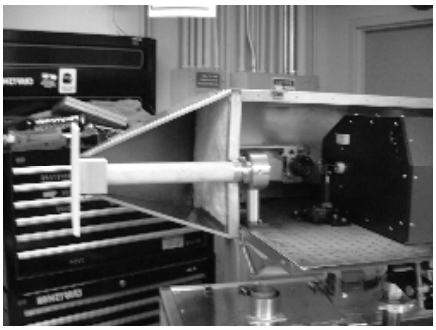
Task3: LIFF Diagnostic Tool Demonstrated Successfully at Univ. MO, Rolla Glass Melting Facility

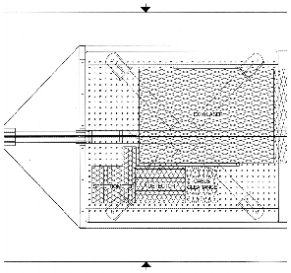
- Models show that predicted corrosion rates are very sensitive to P_{NaOH}
  - Very few experimental measurements are available
- Laser-induced fragmentation fluorescence (LIFF) tool:
  - directly measures NaOH and KOH concentrations
  - provides good spatial resolution
  - excellent time resolution
- December 2001: Sandia and UMR collaborate to test the portable LIFF sensor at the UMR test furnace
- Sept. 2002: second field test at PPG/Fresno underway

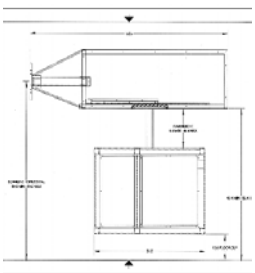


Data Collected At UMR Show That The Integrated Field Unit Works Well

- Portable prototype based on "benchtop" design
- Air- cooling system was adequate but, there is need for improvement
- Optics and delay timing must be upgraded to eliminate spurious signals
- Improve triggering electronics to eliminate temperature-dependent gate drift
- Signal calibration procedure must be systematized







Field Measurements Occurred Over A Period Of 5 Days

Unpacking & Assembly

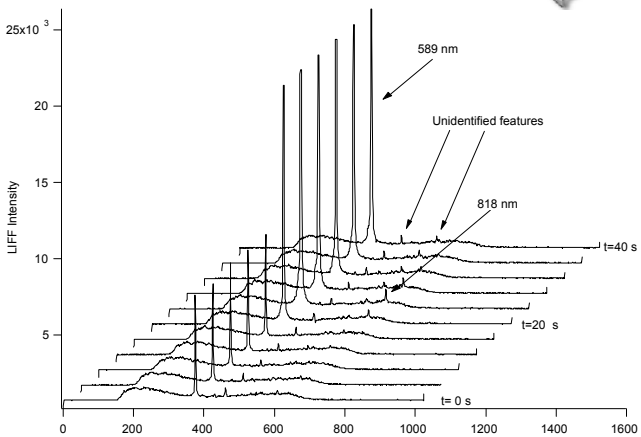
Oxy/Fuel Burner

Alignment & Calibration

Operation. Laser Beam Oriented Perpendicular To Burner Axis

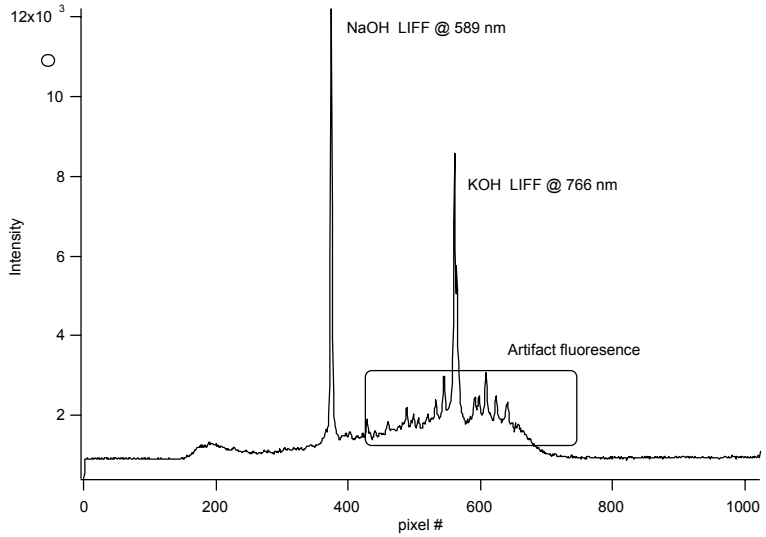
NaOH Can Be Readily Detected In Real Time With Excellent Signal-to-noise

- Na_2CO_3 was fed into the furnace in ~1 kg batches every 15 minutes
- The LIFF spectrum shows both the 589 nm and 818 nm NaOH features
- The 818 nm feature disappears quickly (due to CO_2 release?)
- Two additional lines in the furnace spectrum are not seen in the laboratory



Time development of NaOH LIFF spectrum during batch loading (at t=10 s) of Na_2CO_3. Note the background NaOH followed by a surge in the concentration immediately following the batch addition.

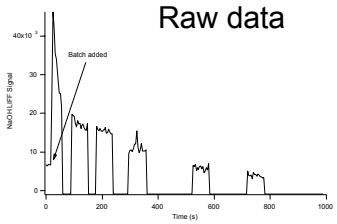
KOH Can Also Be Readily Detected By LIFF In The Furnace Atmosphere

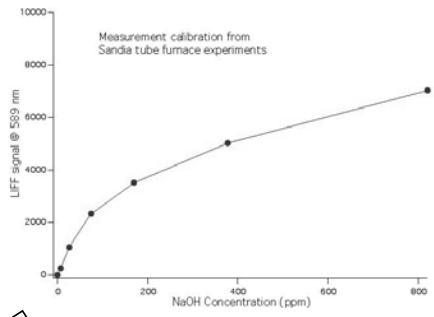


Batches containing K_2CO_3 show a strong KOH signal

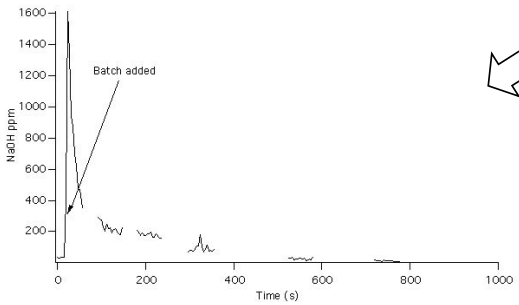
Calibration Indicates That There Is A Large Surge In NaOH Concentration During Batching

Raw data



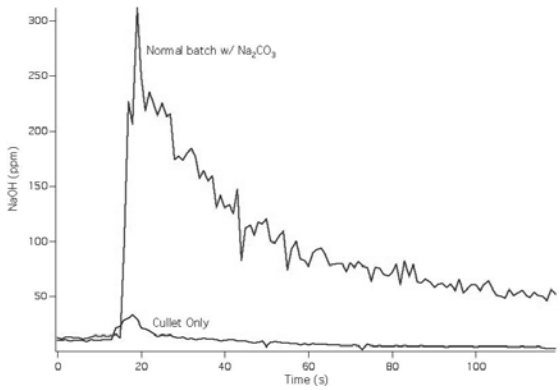


Calibration



LIFF Spectra Taken With And Without Na_2CO_3 In The Batch Confirm That Signals Are Not Artifacts Of Batching

- Signal w/ Na_2CO_3 is > 10X without Na_2CO_3
- Small cullet-only signal may be due to beam optical disturbance during batch operations



FY03 Activities

- Task 1
  - Complete
- Task 2
  - Corrosion modeling software:
    - Complete development of corrosion submodel software for use in CFD furnace models
    - Tech transfer: Prepare version for distribution
    - Recalibrate *Athena* model with experimental NaOH concentrations
    - Use in-depth corrosion model to derive insight into ratholing process
- Task 3
  - Complete two additional field tests in representative full-scale glass facilities
  - Tech transfer;=: Complete definition/description of instrument capabilities for possible future application

Acknowledgements

- Sandia National Laboratories
  - Dr. Robert Nilson (Transport Modeling)
  - Dr. Steven Rice (Laser Diagnostics)
  - Dr. Peter Walsh (Technical Discussions)
  - Dr. Nancy Yang (Electron Microscopy)
- NARCO/Harbison-Walker Refractories
  - Ed Wolfe (Refractory Post Mortem Analysis)
- Monofrax Inc.
  - Dr. Amul Gupta (Corrosion Testing)
- Gallo Glass Inc.: John Neufeld (Furnace Data)
- Pennsylvania State University: Prof. Karl Spear (Thermodynamic Calculations)
- American Air Liquide (CFD Calculations)
  - Dr. Ovidiu Marin
  - Dr. Ben Bugeat

DEVELOPMENT AND VALIDATION OF AN ADVANCED MULTIPHASE GLASS FURNACE MODEL

PRESENTERS: Michael Petrick, Shen-Lin Chang – ANL

Program Participants: Prof. Bob Cook, Mississippi State Univ.
Prof. Ray Viskanta, Purdue University
Ed Olson, Libbey, Inc.
William Anderson, Osram-Sylvania
Christopher Jian, Owens-Corning
John Chumley, Techneglas
Ed Boulos, Visteon
Brian Golchert, ANL
Prof. Chenn Zhou, Purdue-Calumet

PRESENTATION OUTLINE

- **Program Overview**
  - **Goals, technical approach, program description**
  - **Program Status**
    - **Shift in program emphasis resulting from IP's guidance**
- **Technical Progress/Accomplishments**
  - **New version of Glass Furnace Model (GFM 2.0) completed/issued**
    - **Improvements/refinements made in code and pre/post processors**
  - **Spectral radiation model embedded in combustion space and glass melt models**
  - **Incorporated reduced chemistry/kinetic models (batch & glass) into glass melt model**
    - **Derived from soda-lime-silicate glass data in literature**
  - **Parametric/sensitivity studies underway**
  - **IP's, using a beta test version of GPM code, are creating simulations of their furnaces with assistance from ANL**
    - **Defacto user center established**
- **Technology Transfer**
  Original Strategy Under Review
- **Expected Progress in FY 2003**

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
- 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 to be completed at end of CY 03
- Deliverable: User Friendly, Validated, Glass Furnace Model for Use by Engineers
  - A step change in modeling capability
  - Supported by a user service center

Technical Approach for Achieving Program Goals

- ANL's Multiphase Reacting Flow CFD Codes (ICOMFLO, ICRKFLO) Used to Develop a Coupled Glass Furnace Model (GFM)
  - Incorporate advanced phenomenological models for spectral radiation heat transfer, batch melting, foam layer formation, etc.
- Construct Simulations of Selected Furnaces
- Develop/Install Diagnostics in Selected 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

Part I Program Objectives

COMPLETED

- Develop/Validate Combustion Space Model
  - Incorporate rigorous spectral radiation model
  - Radiation to and from crown to glass melt
- Develop Model of Glass Melt with ANL's Multiphase CFD Code
  - Develop/incorporate multiphase batch model
- Couple Combustion Space and Glass Melt Models Through Radiation Model into an Overall Furnace Model
- Develop Diagnostics and Acquire Furnace Performance Data for Furnace Model Validation
- Conduct Initial Validation Studies

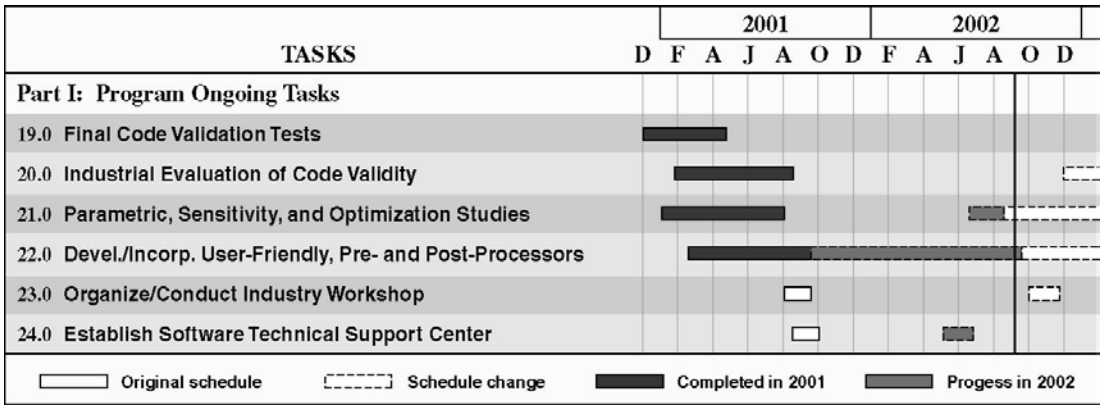
DEFERRED

- Transfer of Furnace Model to Industry Via Workshop and Establish a User Technical Support Center
  - Deferred to later date with integration of Part I and Part II Programs

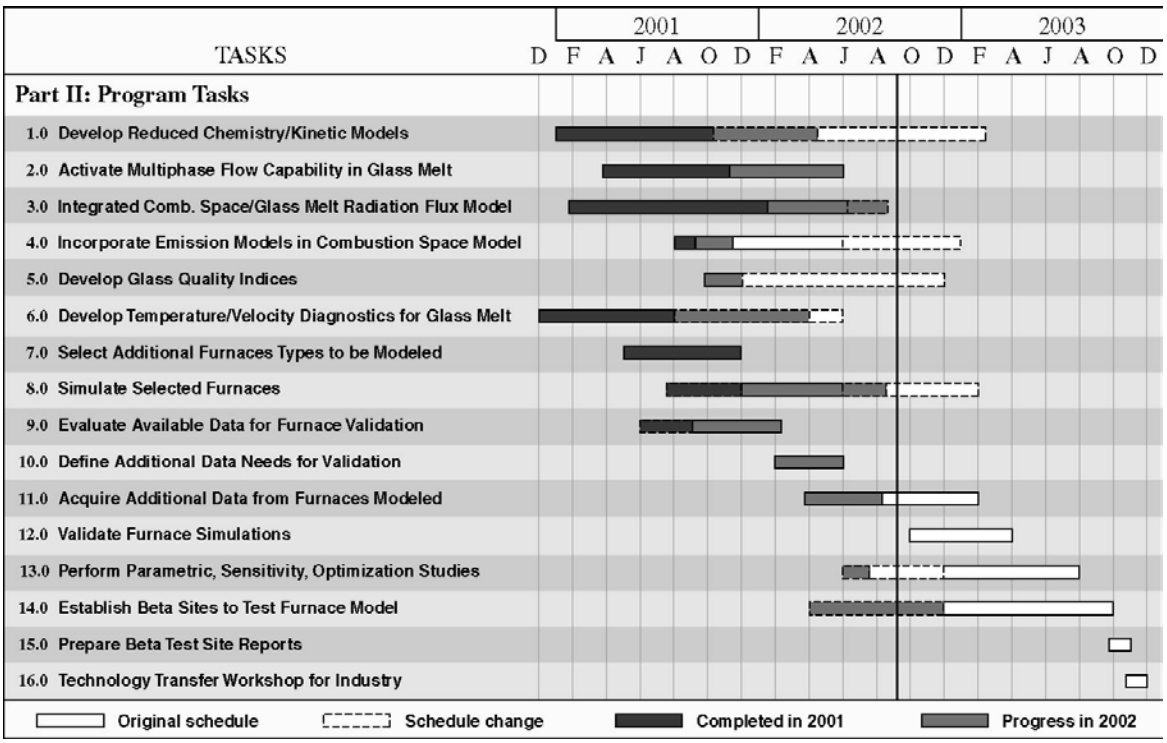
Part II Program Objectives

- Incorporate Glass Chemistry models into Glass Melt
  - Compute/track key solid, gaseous, liquid species
- Activate Gaseous Phase Transport in Glass Melt Model
  - Source terms derived from chemistry models
  - Compute gaseous species production, bubble nucleation, bubble growth, dissolution, and release at glass surface
- Develop/Incorporate Glass Quality Indices into Glass Melt Model
  - Facilitate optimization studies re energy use and productivity
- Validate GFM Model on Other Types of Glass Furnaces
- Technology Transfer to the Industry
  - Release of Beta versions of code to industrial participants (ongoing)
  - Release of Demo version to GMIC Membership at Workshop which will be held during the fall Glass Problems Conference
  - Release of final version to industry at program conclusion
    - Establish User Service Center to provide technical support

PROGRAM WBS AND SCHEDULE



PROGRAM WBS AND SCHEDULE

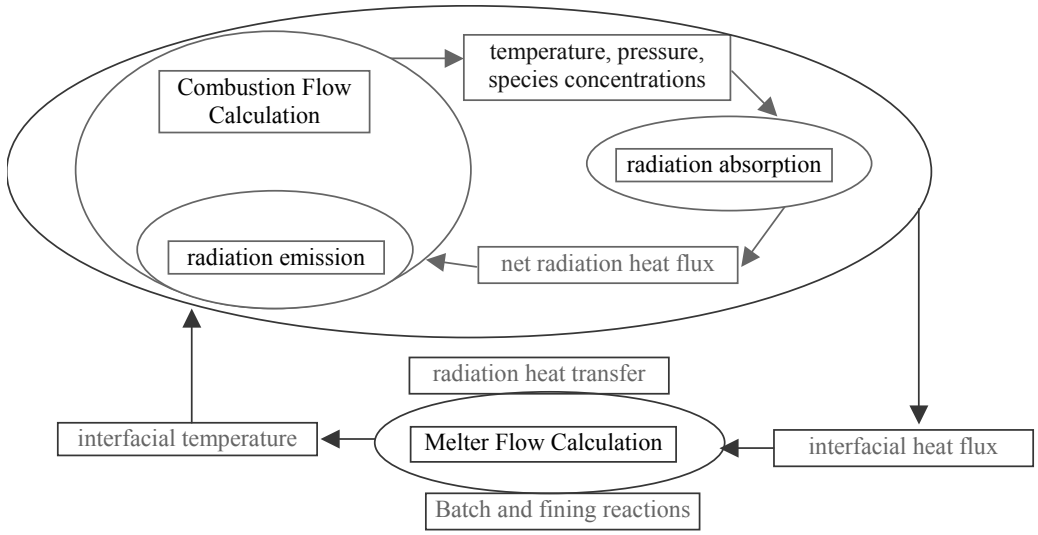


TECHNICAL PROGRESS AND ACCOMPLISHMENTS

Recent Accomplishments

- **Model Development**
  - **Radiation heat transfer in glass melt flow**
  - **Glass reactions, transport of bubbles, and foam models**
  - **GFM2 with window based pre- and post-processors and executables**
- **Experimental Measurements**
  - **Development of glass temperature probes**
  - **Preparation of two measurement campaigns**
  - **Determined glass foam bubble number density distribution**
- **Technology Transfer**
  - **Transferred GFM2 to industrial participants**
  - **Industrial participants simulated furnaces with GFM2**

Glass Furnace Simulation



Radiation Heat Transfer in Glass Melt Flow

- **Radiation Transport Equation**

$$q_r(x,y,z) = \int_0^\infty [\oint \kappa'_\lambda(species) e'_{b\lambda}(T') e^{-\int \kappa'' dl''} dv'] - \kappa_\lambda(species) e_{b\lambda}(T)] d\lambda$$

- Applicable to all grid sizes and all viewing angles

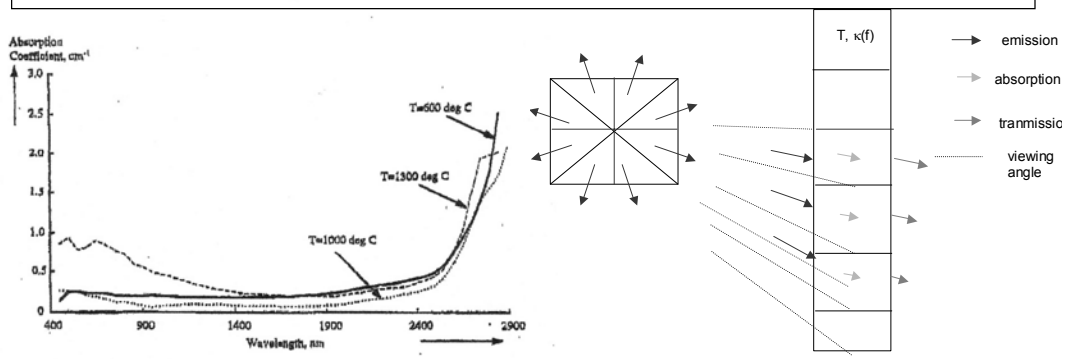
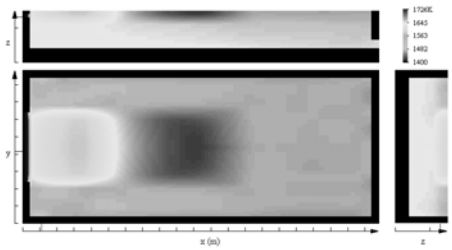
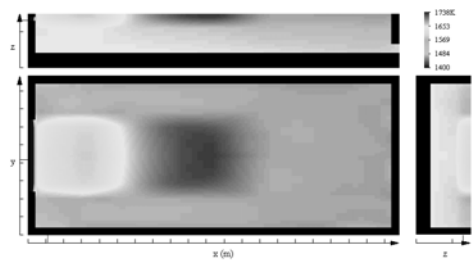


Figure 2. Absorption Coefficient for TV Funnel Glass

Radiation Effects on Glass Melt Temperature



Effective conductivity



Radiation heat transfer

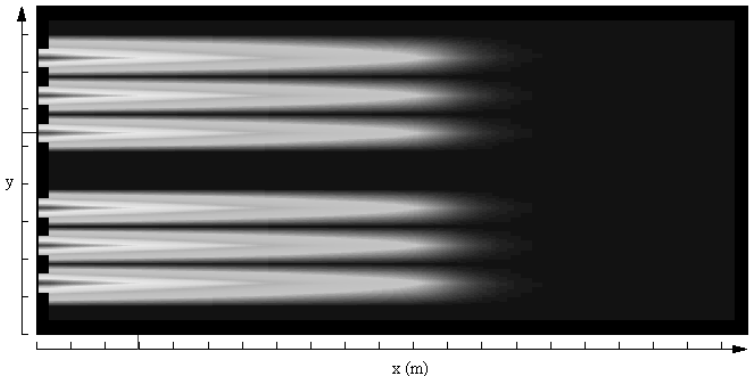
- **Radiation transmits the thermal heat flux over a larger distance than effective conductivity-->hot spots cool, cool spots warm up**

Batch Reaction

- Soda lime silicate glass batch reaction with Antimony:

$$(CaCO_3)_2(Na_2CO_3)(SiO_2)_8 + a_1 Sb_2O_5 \xrightarrow{k_1} (CaO)_2(Na_2O)(SiO_2)_8 + 3CO_2 + a_1 Sb_2O_5$$

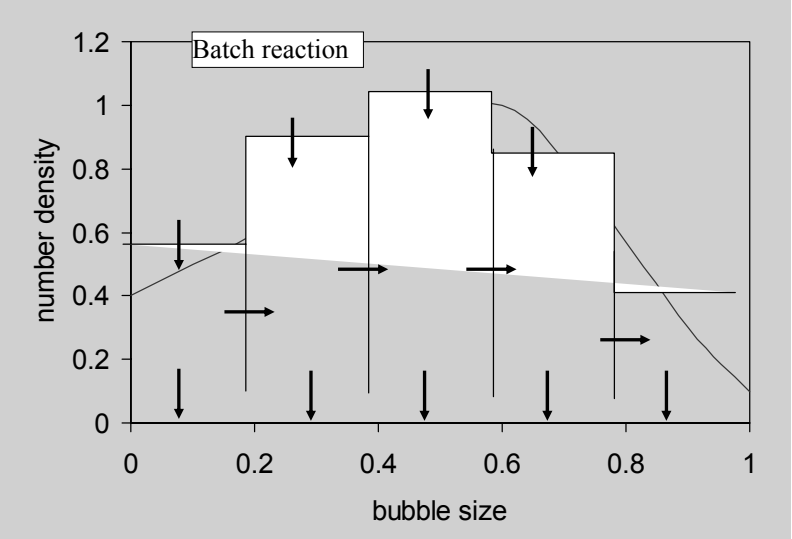
$$k_1 = 10^{-2} T^2 \exp(-2 \times 10^4 / T)$$



Solid Volume Fraction

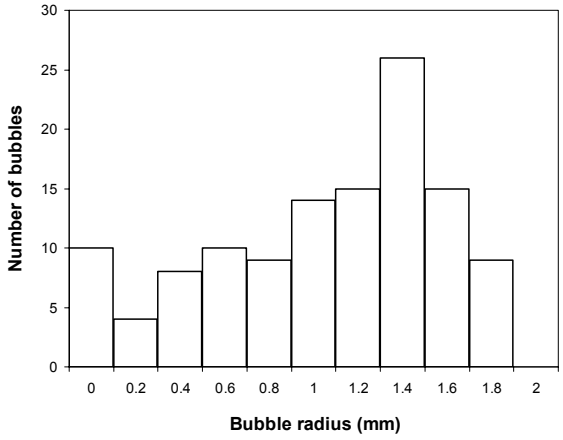
Bubble Flow

- **Bubbles are divided into size groups.**
- **Bubbles of a size group are treated as a continuum flow.**



Experimental Determination of Bubble Size Distribution

- ***Purdue University Experimentally Analyzed Glass Foam Samples taken from an Osram-Sylvania Furnace and Determined the Bubble Size Distribution***

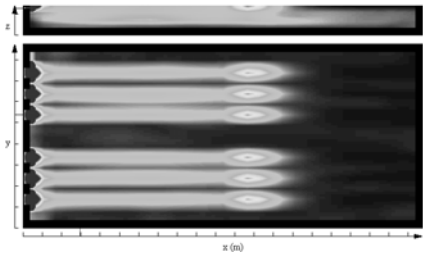


Fining Reaction and Species Transport

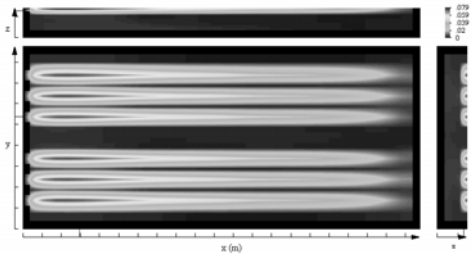
- Fining reaction

$$Sb_2O_5 \xrightarrow{k_2} Sb_2O_3 + O_2$$

$$k_2 = 2.347 \times 10^{11} \exp(-4.248 \times 10^5 / RT)$$



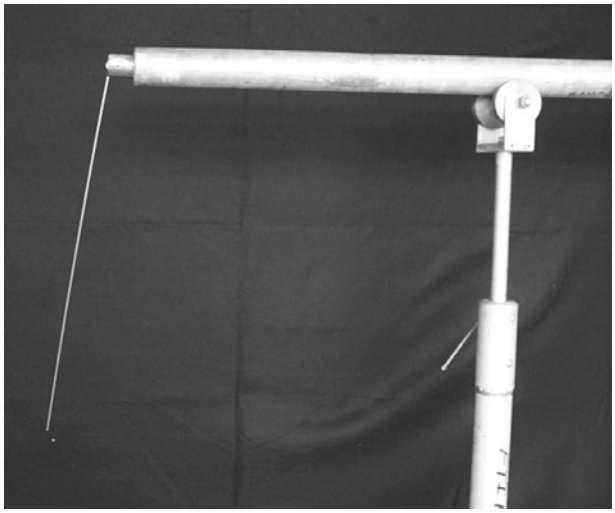
Bubble Number Density



Fining Species Concentration

Glass Temperature Probe Development

- **New probe design allows for sub-surface glass temperature measurements**

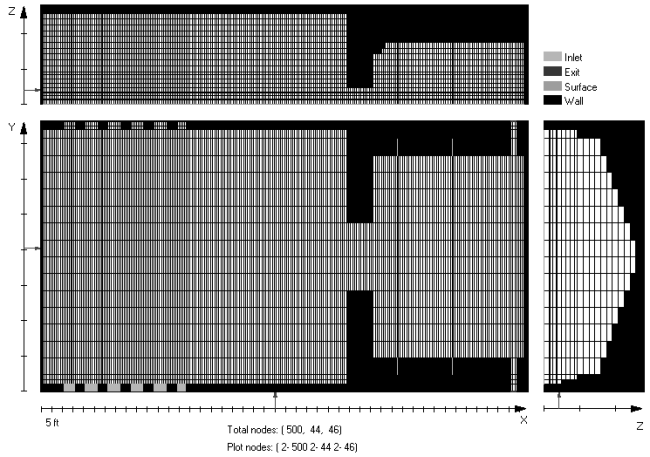


Measurement Campaigns

- **Two validation measurement campaigns planned**
  - **End fired furnace (Libbey, begins 10 Sept 2002)**
    - **Testing new glass temperature probe**
    - **Testing GFM on a regenerative furnace**
  - **Recuperative furnace (Owens-Corning, starting in early October 2002)**
    - **Testing electric boost and foam models in GFM2**

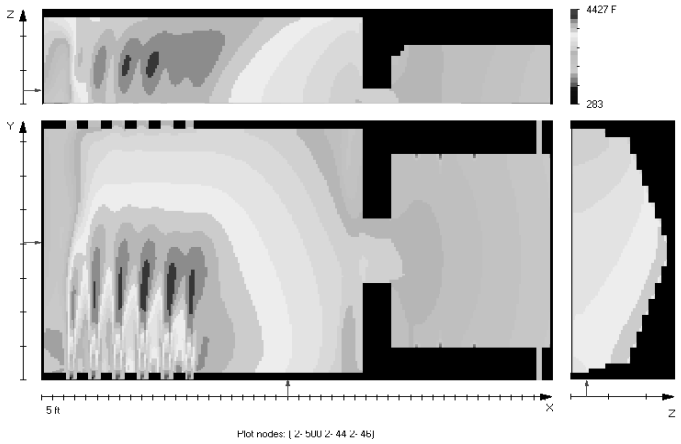
GFM2 Pre-Processor

- **Able to handle complex geometry and multiple burners/exhausts**
- **Float glass furnace shown below**



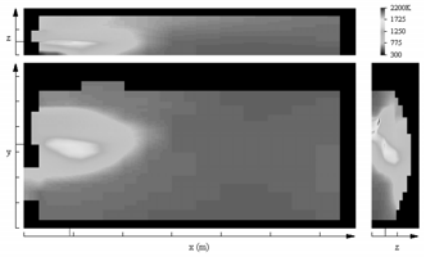
GFM2 Post-Processor: Preliminary Gas Temperature in Visteon Furnace

- **Post-process can display all computed quantities in any plane of the furnace**

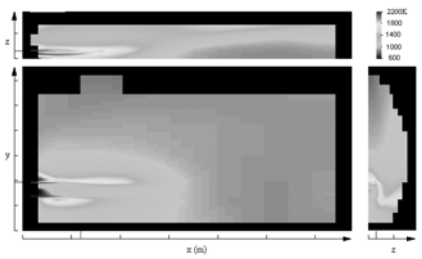


Effect of Firing Locations on Temperature

- **Preliminary calculations of Libbey, Inc. Toledo end fired furnace**



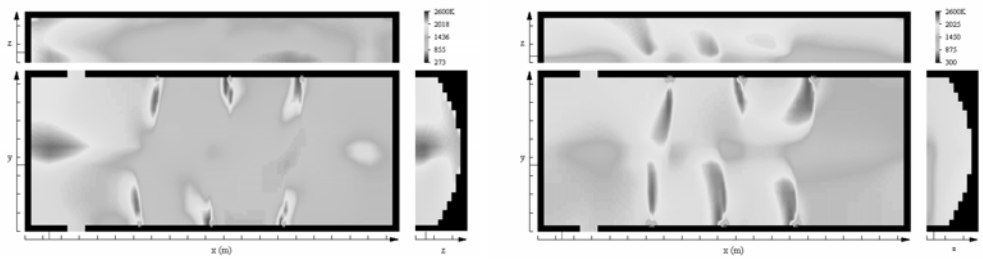
Left side firing



Right side firing

Effect of Batch Gas Release on Combustion Space Gas Temperature

- **Gas released from batch/melt into the combustion space changes the temperature and flow fields in a glass furnace**



No gas released **Batch gas released**

COMMERCIALIZATION STRATEGY

Transfer of GFM Code to Industry

- **Original Strategy**
  - Demonstrate Code Capabilities at Two Workshops
    - Initial workshop for GMIC members
    - Final workshop for entire industry
  - Make Codes Available Via Licensing Thru ANL's Technology Transfer Office
  - Technical Support Provided to Users by ANL for a Fee

Transfer of GFM Code to Industry (con't)

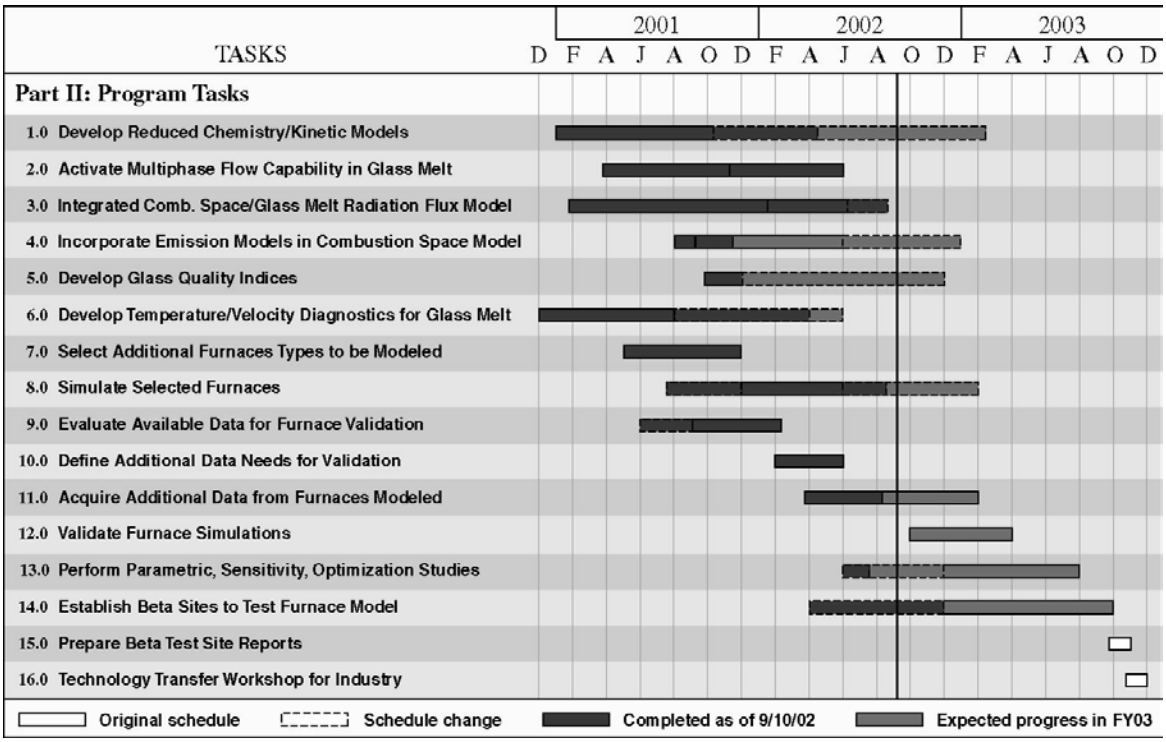
- Issues That Have Surfaced During the Program Which Suggest a Revision of Strategy Needed
  - GFM Code is Relatively Complex
    - Testing of code will not be completed prior to end of program
    - Problems will be encountered by initial users
  - Users Must Commit Requisite Resources to Master Use of Code
    - Reluctant to do so until benefits from use proven
  - Long Term Technical Support Essential if Code is to Become Widely Used
    - Is this an appropriate role for a national lab?
  - Strong Industry View that Costs Associated with Using Code Must be Minimized for Widespread Application

Transfer Of GFM Code to Industry (con't)

- Original Commercialization Plan Currently Under Review by IPs
  - Four Revised Strategy Options Being Evaluated to Assess Potential For:
    - Resolving Issues of Concern
    - Promoting Widespread Use of Code in Industry
  - Goal: Finalize Commercialization Strategy by 2nd Quarter FY 03

EXPECTED PROGRESS IN FY03

PROGRAM WBS AND SCHEDULE



Advances/Innovations in the "State of the Art" in Furnace Modeling/Simulation That will Exist at the Conclusion of the Program

- **A Rigorous Treatment of Radiation Heat Transfer Throughout the Whole Furnace Volume**
  - **Spectral radiation from combustion species such as H_20, CO_2, and soot**
  - **Radiation to and from crown and glass melt**
  - **Radiation through foam layer**
  - **Global and local heat balance throughout furnace volume**
- **A Three-Phase (liquid,gas,solid) Reacting Flow model of the Glass Melt**
  - **Compute batch coverage**
  - **Chemical species reactions and transport**
  - **Evolution and transport of gas phase species**
- **Direct Calculation of Glass Quality Indices as a Function of Furnace Operating and Design Parameters**
  - **Basis for optimization of furnace performance, re throughput, energy use, and emissions**
- **Nucleation Models of Particulate Formation/Transport for gases Emanating from Glass Melt/Batch that Exit Furnace**
- **Validation of Furnace Model with a Comprehensive Database Acquired from Operating Furnaces**
  - **Data obtained from in situ furnace measurements**

Measurement and Control of Glass Feedstocks

DE-FC07-01ID14030

Dr. Arel Weisberg
Robert De Saro
Dr. Joseph Craparo
Energy Research Company
www.er-co.com

DOE OIT Glass Project Review

September 10, 2002

Agenda

- Participants
- Problem Statement
- Concept Description
- Experimental Data
- Industrial Installation Preparations

Participants in Glass Project

- DOE OIT
- Energy Research Company
- PPG Industries (Fiberglass)
- Fenton Art Glass
- Oak Ridge National Laboratory

Two Projects in Glass

- Measure Batch Formulations in Real-Time
  - Measure Oxide Concentrations
  - Determine if Batch is on Spec
- Measure Cullet in Real-Time
  - Identify Cullet Color and Contaminants
  - Remove Contaminants and Separate Color

Future Interest

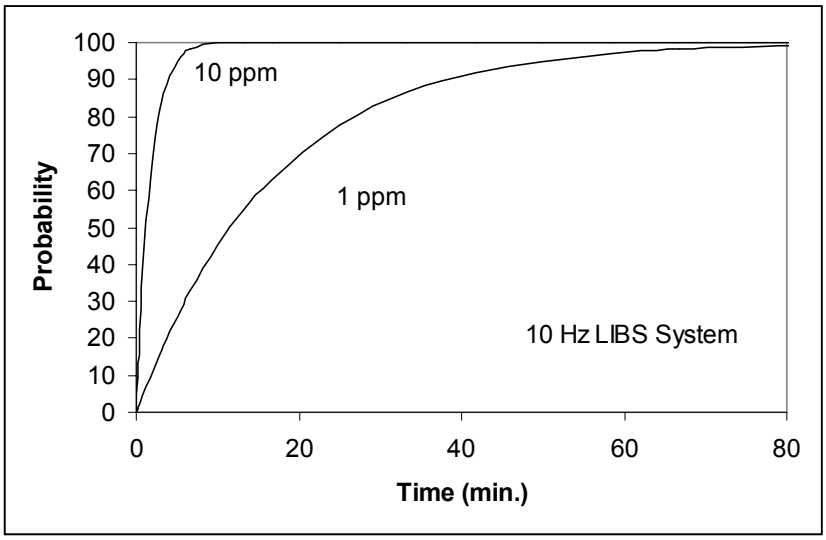
- Measure Concentrations of Molten Glass in Tank in Real-Time, In-Situ

Each Project Requires Different Approach

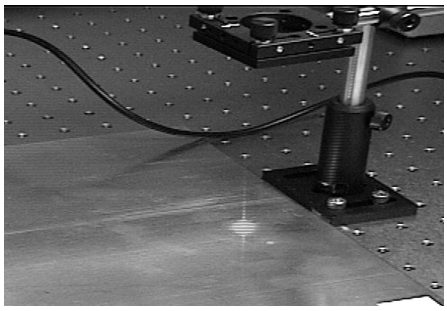
- Batch Requires High Measurement Accuracy of Oxides and Statistical Approach
- Cullet Requires Identification of Color or Contaminant, not of Oxides
- Molten Requires High Measurement Accuracy of Oxides in Extreme Environment

Shared Sensing Technology: LIBS

Probability of Finding a Trace Element

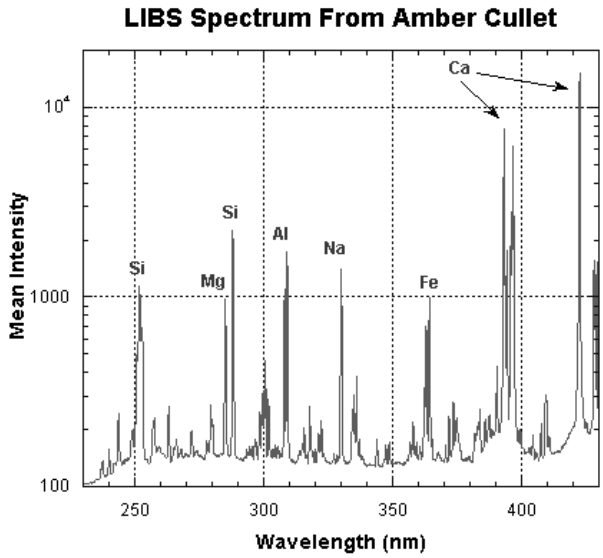


LIBS Description



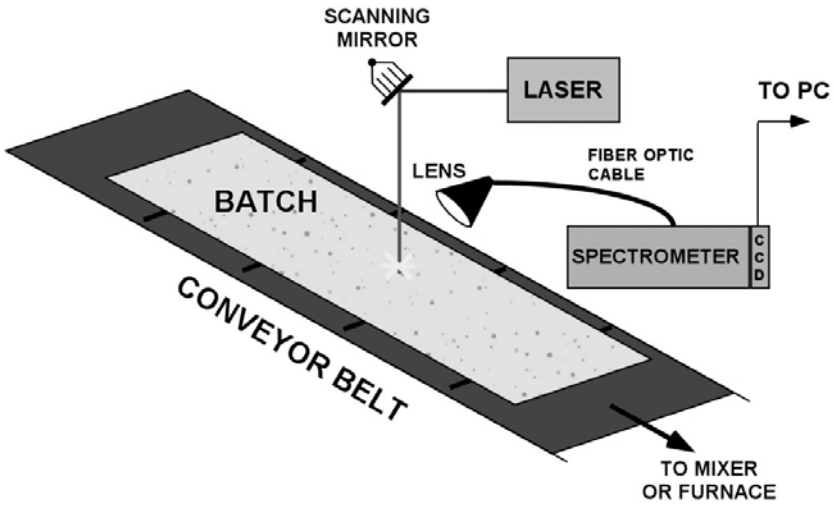
- LIBS=Laser Induced Breakdown Spectroscopy
- Laser vaporizes a minute amount of material resulting in a plasma
- UV light emitted is analyzed by a spectrometer
- The strength of elemental emissions are directly related to their concentration in the material

LIBS Technology



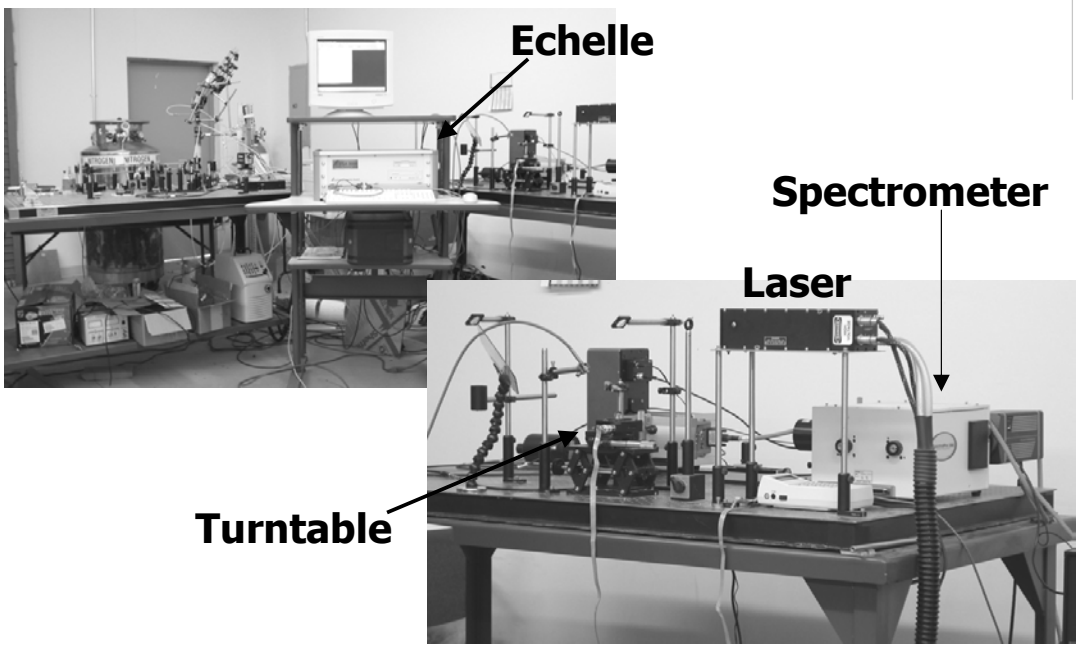
Spectrometer gathers light and spreads it, like a prism, into a spectrum where the contribution of each element can be seen

LIBS Batch Analyzer



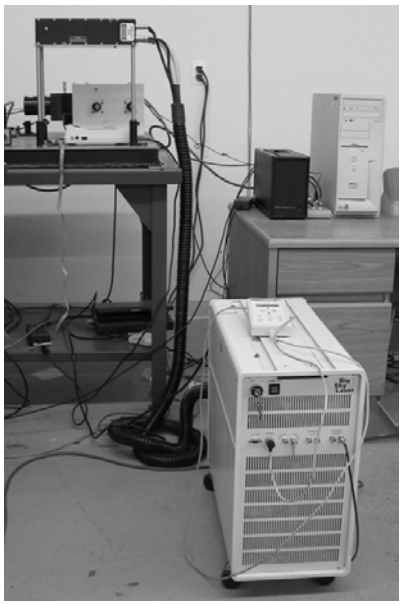
ERCo Experimental Results

ERCo LIBS Facility



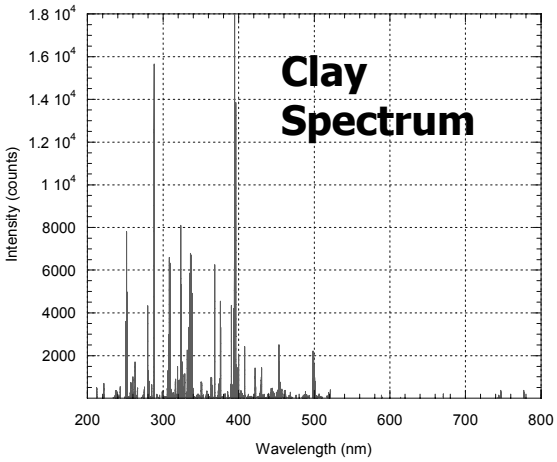
Laboratory Equipment

- Big Sky Laser CFR-400 Nd:YAG, solid state
- Q-switched at up to 20 Hz
- Simultaneous output at 1064nm (70 mJ), 532nm (182 mJ), and 266nm (42 mJ)
- Industrial Design
- Low Maintenance

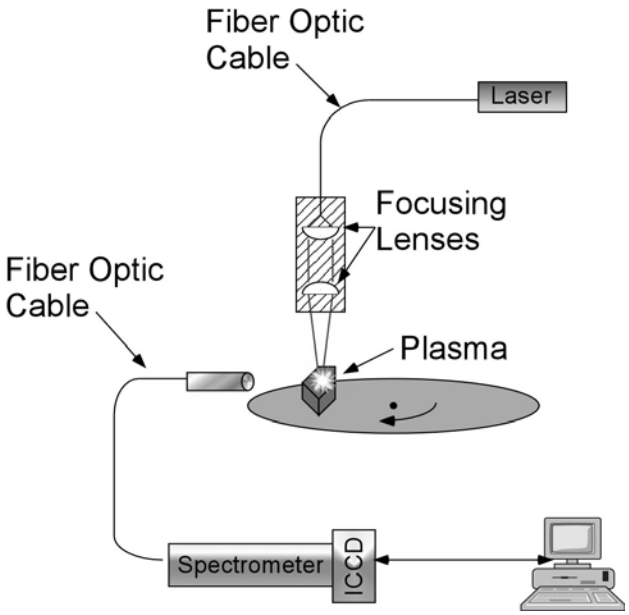


Laboratory Equipment

- Advantages of Echelle Spectrometer
  - Complete elemental analysis with each laser pulse
  - Increased accuracy
  - Greatly reduced analysis time
  - Industrial Design
  - Low Maintenance

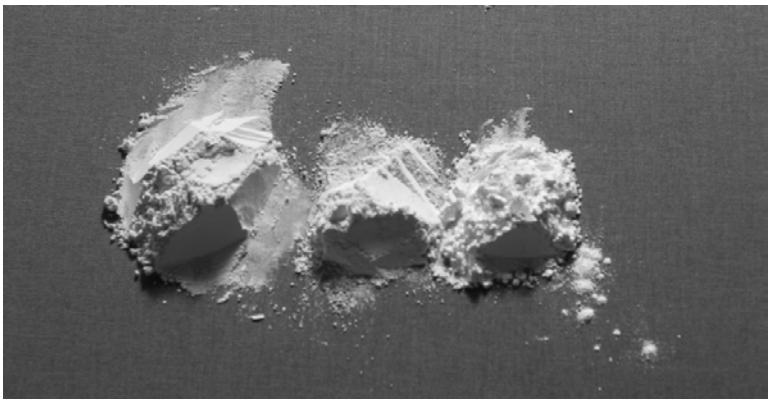


LIBS Apparatus Schematic

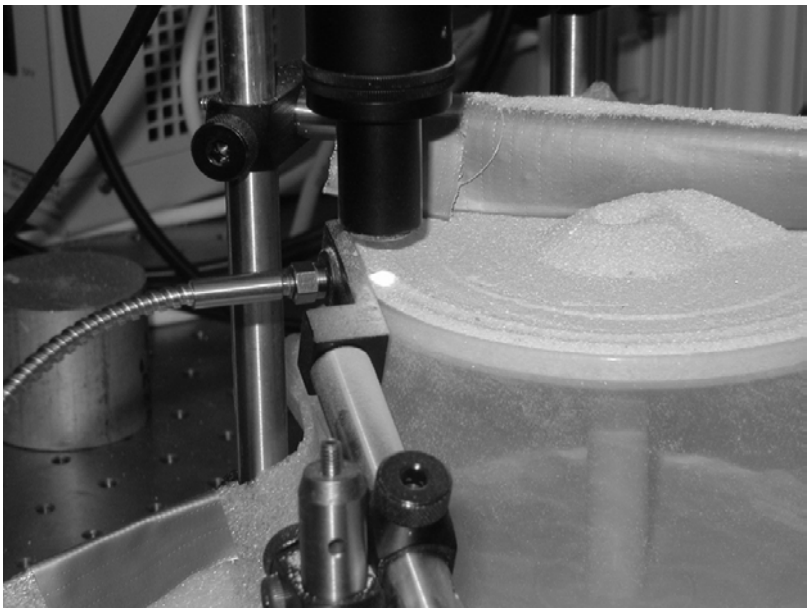


PPG Batch

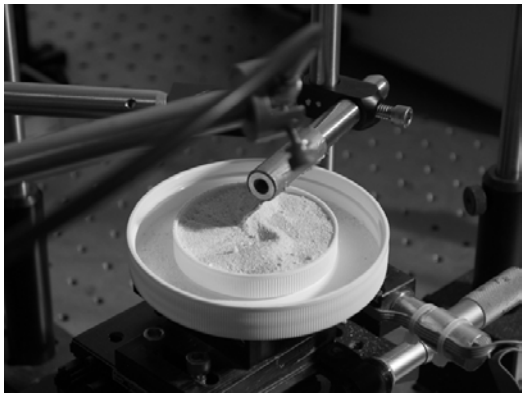
- Silica, clay, colemanite, ulexite, and limestone makeup PPG's batch

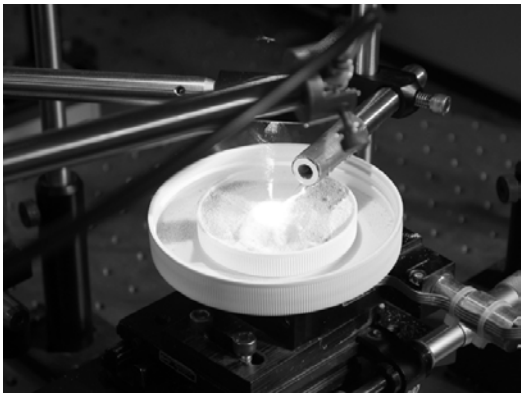


Batch Analysis

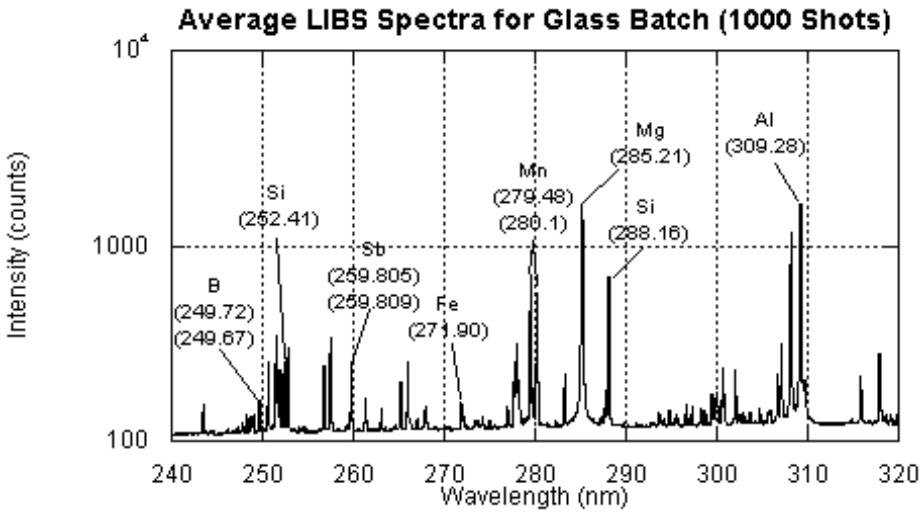


Batch Constituents





Batch LIBS Spectra



(concentrations proprietary, Fenton Art Glass)

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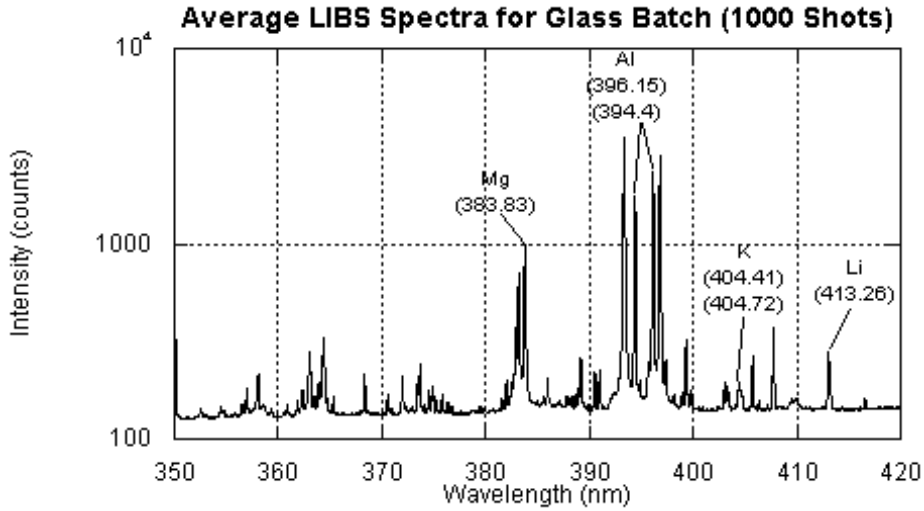
Batch LIBS Spectra



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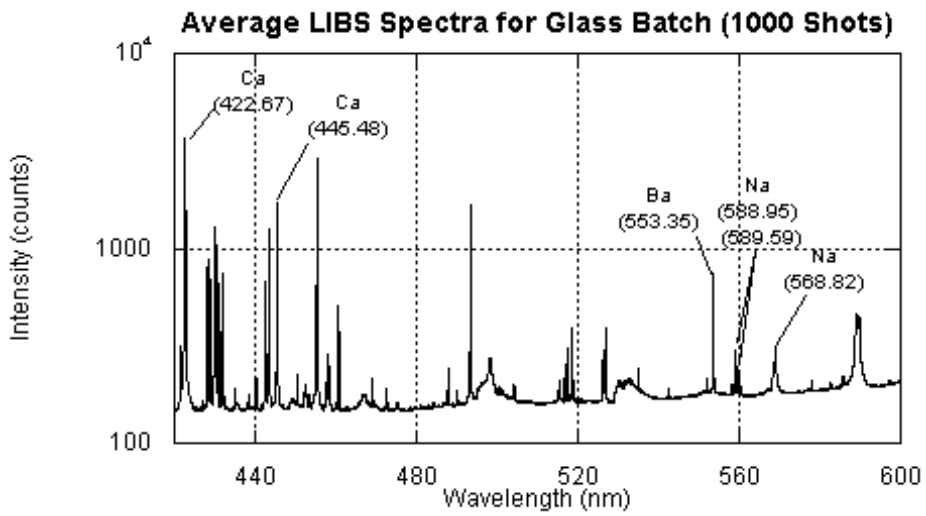
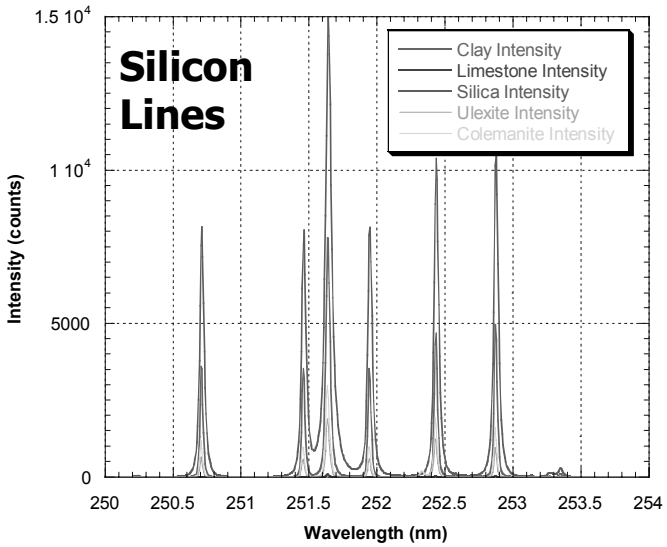


(concentrations proprietary, Fenton Art Glass)

Batch Constituents

- LIBS Spectra Collected from Each Sample



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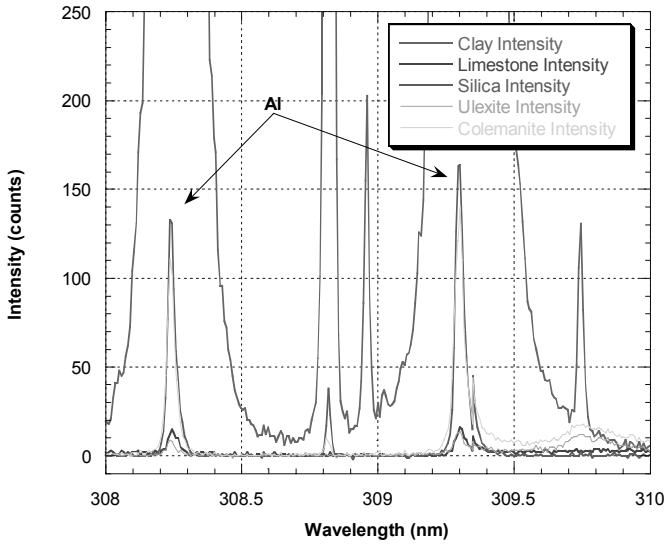

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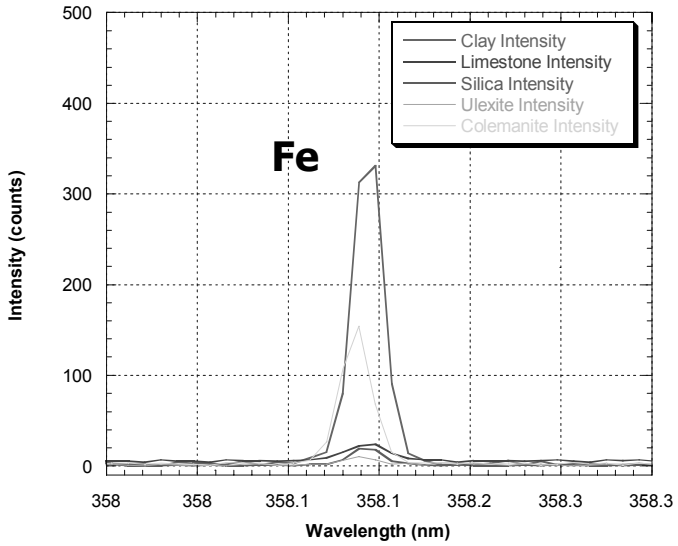

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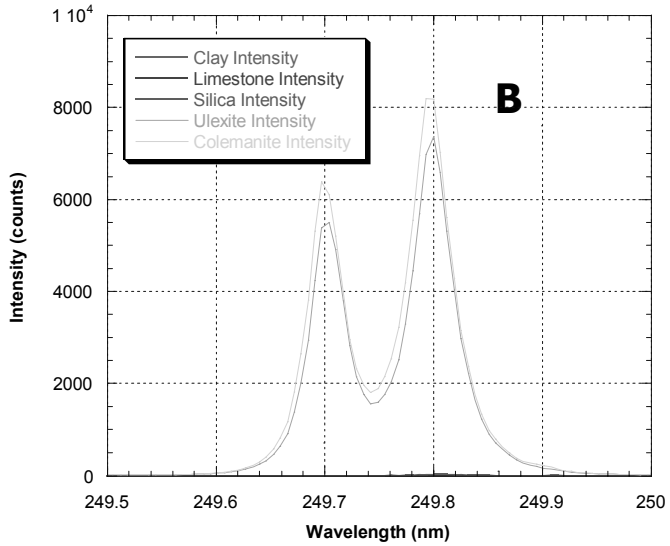

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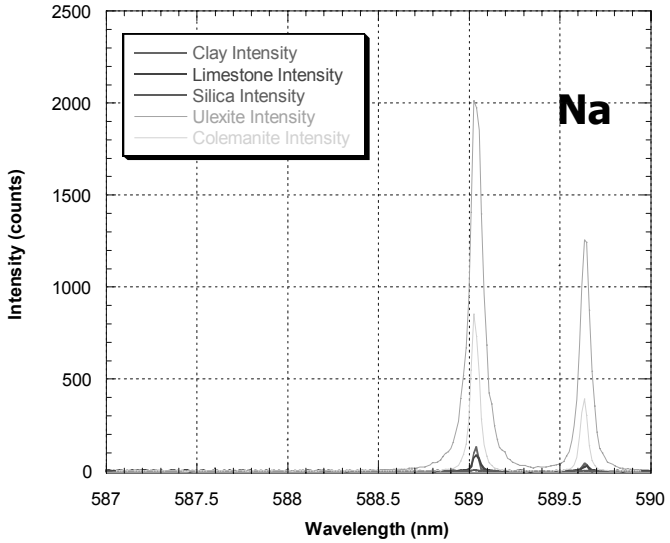
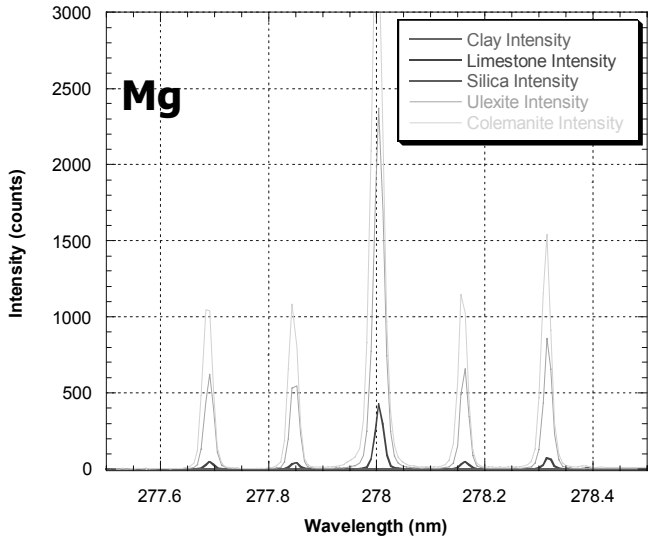
Batch Constituents

- LIBS Spectra Collected from Each Sample



Batch Constituents

- LIBS Spectra Collected from Each Sample



Calibrationless Software

- ERCo has Proprietary Software Using First Principles that Translates LIBS Spectra into Concentration Measurements
- Method Applies to both Molten and Solid Data
- Method is Independent of Experimental Parameters such as Laser Power
- Concentration Calibrations Not Required
- Spectrometer Spectral Calibration is Straight Forward

Clay Analysis

Concentrations are PPG Proprietary

Metal	Sample 1 Mean Error (%)	Sample 2 Mean Error (%)	Signal to Noise
Al	2.0	1.9	Good
Si	1.8	2.3	Good
Ti	2.8	6.9	Good
Fe	8.5	13.5	Poor

Fiberglass Rounds

Concentrations are PPG Proprietary

Metal	Error (%)	Metal	Error (%)
Al	2.9	B	22.4
Si	1.7	Na	3.3
Ti	15.0	Mg	3.1
Fe	4.7	Ca	6.1

Other Materials

	Basalt	Limestone	Hematite
SiO_2	17.96%	0.02%	1.74%
Al_2O_3	9.65%	0.27%	3.52%
Na_2O	0.92%	0.00%	0.00%
K_2O	0.00%	0.00%	0.00%
MgO	48.01%	3.03%	0.11%
$CaCO_3$	15.28%	96.7	0.10%
Fe_2O_3	7.39%	0.01%	94.45%
TiO_2	0.80%	0.01%	0.09%

Commercial Installation

- Installation Scheduled for Year 3 of program (April 03-04)
- Industrial Quality Laser
- Industrial Quality Spectrometer

Commercial Installation

- Laser Class Recertification
  - Class 4 Laser
  - Developing system of interlocks
  - End product will be Class 1 System (same as compact disc player)

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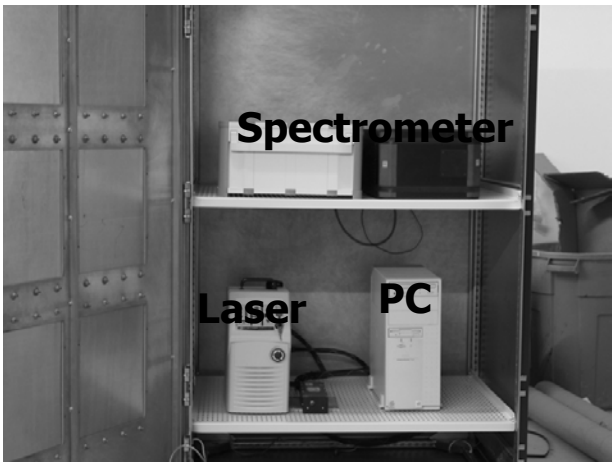
Commercial Installation

- Industrial Cabinet

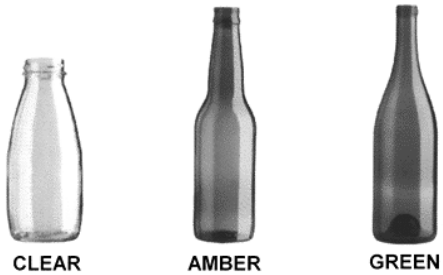


- Sealed, Air Conditioned, EMI Shielded

Cullet Color Sortation

"The industry needs technologies that can reliably identify and eliminate non-glass materials from the stream and efficiently sort glass by color."

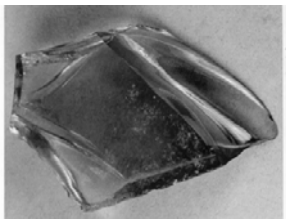
The Glass Industry Technology Roadmap



Recyclable Colors of Container Glass

Cullet Contaminants

- Optical Sensors Cannot Detect Some Common Contaminants Such As Cookware and Window Glass

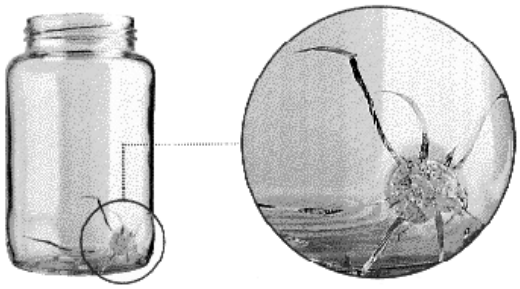


Visions Cookware
A Glass-Ceramic

AMBER

- A LIBS Sensor Would Easily Distinguish Between Container and Non-Container Glasses Because Of Their Different Elemental Makeup

Cullet Contaminants

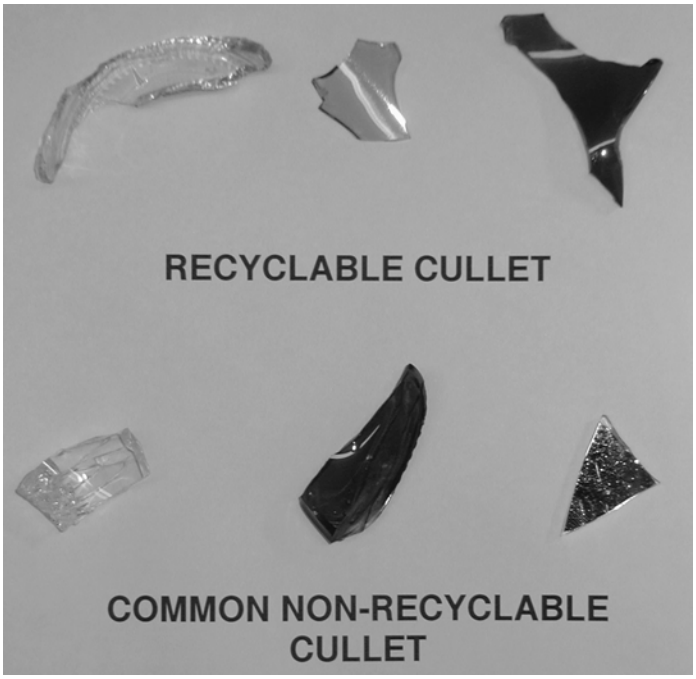


Contaminants Can Produce Severe Defects

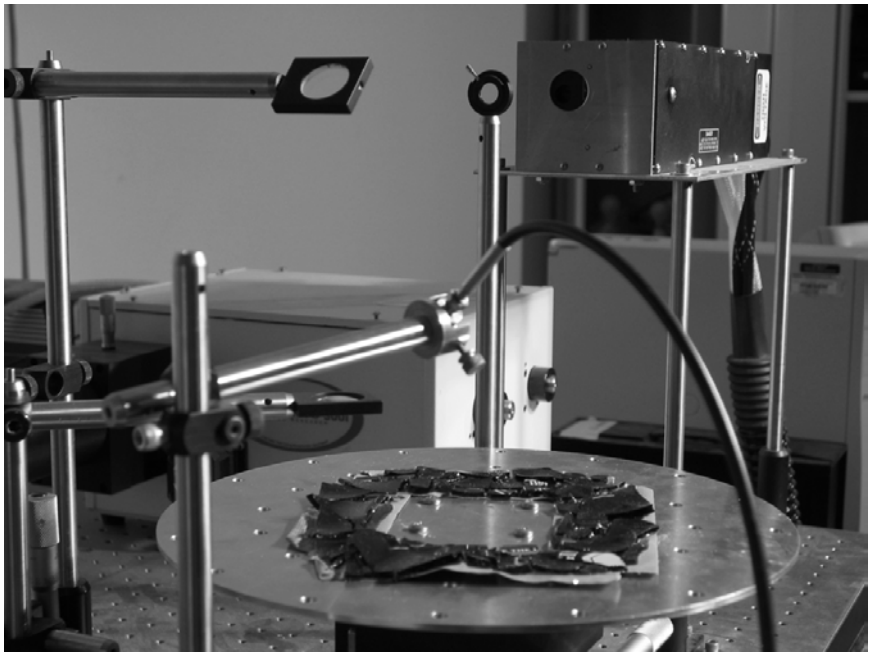
Cullet Sorting

- Test goal is to identify color or identify contaminants with one laser pulse

Cullet and Contaminant Samples



UV Laser Readily Sparks Cullet

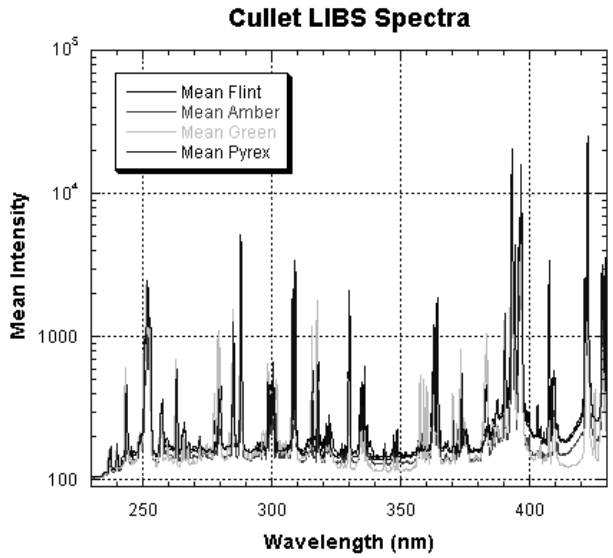


Cullet and Contaminant Samples

UV Laser Readily Sparks Cullet

Cullet Spectra

- Spectra Exhibit Differences That Can Be Exploited In A Sorting Algorithm



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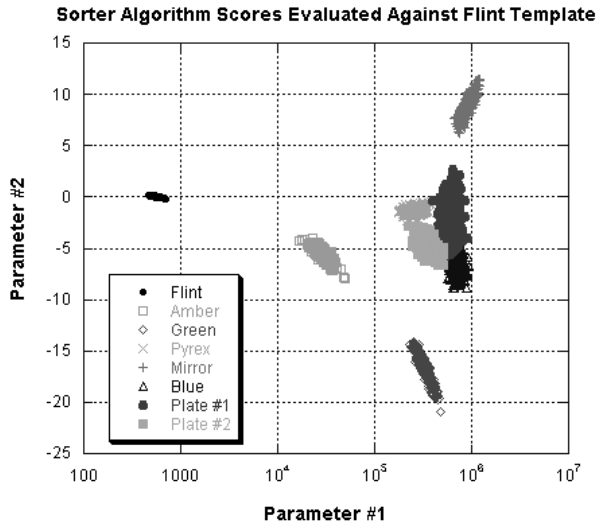
Experimental Results

- Proprietary algorithm uses database of spectra to identify cullet color and contaminants using one laser spark



Initial Cullet Test

- All colors can be sorted simultaneously or one color can be sorted separately
- Percent of spectra correctly identified as a color of cullet: 100%
- Percent of spectra correctly identified as a contaminant: 100%

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Energy Research Company

Cullet and Contaminant Samples

- 12 Flint Samples
- 4 Amber Samples
- 3 Green Samples
- 6 Contaminants
  - Pyrex, blue glass bottle, mirrored tile, glazed ceramic dishware
- Total of 12,000 Data Points Taken

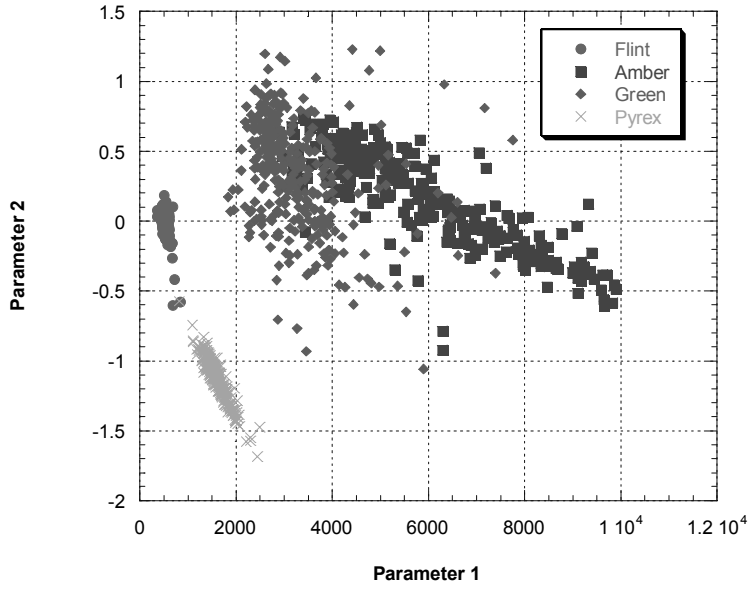
High Speed Algorithm

- Spectrometers are too slow for high speed sorting
- A series of radiometers can detect only a few wavelength ranges, but are easily fast enough
- Software rewritten to simulate radiometer based system
- Reduced data volume increases degree of difficulty

Cullet Sorting Results

Color/ Contaminant	% Correct Identification
Flint	97.5
Green	95.3
Amber	90.8
Contaminants	98.5

High Speed Cullet Sorting



Other LIBS Work at ERCo

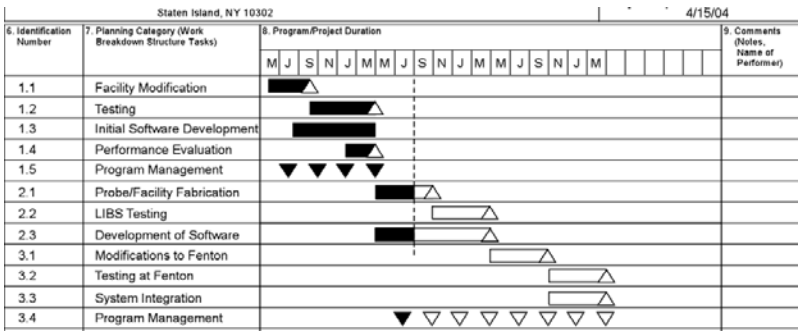
- Molten Aluminum
- Molten Steel
- Alloy Identification
- Industry Interest in Molten Glass Applications

Related Accomplishments

- LIBS Probe developed for *in-situ* analyses of molten aluminum and other materials
- Melt composition can be measured at any point below or on top of the melt surface
- Laboratory and pilot scale probes built
- First LIBS data ever recorded from within molten aluminum

Timeline & Milestones

- Program Started April 2001



- Program is Proceeding on Schedule

Conclusions

- Glass LIBS Sensors' Feasibility Proven
- Technology Tests Successful
- Full-Scale Demonstration at PPG Being Planned

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

Peter M. Walsh, Shane M. Sickafoose, Douglas D. Scott,
Robert Steinhaus, and Howard A. Johnsen
Sandia National Laboratories
Livermore, CA

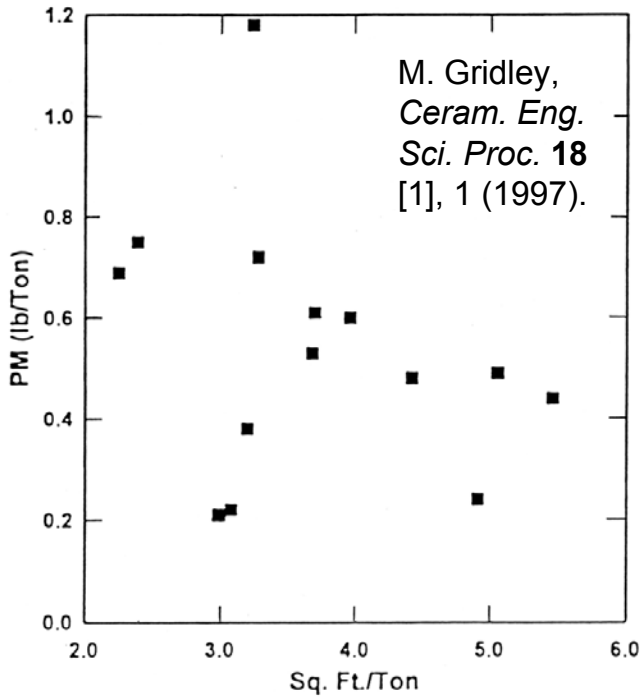
John Neufeld
Gallo Glass Company
Modesto, CA

DOE/OIT Glass Industry Project Review
Sandia National Laboratories, Livermore, CA
September 10, 2002

Particulate Matter Emissions Highly Variable

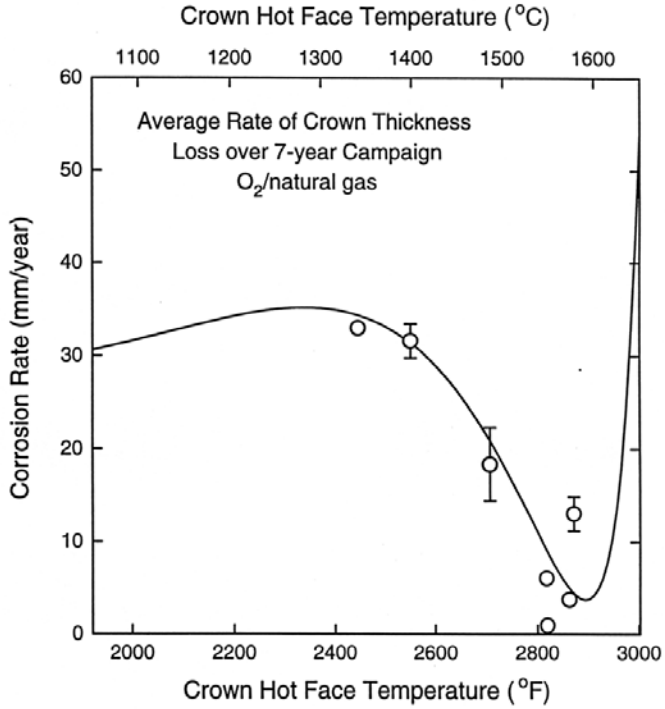
Even disregarding the outlier at the top of the figure, there is still a factor of 4 difference between the best performing and least well performing furnaces.

There are evidently design or operational influences on volatilization that are not well understood.



Comparison of Calculation and Measurements

- Equilibrium NaOH partial pressures from the associate species model give corrosion rates in good agreement with the observations.
- Corrosion rate expected to increase markedly above about 2900 °F.
- Window between the temperature at the minimum corrosion rate and the maximum service temperature of silica is quite narrow.

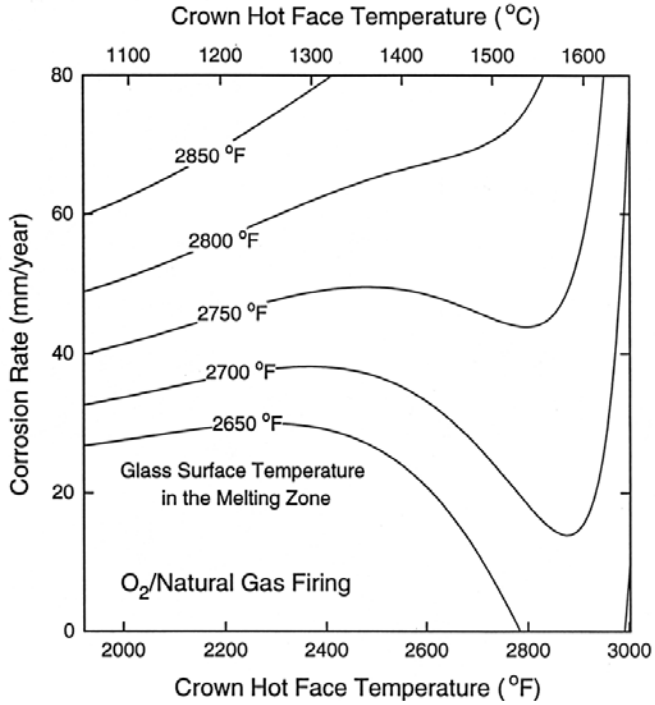


Dependence of Corrosion Rate on Glass Surface Temperature

Increasing glass surface temperature increases the concentration of NaOH vapor in the gas. The values corresponding to the temperatures shown in the figure are:

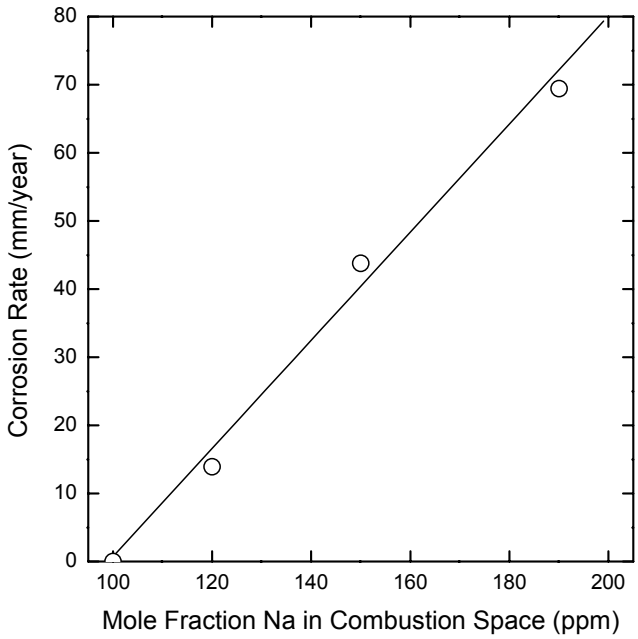
2650 °F	100 ppm NaOH
2700	120
2750	150
2800	190
2850	230

In the presence of 190 ppm NaOH, the minimum in the corrosion rate vs. temperature curve disappears.



Sodium Volatilization and Crown Corrosion Rate

- Corrosion rate at optimum crown temperature directly related to sodium concentration.
- Sodium measurements combined with sufficiently accurate model permit estimate of thickness loss.
- On-line assessment of benefit from increasing pull versus cost of tank repair is then possible.



Laser-Induced Breakdown Spectrometry (LIBS)

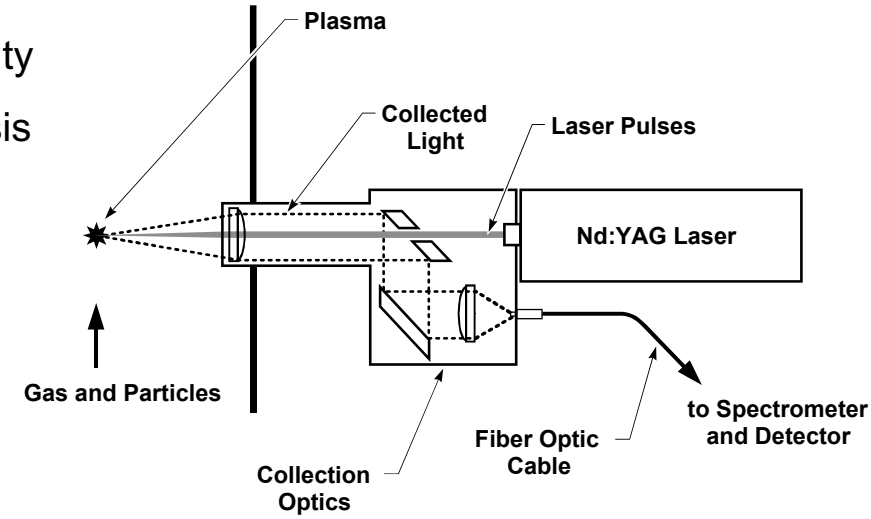
High sensitivity

In-situ analysis

Elemental signature

Good time resolution

Portable



Objectives

- Identify conditions influencing volatilization and batch carryover, in order to control:
  - Particulate matter emissions.
  - Superstructure and crown corrosion.
- Develop prototype of lower-cost instrument for use as diagnostic tool.

Measurements

- Sandia:
  - Furnace radiation
  - Flue gas composition (O_2, CO, NO, SO_2)
  - Flue gas temperature
  - Metals in flue (Na, K, Ca, Mg, Si, Al, B)
- Gallo Glass:
  - Flows and boost
  - Temperatures
  - Pressures
  - Batch and glass composition

Activity During FY02

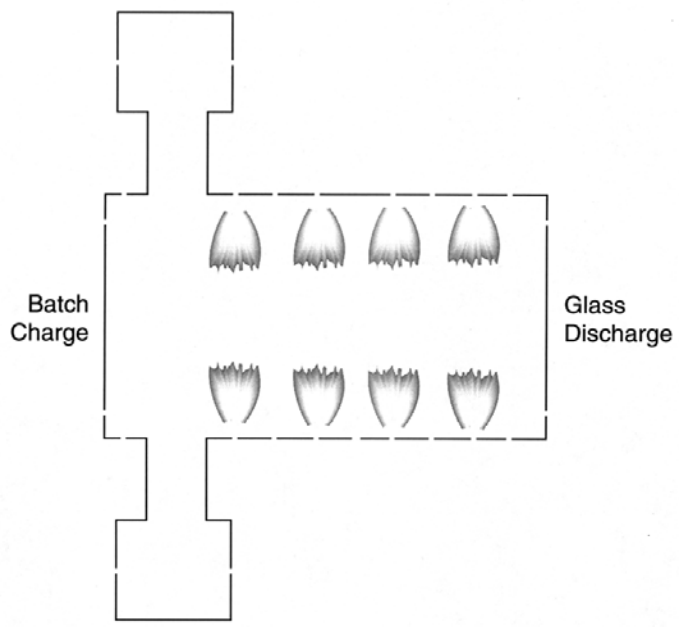
- Implemented echelle spectrometer, able to collect entire spectrum from 200 to 900 nm and measure all metals of interest in each laser spark.
- Conducted two field trials:
  - December 2001 - 1 week, first time out with echelle spectrometer, measurements in EP duct.
  - June 2002 - 1½ weeks, both conventional and echelle spectrometers, measurements in vertical flue just downstream from furnace exit.

Sampling EP Duct

- Have access to entire gas flow and can measure it.
- Long distance to furnace, so some particles may have been lost.
- Flow diluted with steam and unknown amount of air.

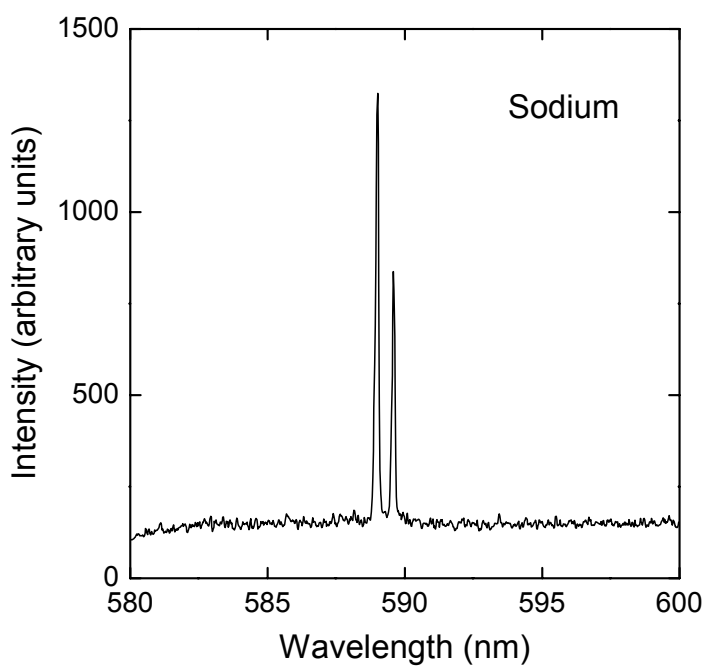
Sampling Vertical Flue

- Each flue contains only ~half the flow.
- Duct cross section too large to sample
- Short distance to furnace; negligible particle loss.
- Only dilution is by inleakage into the furnace and flue.

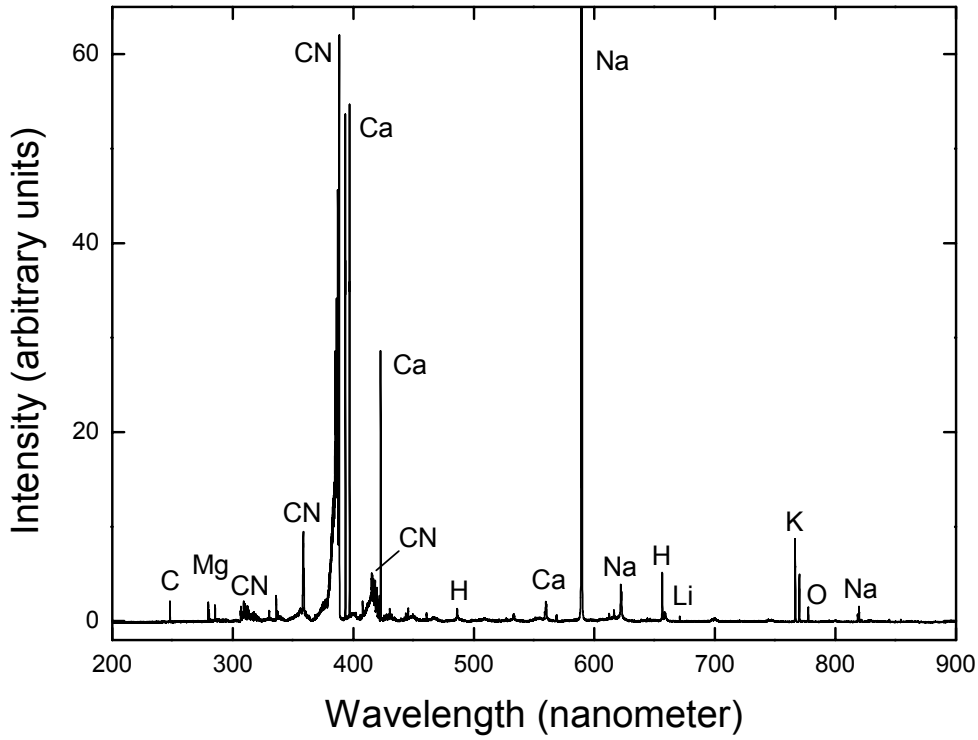


Conventional Spectrometer

- Wavelength range limited to 20 to 40 nm.
- Can see only one or a few elements at a time.
- Has high sensitivity.



LIBS with Echelle Grating Spectrometer

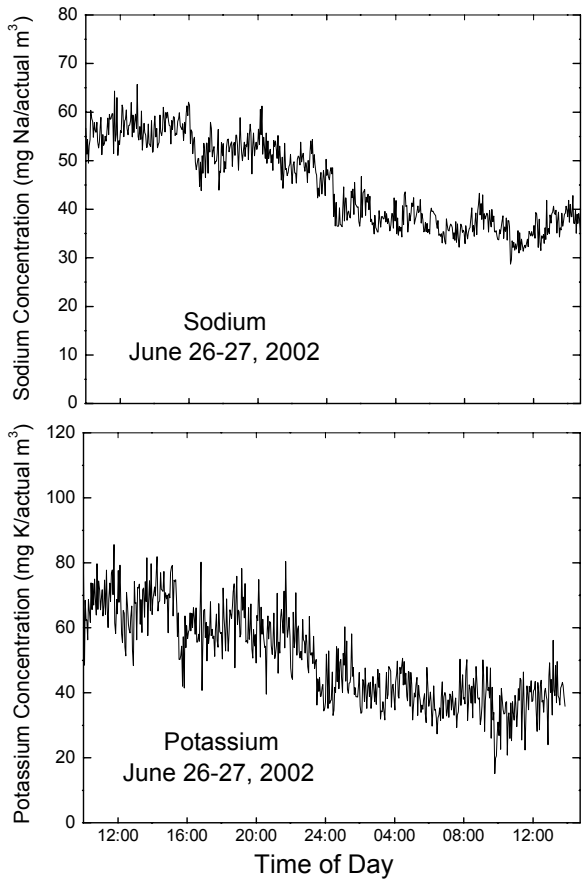


Sodium and Potassium

The two alkali elements track each other closely.

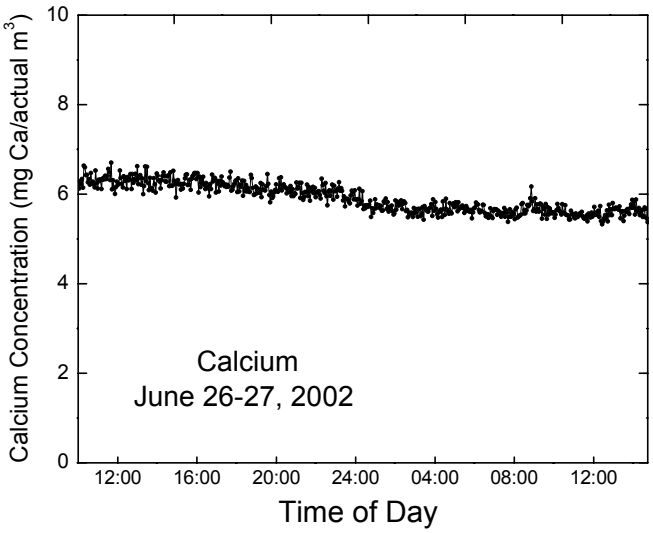
Average sodium concentration corresponds to 0.42 lb Na_2SO_4/ton glass.

High potassium concentration is surprising. It is not consistent with an earlier EP dust analysis.

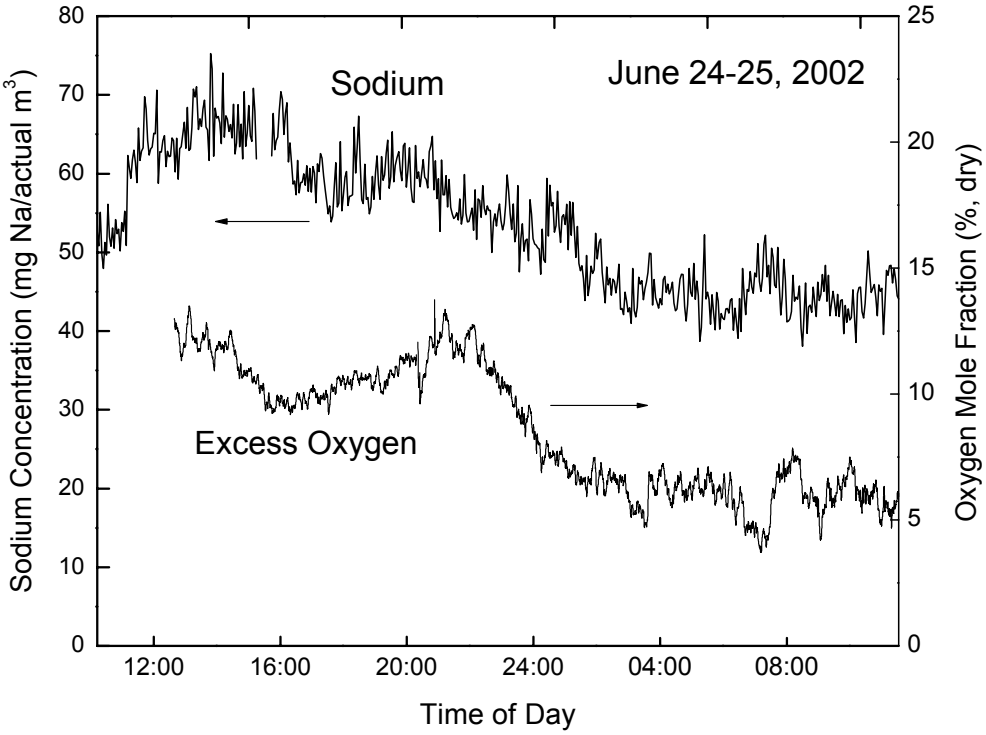


Calcium

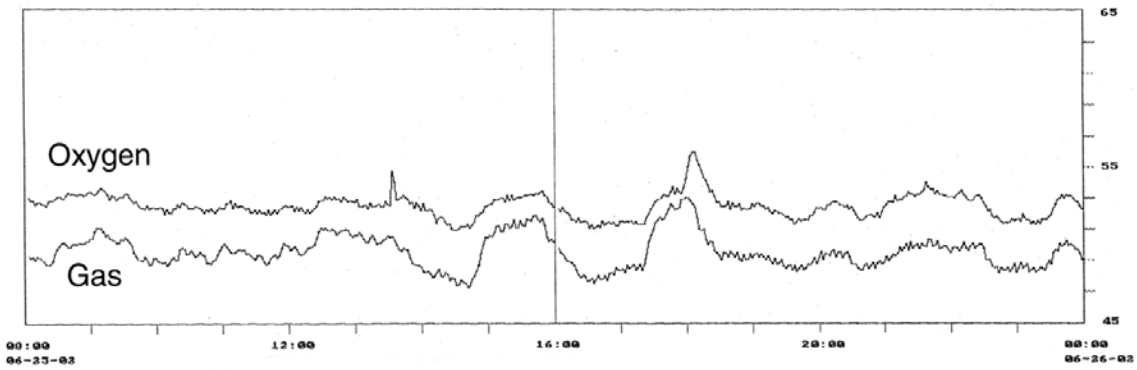
- Calcium concentration is an order of magnitude smaller than sodium and potassium.
- Small scatter of data indicates that origin of calcium is volatilization, rather than carryover.
- Small amounts of calcium and potassium could lower the melting temperature of the sodium silcate layer on the crown.



Correlation between Sodium and Excess Oxygen

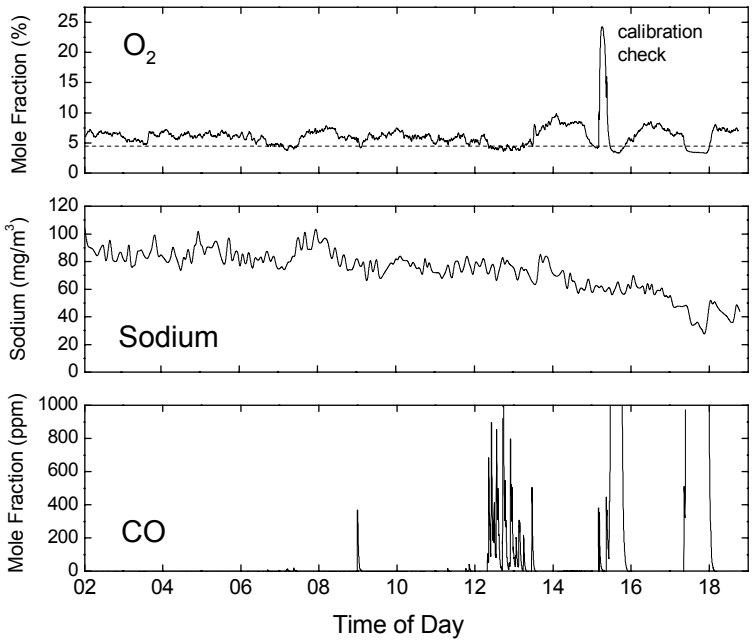


Oxygen and Gas Flows



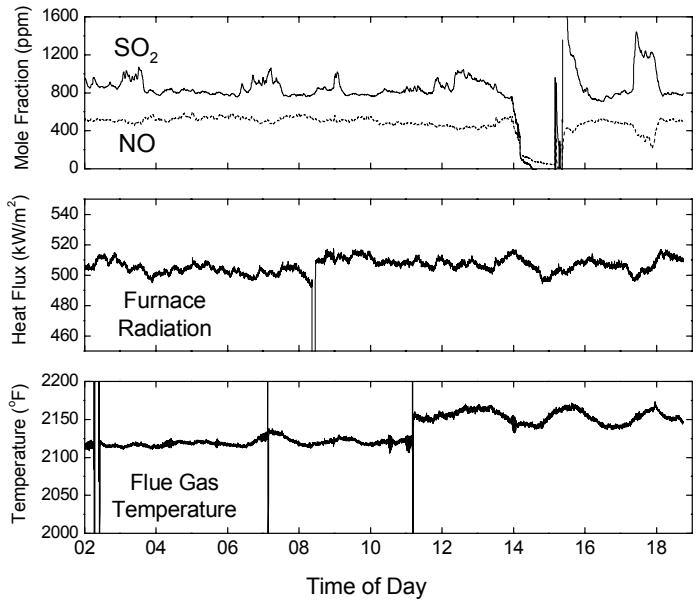
Response of Excess O_2, Sodium, and CO

- Though the correlation is by no means perfect, sodium tends to decrease with decreasing oxygen concentration.
- Optimum excess O_2, to minimize sodium and avoid CO in the flue, is ~5 vol%(dry).



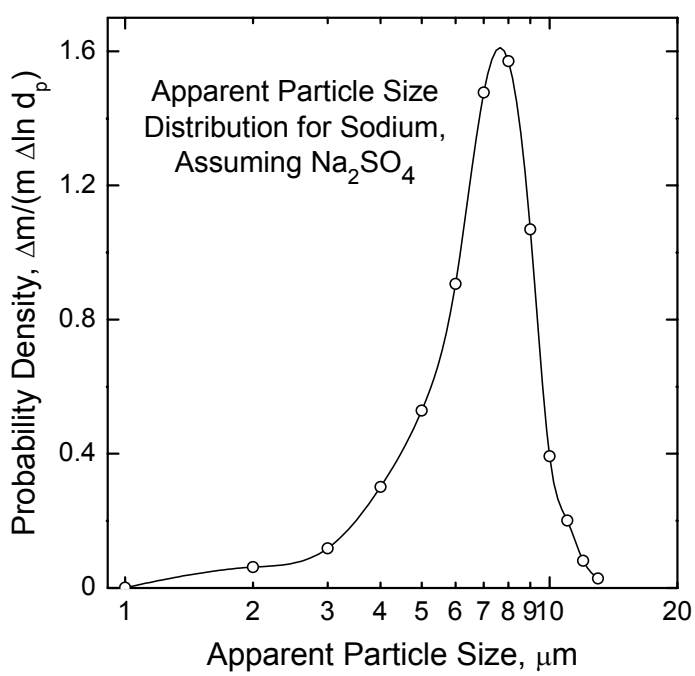
Response of SO_2, NO, Radiation, and Flue Gas Temperature

- SO_2 released from glass or Na_2SO_4 deposits under reducing conditions.
- NO response weak, except under strongly reducing conditions.
- Flue gas temperature increases as excess oxygen decreases.
- Radiation slow to respond - due to change in refractory temperature rather than flame luminosity.

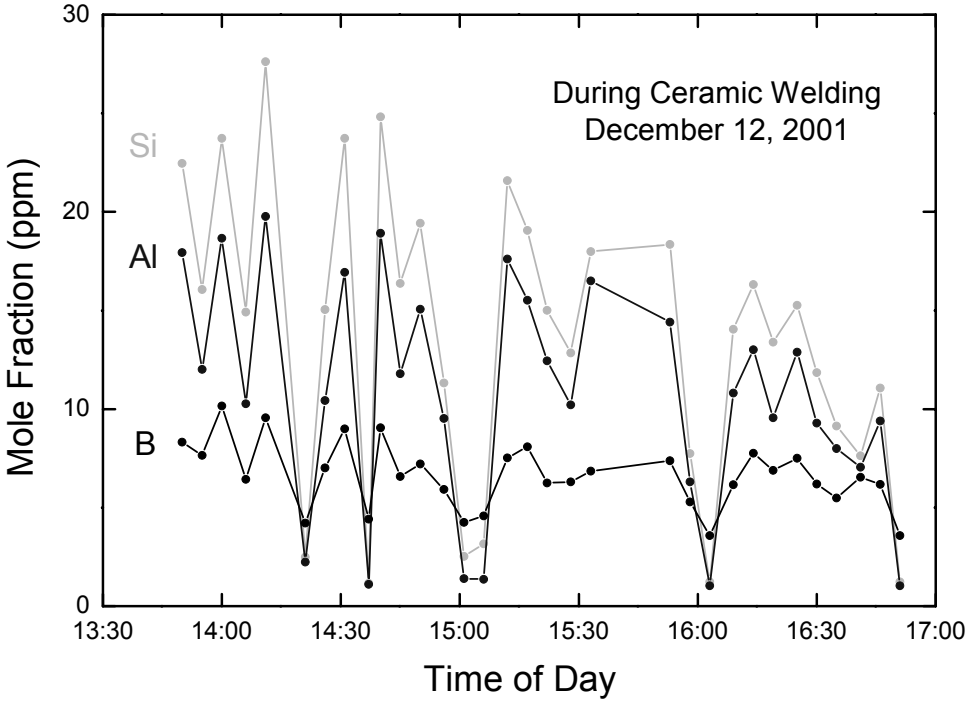


Apparent Particle Size Distribution for Sodium

- Assume sodium present as liquid or solid Na_2SO_4.
- Calculate apparent size, assuming only one particle in laser spark.
- Sizes are large and distribution is narrow.
- Suggests a high number density of fine particles and few large particles.
- All from volatilization with negligible carryover.



Elements Seen in Flue During Ceramic Welding



Task / Milestone Status

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	

Task / Milestone Status (continued)

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	
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	
17	Optimum stoichiometry	9/30/03	
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 FY03

- Test the correlations between sodium, potassium, and calcium volatilization and O_2/gas ratio by controlled experiments.
- Establish the critical O_2/gas ratio for CO formation in the same experiments.
- When the influence of O_2/gas ratio on sodium, potassium, and calcium is better quantified, look for effects of other variables, such as furnace temperatures.
- Examine the potassium measurement critically to determine whether concentration in flue is as high as the data suggest.
- Continue to search for conditions under which batch dusting is observed.
- Develop concept for prototype of lower cost instrument able to measure two or three elements, e.g. Na, K, and Ca.

Budget

Budget Data as of September 7, 2002:

			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	107	125	232
Year 3	6/03	5/04	350	350	700	0	0	0
Totals			1,050	1,050	2,100	457	475	932

Development of a Process for the In-House Recovery and Recycling of Glass from Glass-Manufacturing Waste

Prepared for

DOE GLASS PROJECT REVIEW

September 9-10, 2002

Sandia National Laboratories- Livermore, CA

Sponsored by

U.S. Department of Energy

DOE Headquarters Contact-
Mike Soboroff

Pioneering Science and Technology
ARGONNE NATIONAL LABORATORY A U.S. Department of Energy laboratory operated by The University of Chicago

Project Team

- Argonne National Laboratory
  Sam Jody, Joe Pomykala Jr. & Ed Daniels
- Saint-Gobain Vetrotex America
  John Wells
- CertainTeed Corporation
  Terry Berg

Presentation Outline

- ➔ Overview
- ➔ Technical Progress
- ➔ Summary & Conclusions
- ➔ Schedule & Milestones
- ➔ Financial Report
- ➔ Future Plans

Pioneering Science and Technology
ARGONNE NATIONAL LABORATORY A U.S. Department of Energy laboratory operated by The University of Chicago

Problem/Need

- ➔ Waste is presently landfilled and cost of disposal is rising.
- ➔ Earlier attempts to recycle the waste resulted in more frequent breakage of the filaments.
- ➔ The industry needs an energy-efficient and cost-effective process to recycle their waste.

Objective

Develop a technology to enable the Glass Industry to recycle its glass-fiber waste

Pioneering Science and Technology
ARGONNE NATIONAL LABORATORY A U.S. Department of Energy laboratory operated by The University of Chicago

Approach

- ➔ Identify the cause for increased filament breakage - Identify species in the waste glass not present in the virgin glass:
  - -- Qualitative analysis
  - -- Quantitative analysis
- ➔ Develop a process to remove contaminants from the waste material.
- ➔ Conduct economic evaluation of the process.
- ➔ Demonstrate the process in the field.

Accomplishments

I. Identification of Impurities in Glass-Fiber Waste:

- ➔ Nobel metals were not found at a detection limit of 5PPB even after we conducted froth-flotation on a large sample to concentrate the metals.
- ➔ Except for the polymeric-coating layer, same elements were present in the waste glass and in the virgin glass and at the same concentrations.
- ➔ Shredding and conveying of the waste could introduce contamination in the form of tiny solid particles.

Accomplishments

I. Identification of Impurities in Glass-Fiber Waste Cont'd:

➔ Excess liquid that drains off the waste-glass fibers is likely to contain most of the tiny Nobel-metal particles that abrade off the dies.

➔ Conclusion: We need a process to remove the polymeric-coating layer off of the glass before it can be recycled.

Accomplishments

II. Development of a Process to Remove the Polymeric Coating and Binders:

➔ We tested and evaluated 2 methods to remove polymeric coatings:

-- Thermal processing

-- Chemical processing

➔ Both methods were successful in removing the polymeric layer.

➔ The thermal method is more efficient and more economical.

➔ The thermal method produces no liquid waste or sludge.

Accomplishments– Thermal Method

- ➔ It is crucial that the treatment be conducted at temperatures below the melting point of the glass fibers.

  -- 1250 ºF for glass-fiber waste

  -- 1050 ºF for glass-fiber waste

- ➔ Washing the glass fiber waste reduces potential contamination with metallic particles.

Accomplishments– Thermal Method- Cont'd

- ➔ Removed polymeric coating off of glass-fiber waste and reduced the total carbon content of the treated material from several thousand ppm to less than 100 ppm.
- ➔ Removed over 99.5% of the binder materials off of the fiberglass scrap. Washing the glass fiber waste reduces potential contamination with metallic particles.
- ➔ The required residence time is about 10 minutes.
- ➔ Packing density of the waste material is important.

Accomplishments– Thermal Method- Cont'd

III. Economic Analysis of the Thermal Process:

➔ We developed process conceptual designs.

➔ We conducted economic analysis on the conceptual design using operating data developed in the lab.

➔ The thermal method can be easily integrated with existing operations.

➔ The payback is less than 2 years.

Accomplishments– Thermal Method- Cont'd

IV. Environmental Analysis of the Thermal Process:

➔ In an oxygen-deficient environment (with some air
➔ Leakage)

< 0.009 wt% of the glass fiber waste &
~ 0.001 wt% of the fiberglass waste evolved as VOCs.

➔ The collected VOCs can be readily oxidized in an after burner.

Accomplishments– Thermal Method- Cont'd

Major VOCs Emitted in an O_2-Deficient Environment:

Compound	% of Total	% of Total in
	Glass Fibers	Fiberglass
Acetone	77	65
Isopropyl Alcohol	08	
Benzene	06	
Acrylonitrile	04	21
Vinyl Chloride		06
Dimethyldifluorosilane		04
Others	05	04

Conclusions

- ➔ We developed a process for removing the polymeric-coating layer off of the glass-fiber waste and the binder material off of the fiberglass waste.
- ➔ The process can be integrated with existing glass-manufacturing operations.
- ➔ The process has a potential payback of less than two years.

Tasks to be Completed

- ➔ Produce treated glass for testing by industrial partners.
- ➔ Complete evaluation and characterization of recycled products.
- ➔ Develop implementation/ commercialization plan & submit final report.

Future Plans

- ➔ Demonstrate the process at an industrial site.

FY 2001 Milestones

Milestone	Scheduled Comp. Date	Status
Identify "impurity" causing filament breakage	07/01	Done
Complete thermal treatment set-up and start experiments	07/01	Done
Send thermally-treated samples to the industrial partners	08/01	Done
Complete set-up for chemical treatment and start experiments	09/01	Done

2002 Milestones

Milestone	Scheduled Comp. Date	Status
Complete technical & economic evaluation of the thermal-treatment method	3/02	Done
Complete technical & economic evaluation of the chemical-treatment method	5/02	Done
Produce treated glass for testing by industrial partners	08/02	In progress*

*Maybe delayed because the lab for conducting evaluation may not be ready in time.

2003 Milestones

Milestone	Scheduled Comp. Date	Status
Complete evaluation and characterization of recycled products	10/02	
Develop implementation/ commercialization plan & submit final report	2/03	

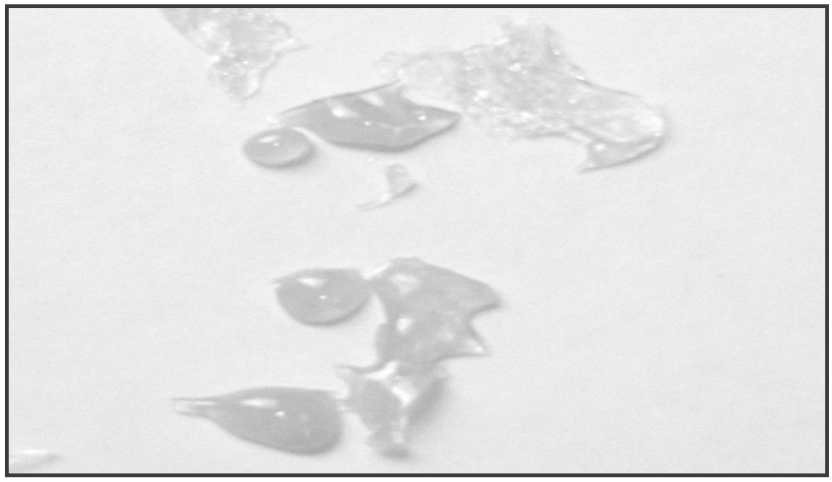
Budget

			Approved Spending Plan			Actual Spent to 6/30/02		
Phase/Budget Period			DOE	Cost Share	Total	DOE	Cost Share	Total
	From	To						
Year 1	7/01	9/01	200	200	400	58,966	4,374	63,340
Year 2	10/01	9/02	200	200	400	219,868	21,148	241,016*
Year 3	10/03	2/03	100	100	200			

***Costs shown as of 6/30/02.**

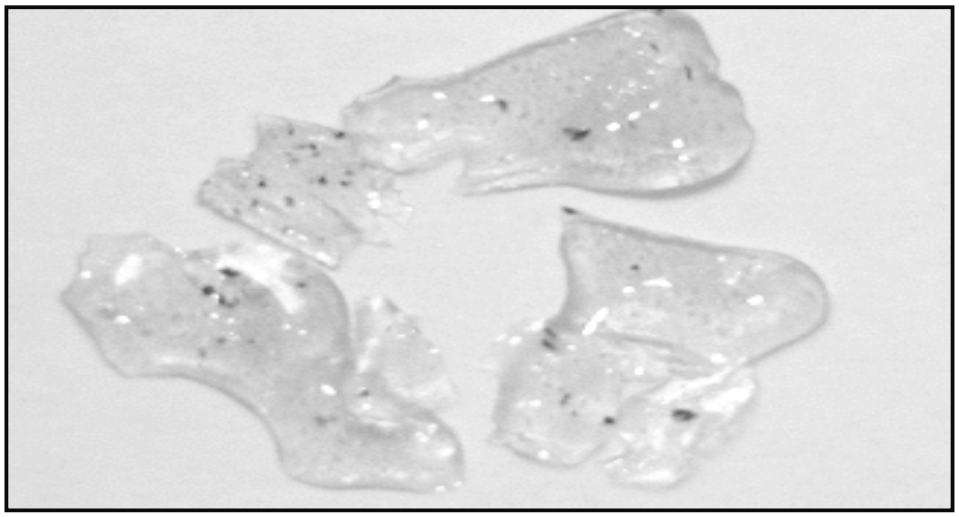
Thermal Treatment of Fiberglass Scrap at Temps. Above the Melting Point of Glass Traps the Solid Particles & Air Bubbles

Thermal Treatment of Fiberglass Scrap at Temps. Above the Melting Point of Glass Traps the Solid Particles & Air Bubbles



Pioneering Science and Technology
ARGONNE NATIONAL LABORATORY A U.S. Department of Energy laboratory operated by The University of Chicago

Thermal Treatment of Fiberglass Scrap at Temps. Above the Melting Point of Glass Traps the Solid Particles & Air Bubbles



Thermal Treatment of Fiberglass Scrap at Temps. Above the Melting Point of Glass Traps the Solid Particles & Air Bubbles

Pioneering Science and Technology
ARGONNE NATIONAL LABORATORY A U.S. Department of Energy laboratory operated by The University of Chicago

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

Jill Aaron
PPG Industries, Inc.

Mark D. Allendorf
Sandia National Laboratories
Livermore, California

Funding from the U.S. DOE/Office of Industrial Technologies
Glass Industry of the Future Team

Program review meeting
Livermore, CA
September 9-10, 2002

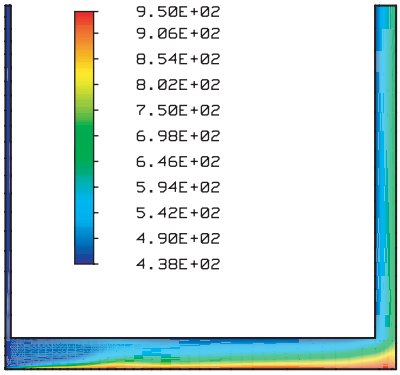
Atmospheric Pressure Chemical Vapor Deposition (APCVD) In The Glass Industry

- **Approximately 110 million ft^2/year of float glass are coated using APCVD.**
- **Primary uses of APCVD-coated glass:**
  - **low-emissivity and solar-control windows**
  - **solar cells**
  - **computer screens**
  - **automotive glass**
  - **xerography glass**
- **The dual pane insulating window market for APCVD coated glass is nearly $600 million. This is only a fraction of the value of the final product considering the framing.**

Molten glass on on a float line prior to APCVD

Tin Oxide APCVD Involves A Complex Mix Of Reactants With Both Gas-phase And Surface Chemistry

- **Deposition conditions:**
  - **MBTC, O_2, H_2O**
  - **High temperatures (600 - 700 ºC)**
  - **Residence times ~ 1-3 sec**
  - **Preheated reactants**
- **Gas-phase reactions play a key, possibly rate-limiting, role in tin oxide APCVD**
  - **Sn-C bond in $Cl_3SnC_4H_9$ = 69 kcal/mol**
  - **C-C bond in C_2H_6 = 91 kcal/mol**
- **Temperature dependent surface reactions affect film uniformity**



CFD simulation of PPG pilot-scale reactor. Temperature scale is in degrees Kelvin.

Optimizing an APCVD Process Presents Numerous Difficulties

- **Low deposition efficiencies lead to**
  - **wasted chemical**
  - **high costs associated with purchase, waste treatment, and disposal of the unconverted chemical ($23 million/year)**
  - **doubling reaction efficiency from ~11% to ~22% would halve this cost**
- **Low process yields due to coating defects result in unproductive energy usage for re-melting the glass**
  - **4.5×10^{10} BTU per year are used to remelt glass due to coating defects**
  - **reducing the fraction of coating defects from 15% to 5% would reduce the amount of unproductive energy usage by ~3×10^{10} BTU per year**
- **Difficulty in scaling new APCVD processes from laboratory to manufacturing facility requires extensive investment of time and money to determine the correct parameters for the manufacturing facility**

Project Objectives

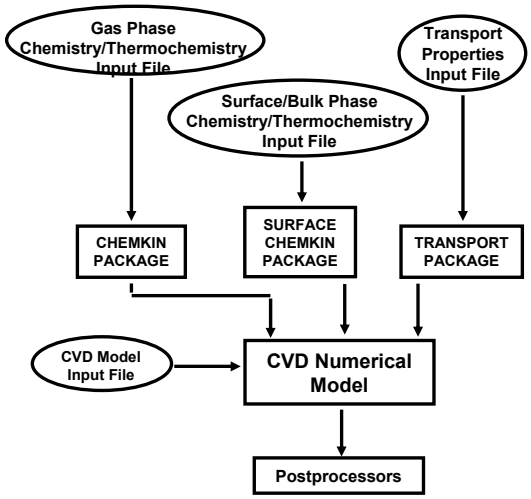
- **Identify modified/new APCVD coater designs that double the efficiency of reactant utilization**
- **Develop validated process models and use them to reduce coating defects (non-uniform coating thickness, haze, chlorine pitting, etc.)**
- **Generate database of fundamental thermodynamic and kinetic information for chemical precursers**
- **Provide enhanced understanding of underlying chemistry and physics of APCVD**

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)**

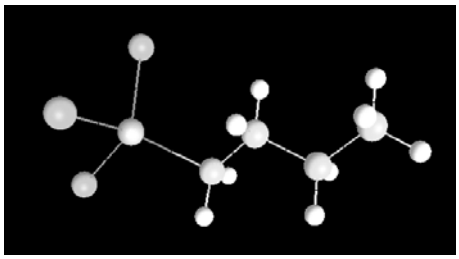
Modeling Chemically Reacting Flows Requires Detailed Information About Chemistry And Transport Processes

Approach to modeling a chemically reacting flow



- **Thermochemistry**
  - **Heats of formation**
  - **Heat capacities**
  - **Entropies**
- **Gas-phase kinetics**
  - **Arrhenius parameters (A, Ea)**
  - **Pressure dependence**
  - **Thermochemistry (to calculate reverse reaction rates)**
- **Surface kinetics**
  - **Deposition kinetics**
- **Mixture transport properties**
  - **Diffusion constants**
  - **Viscosities**
  - **Heat transfer coefficients**
- **Numerical models used to date:**
  - **0-D : CSTR**
  - **1-D : Sandia stagnation-flow**
  - **2-D : Boundary Layer Flow**

Task 1: A Database of Thermodynamic Information For Gas-phase Tin Compounds Is Complete



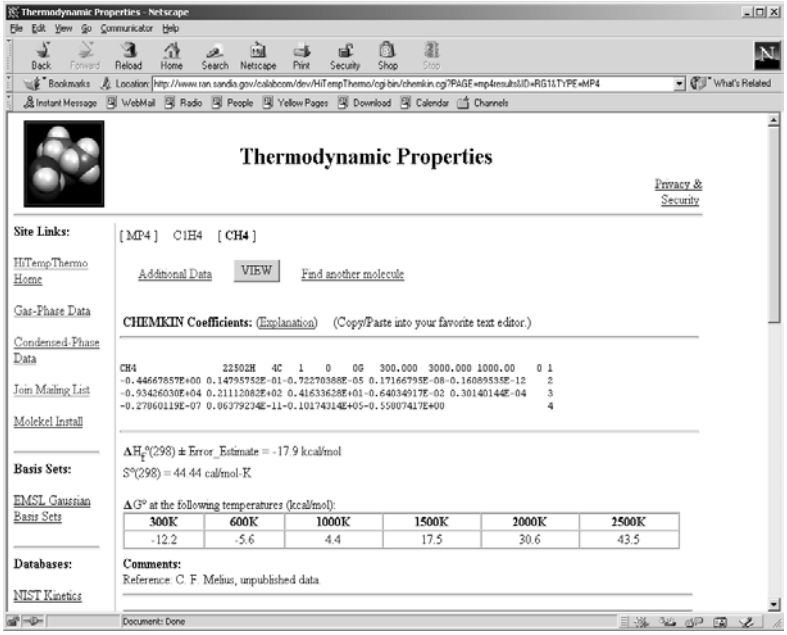
Structure of $C_4H_9SnCl_3$ precursor

Species	Theory	Literature
$Sn(CH_3)_4$	-4.9*	-4.9±0.5
$SnCl(CH_3)_3$	-38.7±1.0	-46.4
$SnCl_2(CH_3)_2$	-68.8±1.0	-70.9±5
$SnCl_3(CH_3)$	-94.1±1.0	-95.7
$SnCl_4$	-114.4*	-114.4±0.5
$SnCl_3$	-59.2±1.3	-69.9±12
$SnCl_2$	-45.3±2.2	-48.4±1.7

*Reference value. All data in kcal/mol.

- Thermochemistry is the foundation for process model development
- Quantum-chemistry methods extended and developed for accurately predicting tin thermochemistry
  - Thermochemistry
    - Heats of formation (±2 kcal/mol)
    - Entropies and heat capacities
- Energies for > 75 tin species calculated to date
  - Bonds to H, CH_3 (and other organics), Cl, OH
  - Predictions are in good agreement with available experimental data
- Several important complexes with water identified:
  - Cl_3SnOH_2 and $Cl_3Sn(OH_2)_2$
  - Cl_2SnOH_2 and $Cl_2Sn(OH_2)_2$
- High-level theory used to calculate data for tin-oxygen compounds

Tin Thermochemical Data Will Soon Be Available On The Web, With Support From The OIT/IMF Program

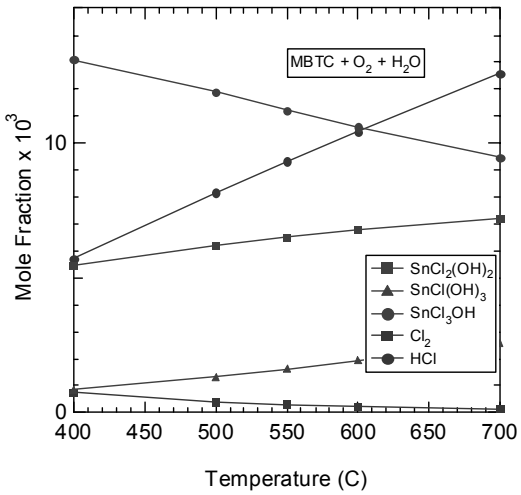


http://www.ca.sandia.gov/HiTempThermo/index.html

Calculated Bond And Reaction Energies Provide Cues To Likely Reaction Pathways

Reaction	ΔH° *
MBTC Decomposition:	
$C_4H_9SnCl_3 \leftrightarrow SnCl_3 + C_4H_9$	69
$SnCl_3 \leftrightarrow SnCl_2 + Cl$	43
Reactions with water:	
$SnCl_3 + H_2O \leftrightarrow Cl_3Sn\text{-}OH_2$	-13
$SnCl_2 + H_2O \leftrightarrow Cl_2Sn\text{-}OH_2$	-21
$Cl_3Sn\text{-}OH_2 + Cl \leftrightarrow Cl_3SnOH + HCl$	-67
Reactions with oxygen:	
$SnCl_3 + O_2 \leftrightarrow Cl_3SnOO$	-28
$SnCl_2 + O_2 \leftrightarrow -O(SnCl_2)O-$ (cyclic)	5

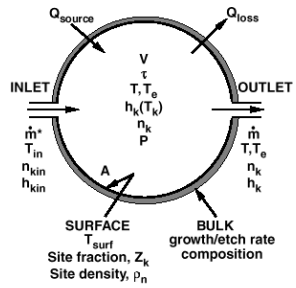
* kcal/mol



Predicted Equilibrium Mole Fractions

CSTR Experiments At TNO Provided The First Experimental Data For MBTC Decomposition Kinetics

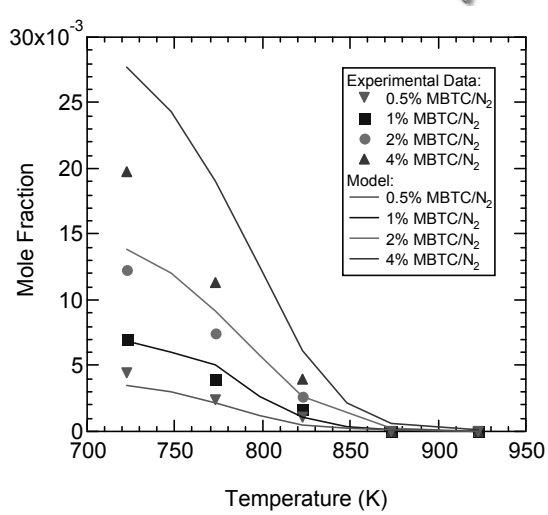
- **Experimental matrix:**
  - **T = 450 - 650 °C**
  - **Pressure = 1 atm**
  - **Vary MBTC at fixed O_2 and H_2O**
  - **Vary H_2O at fixed MBTC and O_2**
- **Key results:**
  - **MBTC completely decomposed at process temperatures**
  - **<u>Pyrolysis</u>: HCl, C_2H_4.**
  - **<u>MBTC+O_2</u>: CO, HCl, C_2H_4, CH_2O formation**
  - **Addition of H_2O dramatically increases MBTC consumption rate (> factor of 2)**
  - **SnO_2 deposition rates also measured**
  - **No SnO_2 forms from MBTC/H_2O**



- **Continuously-stirred tank reactor (CSTR)**
- **1 atm**
- **FTIR species detection (0.1% limit)**
- **Growth rate via microbalance**

Kinetic Model Based On Experimental Data Predicts MBTC Decomposition Over A Range Of Conditions

- **Model includes:**
  - **MBTC pyrolysis**
  - **Formation of hydrocarbons**
  - **HCl formation**
- **Rate constants**
  - **Theoretical predictions (RRKM)**
  - **Literature values**
- **CSTR experiments at TNO used to optimize some rates**
- **Model accurate for typical process conditions:**
  - **450 - 650 °C**
  - **1 atm**
  - **0 - 2.0 % MBTC**



This model provides the basis for predicting MBTC utilization, a key project goal

Task 2: Extensive Measurements Of MBTC Reactions Rates Completed This Year

Continuously stirred tank reactor (CSTR) measurements: TNO collaboration

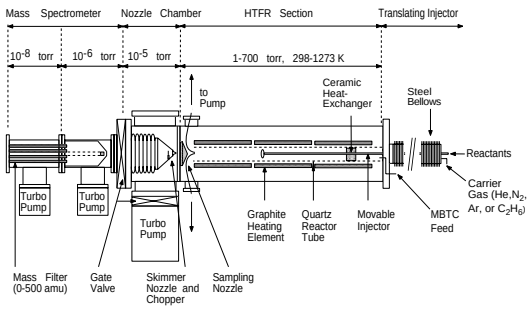
- **MBTC reaction kinetics (1 atm experiments):**
  - **MBTC pyrolysis**
  - **MBTC + O_2**
  - **MBTC + H_2O**
- **Tin oxide deposition rates**

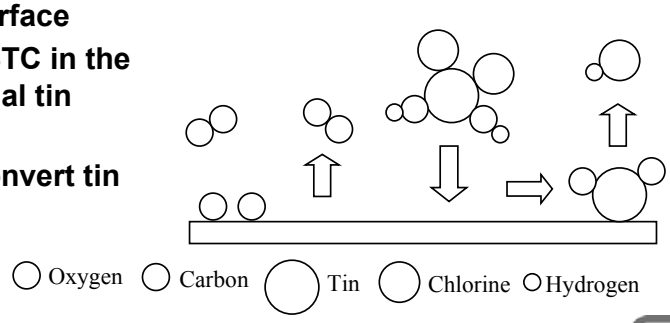
High-temperature flow-reactor measurements (Sandia)

- **Modified experimental system to handle tin compounds**
- **Developed mass-spec detection/calibration scheme reactants/products**
- **Extensive measurements of MBTC decomposition; varied:**
  - **Temperature**
  - **Pressure**
  - **Carrier gas**
  - **Surface-to-volume ratio (to assess wall effects)**
  - **Addition of radical scavengers (e.g., C_2H_6)**

Flow-Reactor Experiments Provide Key Insight Into Deposition Mechanism

- **Condition of reactor walls strongly affects MBTC reaction rate**
- **Walls coated with reaction byproducts (carbon, tin,…) are essentially unreactive**
- **Clean walls react rapidly with MBTC**
- **Possible SnO_2 deposition mechanism:**
  - **O_2 keeps carbon off the surface**
  - **H_2O reacts rapidly with MBTC in the gas-phase to form the actual tin carrier (a tin hydroxide?)**
  - **Rapid surface reactions convert tin carrier to SnO_2**





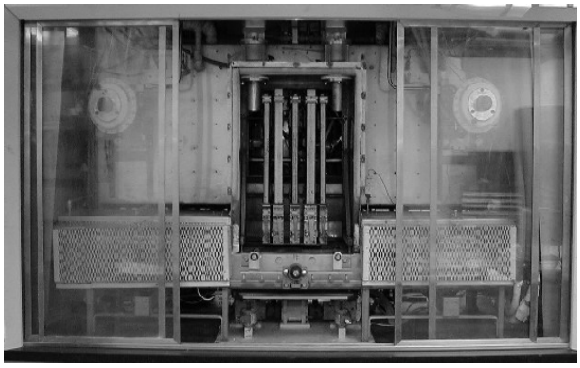
Task 5: PPG's Pilot-scale Coater Provides A Realistic Environment For Model Testing and Validation

Experimental matrix:

- **MBTC + O_2**
  - **Temperature: 600 - 640°C**
  - **MBTC concentration: 0.5-3 vol%**
- **MBTC + O_2 + H_2O**
  - **Temperature: 600 - 660°C (constant MBTC, H_2O)**
  - **MBTC variation: 0.4-1 vol% (constant T and H_2O)**
  - **H_2O variation: 0.8-3.2 vol% (constant T and MBTC)**

Coating Analysis:

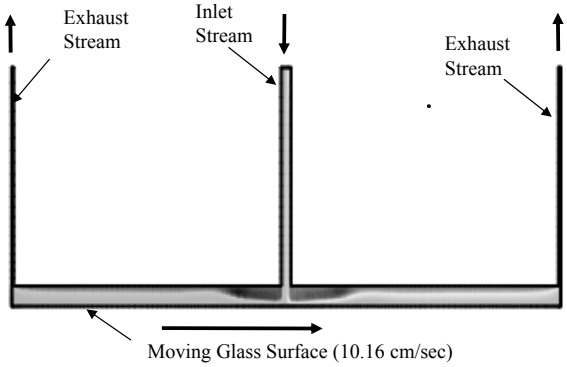
- **Film thickness along centerline**
- **Color map of sample surface**
- **Resistivity measurements**
- **Haze measurements**



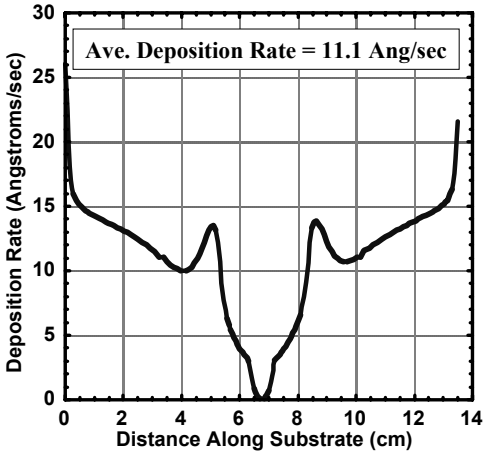
Side view of pilot-scale coater interior

Task 4: Species Transport and Surface Reaction in the Pilot CVD Coater Have Been Modeled Using a Gas-Phase Precursor

Streamlines (color contours) from Pilot Coater Reacting Flow Simulation



SnO_2 Deposition Rate on Glass Surface



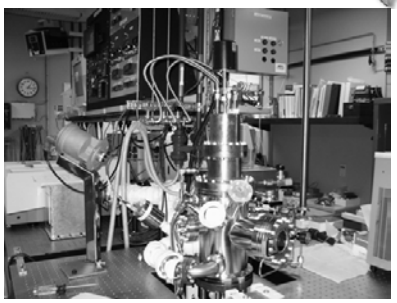
Flowrate = 85 slpm
Pressure = 1 Atm
Gas Inlet Temp. = 450 K
Substrate Temp. = 914 K
Inlet Mole Fractions: 0.5% $C_4H_9SnCl_3$
16% O_2
83.5% N_2

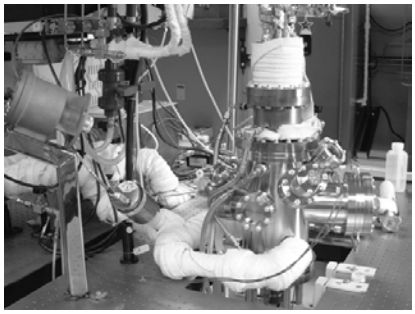
- **Predicted thickness profile qualitatively agrees with experiment**
- **Gas-Phase Reaction**
  $2\ C_4H_9SnCl_3 + 9\ O_2 \rightarrow 2\ SnO_2(g) + 6\ HCl + 8\ CO + 6\ H_2O$
- **Surface Reaction**
  $SnO_2(g) \rightarrow 2\ SnO_2(D)$

Sticking Coef. = 1

New Sandia Reactor Provides An Easily Modeled Environment With Quantitative Process Diagnostics

- Stagnation-flow reactor is complete and on line
- GC/Mass Spec and FTIR diagnostics are interfaced to the reactor
- Liquid precursor delivery systems built and installed
- FTIR gas calibrations complete
- Tin oxide deposition experiments underway

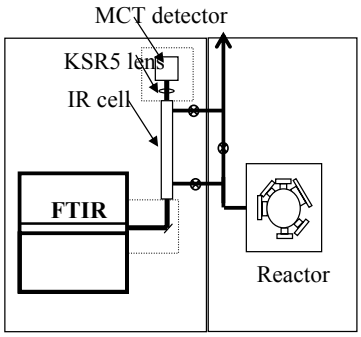


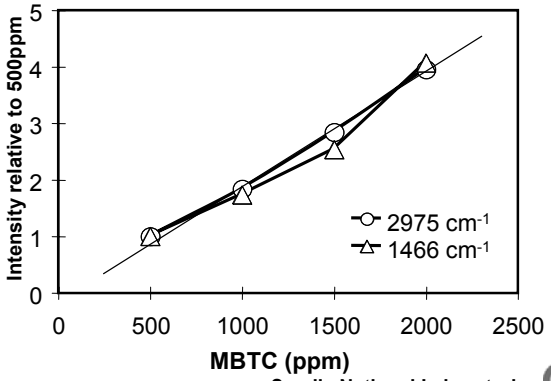


Sandia National Laboratories
Combustion Research Facility

Fourier Transform Infrared Spectroscopy Will Be Used to Monitor Reactants and Products

- Provides adequate sensitivity to
  - MBTC
  - CO
  - C_2H_4
  - HCl
- Utility already demonstrated in previous experiments at TNO
- Transition to GC/MS will provide better sensitivity to products





Sandia National Laboratories
Combustion Research Facility

Task 3: An On-line Monitoring Strategy Is Now In Place

- Gas chromatography appears to be the best option for tin oxide APCVD process monitoring/control
  - Can detect MBTC and major product species
  - Standard analytical technique
  - Interference from complex mixtures can be eliminated
- A GC-Mass spectrometer is on loan to the project from the DOE/BES-Chem Sciences program
- PPG has also located a GC for use in the project

GC/Mass spectrometer interfaced to new stagnation-flow deposition reactor

On-line Coater Effluent Analysis

- Several modifications of the pilot-scale coater at PPG will be made by 10/1/02 for this phase of experimentation
  - Heater directly under coater face will be installed
  - New coater face with channels for oil circulation will be installed to keep coater face at constant temperature
  - Oil circulation system will be installed
  - Gas chromatograph will be added to system to analyze effluent

Summary Of Progress To Date

- Task 1: Deposition mechanism development (in progress)
  - Tin thermochemistry predictions (complete)
  - Gas-phase mechanism (in progress)
- Task 2: Reaction rate measurements (in progress)
  - gas-phase (in progress)
  - Surface (in progress)
- Task 3: On-line coater effluent analysis (in progress)
- Task 4: CFD modeling (in progress)
  - non-reacting pilot-scale (complete)
  - reacting pilot scale (in progress)
- Task 5: Deposition experiments (in progress)
  - PPG pilot-scale measurements (in progress)
  - CSTR measurements (complete)
  - New stagnation-flow reactor (complete)
- Task 6: Validation of optimization strategies

What's Up for FY03 (Spanning Project years 2 and 3)

- Model enhancements and improvements:
  - Predict MBTC oxidation and hydrolysis rates
  - Mechanism reduction for CFD modeling
  - Rate constant adjustments to predict deposition rates more accurately
- Sandia stagnation-flow reactor experiments
  - Deposition rates
  - Improved rate constants for MBTC reaction
  - Development of GC process diagnostic
- PPG pilot-scale experiments
  - Additional data as needed for model development (stationary substrate)
  - GC measurements
- Process optimization strategies
  - Improvements to existing reactor designs?
  - Novel deposition approach?

4

Final Project Evaluation Results and Presentations

Advanced Process Control for TV Glass Manufacture

CL Shepard, KI Johnson, MA Khaleel,
VN Korolev, LJ Kirihara, JT Munley — PNNL

K. Matin, M. Schwenk, A. Hogue,
M. Ehrlich — Thomson Multi-Media

DOE Industrial Program -
Glass Project Review

Livermore, California
September 10, 2002

Overview of Presentation

- Measurement of Stress in Television Glass
  - Measurement concept
  - Laboratory results
  - Instrument concept
- Modeling of Television Glass Forming
  - Heat transport code
  - Coupling with commercial codes
  - Modeling results
  - Parametric studies
- Project Summary

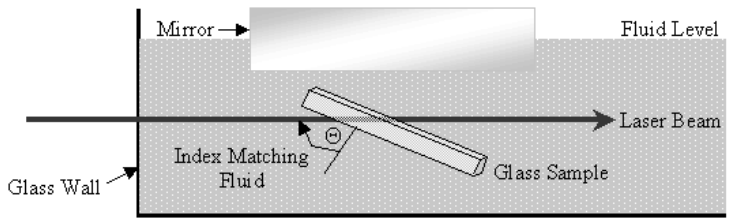
Motivation for the Work

- Reject rates in TV panel production significantly impact energy efficiency and production cost.
- Improved methods of monitoring stress and temperature in glass forming are needed for better process control.
- Processing standards call for limits on residual stress, but accurate methods for predicting stress and its relation to process parameters have not existed.
- A heat transfer code including the contribution of internal radiation in glass has not existed until now. This has limited the accuracy of thermal and thermal stress analysis methods.
- Advanced codes in combination with better diagnostics will allow for improved glass production efficiency.

Measurement of Stress in Television Glass

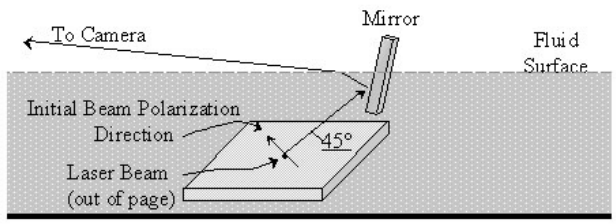
- Method for measuring in-plane stress throughout glass thickness has been developed — results shown
- Method is applicable to other glass products (e.g., auto glass)
- Method is applicable to a plant environment
- Research results submitted for publication in *The Journal of the American Ceramic Society*
- Invention disclosure filed

Diagram of Experimental Arrangement

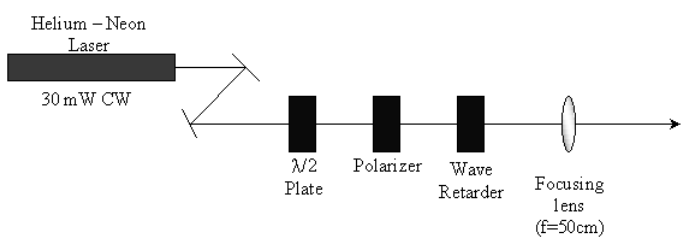


Side view

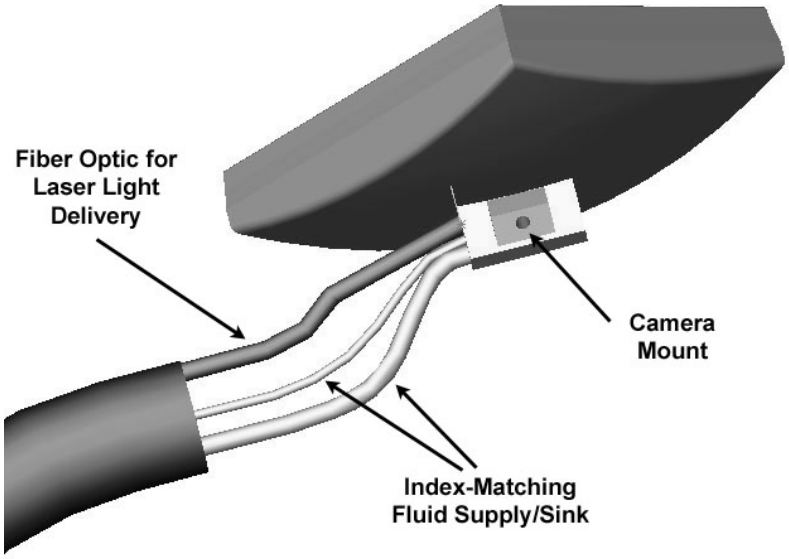
End view



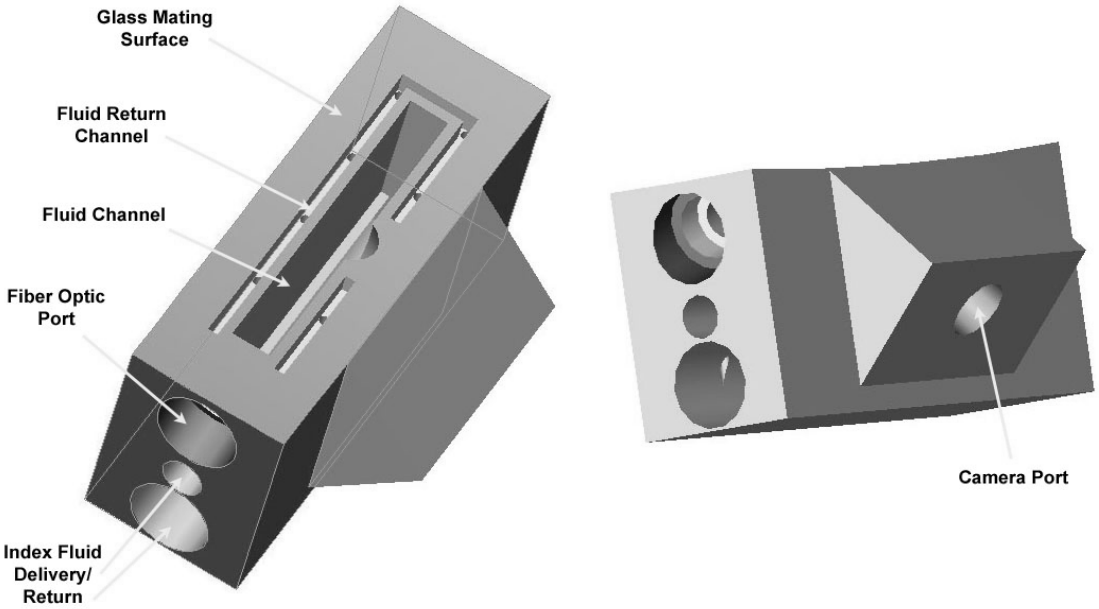
Optical Elements Used for Polarization of Laser Beam



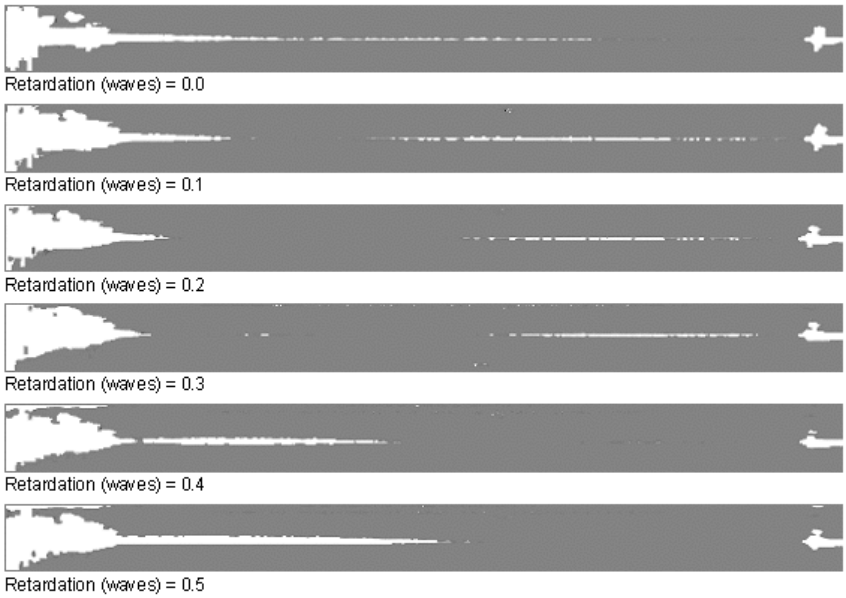
Concept for Plant Stress Measurement Instrument



Concept for Plant Stress Measurement Instrument (cont'd)



Images of the Laser Beam Formed from Rayleigh Scattered Light Propagating Through the Glass



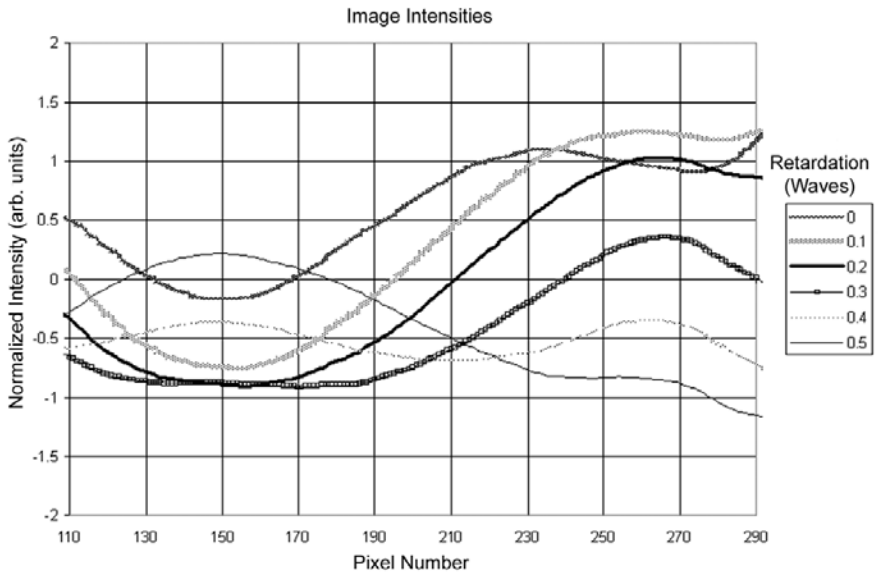
Theory – Image Intensity at Any Image Location Depends on Integrated Stress and Known Compensator Settings

$$I_i(x) = \frac{I_o}{2}\exp(-\alpha x)[1+\cos(\Phi(x)+\eta_i)]$$

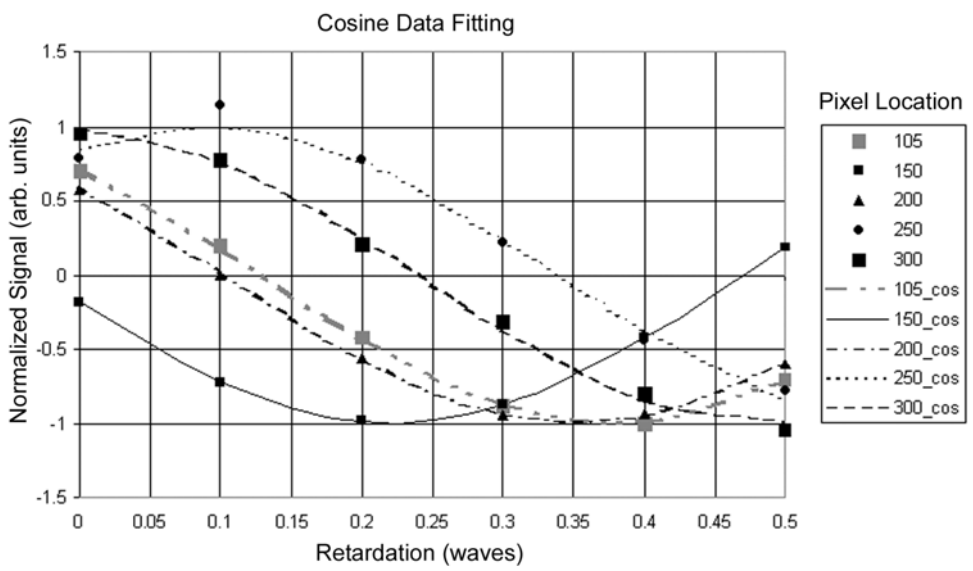
- Plot of intensity [I_i (x)] vs. compensator setting (η_i) allows determination of Φ(x), the integrated stress up to location x.
- The stress S(x) is determined from:

$$S(x) = \frac{\lambda}{2\pi B \sin^2\theta}\cdot\frac{d\Phi(x)}{dx}$$

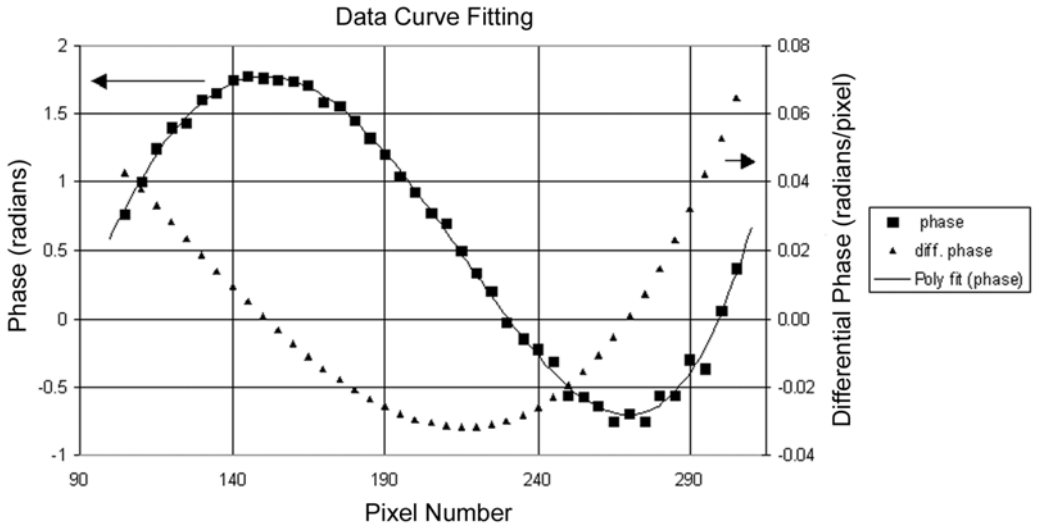
Plots of Normalized Light Intensity vs. Image Location Obtained from Images



Plots of Normalized Image Intensity vs. Compensator Retardation Settings at Specific Image Locations

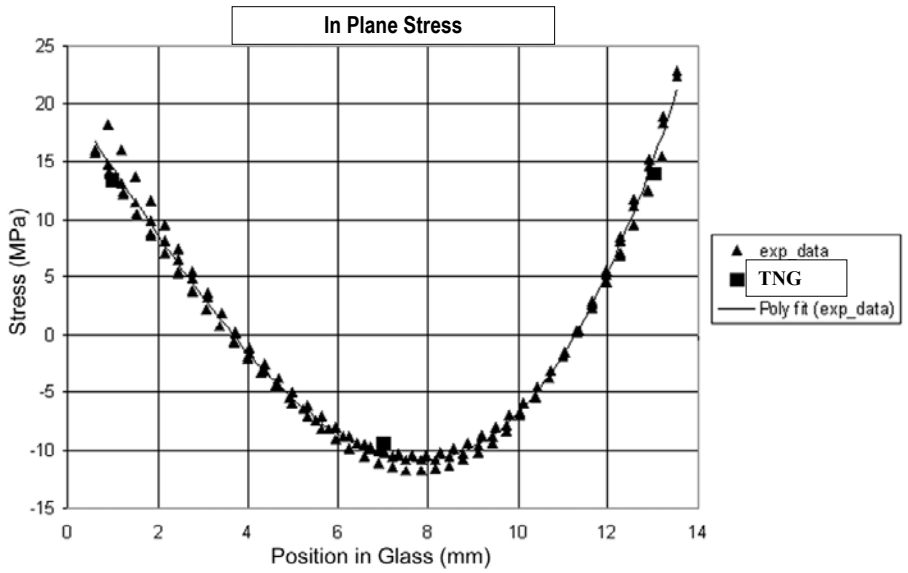


Initial Phases Determined from the Image Data vs. Position in Glass



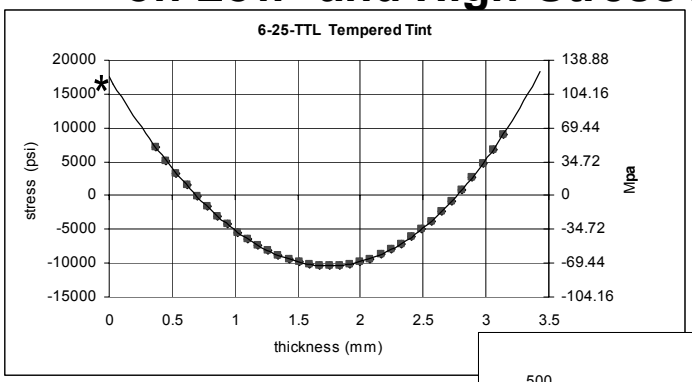
Battelle

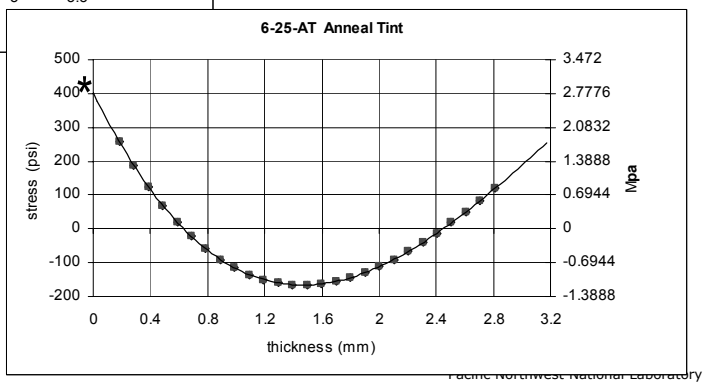
Plot of the In-plane Stress Through the Thickness of the TV Glass Sample



Battelle

In-plane Stress Measurements Through the Glass Thickness have been Achieved on Low- and High-Stress Automotive Glass



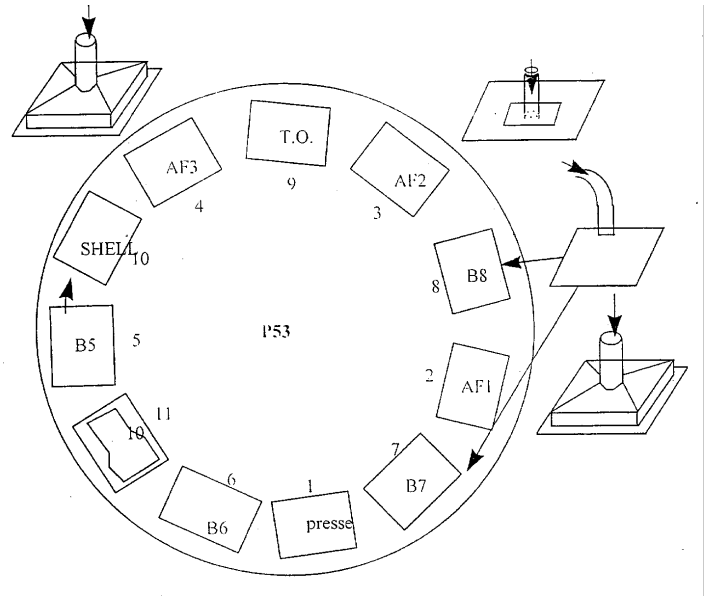


* = GASP Measurements

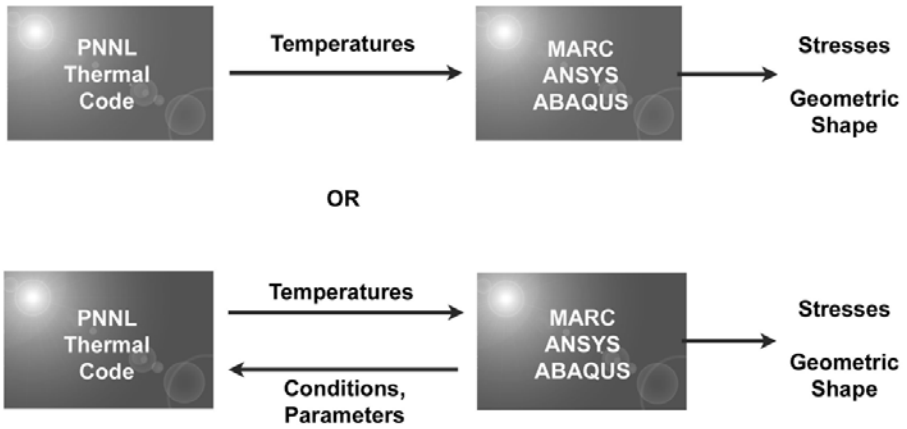
A Finite Element Heat Transport Model Has Been Developed for the Cooling Stages of the Eleven-Step Forming Process

1. Press – forms panel
2. Air former 1
3. Air former 2
4. Air former 3
5. Shell Take Off
6. Air Pipe 6
7. Air Pipe 7
8. Air Pipe 8
9. Panel Take Out
10. Shell Transfer
11. Glass gob loaded

Cooling Stages



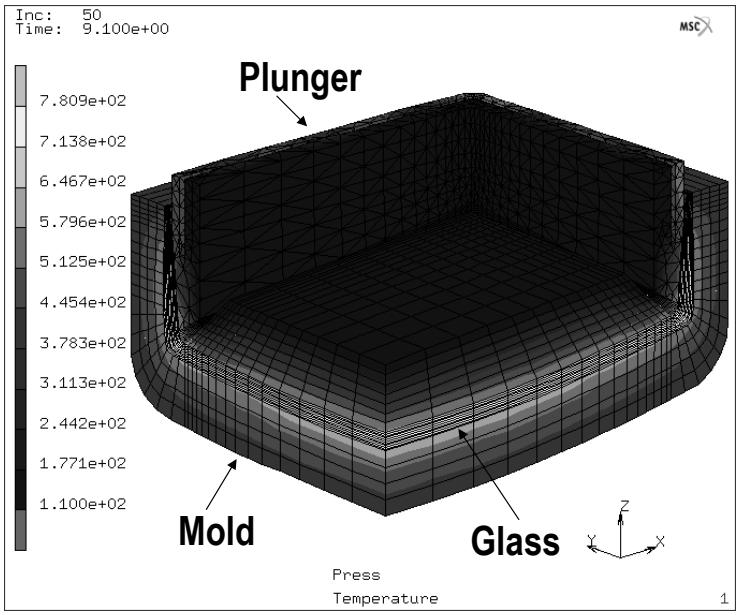
PNNL Thermal Code Links with Any Commercial Visco-Elastic Code



The 3-D TV Glass Cooling Model

Part	Nodes	Elements
Mold	2520	1860
Shell	3131	2340
Plunger	5169	10101
Glass	7931	6750
Totals	18596	21051

10 Elements through the glass thickness capture temperature and stress gradients

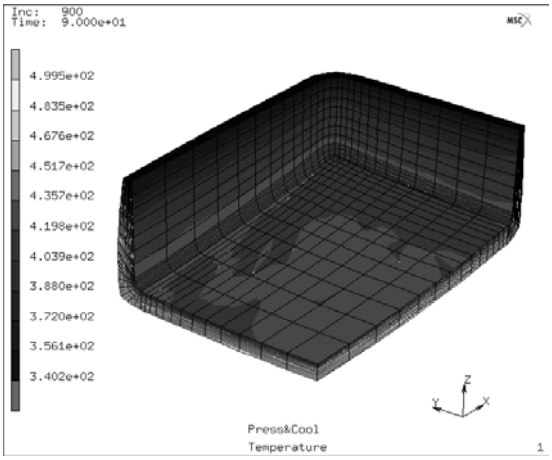


Comparison of Solution Times - 3D Model (Quarter Symmetry)

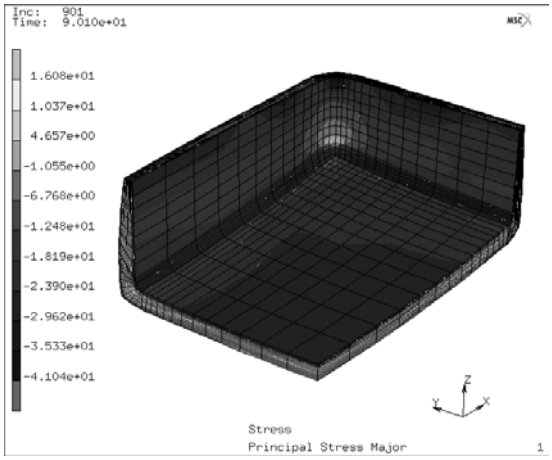
Model	Real Time	Solution Time
Commercial code with effective thermal conductivity with contact	90 sec	16 hrs
PNNL code with internal radiation solution and with contact	90 sec	50 min
PNNL 1D model + Commercial code, 40 elements total	5210 sec	10 min

Model Temperatures and Stresses at the End of the Panel Cooling Cycle

PNNL Thermal Solution

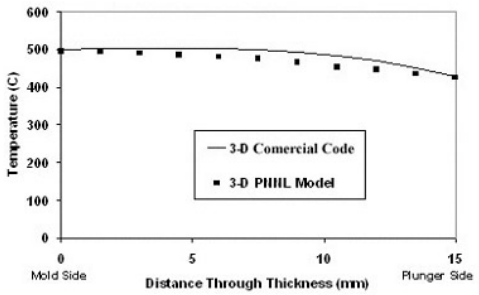


Commercial Code Stress Solution

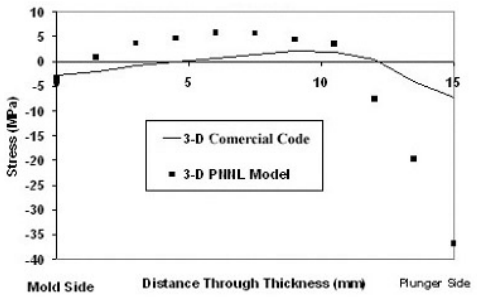


Comparison of Results from 3-D Effective Thermal Conductivity and PNNL Thermal Models

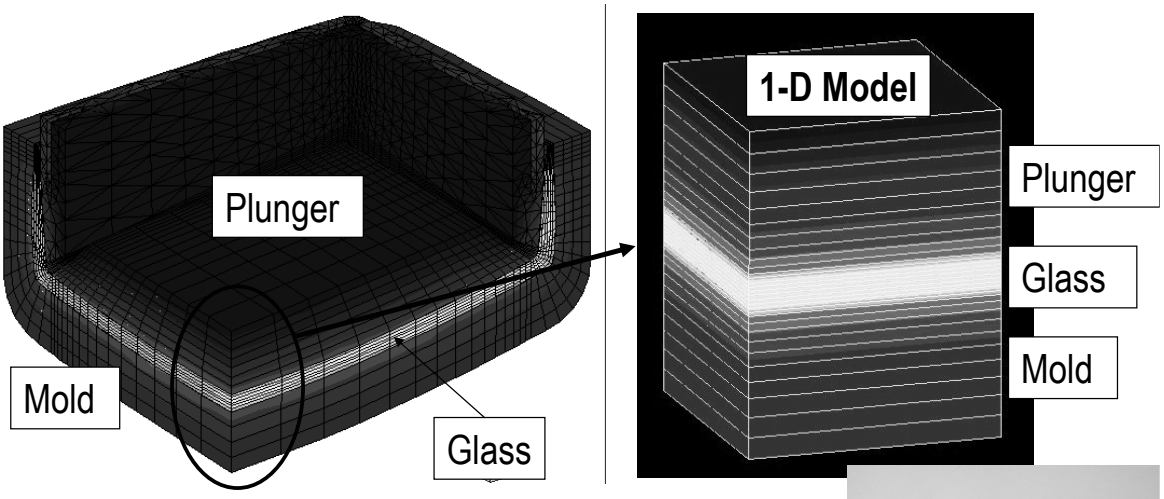
Temperature at End of Panel Cooling



Stress at End of Panel Cooling



The 1-D Model of the Panel Center



The 1-D model was used to simulate cooling and annealing

Model Variation of Process Parameters

- 1D code calculations were performed with variations of:
  - Forming/annealing time
    - increased 10%
    - decreased 10%
  - Initial gob temperature
    - increased 50°C
    - decreased 50°C
  - Convective film coefficients
    - increased 50°C
    - decreased 50°C

Project Summary

- Project Duration: ~ 3 years
- Project Cost (DOE/Industry): ~ $900K/$900K
- Results:
  - Three tools have been developed under this project:
    - temperature measurement (described in earlier reports)
    - stress measurement
    - finite element model
  - Tool characteristics:
    - novel (none available three years ago)
    - broad industry application
    - applicable for plant use

Auto-Glass Process Control - Modeling and Simulation of Glass Forming

VN Korolev, KI Johnson, CL Shepard,
MA Khaleel — PNNL

R Rueter, PPG

M Brennan and Ed Boulos, Visteon

DOE Industrial Program -
Glass Project Review

Livermore, California
September 10, 2002

Project Objectives

- Optimize furnace construction for energy efficiency
- Minimize rejection rates of new products
- Enable manufacturing of complex windshields

Objectives met through development of numerical models that model the furnace and forming of glass

Project Tasks

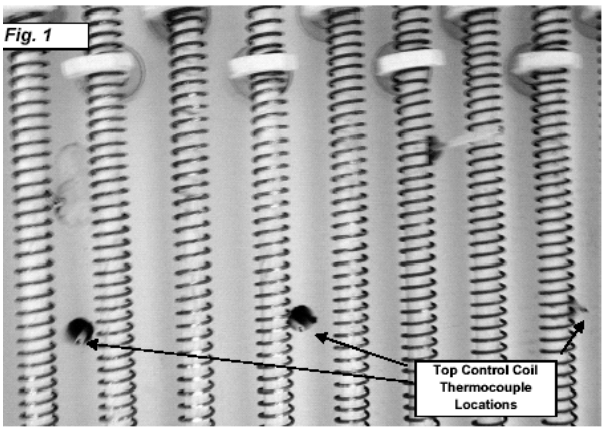
- Task 1 - Instrumentation of experimental furnace at PPG and collection of data
- Task 2 - Development of versatile modeling tool for furnace optimization and glass thermal analysis
- Task 3 - Model coupling to commercial codes
- Task 4 - Model validation

Task 1 - Instrumentation/Testing of PPG Experimental Furnace

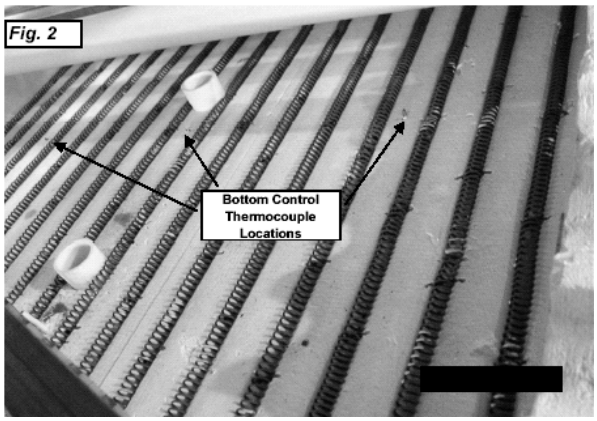
- Furnace
  - Single zone electric furnace
  - Central rolls removed, replaced with gravity sag glass frames (3)
  - 35 data channels recorded with 1-second intervals
    - 8 power meters for 8 electrical coil sections (3 at furnace top, 5 at furnace bottom)
    - 8 control thermocouples corresponding to coils
    - 10 thermocouples in various locations within furnace
    - 6 thermocouples attached on top and bottom of 3 glass sections
    - 2 thermocouples on outer skin of furnace
    - 1 thermocouple for measuring ambient temperature

Thermocouple Location for Control Coils

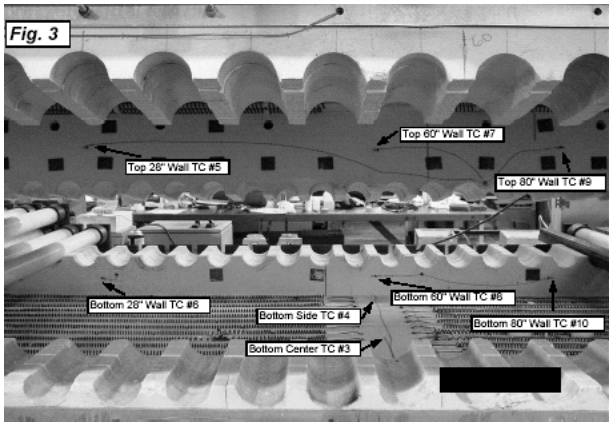
Roof

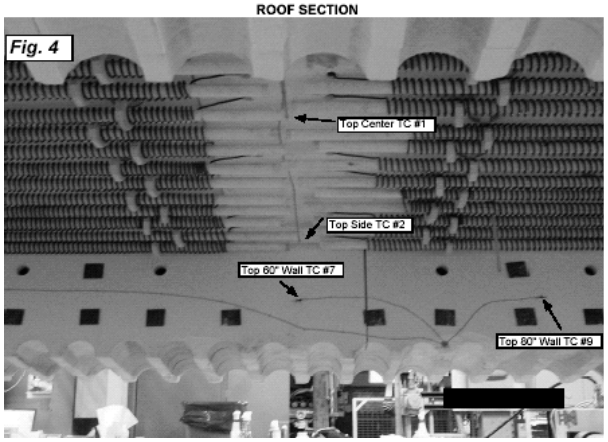


Floor



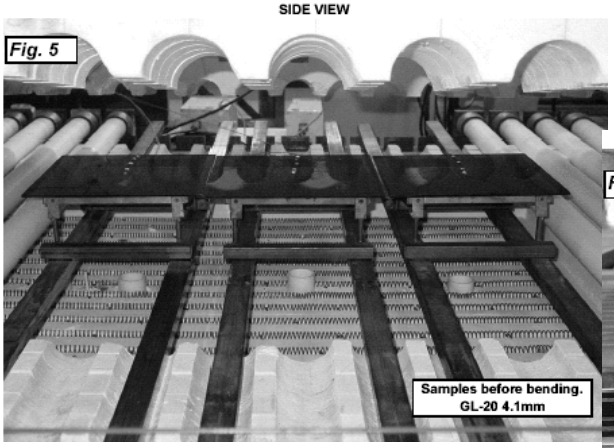
Furnace Thermocouple Locations





Glass Samples and Frames within Furnace

SIDE VIEW



VIEW FROM EXIT END

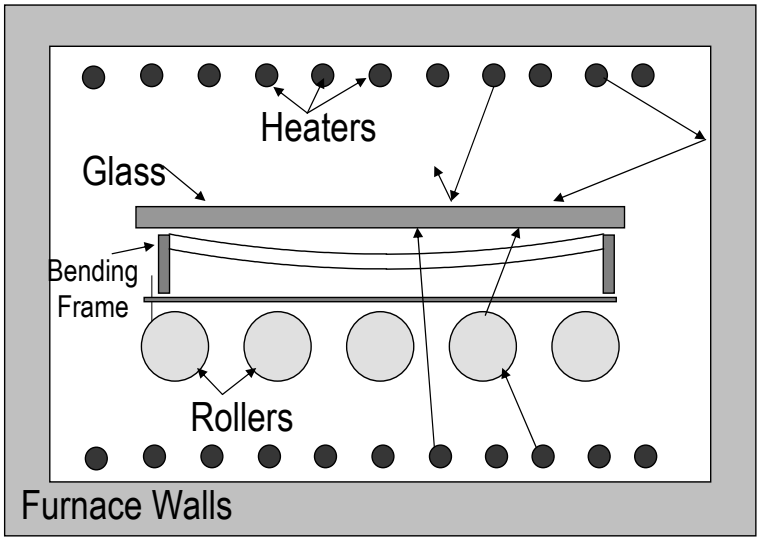
Experimental Procedure

1. Prepare glass samples by cementing thermocouples on top and bottom surfaces
2. Close furnace roof, insulate all holes
3. Heat oven from ambient to 900°F over 5 hours
4. Increase oven temperature to 1000°F over 1 hour
5. Increase oven temperature to 1050°F over 1 hour
6. Remove power after another hour

Glass Samples Used in Experimental Studies

- 4.1 mm Type GL-20
- 2.3 mm Clear single ply
- 2.3 mm Solex single ply
- 2.3 mm Clear double ply
- 2.3 mm Solex double ply

Description of the Furnace Heating Model



Heaters
- uniformly distributed planar heat source

Walls
- diffuse radiation to and from walls
- heat conduction through layered walls with convection on the outside

Glass
- specular reflection on the surface
- DOM for heat transfer in glass (1-D and 2-D through thickness and plane of glass respectively
- conduction solved implicitly

Rollers
- omitted at this point
- moving temp field with fixed mesh for rollers

Efficient Numerical Methods

- Lighting Network (interactive sub-domains with complete physics and information sharing) used as the framework for radiative heat transfer simulation
- Explicit Runge-Kutta-Chebyshev Methods with extended real stability intervals used for transient simulation
- Hierarchical clustering (adaptive patch sizing) for the global Illumination from/to furnace walls
- Result: Simulation of 3-hr furnace heating experiment can be simulated in 30-minutes on a 2.8Ghz PC

RAD3D Benchmarking: PPG Model of Radiant Heating in Glass

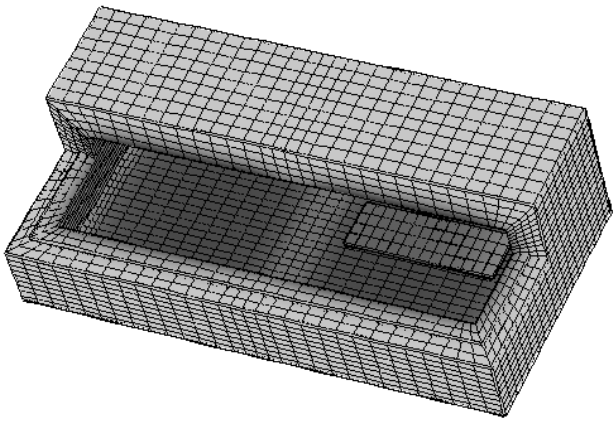
Model Size

15770 Nodes

12512 Elements

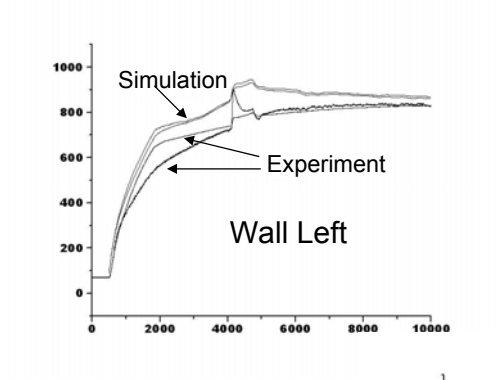
10 Nodes through the glass thickness to capture internal radiation

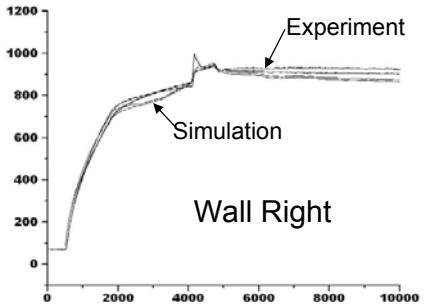
10,000-second transient simulated

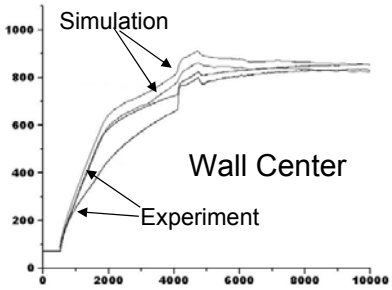


PNNL Model of PPG Single zone furnace.

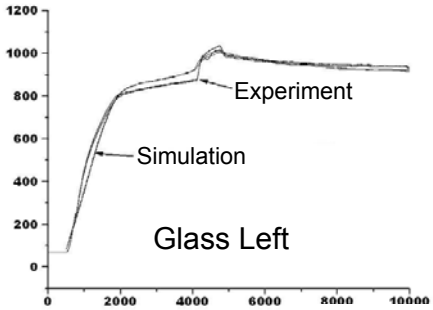
Comparison of Experimental and Model Furnace Wall Temperatures vs. Furnace Heating Time

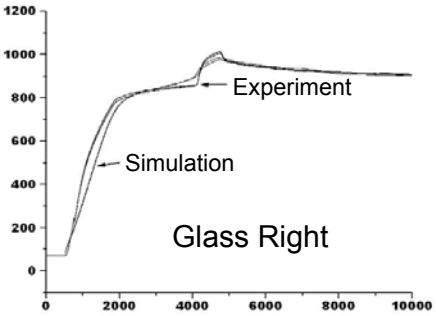


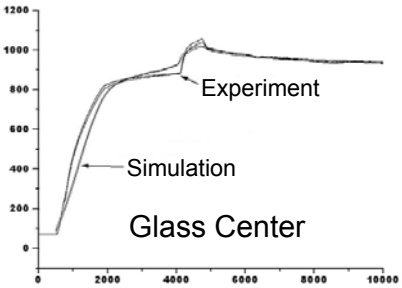




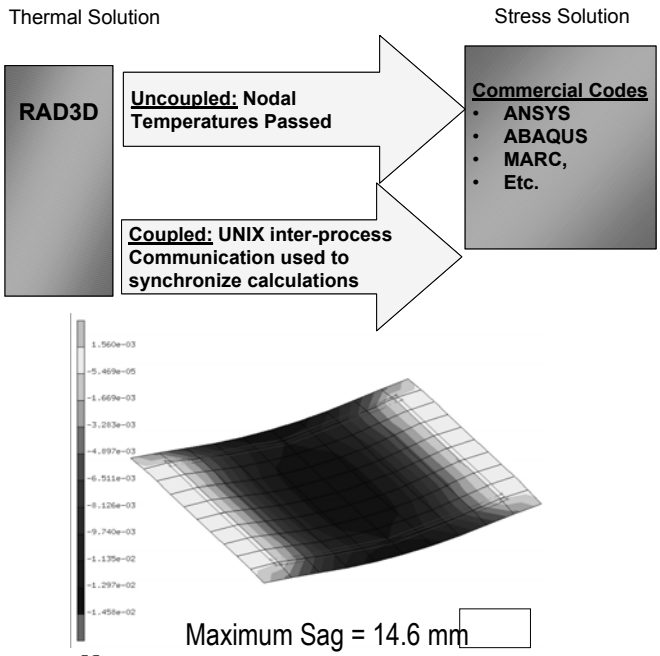
Comparison of Experimental and Model Glass Temperatures vs. Furnace Heating Time







Integration of Thermal Solution with Commercial Codes



- RAD3D uses Unix Interprocess Communication (IPC) for coupling with commercial codes.
- C++ classes support shared memory operations and semaphors.
- RAD3D can run concurrently with any number of commercial codes using the synchronization logic in RAD3D.
- Socket-based communications are being developed to allow RAD3D to communicate through the internet.

Model Capabilities

Near Future

- Multi-layered glass with surface coatings.
- Proper accounting for gaps between glass layers.
- Discrete models for multiple heat sources.
- Inclusion of rollers in models.

Far Future

- Multiple boundary conditions for furnace walls – diffuse and specular reflection (for new furnace materials to direct heat in coated glass without damage to the coating).
- Microwave and other advanced heating methods (selective and energy efficient heating)

Summary

- Past accomplishments include development of: novel non-contact measurement methods and initial numerical codes.
- A first of a kind experimentally validated computer code for glass product forming and furnace development/ optimization has been developed.
- The computer code is versatile (runs on multiple hardware platforms and couples with multiple commercial codes) and computationally efficient (*fast-faster than real time*).
- With remaining resources, we will conclude experiments and near term modeling efforts.
- Gonna have a workshop on code usage, wanna attend?

Electrostatic Batch Preheater System Demonstration ("E-Batch")

USDOE
Office of Industrial Technologies
2002 Glass Industry Project Review
Neil G Simpson - Principal Investigator
Carl Schatz - Former PI
Jeff Alexander - Technical Manager

Summary

- Leone Project Status
- E-Batch Overview
- Project Goals
- Gallo Testing
- Impact on Design
- The E-Batch Future

Progress and Status of Work - Overview

- DOE contract awarded to BOC June 28, 2001
- Design and validation of design are 95% complete as of 9/30/01
- BOC has held two meetings with NJ environmental permitting authorities
- Delay in submitting permit application has delayed the project
- All big ticket items are on hold until Leone's permit application is submitted and approved
  - estimate submittal December 01
  - estimate approval March 01
  - project schedule has been adjusted accordingly....

- BOC starts to approach potential alternate host sites in December 2001
- DOE requests go/no go decision by April 15th
- 5th April(am) Leone advises BOC that it will not apply for a permit.
- 5th April(pm) unable to find an alternate host site in US, BOC regrettably advises DOE that project will not proceed in US and declines further DoE funding

E-Batch Overview

Patented "One Box" Solution for

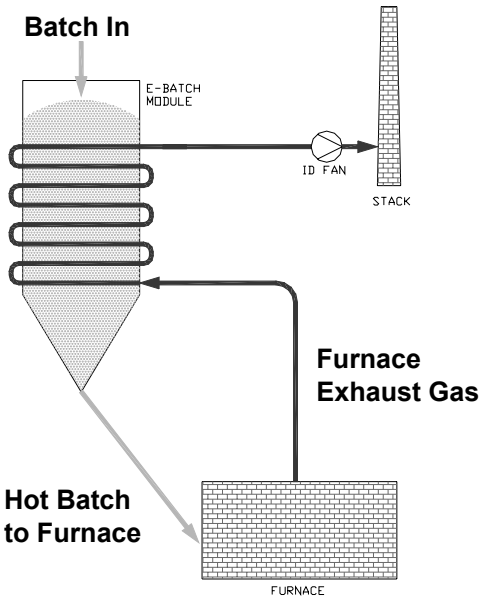
- Batch + cullet preheat
  - using furnace exhaust gases
- Particulate + SOx control

Performance Features

- Batch/cullet preheat to 750°F (400°C)
- 90% Particulate reduction
- 60% SO_x reduction

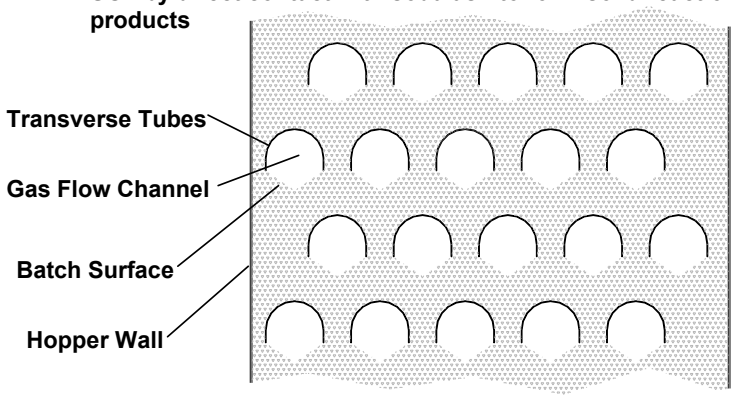
Benefits to User

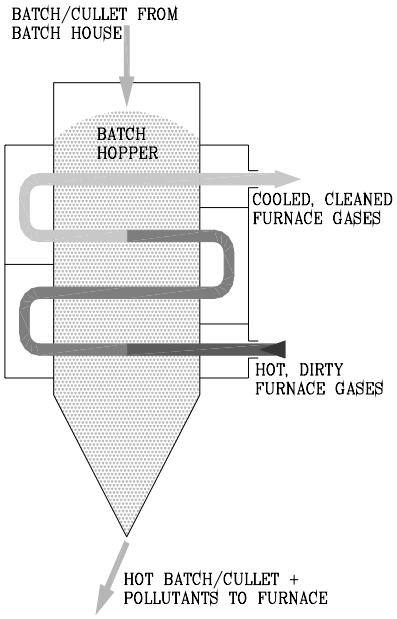
- Compliance with EPS-NSPS, IPPC
- 10-20% reduction in energy costs, or
- 10-20% increase in pull rate



E-Batch Concept

- Hot furnace gases flow through channels in hopper
- Heat transfer by direct contact with batch
- Cross/counterflow of gases
- Pollutants captured and deposited into batch
  - PM by electrostatic capture
  - SO2 by direct contact with soda ash to form solid reaction products





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Goals of OIT Demonstration Project

- Construct a full sized system
- Operate the system long term (24 months)
  - determine/resolve operability issues
  - confirm basic engineering results (nuts and bolts)
  - confirm broader engineering results (melting process interactions)
- Confirm the economics....
- Provide the fundamentals for commercializing the technology in Glass

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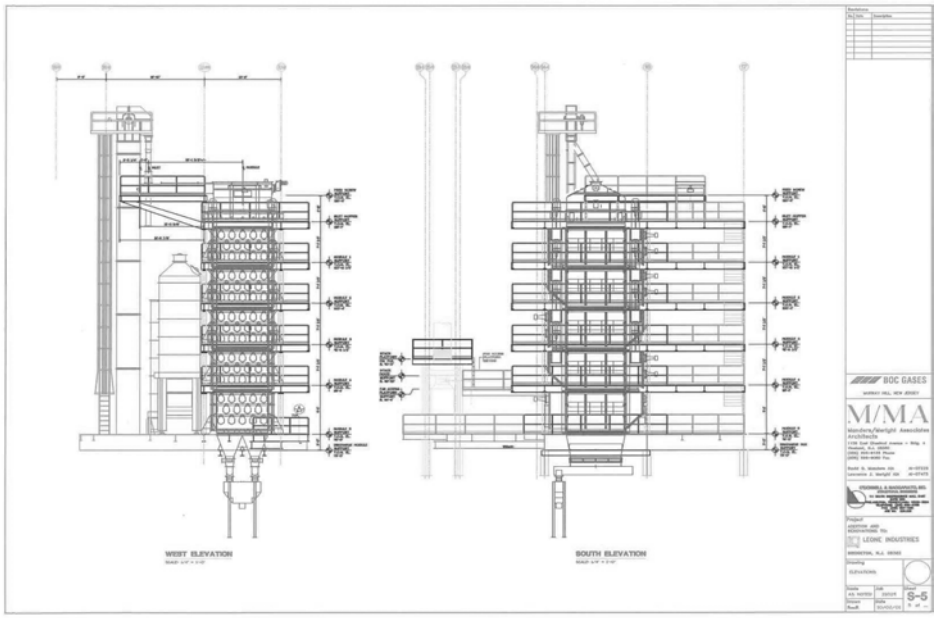
Technical Reporting Deliverables (quarterly after startup)

- **Heat recovery**
  - quantitative determination of E-Batch effect on amount of waste heat recovered from an oxy-fuel furnace and the resultant effect on the furnace's input energy.
- **Emissions abatement**
  - quantitative determination of E-Batch functionality as an emission control device.
- **Capacity vs size and cost data**
  - quantitative determination of E-Batch projected costs with respect to a range of furnace capacities as normally used in the glass industry and taking into account the waste heat, emission control information and as-built cost and size at Leone.
- **Maintenance**
  - quantitative determination of E-Batch maintenance requirements and costs.
- **Operation**
  - qualitative determination of operability issues of E-Batch.
- **Effect on furnace**
  - quantitative determination of the effect of highly preheated batch on furnace operation, control, and glass quality.
  - quantitative determination of the effect of highly preheated batch on furnace refractory structure.

System Design and Construction Planning

- System engineering, P&ID's
- Detail engineering
  - shop drawings
  - purchase specs
- Structural and field related design
- Process safety and hazop reviews (with Leone)
- Execution/construction plan
- Bids and cost confirmation

Elevation View



Evaluated E-Batch over EP/Scrubber Systems

- **Energy savings**
  - **10 - 20% in oxy-fuel furnaces**
  - **8 - 12% in air-fuel furnaces**
- **Increased productivity**
  - **believe it can be gained in trade for fuel savings**
  - **10 - 20% in oxy-fuel furnaces**
  - **8 - 12% in regenerative air-fuel furnaces**
- **Simpler design**
  - **fewer ductwork requirements**
  - **no dust handling system required**
- **Equivalent air pollution control**
  - **95% dust abatement (comparable with EP)**
  - **56 - 66% SOx abatement (comparable with Scrubber)**

E-Batch Demonstration Project Costs ($000)

FY	OIT	BOC	Total
2001 (act.)	121.6	121.6	243.2
2002 (act.)	30.0	41.5	71.5
Totals	*151.6*	*163.1*	*314.7*

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E-Batch Development Program

Lab testing

- √ BOC's Holbrook UK facility
- √ Demonstration of concept at 3 tpd
- √ Demonstration of batch retention by electrostatics
- √ Measure basic heat transfer parameters

Pilot plant

- √ Gallo Glass in US
- √ Slipstream of oxy-fuel furnace exhaust
- √ 12 tpd capacity
- √ Measure particulate and SOx collection
- √ Demonstrate continuous operation

Beta Unit

- – Full scale permanent installation
- – 100-200 tpd capacity
- – Demonstrate effects on furnace operation

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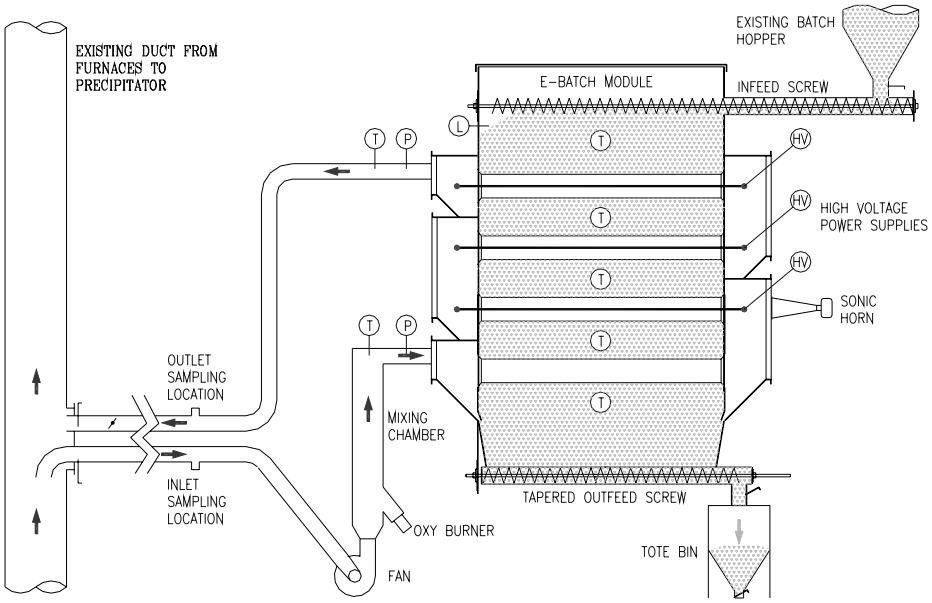
Pilot Unit Test at Gallo Glass



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Gallo Glass Pilot Unit Setup

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Pilot Unit Preheat Results

Operation

- Material throughputs from 6.0 - 14.4 US tpd (5.5-13 mtpd)
- Gas flow rates from 10,000 - 30,000 SCFH (264-792 Nm^3/h)
- Cullet ratios from 0 - 100 %

Preheat Results

Gas inlet	950°F (510°C)	1050°F (566°C)	1150°F (621°C)
Batch outlet	620°F (327°C)	720°F (382°C)	810°F (432°C)

Pilot Unit Emission Results

Gas flow volume (Nm^3/h):	264	528	792

SOx Results

– Inlet avg. (mg/Nm^3):	1089	1302	1262
– Outlet avg. (mg/Nm^3):	144	502	461
– Efficiency (%):	87%	61%	63%
– Projected (kg/tonne):	0.29	1.0	0.92

IPPC limit = 1.8 kg/tonne

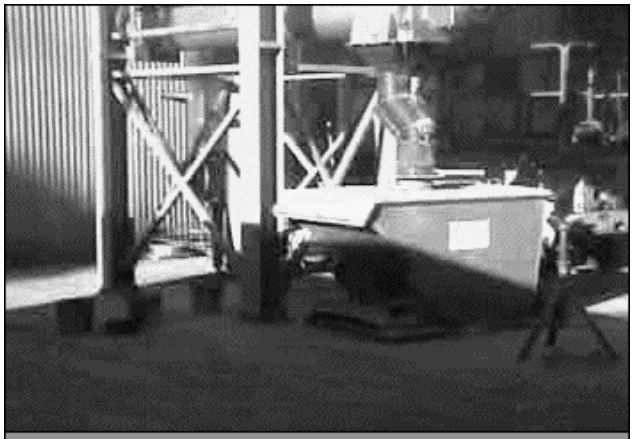
Particulate Results

– Inlet avg. (mg/Nm^3):	258	322	290
– Outlet avg. (mg/Nm^3):	3.86	9.66	20.9
– Efficiency (%):	99%	97%	93%
– Projected (kg/tonne):	0.0077	0.019	0.042

IPPC limit = 0.1 kg/tonne

Pilot Unit Demonstration

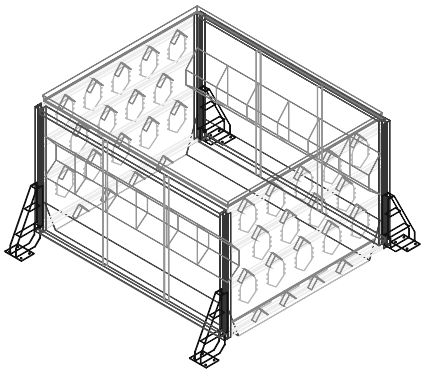
- High temperature structural integrity of tubes and electrodes verified
- High voltage: stable, non-sparking operation
- "On-line" method of cleaning electrodes and tube internals demonstrated
- Hopper mass flow demonstrated
- 11 day continuous run
- Reliable material flow - no pluggages
- Cullet ratios from 0% to 100%
- Cold start-ups and shut downs
- Inlet gas temperature up to 1150 F
- No batch / cullet segregation observed
- No adverse effects on glass melting
- Typical soda-lime container batch
- Input material moisture < 1%
- Oxy-fuel furnace exhaust gases
- Low dP confirmed

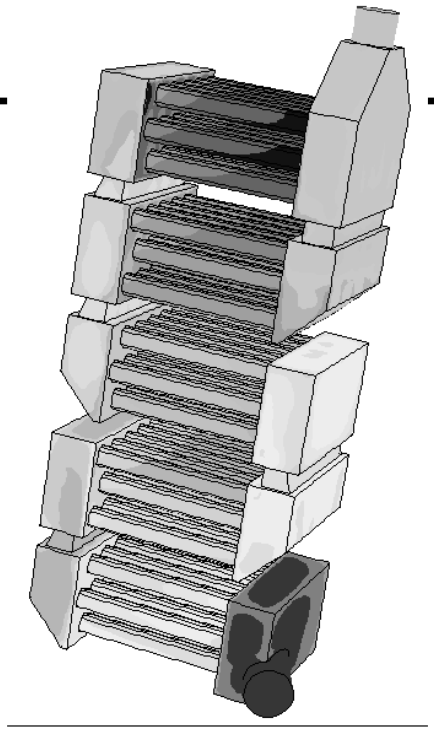


515cut

Computer Modeling

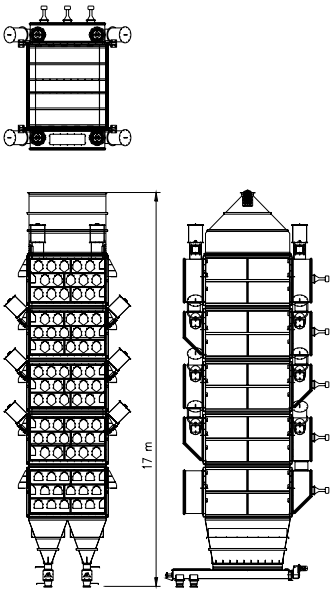
- Optimize flow distributions
- Plenum design
- Determine dP <0.5" w.c. (10 mm w.c.)
- Verify heat transfer rates
- Structural integrity of modules





Original 200 tpd Beta Unit Overview

- About 12 x 12 x 55 feet tall
- Constructed of 5 individual modules
  - 4 electrostatic zones, 3 required
  - bottom zone preheat only
- Holds ~200+ t. mixed batch and cullet
  - any cullet ratio
- Expect to prove that this unit will be well oversized for a 200 tpd furnace
- Expect this size to handle a 400 tpd oxy fuel furnace
  - NSPS particulate levels
  - to 800 deg F preheat



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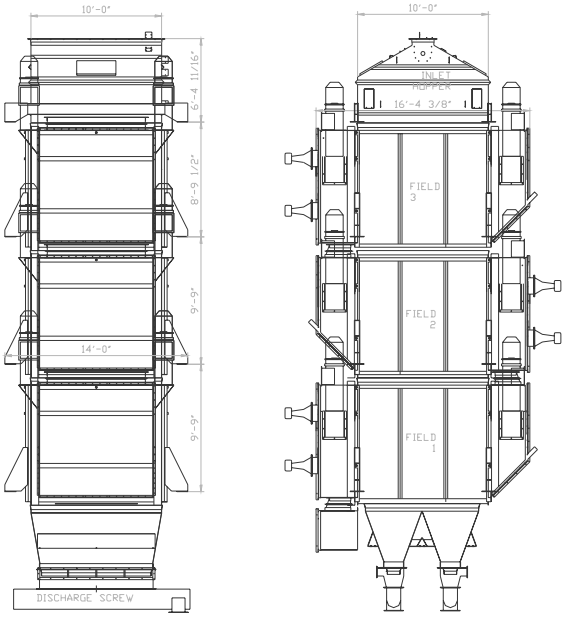
New Equipment Design (Smaller - Lower Cost)

- Furnace size
  - 220 mtpd air fuel
  - 420 mtpd oxy-fuel
- IPPC performance
- Three module stages
- Sonic Horn cleaning on-line
- Standard HV components
- Mass flow discharge hopper
  - dual chisel hoppers
  - tapered screw feeders
- Upper surge hopper, 40 ton
- Loaded weight: 212 tons



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The E-Batch Future

- Significant interest from European Glass Industry
- New European environmental legislation (IPPC) becoming more stringent than US
- Requirement for PM abatement on new and re-built furnaces
- Climate Change Levy - Carbon/CO2 Tax - Kyoto
- Incentives (75%Tax Rebates) available for improved energy efficiency
- Potential Beta site in UK by a consortium of Glass Container Manufacturers to meet both environmental and energy efficiency requirements
- EPA Hurdles in US still a concern to US Manufacturers combined with concerns of being first to try a new technology.

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HIGH-HEAT TRANSFER LOW-NO_x NATURAL GAS COMBUSTION SYSTEM

by

David Rue, Hamid Abbasi

Gas Technology Institute

Val Smirnof, Dan Wishnick

Combustion Tec / Eclipse

2002 Project-Industry Review

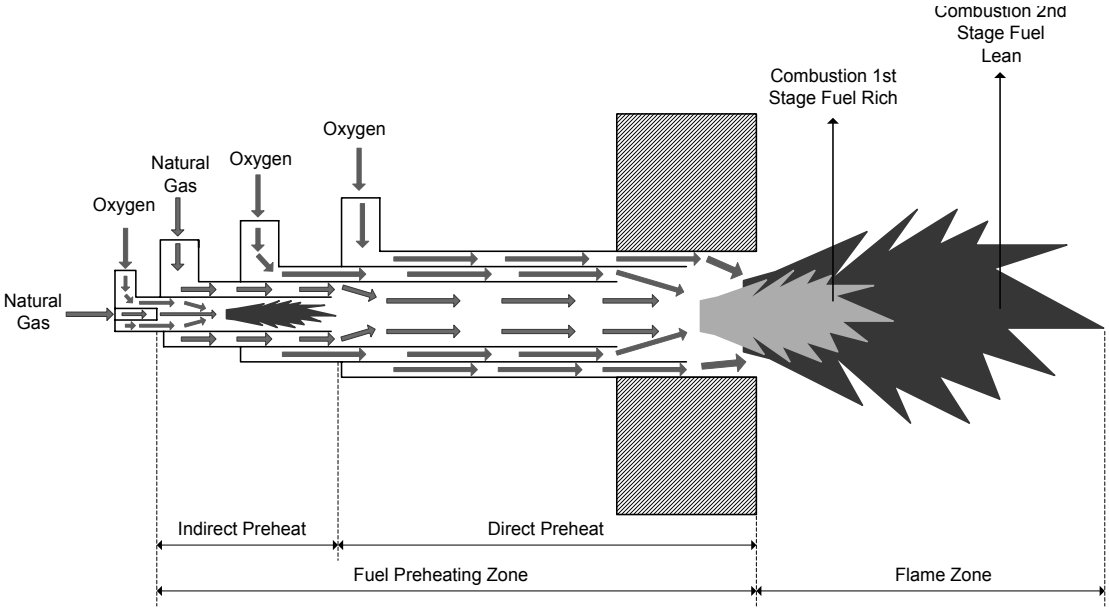
Sept. 10, 2002

PROJECT TEAM - SUPPORT

- US DOE
- IGT Sustaining Membership Program
- Gas Research Institute (now Gas Technology Institute)
  - Phase III
- NYSERDA
  - Phase III
- Eclipse / Combustion Tec
  - 20% of their efforts
- Owens Corning
  - technical review, host site, testing support

Co-funding - 20% of Phase I and II, 50% of Phase III

HIGH LUMINOSITY BURNER - CONCEPT



HIGH LUMINOSITY BURNER PROJECT

3-Phase, project to bring burner from concept to commercialization

Phase	Activity	Length	Status
I	Burner Modeling and Design	15 mo.	Complete
II	Laboratory Testing	24 mo.	Complete
III	Commercial Demonstration	36 mo.	Began 1/99

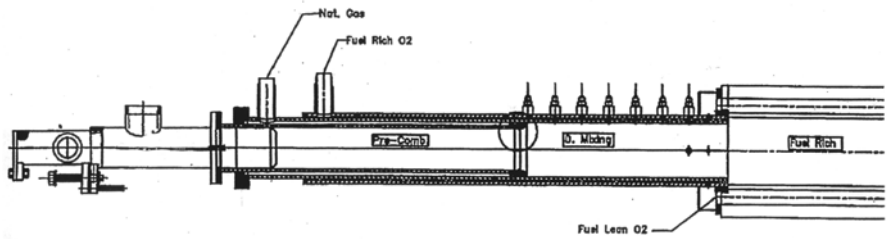
PHASE I - MODELING RESULTS

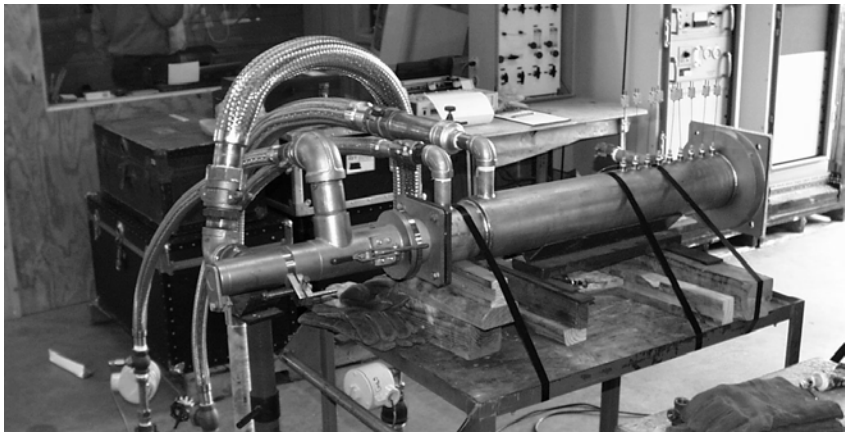
- Soot concentrations increase from 0.1 to 2.0% at optimum Fuel Preheat Zone conditions
- Soot concentrations in fuel and furnace inlet affect furnace thermal performance
- Thermal efficiency of luminous flames can be increased by 25%
- Flames covering a large part of the glass surface enhance thermal performance
- Short flames produce non-uniform profiles
- Increasing soot concentration lowers temperature and decreases NO_x

PHASE II - LAB-SCALE BURNERS

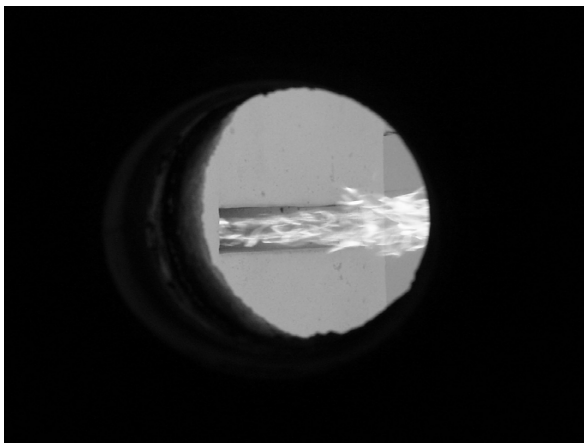
Burner	Design
1	• All zones lengths adjustable • Separate preheat zone
2	• All zone lengths fixed except for adjustable fuel-rich combustion zone • Separate preheat zone
3	• Adjustable direct mixing zone length • No fuel-rich combustion zone • Combined preheat and direct mixing zones

PHASE II - PILOT-SCALE BURNER





PILOT SCALE TESTING – BURNER HOT FACE PICTURES



Primefire 300 – 2 MMBtu/h

Pilot-Scale High Luminosity Burner – 2 MMBtu/h

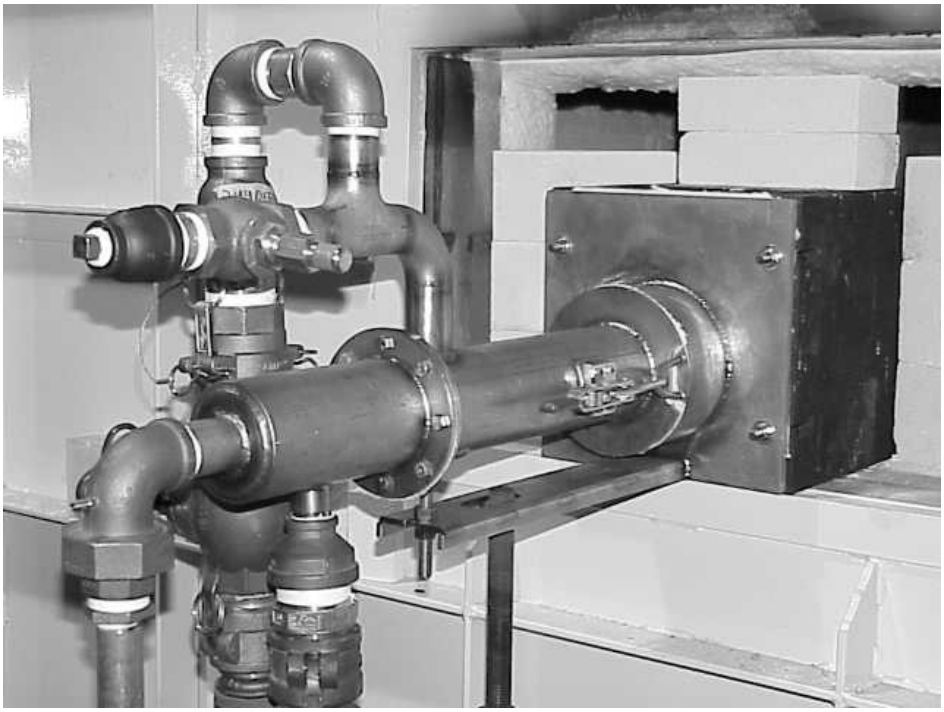
PHASE II CONCLUSIONS

- Heat transfer to simulated load increased 10-12% over baseline
  - CTI Primefire 100 used as baseline burner
  - greater increase expected for a glass load
- Total heat flux increased along with heat transfer to simulated load
- Temperature of furnace roof increased and exhaust gas temperature decreased with higher heat transfer to load
- NO_x emissions not significantly affected in the lab-scale furnace
- CO values <40 vppm for high-luminosity burner tests
- Precombustor and direct mixing zones can be combined
- Heat transfer is higher with combustion zone divided into fuel-rich and fuel-lean sections

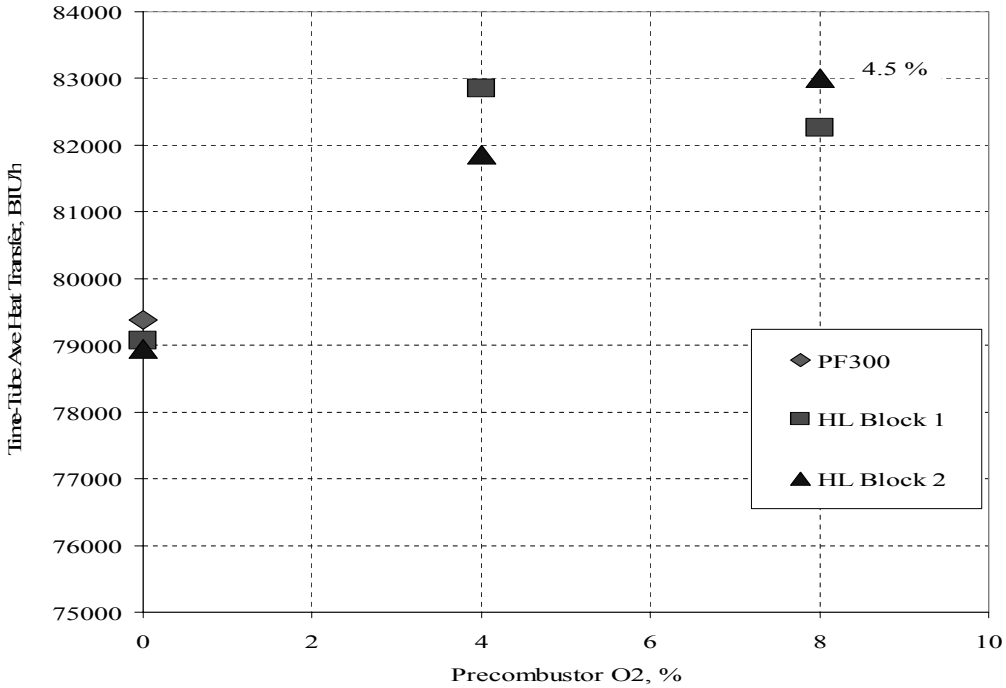
COMMERCAIL PROTOTYPE HIGH LUMINOSITY BURNER DESIGN

- Flat flame burner
- Inlets reduced to one for gas and one for O_2
- Burner length reduced by using the block as part of the direct mixing zone
- HELN 'A' multiple jets
  - Center preheated fuel slot
  - O_2 slots above and below fuel slot to create fuel-richand fuel-lean flame zones
- HELN 'B' single jet
  - Proprietary means of staging combustion using a single slot
  - Burner capacities from 1 to 20 MMBtu/h

DEMONSTRATION-SCALE HIGH LUMINOSITY BURNER



HEAT TRANSFER INCREASE WITH HELN 'A' BURNER

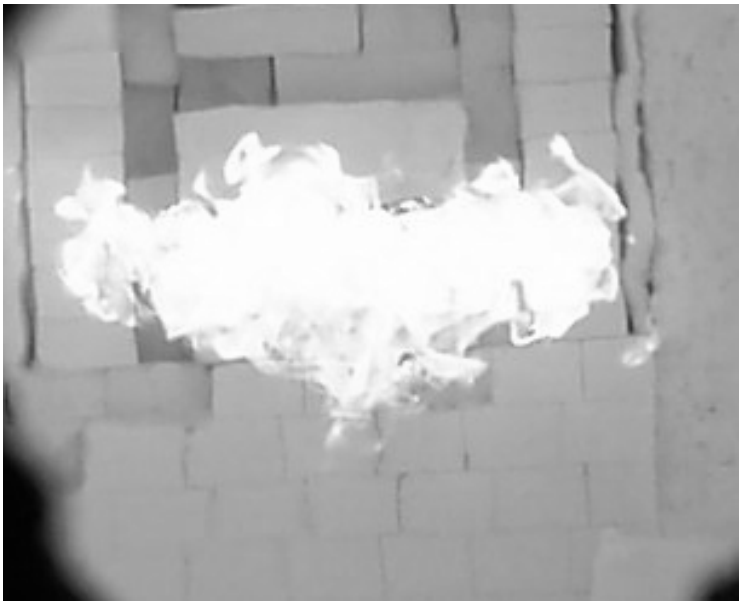


FLAT FLAME OXY-GAS BURNERS AT 1.75 MM/Btu/h

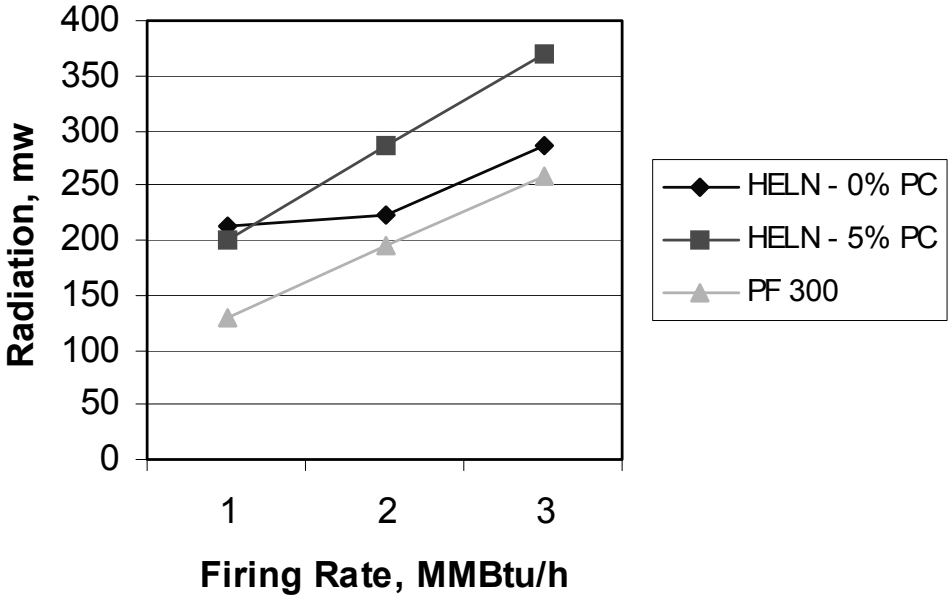
Combustion Tec
Primefire 300 burner

HELN 'A' Prototype burner
8% O_2 precombustion

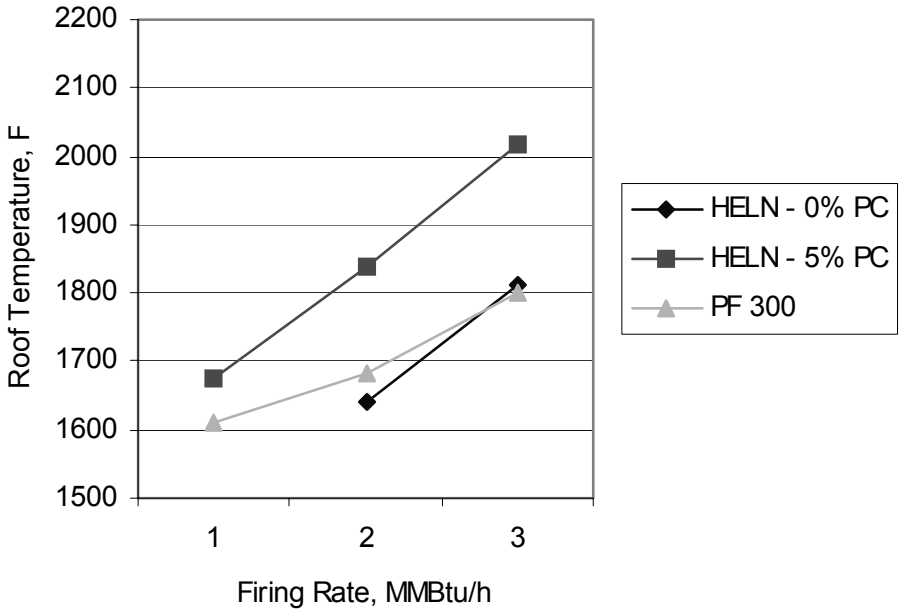
HELN 'B' AT 3 MMBtu/h WITH 5% O_2 PRECOMBUSTION



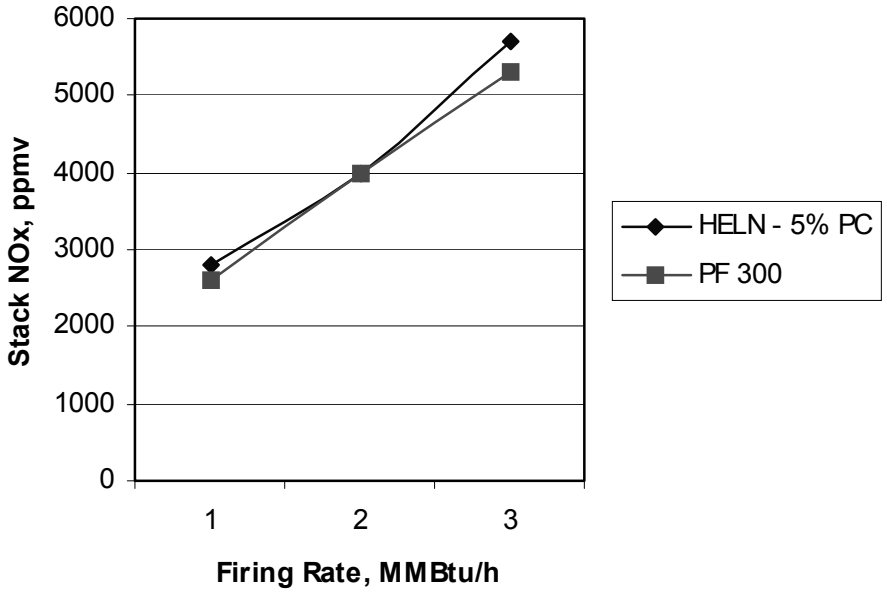
HELN 'B' AND PF300 – MEASURED TOTAL RADIATION



HELN 'B' AND PF300 – REFRACTORY TEMPERATURES



HELN 'B' AND PF 300 – MEASURED STACK NO_x



BURNERS FOR INITIAL DEMONSTRATION TESTS

- Burners have been designed to cover the range commonly used in glass melters
  - Small 1 – 4 MMBtu/h
  - Medium 2 – 8 MMBtu/h
  - Large 5 – 20 MMBtu/h
- Burners for demonstration tests
  - Fiberglass – Owens Corning – 7 burners (mix of small and medium
  - Flat glass – PPG – 10 burners (all large)

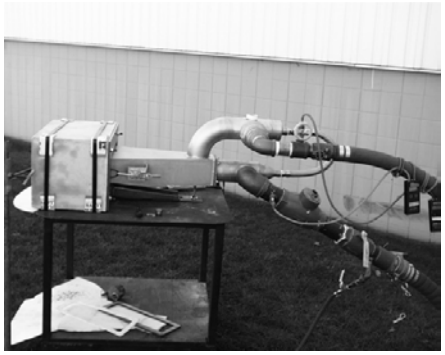
DEMONSTRATION TESTING

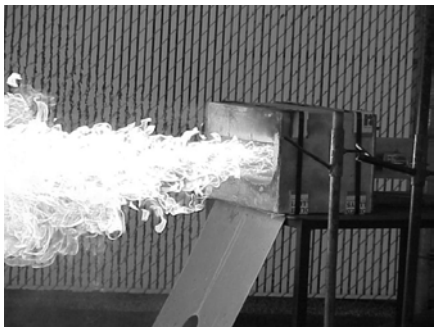
Owens Corning – Delmar, NY

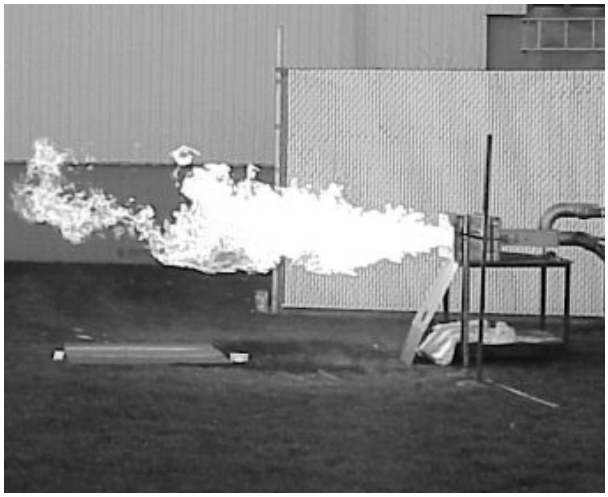
- One 3 MMBtu/h burner installed Nov. 2001
- NO_x and efficiency data was positive but not quantifiable with only 1 of 7 burners changed
- Burner generated small amount of soot – corrected in Feb. 2002
- Continuous operation for more than 8 months
- Remaining 6 blocks and burners fabricated and at plant ready for installation

20 MMBtu/h HELN 'B' FIRING

10 MMBtu/h







DEMONSTRATION TESTING

PPG – Meadville, PA

- Testing funded by DOE NICE3 and PPG
- Furnace is a new flat glass melter using 10 large burners firing >10 MMBtu/h
- Long-term combustion system performance will be evaluated and documented
- One burner has been running continuously since Dec. 2001 in a second furnace with good performance
- All burners have been fabricated and installed on Meadville, PA furnace in preparation for firing

COMMERCIALIZATION PATH

- Demonstration testing by GTI and Combustion Tec with Owens Corning in Sept.-Nov. 2002
  - Burners and burner blocks at Delmar, NY plant read for installation on full furnace
- Demonstration and long-term performance by GTI with PPG beginning in Oct. 2002
  - Burners already installed in Meadville, PA furnace
- GTI holds the initial technology patent. A second joint GTI/Combustion Tec patent is in preparation
- Combustion Tec will sell, fabricate, install, and support the high luminosity burner as Primefire 400, the upper end of their oxy-burner line
- Technology will be extended to other industries with GRI and NYSERDA support

Melt Properties Measurements at the Center for Glass Research

Thomas P. Seward III, Director

September 10, 2002

Outline

- Project participants
- Objectives of this study
- Properties being investigated
- Methodology and example results
- Status

DOE-CGR Project at Alfred University

- Grant # DE-FG07-96EE41262
- Title
  - » Modeling of Glassmaking Processes for Improved Efficiency
- Sub-title
  - » High Temperature Glass Melt Property Database for Modeling

DOE-CGR Project at Alfred University

- Multi-year, multi-investigator project
- Two phases
  - » Property measurements and database generation
  - » Evaluation by industry process modelers
- Principal Investigators
  - » T.P. Seward, W.C. LaCourse, A.G. Clare, J.E. Shelby, A.K. Varshneya, D.Oksoy, D. Earl
- Sub-contracts
  - » CELS (Corning), Thermex Company (St. Petersburg, Russia) and Pacific Northwest National Laboratory

Project Objective

- To develop a high-temperature melt properties database with sufficient reliability to allow mathematical modeling of glass melting and forming processes
- In response to melt properties measurements needs established at the DOE-CGR jointly sponsored 1996 “Modeling Workshop”

DOE Melt Properties Project

- Glass Families Studied
  - » Low-expansion Borosilicate
  - » Container
  - » E-glass
  - » Float
  - » TV Panel
  - » Wool

DOE Melt Properties Project

- Procedures
  - » Target Compositions Developed
  - » Experimental Compositions Melted
  - » Chemical Analysis Performed
  - » Melt Properties Measurements Performed

DOE Melt Properties Project

- Melt Properties Measurements
  - » Melt Density and Surface Tension
    - – Base Glass Compositions Only
  - » Viscosity
    - – Beam Bending
    - – Parallel Plate
    - – Rotating Spindle
  - » Electrical Resistivity
  - » Radiative Conductivity

Properties Being Studied with CGR funding

- Gas solubility and diffusion
  - » Helium, neon, argon, nitrogen, CO_2, H_2O (Shelby) and SO_2 (Prokhorenko)
- Glass physical properties (Shelby)
  - » Density,refractive index, coefficient of thermal expansion, dilatometric softening point, glass transition temperature, dissolved water concentration, and electrical conductivity (at 200°C & 300°C)

Families of Glasses (Commercial Base Glasses)

Component	Container	Float	E-Glass	TV Panel	Low α Borosilicate	Wool
SiO_2	74.05	73.1	55	61.29	81	62
Al_2O_3	1.26	0.10	15	1.96	2	4.0
Fe_2O_3	0.031	0.5	0.4	0.044		0.3
TiO_2	<0.01	0.02	0.5	0.42		
CaO	10.53	8.9	18	0.06		8.0
MgO	0.20	3.8	4.0			4.0
SrO	<0.01			9.15		
BaO	<0.01			9.32		
PbO				0.03		
Na_2O	13.49	13.7	0.5	7.46	4	16
K_2O	0.27	0.1		7.59		1.0
B_2O_3			7		13	5.0
Li_2O				0.002		
As_2O_3						
Sb_2O_3				0.27		
CeO_2				0.27		
MnO_2	<0.007					
Cr_2O_3						
SO_2	0.22					0.2
ZrO_2	<0.03			1.46		
ZnO				0.48		
F_2			0.2	0.002		

All Values in Weight %

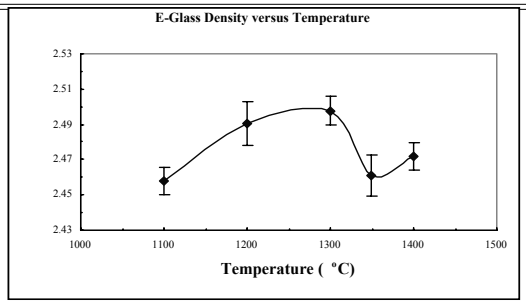
Melting and Chemical Analysis

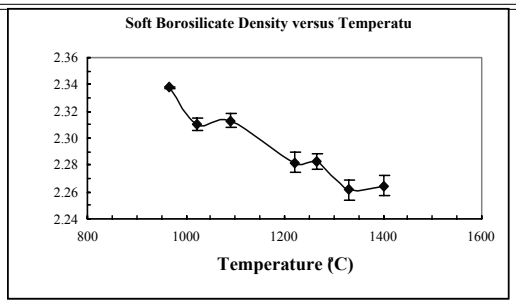
- Composition variations statistically designed about the six base glasses
- Melting program:
  - » Phase I - 15 melts per “family”
  - » Phase II - 10 additional melts per “family”
- Phase II now complete in three of six families, almost complete in other three (approximately 140 glass melts to date)

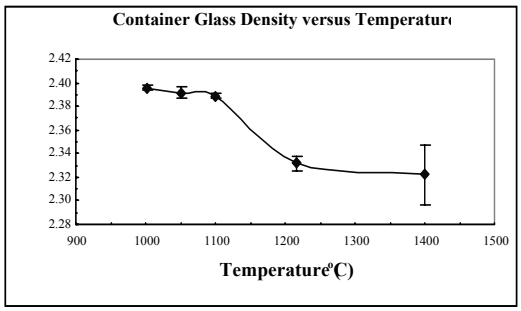
Density and Surface Tension

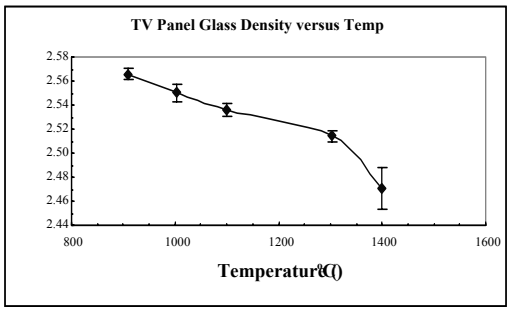
- Sessile and pendent drop techniques developed; algorithms written
- Atmosphere varied
- Volatility effects studied
- Measurements completed on five of the six commercial base glasses
- Some examples follow:

Melt Density

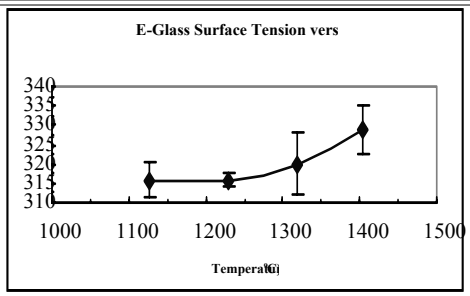


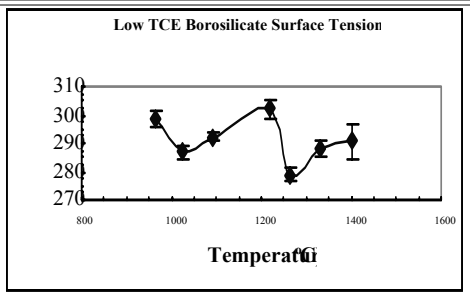


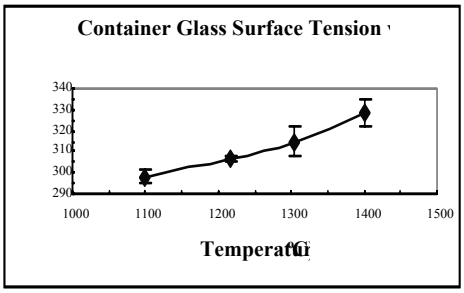


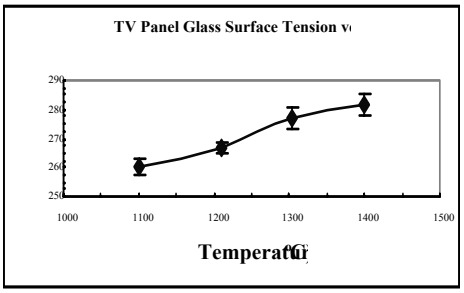


Melt Surface Tension









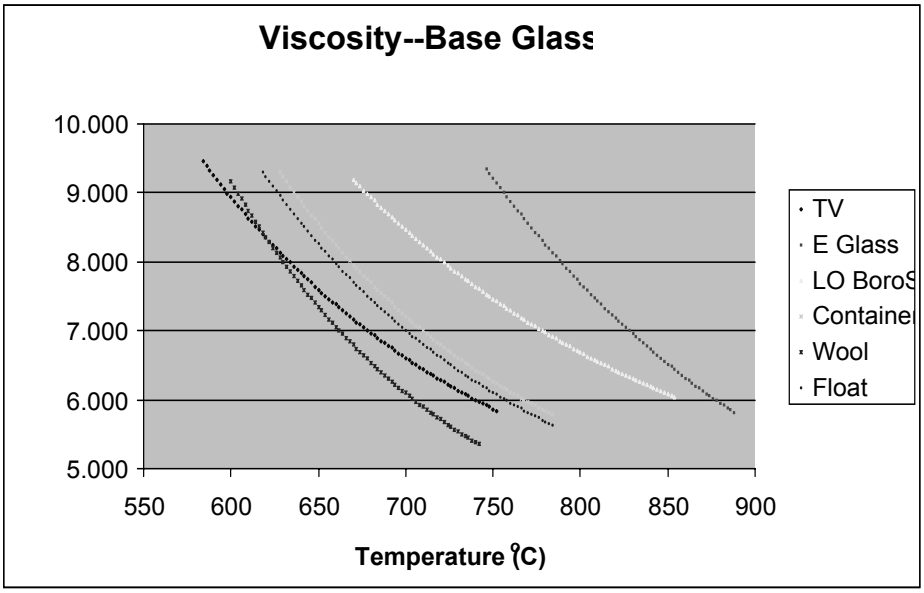
Viscosity

- Rotating Spindle (10^1 to 10^4 Poise)
  - » Measurements complete for all six commercial base glasses
  - » Measurements partially done for container and “wool” composition variations
  - » Plagued during 2000-2001 by equipment failures
  - » Significantly behind schedule; still 128 glasses remained to be measured in June, 2002
  - » Schott Glass Technologies 2002 G-Plus DOE funding committed to measurements at PNNL; work in progress

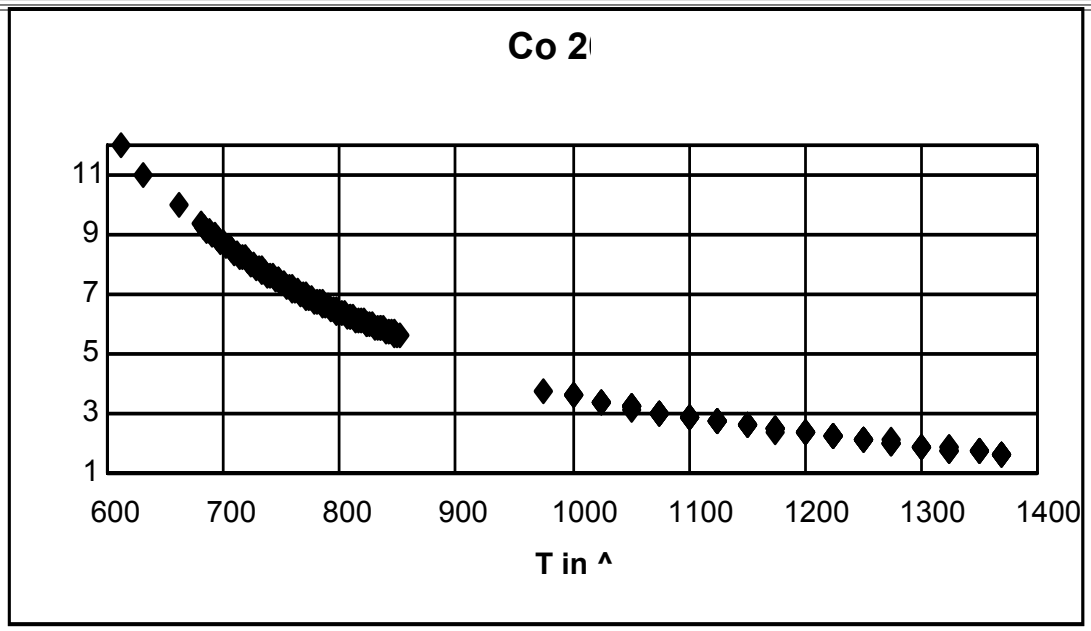
Viscosity continued

- Parallel Plate (10^5 to 10^9 Poise)
  - » Software rewritten
  - » Measurements started again in January, 2002 with postdoctoral researcher
  - » Measurements complete on all low- expansion borosilicate, E-glass and “wool” glass and most container and float glasses
- Beam Bending (10^{10} to 10^{13} Poise)
  - » Work conducted in 2001, funded by CGR
  - » Measurements complete on 13 container, 10 float, 23 E-glass, 25 TV Panel, 25 low- expansion borosilicate and 14 “wool”

Viscosity--Base Glasses



Viscosity



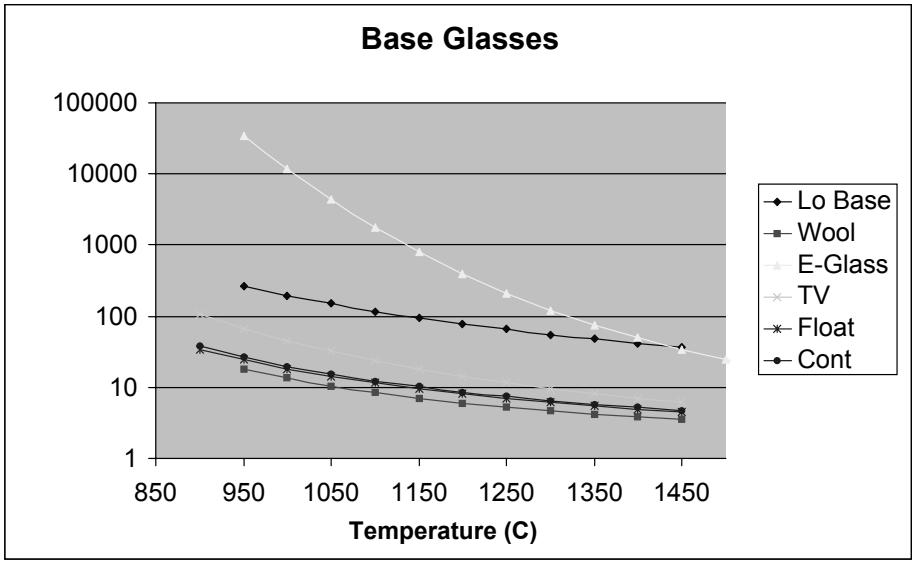
Non-Newtonian Viscosity

- Installed parallel plate viscometer on hydraulic Instron™ testing machine
- Measured six base glasses at ~ 10^{10} Pa·s and seven strain rates
- Deviations from Newtonian behavior characterized
- Data being used by at least one CGR member

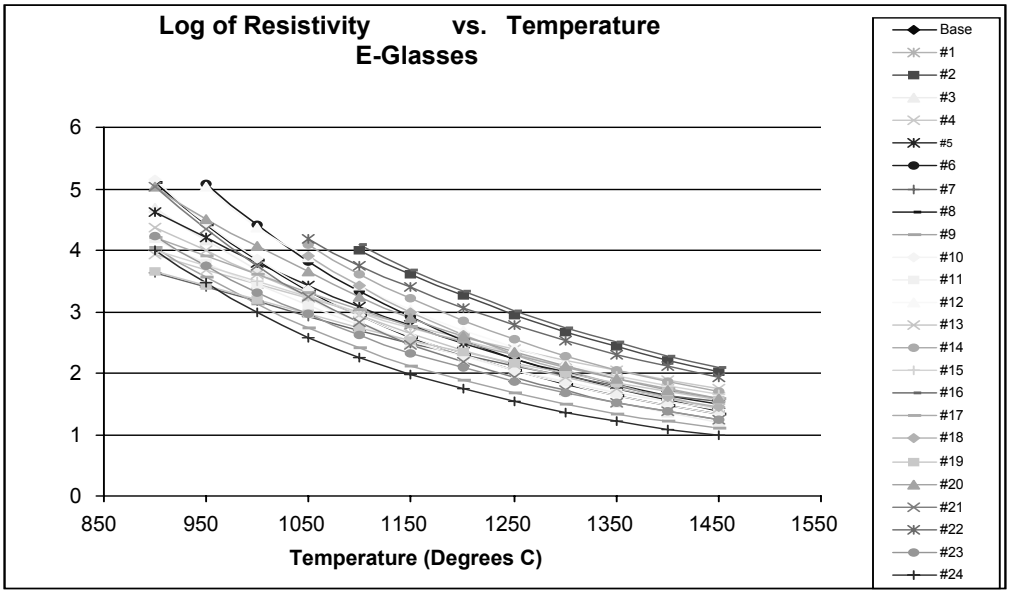
Electrical Resistivity

- Two-probe system operating and calibrated
- Resistivity measured between 900˚C and 1450˚C for
  - » SRM 1414 NIST standard glass
  - » All six commercial base glasses
  - » All 24 TV panel glass compositions
  - » Most of the low expansion borosilicates
  - » Measurements to be completed - Fall 2002

Electrical Resistivity



Electrical Resistivity--E Glass



Radiative Conductivity

- Work conducted at Thermex Company (St. Petersburg, Russia - O. Prokhorenko)
- High temperature (600ºC-1450ºC) spectrophotometer and sample cells constructed; Measurement techniques developed
- Measurements complete on all six commercial base glasses
- Examples follow:

Radiative Conductivity

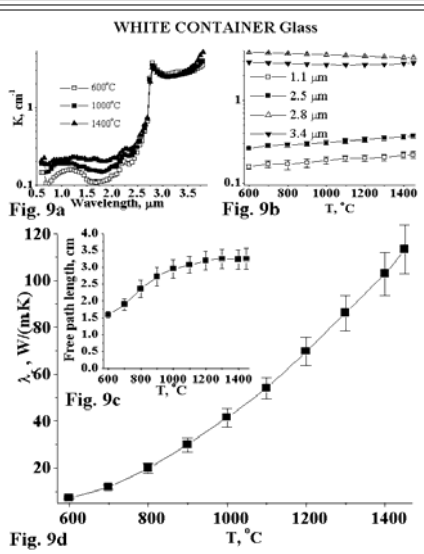


Fig. 9. Absorption spectra at temperatures 600, 1000 and 1400°C (a), and temperature dependences of absorption coefficients at 1.1, 2.2, 2.8 and 3.4 μm (b) measured for white container glass. Temperature dependences of free path length (c) and radiative conductivity (d) calculated for white container glass by using Rosseland formula

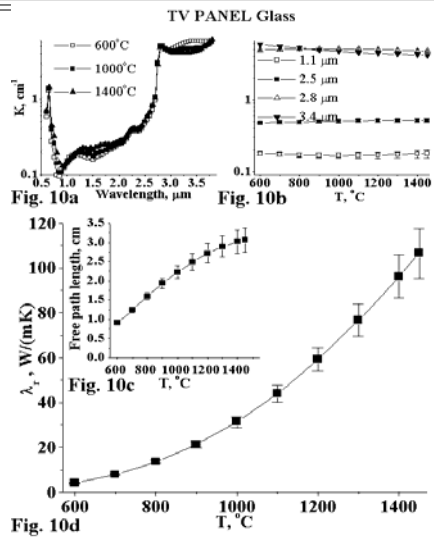
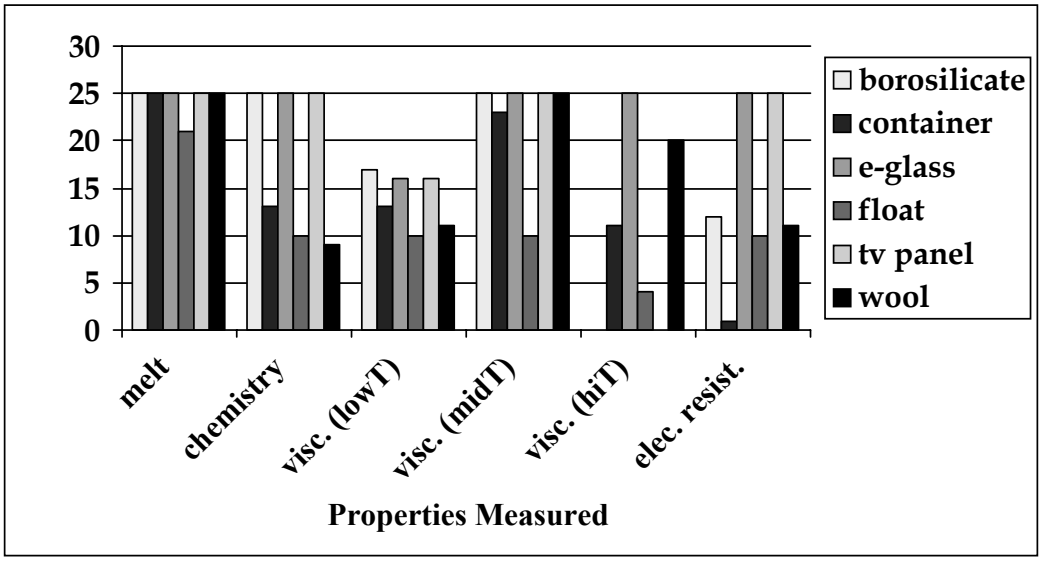


Fig. 10. Absorption spectra at temperatures 600, 1000 and 1400°C (a), and temperature dependences of absorption coefficients at 1.1, 2.2, 2.8 and 3.4 μm (b) measured for TV-panel glass. Temperature dependences of free path length (c) and radiative conductivity (d) calculated for TV-panel glass by using Rosseland formula.

Measurements Progress



Status

- Measurements completed on all six commercial base glasses, for most properties
- Melting of Phase I and II glasses (with designed composition variations) is about 95% complete; some float glasses yet to be melted

Status continued

- Remaining to do:
  - Complete melting, chemical analysis and property measurements on Phase II composition variations
  - Perform statistical analysis of data
  - Obtain evaluation of database by CGR member companies

Approximate Milestones

- September 2002 - Complete Phase II melting; Begin statistical analysis of available data
- November 2001 - Complete viscosity measurements
- December 2002 - Complete property measurements; Begin data transfer to member companies
- Spring 2003 - Begin writing for publication

Examples

- Glass composition ranges and examples of measurement results can be found on the CGR Web site at:
  http://cgr.alfred.edu/meltprops/meltprops.html

- More complete information at
  http://cgr-members.alfred.edu

Enhanced Cutting and Finishing of Hand Glass using a CO_2 Laser

Steven D. Woodruff,
National Energy Technology Laboratory

John E. Sneckenberger
West Virginia University

Project Components

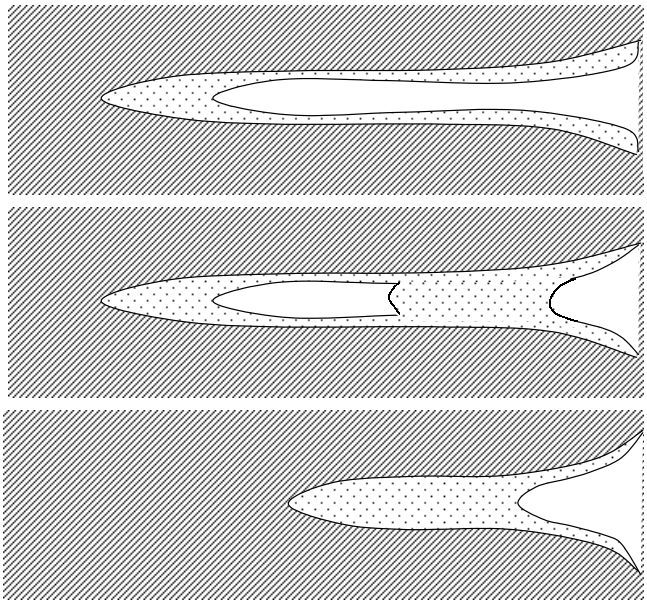
- Development of lab prototype laser-glass cutting machine
- Enhancement to laser-glass cutting process
- Development of plant prototype laser-glass cutting machine
- Factory Testing

Initial Work

Initial findings

- The Laser Glass Cutting Machine cuts glass by melting and vaporization
- The laser glass cutting machines on the market today cut by thermally cracking the glass and are applied to plate glass and circuit wafers
- The Art Glass Industry requires the more controlled cutting action offered by melting and vaporization

Melting/Vaporization Mechanisms

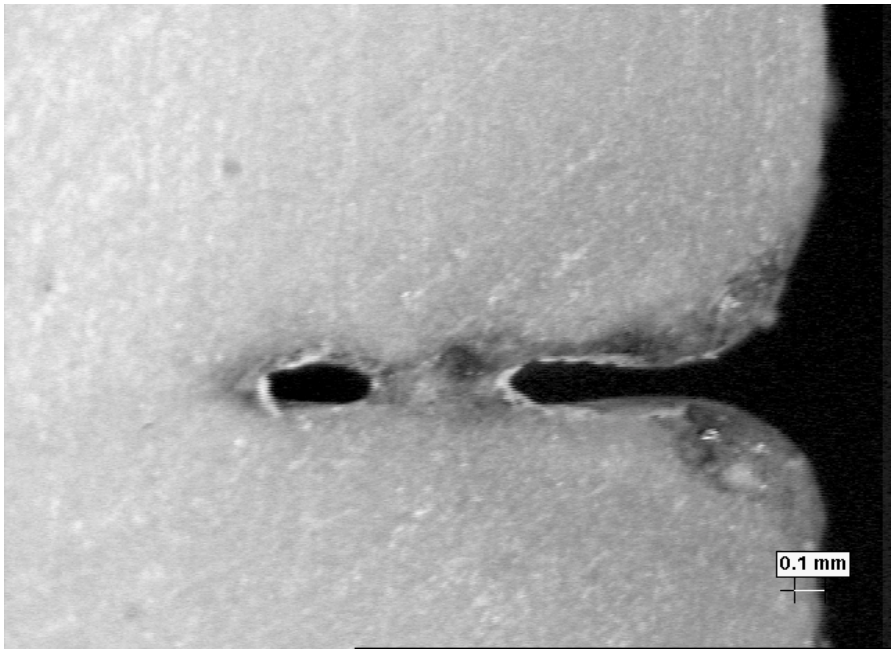


a. Ideal, no resealing, control at this point necessary for successful cut

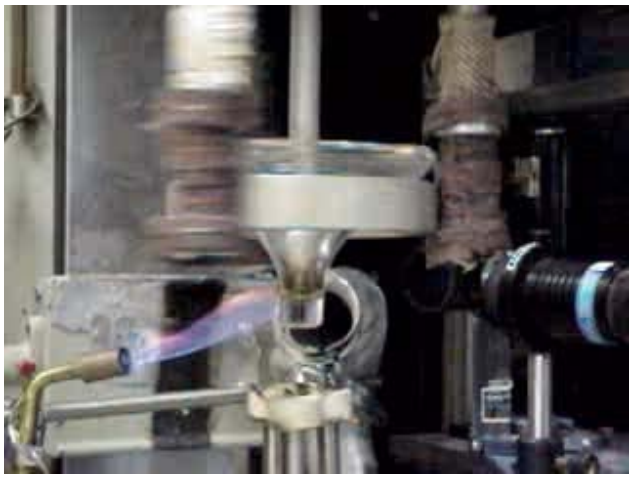
b. Resealing occurs during cutting if glass becomes too liquid from excess heat

c. Resealing prevents cutting by filling in the grove faster than material can be removed

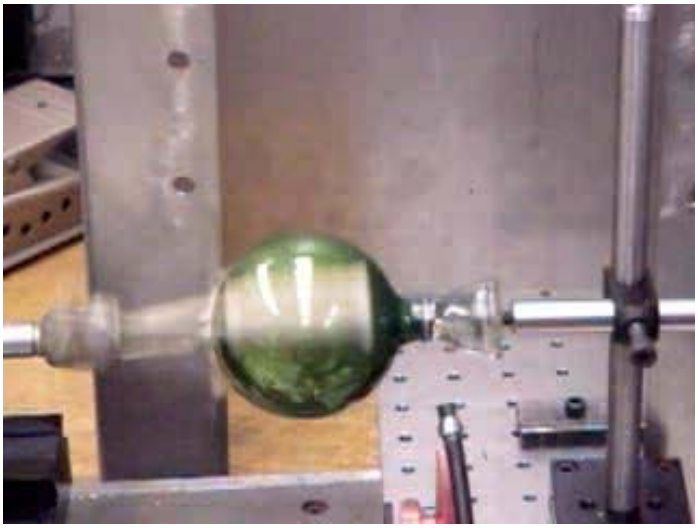
Evidence of Resealing



St. George Crystal Projector Base



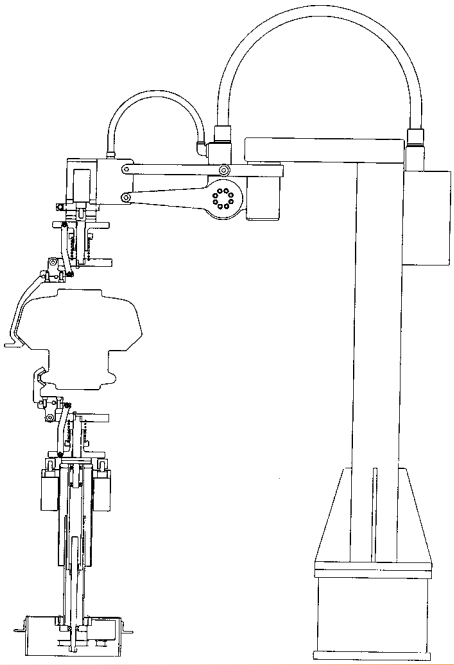
Christmas Tree Bulb



4000 Watt Laser at Laser Processing Company Morgantown, WV

The Continental Laser Energy 1300 watt CO_2 Laser

Nimbl Glass Handling Robot



Nimbl Glass Handling Robot

Robot Positioning Schoolhouse Globe at Davis Lynch Glass, Morgantown, WV

Laser Cutting Schoolhouse Globe

Planned Factory Tests

- Davis-Lynch Glass in Morgantown, WV
  - School House Globes, Milk Glass
- Fenton Art Glass in Williamstown, WV
  - Lamp Shades, Vases, colored glass products
- Third company to be determined
- Tests were not completed because of safety considerations with the robot
- St. George Crystal
  - In-house tests on Television projection base

Current Status

- 1300 Watt, TEM00 CO_2 Laser, by Continental Laser Energy acquired and installed
- Robotic glass handling system developed by the Nimbl-Larew Consortium completed and installed at Davis-Lynch Glass
- The ability to handle hot glass without breakage was demonstrated successfully
- The Robot failed to operate at the speed required to deliver sufficiently hot glass to the lehr due to software problems, Nimble-Larew was unwilling to correct the problem
- Our belief is the problem can be solved with a willing partner

Future Plans

- Funding is virtually gone, the term of the project is at an end
- Two companies are interested in developing a glass handling system: PTG Industries, LLC of Orlando, FL; RTW, Inc. of Fort Meyers, FL
- Fenton Glass is working on a glass handling system, NETL will supply the laser for testing
- Additional tests may yet result in a patent
- Additional funding may be sought pending formation of a restructured team

Academic Accomplishments

Process Control of Laser System for Enhanced Glass Production
http//etd.wvu.edu/templates/showETD.cfm?recnum=1718

Dissertation By Liyun Zheng

Development of System Parameters for Enhanced Cutting and Finishing of Handglass Using a CO_2 Laser
http//etd.wvu.edu/templates/showETD.cfm?recnum=1347

Thesis By Chris Thompson

Academic Accomplishments

Modeling and Controls for Laser Glass Cutting Machine Workcell Robot

Thesis by Asif M. Mohammad in preparation

Additional Personnel

- Jeff Rice – Robotics consultant
- Alexander Krasnov – founder of Continental Laser Energy, recently granted resident alien status
- Society for Glass Sciences and Practices
- John and Bob Lynch, Davis Lynch Glass Company, Star City, WV
- Tom Fenton, Fenton Art Glass Company, Williamstown, WV

The End

but more to come…

The Glass Furnace Combustion and Melting Research Facility

John J. Connors
PPG Industries
Pittsburgh, Pennsylvania

Peter M. Walsh and Robert J. Gallagher
Sandia National Laboratories
Livermore, California

DOE/OIT Glass Industry Project Review
Sandia National Laboratories, Livermore, CA
September 10, 2002

Three Phases

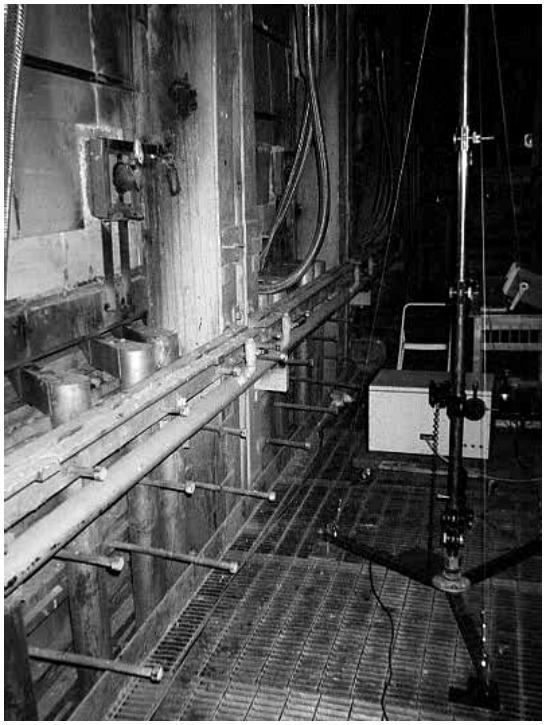
I. Survey industry to establish research needs and requirements for the facility and furnace. Evolution of scope and objectives.

II. CFD modeling of flow and heat transfer (PPG). Calculations and analysis providing the basis for conceptual design (PPG).

III. Engineering

Phase I: Industry Input

- Workshop at Argonne, IL, following 1999 Glass Project Review
- Glass Project Reviews, 1999, 2000, and 2001
- Survey distributed by GMIC
- Technology Roadmap
- Visits to plants and research centers
- Discussions with glass manufacturers



Initial Research Focus

Full potential of oxygen firing for improving the efficiency and productivity of large furnaces has not yet been realized.

- Radiative and convective heat transfer characteristics of the flames and combustion products are different from those in air firing.
- Combustion product - refractory - manufactured product mass exchange and chemistry are different.
- The absence of reversal makes possible a higher degree of automatic control.

From the Technology Roadmap: "By looking at oxy-fuel firing systematically, significant operational improvements may be identified."

Phase II: Project Team

PPG Industries: John Connors (PI), James Harris, Warren Curtis, David Bivins, Bill Cullum, Joseph Yu, Tom Smith

Sandia National Laboratories: Bob Gallagher, Peter Walsh (PI), Blake MacDonald

Advisors: Vince Henry and John McConnell

Furnace: A. C. Leadbetter & Son

Batch and Cullet Systems: Lilja Corp.

Charger: Merkle Engineers

Burners: Maxon Corp.

Ejector: Laidlaw Drew (Morgan Construction Co. design)

An Industrial Research Facility

Firing: O_2/gas

Heat input:
8.6 x 10^6 Btu/hour

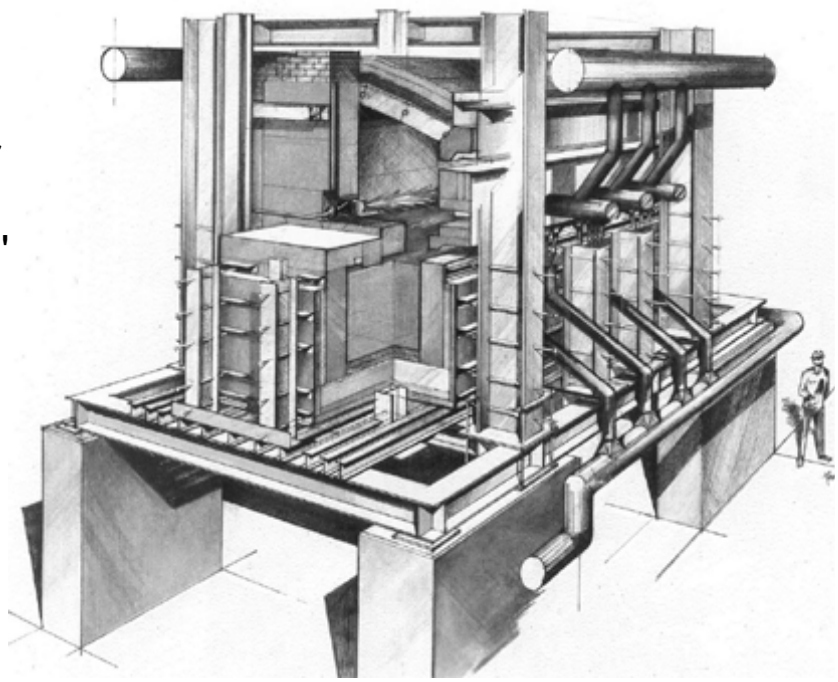
Melting area: 6' x 13'

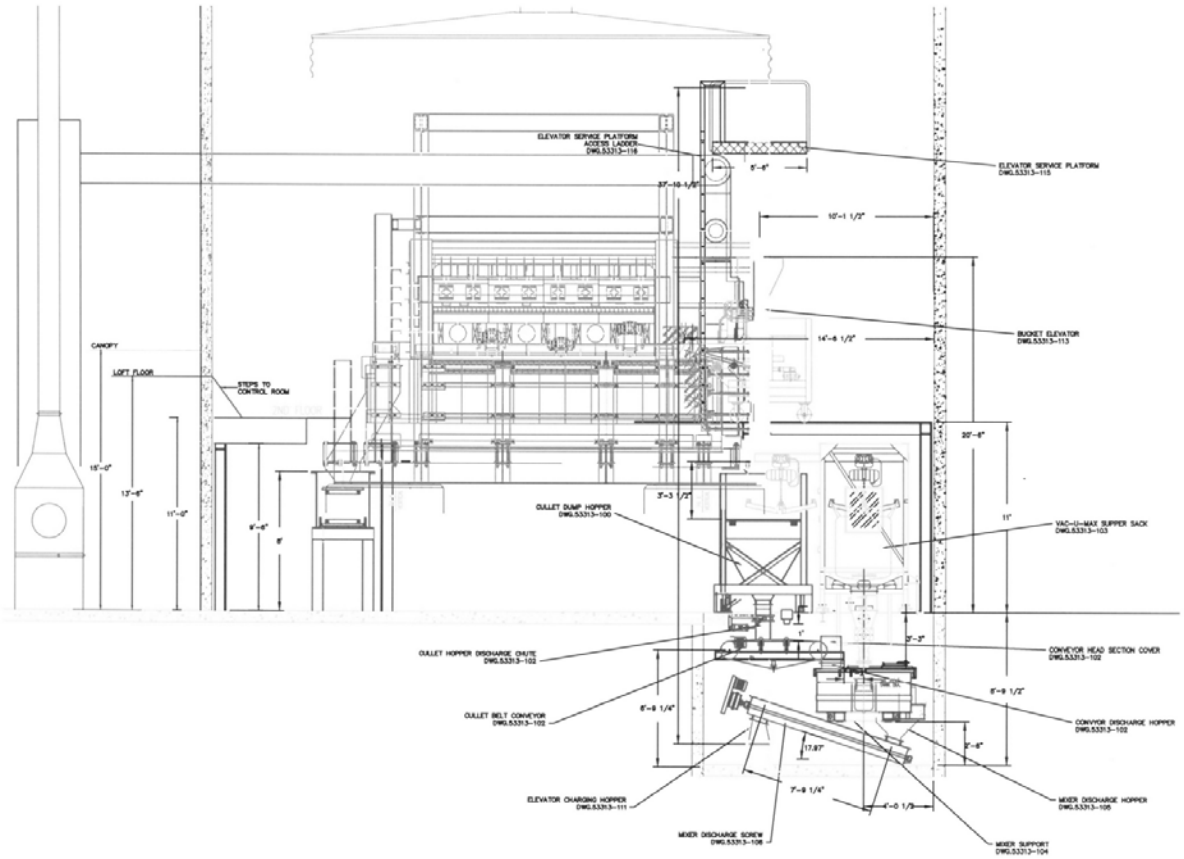
Glass depth: 3'

Maximum pull:
25 ton/day

Full width doghouse

Bubblers



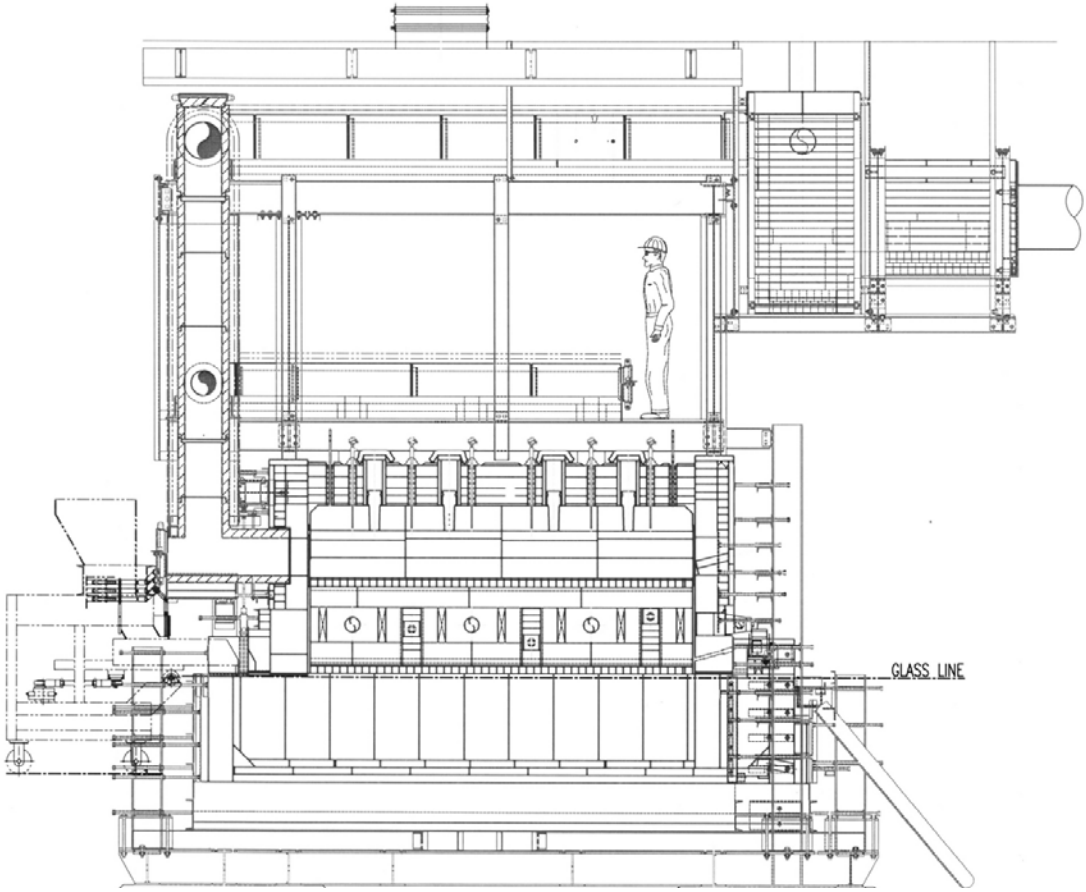


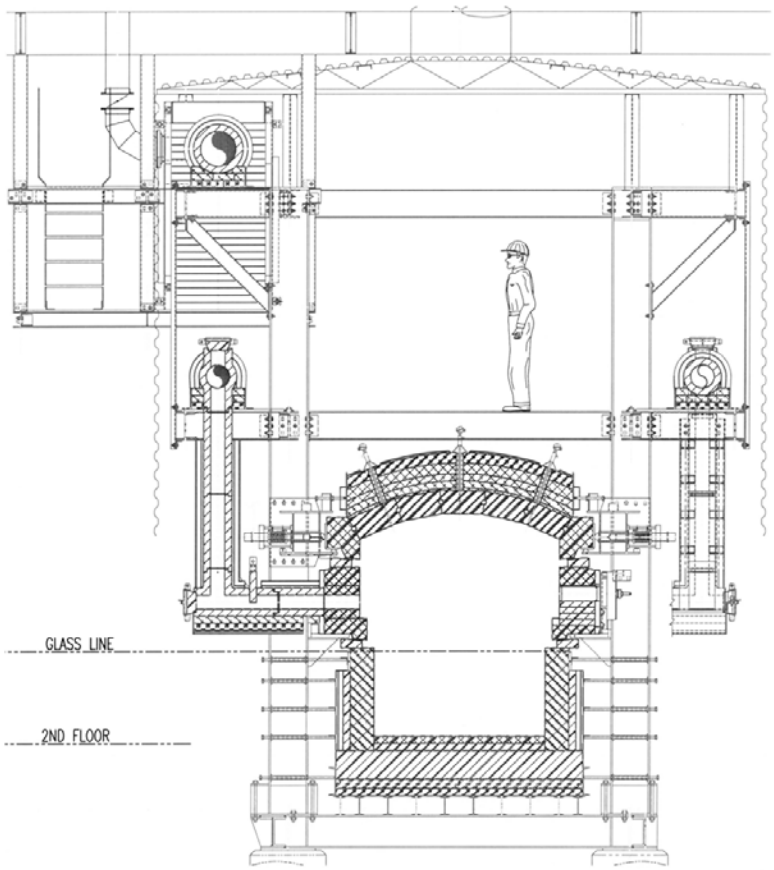
Phase III: Engineering

Furnace: A. C. Leadbetter & Son

Batch and Cullet Handling: Lilja Corp.

Site: Sandia Facilities Planning and Engineering


GLASS LINE

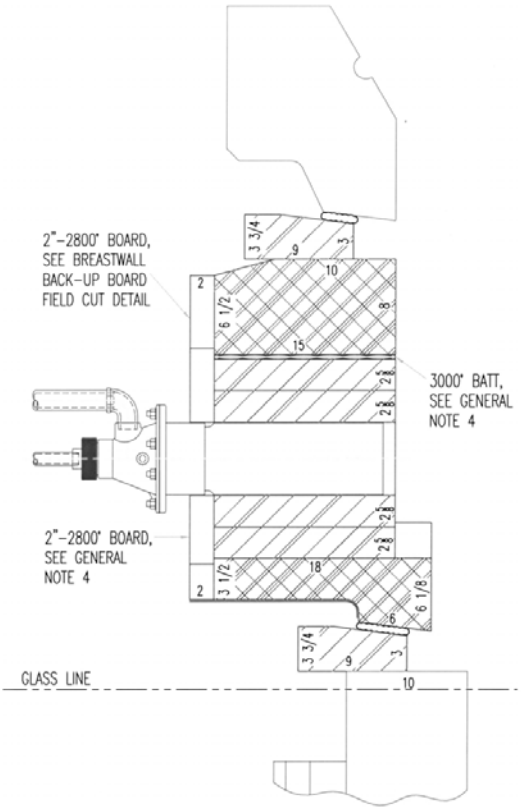

GLASS LINE
2ND FLOOR

Breastwall, Probe Slots, and Burner Detail

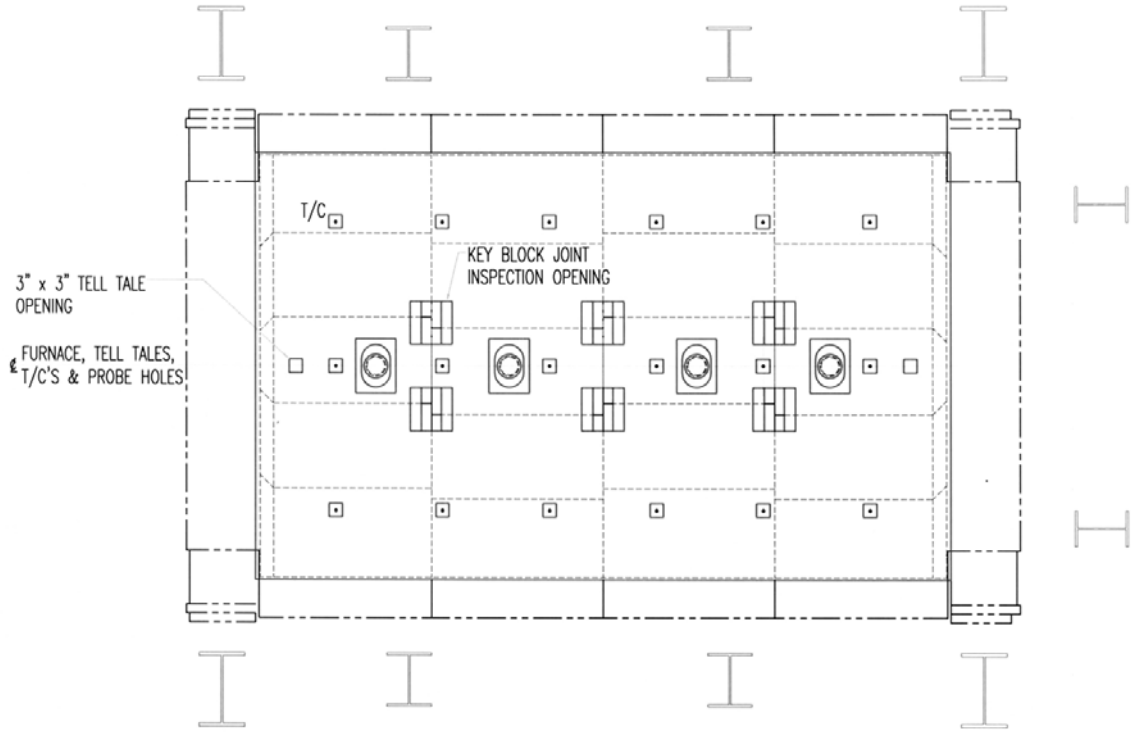
Burner change-out facilitated; elevation adjustable.

Probe slots run length of furnace at skew and tuck lines (shown with tapered plugs in place).

Glass surface accessible through slot at tuck line.

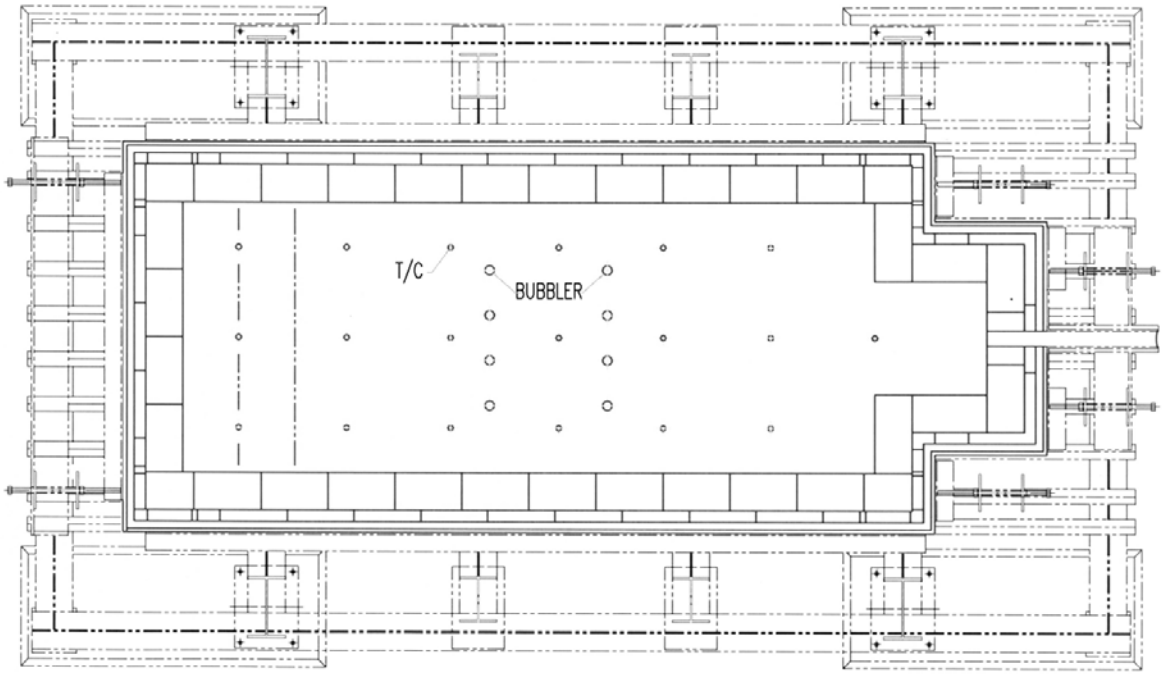


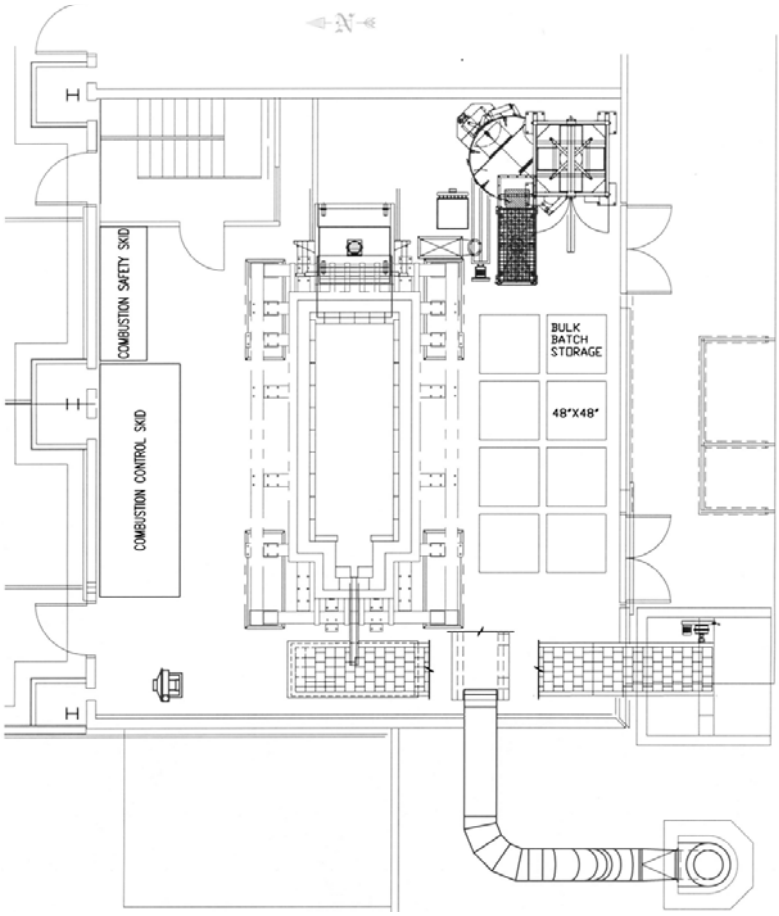
BURNER SHOWN AT CENTER POSITION

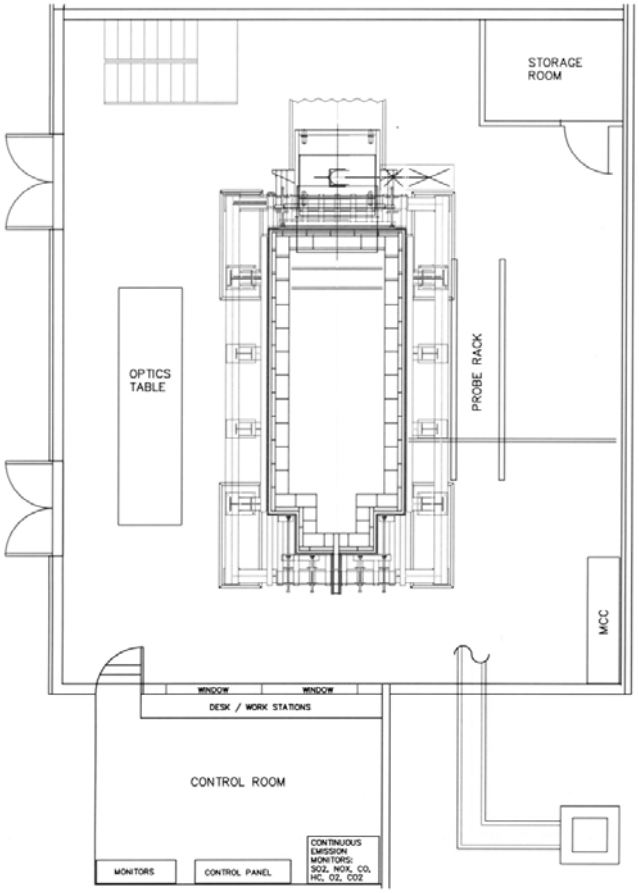


PLAN VIEW OF CROWN INSULATION
(OPENINGS SHOWN BEFORE SEAL-UP FOR CLARITY)

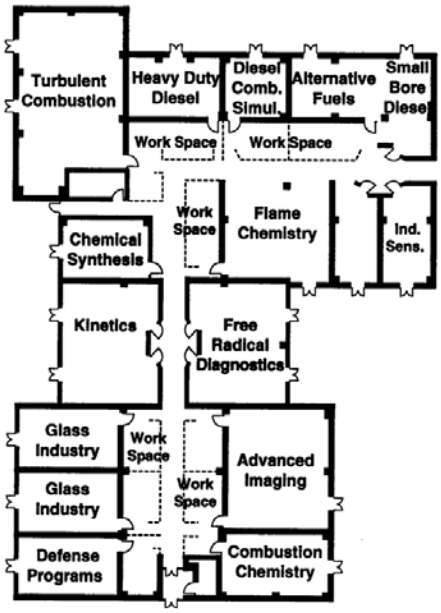
Bottom Thermocouples and Bubblers







CRF Phase II Laboratories



Sandia National Laboratories
Combustion Research Facility

Livermore, California Site

- Combustion Research Facility
  - Fluid mechanics
  - Chemistry
  - Radiation
- Optical diagnostics expertise and instrumentation
  - Flame and flow imaging
  - Temperature and radiation
  - Atomic, molecular, and particulate species
- Maintenance and construction support are available locally

Schedule

Beginning with authorization and funding to proceed

Complete site engineering: 3 months

Bid package to Sandia purchasing dept.: 1 month

Bids due: 1 month

Contract in place: 1 month

Materials to site and site preparation: 3 months

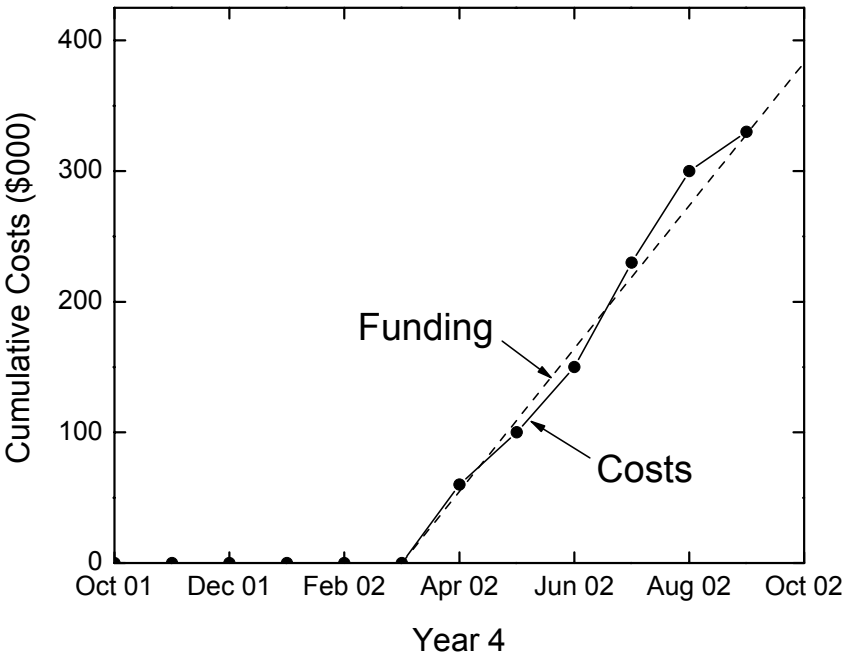
Furnace installation: 4 months

Heat up and shake down: 1 month

Results to industry: 4 months

Total: 18 months

Funding and Costs - FY02



A

Appendix A

Sample Evaluation Forms

PROJECT:
Project Title Here (Principal Investigator, Organization)

Reviewer:_____

1 = lowest rating; 5 = highest rating

I. Technical Merit

A. Technical Need 1 2 3 4 5

(Does the project address an important technical need of the glass industry?)

B. Contribution of Knowledge 1 2 3 4 5

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

Comments: _____

_____

II. Technical Progress

A. Adequacy of Progress 1 2 3 4 5

(Is the research being performed competently and proceeding at a reasonable pace?)

B. Expectations for Successful Completion 1 2 3 4 5

(What is the likelihood that the project will meet its technical objectives as scheduled and budgeted?)

Comments: _____

_____

III. Market Application

A. Broadness of Application 1 2 3 4 5

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

B. Adoption Potential 1 2 3 4 5

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

Comments: _____

_____

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

IV. Commercial Benefits

A. Energy, Economic, and Environmental Benefits 1 2 3 4 5

(If successful, will the research results provide tangible energy, economic, and environmental benefits to the glass industry?)

Comments: _____

_____

V. Budget Considerations

A. Project Value 1 2 3 4 5

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

Comments: _____

_____

VI. Overall Assessment

A. Overall Rating 1 2 3 4 5

Comments: _____

_____

_____

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

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

PROJECT:
Project Title Here (Principal Investigator, Organization)

Reviewer:_____

1 = lowest rating; 5 = highest rating

I. Technical Success

A. Achievement of Technical Objectives 1 2 3 4 5

(Has the project met its technical objectives?)

B. Contribution of Knowledge 1 2 3 4 5

(Has this project contributed new information or technology to the knowledge base of the glass industry?)

Comments: _____

_____

II. Commercial Readiness

A. Ready for Commercial Use 1 2 3 4 5

(Is the technology/information ready for commercial use, or is further development/ demonstration needed?)

B. End-User Commitment 1 2 3 4 5

(Are potential end-users committed to implementing the technology/information?)

Comments: _____

_____

III. Market Application

A. Broadness of Application 1 2 3 4 5

(Will results be applied in the entire industry, or narrowly applied to a particular segment? Will results be applicable to other industries?)

B. Adoption Potential 1 2 3 4 5

(Will the technology/information achieve widespread adoption? Will adoption be achieved in the near-term, or not until the long-term?)

Comments: _____

_____

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

IV. Commercial Benefits

A. Energy, Economic, and Environmental Benefits 1 2 3 4 5

(Will the research results provide tangible energy, economic, and environmental benefits to the glass industry?)

Comments: _____

_____

V. Budget Considerations

A. Project Value 1 2 3 4 5

(In your opinion, was the cost of the project in line with the anticipated value of the results?)

Comments: _____

_____

VI. Overall Assessment

A. Overall Rating 1 2 3 4 5

Comments: _____

_____

_____

Please provide additional comments to guide the implementation of this technology/ information:

_____

_____

_____

_____

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_____

_____

Appendix B

Other Presentations

Status of GPLUS Efforts

Peter Angelini

GPLUS Coordinating Laboratory Main Contact

Oak Ridge National Laboratory

September 10, 2002

Topics

- Background/Purpose
- FY 2002 activities
- Summary

Purpose

- **GPLUS - (Glass - Project Laboratory User Services) program**
  - Provides GMIC members access to unique capabilities of DOE National Laboratories
  - Industry defined projects ($25K per core GMIC member) - funding to participating national laboratory
  - Projects involve one or more core members, and associate members
  - Project submittals by GMIC core member
  - Program funded by U.S. DOE, Office of Industrial Technologies, Glass IOF

  - Mode of Operation
    - Industry GMIC core member submits a Project Description form
    - GMIC prepares approval form
    - Both are sent to the coordinating laboratory (ORNL) for initiation of funds transfer to the participating national laboratory; Peter Angelini, Coordinator

GMIC Core Members

Current Membership

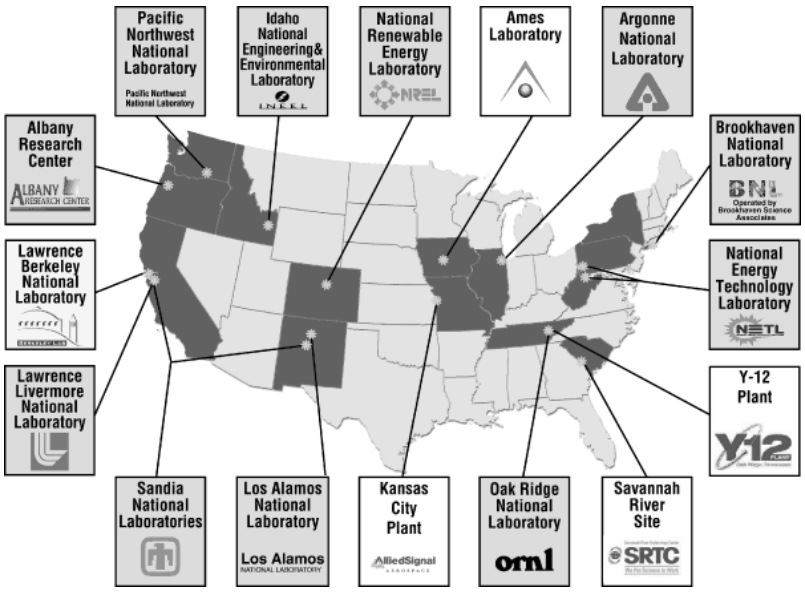
- Ball-Foster
- CertainTeed Corporation
- Corning, Inc.
- Fire and Light Originals L. P.
- Johns Manville
- Leone Industries
- Owens Corning
- Osram Sylvania
- PPG Industries
- PPG (Fiberglass)
- Saint-Gobain Containers
- Saint-Gobain Vetrotex America
- Schott Glass Technologies Inc.
- Society for Glass Science and Practices
- Techneglas
- Visteon - An Enterprise of Ford Motor Company

GMIC Associate Members

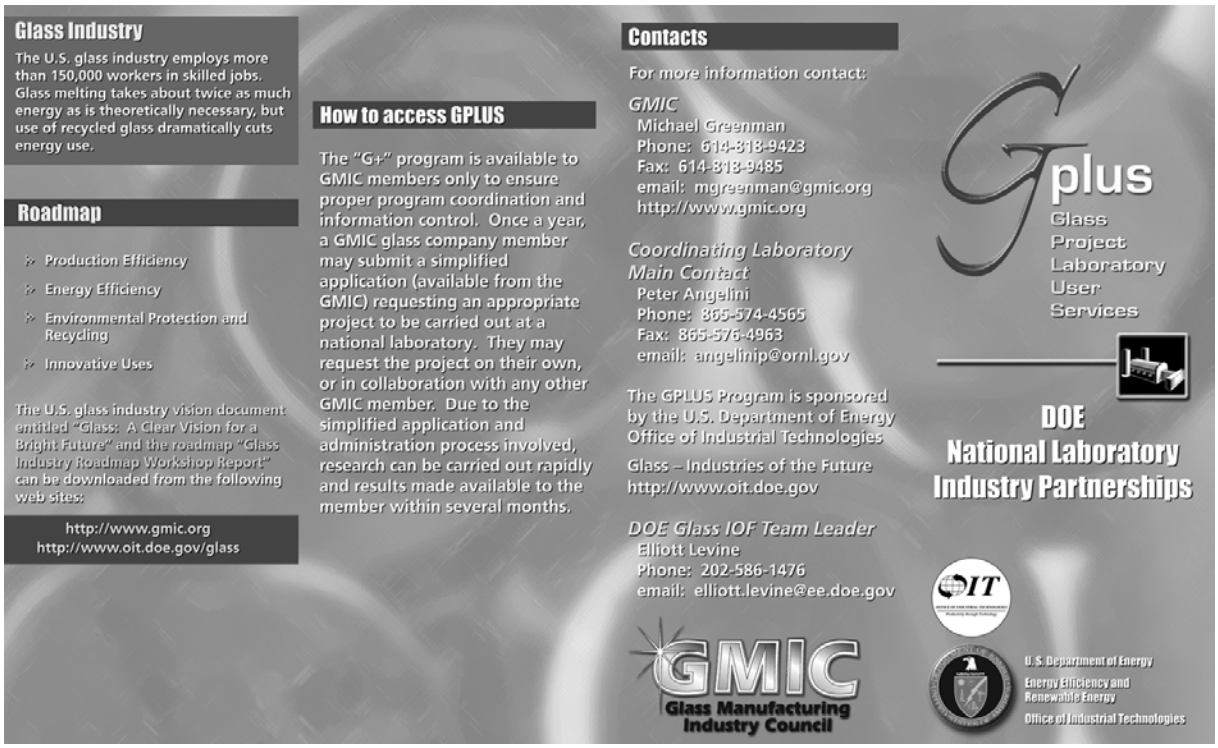
Current Membership
Suppliers, customers, processors, and researchers

- Advanced Manufacturing Center
- Air Liquide America
- B.O.C. Gases
- Center for Glass Research
- Eclipse Inc./Combustion Tec
- Gas Technology Institute
- Glass Service, Ltd.
- Mississippi State University (Diagnostic Instrumentation & Analysis Laboratory)
- Pacific Northwest National Laboratory
- Praxair, Inc.
- Siemens
- U.S. Borax

DOE National Laboratory Participants



A GPLUS Information Flyer is Available



Glass Industry

The U.S. glass industry employs more than 150,000 workers in skilled jobs. Glass melting takes about twice as much energy as is theoretically necessary, but use of recycled glass dramatically cuts energy use.

Roadmap

- Production Efficiency
- Energy Efficiency
- Environmental Protection and Recycling
- Innovative Uses

The U.S. glass industry vision document entitled "Glass: A Clear Vision for a Bright Future" and the roadmap "Glass Industry Roadmap Workshop Report" can be downloaded from the following web sites:

http://www.gmic.org
http://www.oit.doe.gov/glass

How to access GPLUS

The "G+" program is available to GMIC members only to ensure proper program coordination and information control. Once a year, a GMIC glass company member may submit a simplified application (available from the GMIC) requesting an appropriate project to be carried out at a national laboratory. They may request the project on their own, or in collaboration with any other GMIC member. Due to the simplified application and administration process involved, research can be carried out rapidly and results made available to the member within several months.

Contacts

For more information contact:

GMIC
Michael Greenman
Phone: 614-818-9423
Fax: 614-818-9485
email: mgreenman@gmic.org
http://www.gmic.org

Coordinating Laboratory Main Contact
Peter Angelini
Phone: 865-574-4565
Fax: 865-576-4963
email: angelinip@ornl.gov

The GPLUS Program is sponsored by the U.S. Department of Energy Office of Industrial Technologies

Glass – Industries of the Future
http://www.oit.doe.gov

DOE Glass IOF Team Leader
Elliott Levine
Phone: 202-586-1476
email: elliott.levine@ee.doe.gov

GMIC
Glass Manufacturing Industry Council

Gplus
Glass Project Laboratory User Services

DOE
National Laboratory Industry Partnerships

OIT

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Office of Industrial Technologies

Project in FY02

- **Batch Reactions of a Soda-Lime-Silicate Glass**
  - Libbey – Jim McGaughey / Ed Olson
  - Pacific Northwest National Laboratory – Dong-Sang Kim
  - **Objective**: Batch reaction data is being measured to be used in glass furnace simulation model being developed by Argonne. The study includes thermal gravimetric analysis (TGA), differential thermal analysis (DTA), glass batch foam behavior and evolved gas analysis.
  - **Status**: Project and Final Reported are Completed.

Project in FY02

- **Defects in TV Glass**

  - Techneglas – Bill Horan
  - Oak Ridge National Laboratory – Arvid E. Pasto

  - **Objective**: Production Efficiency of any glass manufacturing operation is reduced because of glass defects such as seeds and blisters, batch and refractory stones, and cords. TV panel glass and other high quality glasses require a glass as free as possible of these defects. The glass and furnace engineers can make process changes to minimize these defects if they know the chemical composition and other characteristics of these glass defects.

  - **Status**: One set of samples have been tested.

Project in FY02

- **Measurement of Gas Compositions of Blisters in Container Glass**

  - Saint Gobain Containers, Inc. – Erik Helin
  - Oak Ridge National Laboratory – Roger A. Jenkins

- **Objective:** Blisters (gas bubbles) in amber glass can result in significant losses in production efficiency of one to five percent, requiring additional energy to reprocess the rejected glass. Currently available analytical techniques (mass spectrometry, gas chromatography) require special sample preparation and equipment and results are usually not available for at least two days. Since the partial pressure of various gases in the bubbles are related to changes in process variables which may not be detected, a sensor to determine the gaseous constituents of the bubbles early in the manufacturing process, i.e., shortly after forming, would allow for a timely corrective action.

- **Status:** GMIC members has visited ORNL. First samples are being sent for testing.

Project in FY02

- **Thermal Conductivity Measurements of Glass Fiber Thermal Insulation**
  - Owens Corning – Tom Huff
  - Oak Ridge National Laboratory – Ralph B. Dinwiddie
  - **Objective**: This project will measure the thermal conductivity of the fiber glass material used as acoustic and thermal insulation in automotive exhaust systems. This “texturized” material resembles a typical insulation wool pack in many respects. One major difference is there is no binder on the fibers.
  - **Status:** Samples have been received and measurements are being made.

Project in FY02

- **Fiber Glass Properties Determination**
  - CertainTeed – Terry Berg
  - Johns Manville - Jerry DeMott
  - Lawrence Berkeley National Laboratory – Jeffrey A. Reimer
  - **Objective**: The purpose of the proposed testing is to try to determine the differences in glass properties from fibers produced in different plants using essentially the same batch composition and identify the most likely causes of these differences. One item of particular interest is the ability of some glasses to spring back to their normal configuration rather than breaking. In insulation, this property is none as "recovery".
  - **Status:** Project is funded and just starting.

Project in FY02

- **Glass Coating Enhancement**

  - Society for Glass Science and Practice – Beri Fox
  - Oak Ridge National Laboratory – Craig Blue

  - **Objective**: Presently, glass marbles are coated to enhance the marbles esthetics. The process incorporates heating of the substrates followed by room temperature aspiration of the coating on to the heated substrates. The heating is presently the rate-limiting step, it is not fully characterized, and in some instances, the substrates crack upon heating. A field data acquisition unit will be utilized to obtain the complete thermal history of the glass. Following the full analysis of the process, a design/procedure will be developed for implementing changes in the present process to increase energy efficiency, throughput and decrease scrap.

  - **Status:** Project is almost completed and the final report is being prepared.

Project in FY02

- **Application of Strength Test Data to the Design of Automotive Glazing With and Without Holes**

  - Visteon Corp. – Edward N. Boulos and Tom Cleary
  - Pacific Northwest National Laboratory – Fredric A. Simonen

  - **Objective**: The main objective of this project is to develop a design procedure, including recommendations for limits on design stresses, for automotive glazing subject to strength reductions caused by hole penetrations. To this end, PNNL will build on an existing data base from recent structural failure tests on glass specimens which were performed on samples of glass provided to PNNL by Visteon.

  - **Status**: Project is funded and the project is in planning stage.

Project in FY02

- **Analysis of Refractory Metal Needles Formed During Molten Glass Extrusion**

  - Osram Sylvania Inc. – Mark Fieldsend
  - Oak Ridge National Laboratory – Camden R. Hubbard

  - **Objective**: The project is to characterize needles that form near a refractory metal orifice and on a skirt, which potentially can interfere with the flow of extruded molten glass. The needles, orifice and container of a tungsten/molybdenum glass melter will be examined at ORNL using a combination of characterization techniques including optical microscopy, SEM, Electron Microprobe Analysis and x-ray diffraction. Thermodynamic modeling of the system will be undertaken to explain needle formation, transport mechanisms, sensitivity to temperature and environment.

  - **Status**: Project is funded and samples are being tested.

Project in FY02

- **Laser-Induced Breakdown Spectroscopy (LIBS) Software Integration**

  - Corning Incorporated - Preston S. Clemons
  - Sandia National Laboratories, California- Shane M. Sickafoose

  - **Objective**: Laser Induced Breakdown Spectroscopy (LIBS) is an analytical method for in-situ, real-time measurement of particle and gas stream composition. As such, it is of general use to the glass industry for process characterization and exhaust emission monitoring. In this project, we will develop control and data analysis software to complete the next step in the development of the next generation of general purpose LIBS spectrometer. The new echelle grating spectrometer allows simultaneous collection of atomic emission over that entire range.

  - **Status**: Project is funded and work has been started.

Project in FY02

•High Temperature Viscosity Measurements-CGR Glasses

– Schott Glass Technologies – Alex Marker
– Pacific Northwest National Laboratory – Pavel Hrma

– **Objective**: The Center for Glass Research has a project titled "Modeling of Glass Making Processes for Improved Efficiency (Subtitled: High Temperature Melt Property Database for Modeling). This project is almost complete but it needs to have the high temperature viscosity measurements made on 128 glasses. The Pacific Northwest National Laboratory has proposed to make these measurements for the very modest amount of $35,750. This amount is more than the usual G plus project. The Center for Glass Research will fund the additional costs.

– **Status**: More than 20 glasses have been tested.

Project in FY02

• Pollution-Free Fiber Glass with Reduced Melting Temperature

– PPG Industries, Inc. – Cheryl Richards
– Oak Ridge National Laboratory – Ted Bessman

– **Objective**: Project is to use glass composition modeling techniques to design new composition which will have a lower melting temperature and less air pollution.

– **Status:** Project was recently funded.

Project in FY02

- **Using Colored Cullet for Making Beautiful Glassware**
  - Fire & Light Originals – John McClurg
  - Pacific Northwest National Laboratory – Dong-Sang Kim
  - **Objective**: Fire & Light Originals uses recycled cullet from clear (flint) glass containers to make beautiful glassware. This project will develop compositions that will use more recycled cullet. The project will also characterize the current Fire & Light's glasses by measuring the viscosity, density, and thermal expansion. The glasses developed will match these properties. Color is a very important property, so, the chromaticity of the Fire & Light colored glasses will also be measured. Recycled cullet usage will be increased with this project.
  - **Status**: Project was recently submitted

Summary

- **FY 00**
  - Three projects were started
- **FY 01**
  - Seven projects initiated
- **FY 02**
  - Twelve projects initiated

Contact Information

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Glass Manufacturing Industry Council

Telephone: 614 818-9423

e-mail: mgreenman@gmic.org

Peter Angelini, Coordinating Laboratory Main Contact

Oak Ridge National Laboratory

Telephone: 865 574-4565

e-mail: angelinip@ornl.gov

Briefing on the OIT Clearinghouse

Sept 10, 2002

Gilbert McCoy — OIT Clearinghouse
Energy Engineer — WSU Energy Program

OIT Clearinghouse History

- Supported Motor Challenge Program since 1994
- Began supporting Steam and Compressed Air programs in 1998
- Solicitation for "OIT Clearinghouse" awarded in 1999; operation now based on integrated delivery in support of *all* of OIT's goals
- Over 45,000 cases of programmatic and technical assistance for US Industry since 1994
- Since start of OIT Clearinghouse June 1999, we have handled 19,000 cases from 13,000 OIT customers

OIT Clearinghouse Current "Charter"

- Field questions and discuss OIT's portfolio of products/services 11 hours/day (both *programmatic* and *technical* assistance)
- Help promote integrated delivery of all OIT resources
- Continue to provide technical assistance for BestPractices areas

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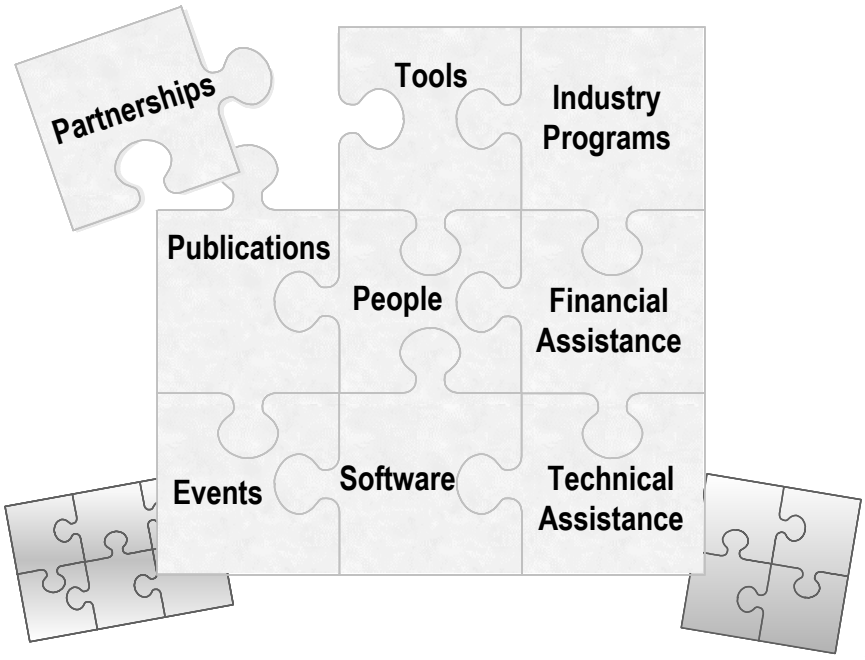
ENERGY PROGRAM

OIT Clearinghouse Integrated Delivery



OIT Clearinghouse Technical & Research Staff

- 11 core staff with 300 years of combined research and field experience and numerous certifications
- Field experience includes working in foundries, manufacturing plants and mills, fuel cells, research, teaching, and more
- Energy Library: 13,000 publications, 350 periodicals, 400 databases
- Particular industrial expertise in motor, pumping, steam, and compressed-air systems, CHP & distributed generation, fuel cells, biomass, NICE3 awards…

- Gil McCoy, P.E.
- Johnny Douglass, P.E.
- Gordon Bloomquist, Ph.D.
- Jim Kerstetter, Ph.D.
- John Ryan, I.E.
- Rob Penney, P.E., CEM
- Jack Zeiger, E.I.T.
- Bob O'Brien, P.E.
- Vicki Zarrell
- Angela Santamaria, MLn
- John Fenker, MLS

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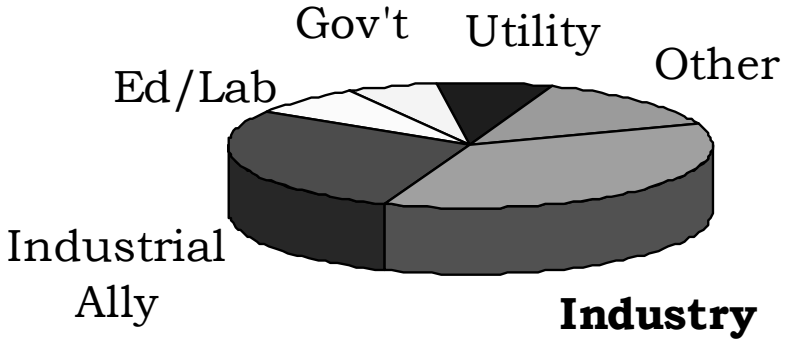
ENERGY PROGRAM

Customer Demographics



(6,890 cases in 2001)

Partners and Customers

- Energy end-users in all sectors
- Industry
- Manufacturers
- Inventors
- Consultants
- Purchasing officials
- Local, state and federal government agencies
- Federal power marketing administrations
- Utilities
- Researchers
- National labs
- Engineers
- Military
- Plant Operators
- Educators

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OIT Clearinghouse Customers—Industries

Air Products & Chemicals
Alcoa
American Precision Castings
BP - Amoco
Cardinal Glass
Cargill
Chevron
Eastman Chemical
Exxon Mobil Chemicals
Georgia Pacific Corporation
Inland Paperboard and Packaging
Kaiser Aluminum
Kennecott Mining
Lake Erie Steel
Logan Aluminum
Lucky Friday Mine
Nalco Chemical Company
Newmont Mining
Owens Corning
Paragon Die Casting Company
PPG Industries
U.S. Steel
UOP
Weyerhaeuser
Wierton Steel

Observations & Summary

- Half of customers take action because of assistance they receive from us.
- As integrated delivery improves, we learn even more about customers' needs and perspectives, and find more opportunities to connect people to resources.
- Our opportunities to play a "facilitator" role continue to grow (between customers, project partners, industry experts, Allied Partners, HQ staff, ROs, IACs, labs

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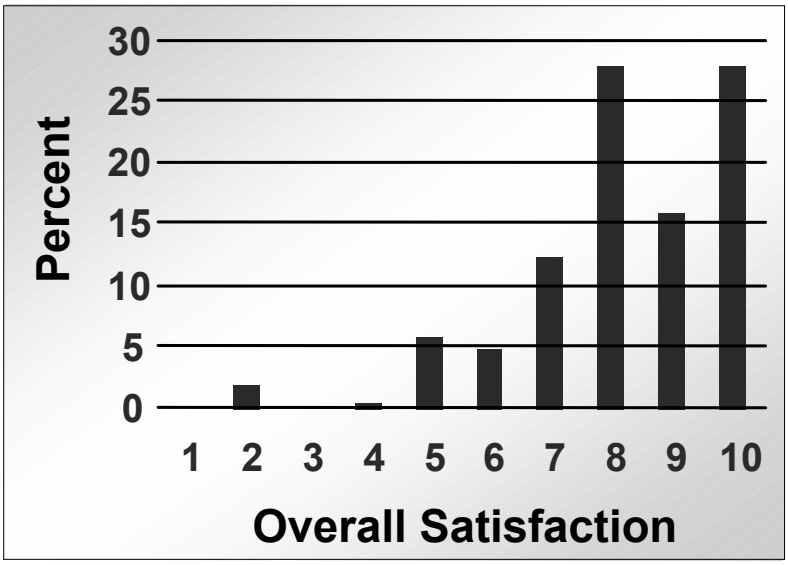
OIT Clearinghouse Customer Satisfaction



(Source: US DOE Motor Challenge)

OIT Customer Appreciation

"Without question, this is the first government program that I have been involved with that provides a value of service well in excess of cost. Keep up the good work."

"Thank you very much for being so responsive. This product is certainly of interest to my company and I will contact [an OIT-funded technology developer] for further questions."

"The quality of service being provided is clearly equal to or better than that internally available at major corporations."

"I found the GOLDMINE here! I am glad DOE is jumping on this, we are very interested in conserving at the plant."

"Your assistance will save us considerable time and expense."

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Contact Information

Contact the OIT Clearinghouse at

(800) 862-2086

Industryline@energy.wsu.edu

Improvement of Performance and Yield of Continuous Glass Fiber Drawing Technology -*"Breaking Through the Glass Fiber Drawing Barrier"*

Dr. Phillip A. Sanger and
Dr. Simon Rekhson
The Industrial Technology Institute
Cleveland State University
Cleveland, OH

@ CSU Ohio Department of Development PPG SCHOTT

Outline

- Project Definition and Team
- Energy and Economic Benefits for Solution
- Tasks and Schedules
- Project Funding Profile
- Physics of Glass Fiber Drawing
  - Analysis of Filament Radius Variation
  - Draw Resonance
  - Initial Testing
  - Preliminary Conclusions

@ CSU Ohio Department of Development PPG SCHOTT

This State IOF project aims to demonstrate a breakthrough four-fold reduction in downtime and un-recyclable waste, 20% yield increase, 15% throughput increase, and 20% reduction in fiber diameter variation.

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

Prime: Ohio Department of Development
Office of Energy Efficiency

Lead Organization: Cleveland State University through The High Performance Glass Forming Consortium

Participating Industrial Partners:
PPG Industries
Schott Glas

Supporting Companies:
Saint Gobain Vetrotex
Owens Corning

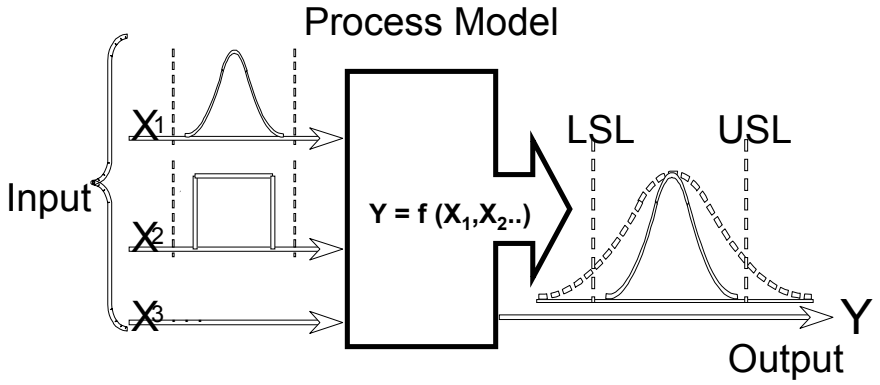
Project Contributors come from government, academia and industry

• Organization	Participant	Role
• Ohio Dept of Development Office of Energy Efficiency	Bill Manz	Program Monitor
• Cleveland State University	Phillip Sanger Simon Rekhson Jim Leonard	Program and Lead Technical Management Simulation, Transfer function Validation
• PPG Industries	Sameer Talsania Cheryl Richards Dean Gaertner Jim Koewing	Consortium member, Equipment design, Data and Validation, Implementation
• Schott Glas	Ulrich Fotheringam	Consortium Member Validation

Converting Scrap into a Higher quality, Salable product Saves Energy

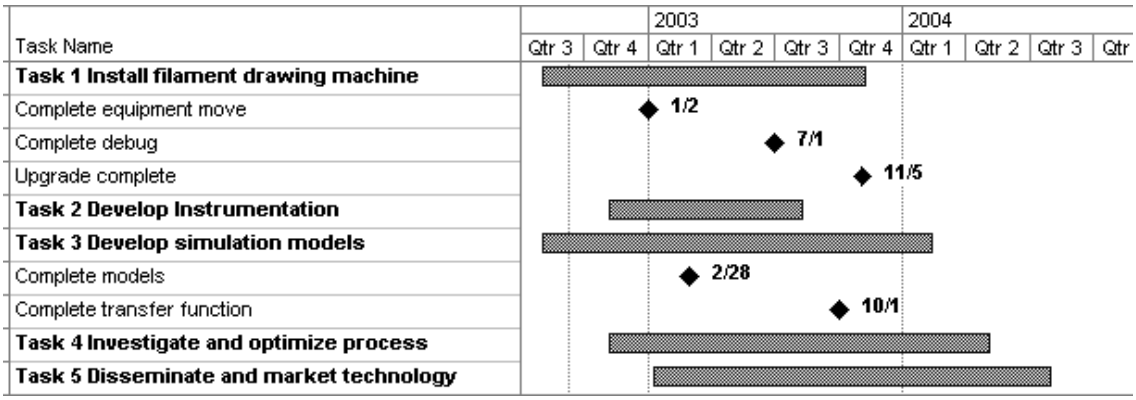
- Reducing breakage by 50% reduces scrap by 67,000 tons per year
- Energy thrown away in the scrap is presently 460-740 BBTU annually which is saved by realizing good product from waste
- Sales of saved product estimated at greater than $500M annually

Applying the 6σ quality methodology and fundamental glass science, we will attack fiber breakage and the waste that results



Define, measure, analyze, improve and control

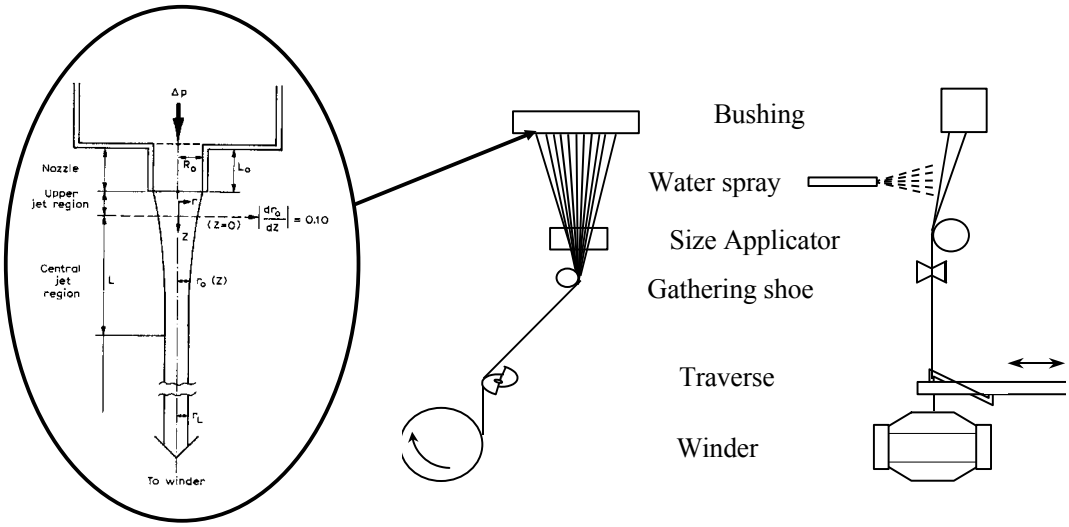
Contract in place on August 1, 2002 with simulation and equipment build initiated



Aggressive goals in a two year, $1,256K project

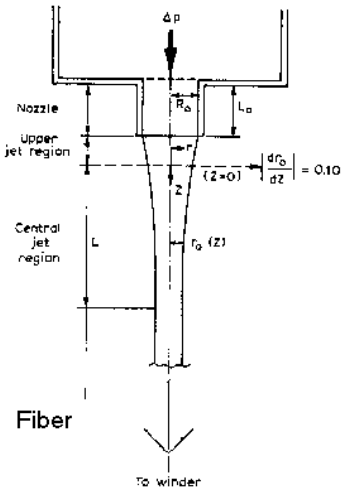
Fiscal year	EERE cost	Cost share	Total
FY 2002	$60K est	$32K	$92K
FY 2003	$495K	$140K	$635K
FY 2004	$413K	$116K	$529K
Total	$968K	$288K	$1,256K

Breakage is a barrier to higher throughput in the challenging 20,000:1 fiber drawing process



Fiber Drawing Process Design - Basic Physics

- Viscosity of molten 710 Glass at ~2200 F is 1000 P; sour cream at R.T. = 1000 P, honey = 100 Poise
- Flows through the channel (bore) of 1.7 mm (~1/16 inches) driven by pressure $\Delta P = \rho g H$ (hydrostatic head)
- Typical bore/filament diameter ratio = 1720/12 (microns) = 140, the ratio of areas (~ratio of d^2) = 20,000
- 0.1 mm-thin sliver of jet (paper sheet) → ~ 2000 mm long fiber
- @ tip V = 7 m/hr; ~7-10 cm below → V ~ 80 - 120 km/hr



Schematic of attenuating glass jet (adopted from Gupta)

Main Effects - Radius Variation

Hagen-Poiseuille law for flow in a nozzle:

$$v_0 = (\rho g H + \sigma_0) R_0^{\,2} \Big/ \left[8 L_0 \eta \left(1 + \frac{3\pi R_0}{8 L_0} \right) \right]$$

where ρ, g and H are the density, gravitational constant and total fluid height
$\rho g H$ = pressure of molten glass column of height H
σ_0 is the pulling stress
R_0 and L_0 are the nozzle radius and depth
η is the molten glass viscosity

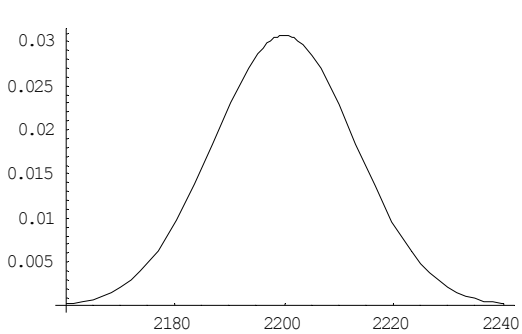
$$\eta = \mathrm{Exp}\left[-\alpha (T - T_0) \right]$$

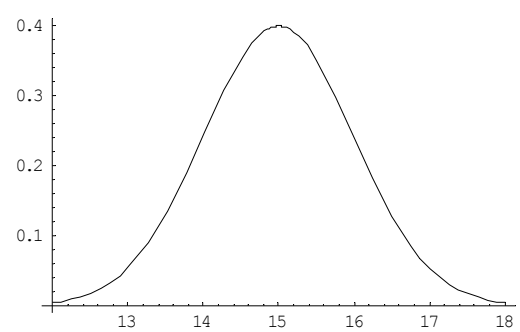
From continuity equation

$$S_L = S_0 \frac{v_0}{v_L}, \qquad r_L = r_0 \sqrt{\frac{v_0}{v_L}}$$

From known process variables and constants - T, R_0, L_0, etc. - and using equations above we calculate resulting radius r_L

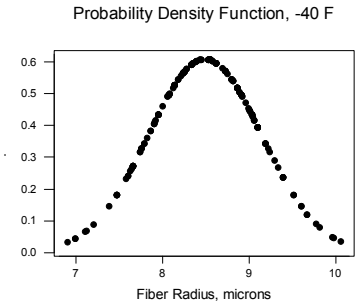
Main Effects - Radius Variation, cont'd

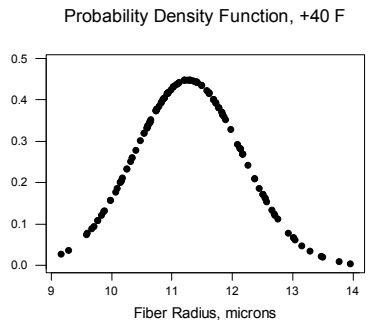


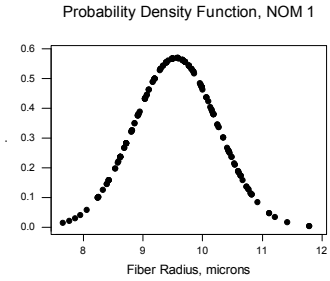


Assuming the range and type of probability density function (normal distribution) for temperature results in 12 to 18 micron range of filament radius variation over the bushing

Fiber Drawing Process Design - Validation

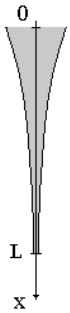






Whereas the shift of mean value is significant so is the overlap: note that the right half of the distribution at -40F overlaps with the left half of distribution at NOM 1 temperature

Computer Simulation: Quasi-one-dimensional model



Conservation equations:

$$\frac{\partial S}{\partial t} + \frac{\partial (vS)}{\partial x} = 0, \qquad \text{- mass}$$

$$\frac{\partial}{\partial x}\left(3\mu \frac{\partial v}{\partial x} S\right) = 0, \qquad \text{- momentum}$$

$$\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial x} = -\frac{1}{\tau_T}(T - T_a) \qquad \text{- energy}$$

Boundary conditions:

$$S = S_0, \quad v = v_0, \quad T = T_0, \quad x = 0$$
$$v = v_L, \quad x = L$$

where S is the jet cross section, v is the axial velocity

$\mu(T)$ is the viscosity, T and T_a are the temperature of glass and air

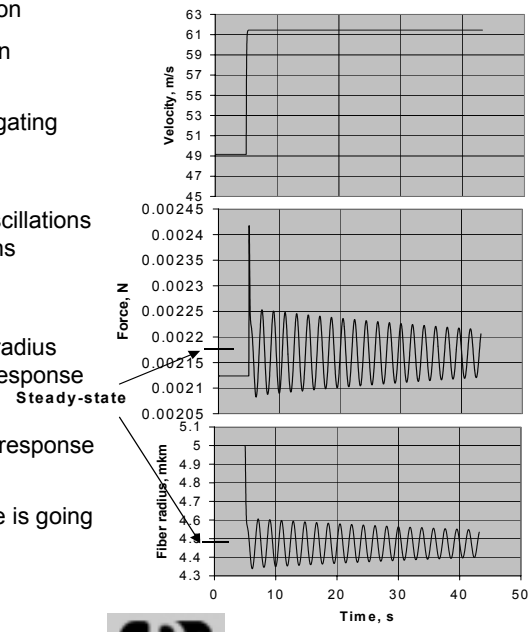
$\tau_T = \dfrac{S}{\pi k Nu}$ is the characteristic time of cooling

k is the thermal conductivity, Nu is the Nusselt number $= h\,D/k$

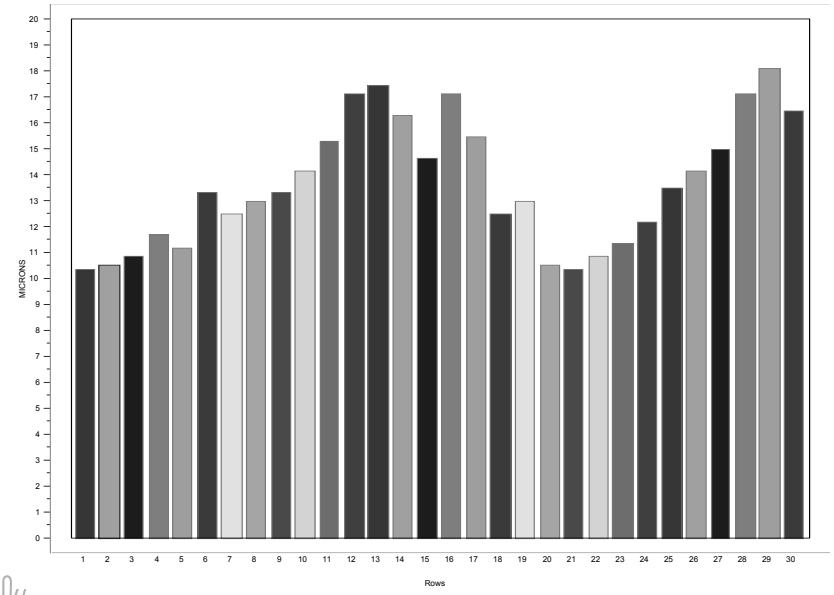
Draw resonance

- Draw resonance is the second source of radius variation

- Observed following the drum velocity drift (also drift in temperature?)
- Periodic swelling and contraction of the fiber - propagating waves
- Purnode reports:
  Viscosity = 460 poise - small, stable and damped oscillations
  Viscosity = 380 poise - sustained but large oscillations
  Viscosity = 280 poise - growing oscillations
- Using our quasi-one-dimensional model (similar to Glicksman's model) observed up to ± 20% fiber radius variation, (i.e. within ± 2 micron on diameter) in response to ± 5% drum velocity variation
- Conducted a systematic study of draw resonance in response to a single step-function change in drum velocity
- When the fiber radius is going down, the pulling force is going down; why both begin to grow one second later?

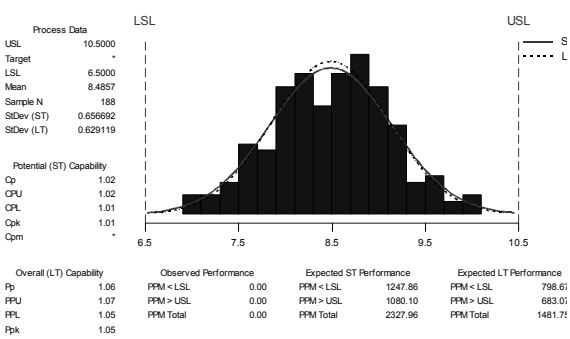


Preliminary validation: **Pulsating was observed on a single tip bushing at 2475 F using a 5 second traverse over a mandrel revolving at 1500 rpm's. Measurements were taken left to right on the mandrel.**



4.5 sigma process, 6 sigma process

Process Capability Analysis for -40 F

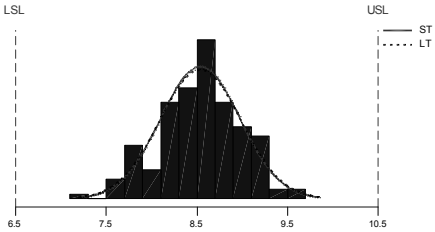


Process Data	
USL	10.5000
Target	*
LSL	6.5000
Mean	8.4857
Sample N	188
StDev (ST)	0.656692
StDev (LT)	0.629119

Potential (ST) Capability	
Cp	1.02
CPU	1.02
CPL	1.01
Cpk	1.01
Cpm	*

Overall (LT) Capability		Observed Performance		Expected ST Performance		Expected LT Performance	
Pp	1.06	PPM < LSL	0.00	PPM < LSL	1247.86	PPM < LSL	798.67
PPU	1.07	PPM > USL	0.00	PPM > USL	1080.10	PPM > USL	683.07
PPL	1.05	PPM Total	0.00	PPM Total	2327.96	PPM Total	1481.75
Ppk	1.05						

Process Capability Analysis for Desired 6 Sigma Process



Process Data	
USL	10.5000
Target	*
LSL	6.5000
Mean	8.5378
Sample N	150
StDev (ST)	0.437708
StDev (LT)	0.448434

Potential (ST) Capability	
Cp	1.52
CPU	1.49
CPL	1.55
Cpk	1.49
Cpm	*

Overall (LT) Capability		Observed Performance		Expected ST Performance		Expected LT Performance	
Pp	1.49	PPM < LSL	0.00	PPM < LSL	1.62	PPM < LSL	2.76
PPU	1.46	PPM > USL	0.00	PPM > USL	3.68	PPM > USL	6.05
PPL	1.51	PPM Total	0.00	PPM Total	5.30	PPM Total	8.81
Ppk	1.46						

This data gives a visual illustration of the “6 sigma” process in terms of filament diameter. The actual process on the left produced DPM(Lower)+DPM(Upper)=1482, which is *z*=3 or 4.5 sigma score. The simulated process on the right yields DPM(Lower)+DPM(Upper)=5.3, which is *z*=4.5 or 5.9 sigma score, ie approximately a 6 sigma process.

Findings

- The simulated variation of molten glass temperature across the bushing within ± 40°F causes filament diameter variation within ± 2 micron
- The simulated drum velocity oscillations within ± 5% cause diameter variation within ±2 micron when melt temperature is above critical
- Tests at several temperatures gauged fiber diameter variation
- Jet pulsation was induced in one of the tests to cause filament diameter oscillations within a range of 10 to 18 micron

A Technical and Economic Assessment for Justifying the Development of a Next Generation Glass Melting System Within a New Business Model

GMIC Project Review Meeting

September 10, 2002

Sandia Laboratory - Livermore, CA

C. Philip Ross – Glass Industry Consulting

Gabe Tincher – N. Sight Partners

NGMS Mission

- Address energy and capital barriers
- Reduce overall production costs
- Maintain and improve glass quality and
- Environmental stewardship
  - Reduce Greenhouse gases by reducing fuel consumption
  - Reduce waste generation through improved productivity

TEA Project Task Elements

I. Data Collection
II. Resource Contracting
III. Analysis of Information Gathered
IV. Findings – Perspectives & Conclusions

V. Report Writing / *Review / Editing*
VI. Report Publication / Presentations

Direct Contact Resources

- AEI
- Air Liquide
- Air Products
- Alfred University
- Arc International
- Asahi Glass
- ATC
- BOC Gases
- British Glass
- BSN
- CGR
- Corning
- Czech Institute of Inorganic Chemistry
- Frazier Simplex
- Gas Technical Institute
- GE Lighting
- German Glass Society, HVG
- Glass Services
- Glass Technology Services Ltd
- GMIC
- GTI
- GTI Library
- Guardian
- H.F. Teichman
- ICG TC-13 (Environmental Committee)
- ISORCA
- Kumgand Korea Chemical
- Kyoto Institute of Technology
- Leone Industries
- Libbey Glass
- Maxon
- Nienburger Glas
- Nippon Electric Glass
- OCF
- OCF Science & Technology
- Owens- Illinois
- Perrier
- Philips Display
- Pilkington
- PPG
- PQ Corp.
- Saint Gobain (France)
- Saint Gobain Containers
- Scholes Library
- Science Production Enterprise (Armenia)
- Sorg
- Stazione Sperimentale Del Vetro (Italy)
- St. George Crystal
- Techneglas
- Techneglas - Japan
- TECHNEGLAS, O-I
- TECO
- Thomson Multimedia
- Ultramax
- Vitro
- Vortec, Inc.
- Zippe

"One Solution for All" Melter

Simple Design
Energy Efficient
Environmentally Friendly
Maximize Quality
Stable Operation

Long Operating Life
Innovative Features
Kryptonite Powered
Economical

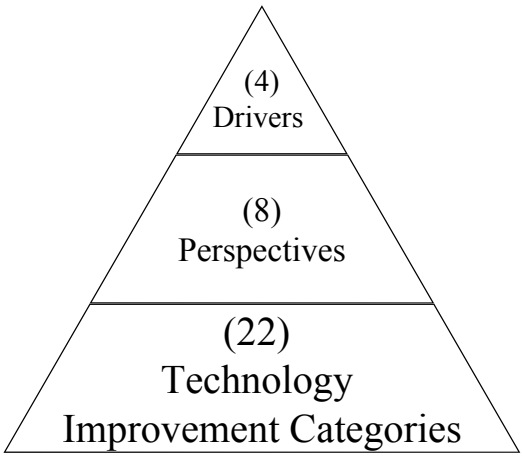
Affordable to All

Laughable Claims
Overly Stated Capabilities
Severely Deficient
Every Compromise Accepted
Recycled Ideas & Concepts

Total Solution for Every Problem
Often Rejected Concepts

Universal Expected Applicability
Sensibility Forgotten

Hierarchy of Findings



Data Gathering & Interviews

Patent & Literature Search

- Relevant Patents Identified > 300
- Relevant Literature Identified > 525
- All Characterized into T & E Improvement Categories 22

Melting Advancement Categories

1) **Glass Quality Improvement**
2) **Manufacturing Flexibility (Compositions / Fuels)**
3) **Raw Material Oxide Source Selection**
4) **Raw Material Beneficiation**
5) **Recycled Cullet Use**
6) **Batch Preparation / Agglomeration**
7) **Batch / Cullet Preheating (or Pre-Reacting)**
8) **Enhanced Heat Transfer**
9) **Waste Heat Recovery**
10) **Fusion (Sand Solution) Process**
11) **"Zonal" Separation (Solids Heating / Melting Fusion / Refining / Conditioning)**
12) **Refining**
13) **Conditioning (Chemical / Thermal)**
14) **Process Controls (Sensors, Analytical / Predictive, Process Analysis & Control)**
15) **Environmental Compliance**

Drivers For Advancing Melting Technologies

- ↗ Quality / Yield
- ↗ Capital Productivity
- ↗ Environmental Compliance
- ↗ Energy Efficiency

Perspectives & Conclusions

1. Quality Requirements to be Competitive Often Justify Capital and Operating Costs for Melting

2. Energy Savings are Driven Only by <u>Net</u> Cost Savings

Perspectives & Conclusions (cont.)

3. Higher Operating Costs may be Acceptable,if Higher Capital Productivity can be Realized

4. The Industry's Technical and Economic Horizon is Short Term

Perspectives & Conclusions (cont.)

5. All Traditional Glass Segments are Adverse to both Technical and Economic Risk

6. While Melting Concerns, particularly Environmental Issues are Common to Most Glass Producers, Perceived Differences Between Segments Limit Interest in Collaboration

Perspectives & Conclusions (cont.)

7. No Significant Consortium Interest in a Large Scale Melting Initiative Unless Key Drivers Change

8. A Clear View of Future Energy, Capital and Environmental Costs Could Provide Drivers to Change Melting Practices, Melting Development, and Interest in Collaboration

Future Scenarios Workshop

August 28, 2002

- Select group of 13 seasoned glass industry experts

- Scenarios for three key drivers:
  - Energy cost at 3-5 times current level
  - Increased environmental pressures
  - Lower and higher capital costs

High Priority Technologies

- Segmentation of melting process
  (“P-10” Type Process)
- High intensity melter (1st melting stage)
- Improved instrumentation and controls
  (Yield and Quality)
- Vacuum Refining
- Melter Operating Service (“Glass, Inc.”)

C

Appendix C

Attendees

Attendees

U.S. Department of Energy

GLASS PROJECT REVIEW

Livermore, California

September 9-10, 2002

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$\mathcal{D}$

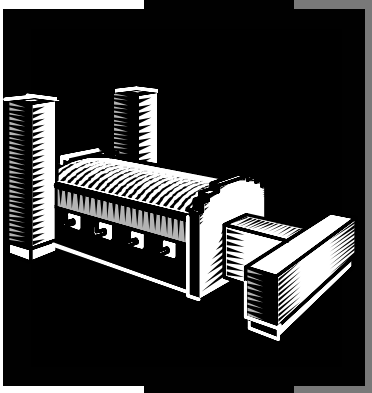
Appendix D

GPLUS Project Posters

GPLUS Current Project

Reduction in Corrosion of Refractories Using Encapsulated Glass Additives

Project Objective and Background



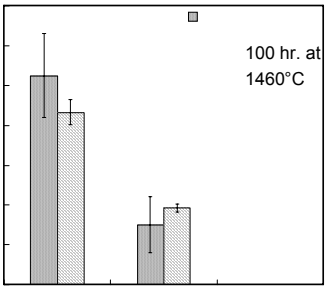
Manufacture of quality glassware requires efficient inclusion of various additives in the starting glass batch material. However, these additives may have adverse corrosive reaction with the refractory lining of the glass melting tank or pot. An improved understanding of the effects of various additives in the glass batch on degradation of refractory lining will help select appropriate refractory material with improved service life and optimize glass batch composition for enhanced glass quality.

The objective of this project is to evaluate corrosion behavior of different candidate refractory materials for glass tank lining as a function of various additives in glass batch using encapsulated technique.

Accomplishments and Knowledge Gained

VISION TILE exhibited the maximum corrosion damage, while L. E. Smith exhibited little or no corrosion.

Corrosion depth for each refractory was observed to be similar in both unpelletized and pelletized glass, suggesting no significant effect of pelletization on corrosion damage.



Refractories

Potential Benefits and Impacts

Results of this study gives information on the effects of additives for improving quality of glassware and identification of refractory material(s) with improved corrosion resistance. This will result in reduced refractory wear, improved glass ware quality, and enhanced campaign life of refractory lining and melting equipment. Minimization of refractory wear will reduce refractory waste with a positive environmental impact, and enhanced campaign life will result in a substantial amount of energy savings.

Information/Technology Transfer Potential or Plans

This work was done in close collaboration with glass industry and refractory manufacturer(s). Industrial partners are informed of the research findings through phone conversations and written reports. Society for Glass Sciences and Practices, at their annual symposium, will partner with the GMIC to present a paper on the project.

Project Participants

- Society for Glass Sciences and Practices (SGSP)
- Argonne National Laboratory

For more info, contact:
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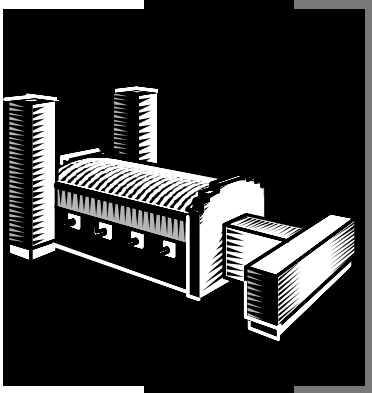
(630) 252-5123

Glass Manufacturing Industry Council

GPLUS Completed Project

Volatilization and Capture of Boron and Sodium



Project Objective and Background

The presence of vapor phase boron species in the exhaust cleanup system of a borosilicate glass melting furnace complicates the removal of boron using an electrostatic precipitator. It was known that the partial pressure of vapor phase boron compounds depends to some extent on flue gas composition and temperature, but the optimum conditions for exhaust treatment were not known. Effects of the following were measured using laser-induced breakdown spectroscopy (LIBS) in two G+ projects: I. Oxygen/gas ratio at the burners, and II. Flow rate, density, and atomizing air pressure of caustic soda injected to convert boron vapor compounds to solid sodium borates.

Accomplishments and Knowledge Gained

Boron leaving the precipitator passed through a minimum as the oxygen/gas ratio was varied. The optimum oxygen/gas ratio was identified. Boron leaving the precipitator decreased slightly with increasing temperature at the outlet from the precipitator. Theoretical calculations predicted that boron passes through a minimum as temperature is increased further. The optimum temperature was identified. Changing the atomizing air pressure had negligible effect.

Potential Benefits and Impacts

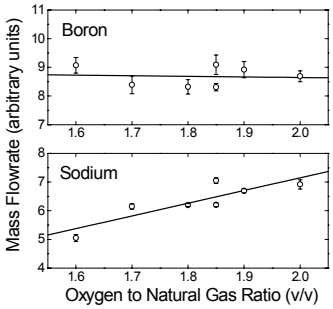
Benefits include: increased boron capture and conservation of raw materials, reduction of boron in stack gas, can reduce caustic soda atomizing air pressure to minimize nozzle wear, and increased control of the exhaust treatment system.

Information/Technology Transfer Potential or Plans

All of the results and conclusions are available in reports to GMIC members (January 2001 and August 2002).

Project Participants

- CertainTeed Corporation
- Sandia National Laboratories



Measurements of boron and sodium using LIBS in the flue upstream from the exhaust treatment system, showing the effect of oxygen/gas ratio on sodium and the absence of any significant effect on boron. Downstream from the electrostatic precipitator the trends were quite different.

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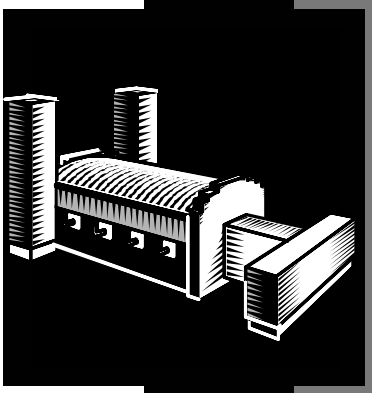
Glass Manufacturing Industry Council

GPLUS Current Project

Application of Strength Test Data to the Design of Automotive Glazing With and Without Holes

Project Objective and Background



The main objective of this project is to develop a design procedure, including recommendations for limits on design stresses, for automotive glazing subject to strength reductions caused by hole penetrations. To this end, PNNL will build on an existing data base from recent structural failure tests on glass specimens which were performed on samples of glass provided to PNNL by Visteon.

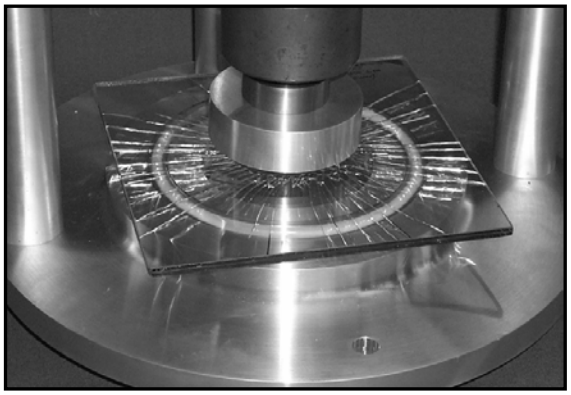
The proposed design approach will have a probabilistic basis which will systematically evaluate the existing data so that one can establish general trends needed to apply the results to design procedures of future glazing systems. Planned activities also include identifying the test conditions that were not adequately covered by the current PNNL data and generating additional test results. The testing will focus on static fatigue and stress corrosion cracking. The potential effects of crack growth caused by long-term stresses on reducing the strength of glazing when subjected to short-term stresses.

Potential Benefits and Impacts

This project will result in generalized data and recommendations for design stress limits for glass components with holes, which will increase production efficiency by providing guidelines for manufacture. Establishment of probabilistic failure models for glass products with penetrations will allow designing new glazing applications in the automotive industry

Information/Technology Transfer Potential or Plans

Statistically based recommendations for setting allowable stress levels for design will be made available for use in the design of glazing systems, which will allow hole penetrations without compromising desired high levels of structural integrity.



Project Participants

- Pacific Northwest National Laboratory
- Visteon Glass Division

For more information, contact:
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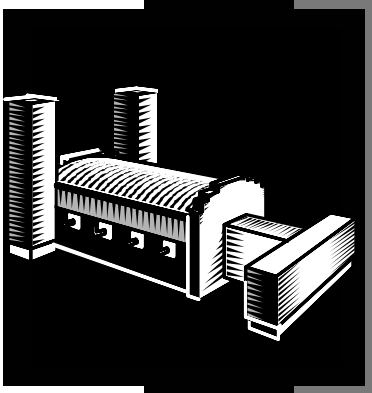
(509) 375-2087

Glass Manufacturing Industry Council

GPLUS Current Project

High Temperature Viscosity Measurements – CGR Glasses



Project Objective and Background

This project is to provide the high temperature viscosity measurements for 128 commercial glasses needed to complete the CGR's "High Temperature Melt Property Database for Modeling."

Potential Benefits and Impacts

The data supplied by this G+ project is required for more accurate glass furnace modeling, which is an important component of the Energy Efficiency section of the Glass Industry Roadmap.

Information/Technology Transfer Potential or Plans

The High Temperature Melt Properties Database for Modeling will be provided to the industrial partners for use in their modeling codes.

Project Participants

- Schott Glass Technologies Inc.
- The NSF Center for Glass Research at Alfred University
- Pacific Northwest National Laboratory

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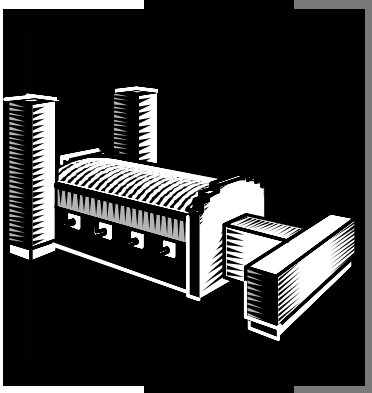
Glass Manufacturing Industry Council

GPLUS Completed Project

Batch Reactions of a Soda-Lime Silicate Glass



Project Objective and Background

The purpose of this project is to develop the batch reaction data for a soda-lime-silicate glass needed to improve the batch part of the glass furnace model being developed for the glass industry.

Accomplishments and Knowledge Gained

Evolved gas analysis combined with batch expansion measurement was successfully applied to obtain batch reaction kinetic data. The heat capacity measurement by differential scanning calorimetry (DSC) was suggested as a promising method to economically derive the heat of fusion data for many different technical glass batches.

Potential Benefits and Impacts

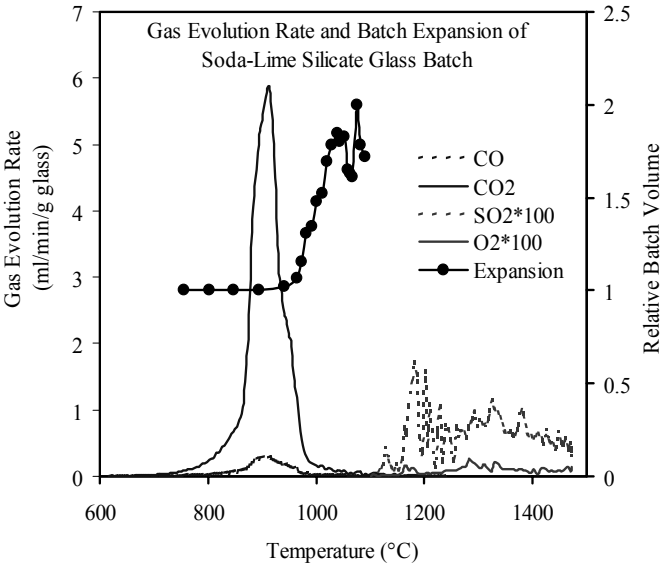
The batch reaction kinetic data developed in this project will be used to improve the batch model, which will in turn enhance the reliability and applicability of the integrated furnace model for optimized and efficient operation of the glass furnaces.

Information/Technology Transfer Potential or Plans

The experimental methods for batch reaction studies and the methodology for obtaining inexpensive heat of fusion data developed in this study can also be applied to various types of technical glasses.

Project Participants

- Pacific Northwest National Laboratory
- Libbey Inc.
- Shell Glass Consulting Inc.



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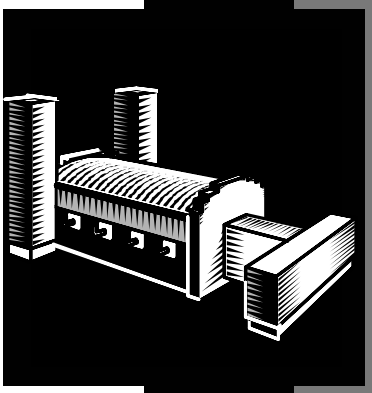
GPLUS Current Project

Defects in TV Glasses



Project Objective and Background

The goal of this project is to improve pack by reducing glass losses due to defects in the glass. Chemical analysis of the defect is very important information to the glass and furnace engineer. The seeds and blisters will be examined using gas chromatography combined with mass spectrometry (GC/MS). These tests will determine the amount of gases (H_2O, CO_2, NO_x, O_2, etc.) in the seeds and blisters.

The electron microprobe and/or scanning electron microscope will be used to identify the chemical compositions of stones and cord defects.

Potential Benefits and Impacts

Production efficiency of any glass manufacturing operation is reduced because of glass defects such as seeds and blisters, batch and refractory stones, and cords. TV panel glass and other high quality glasses require a glass as free as possible of these defects. The glass and furnace engineers can make process changes to minimize these defects if they know the chemical composition and other characteristics of these glass defects.

Information/Technology Transfer Potential or Plans

A major goal of the Production Efficiency section of the Roadmap is to reduce production costs by 20 percent. Reducing glass defects increases glass production rates. This G + project will also assist the High Temperature Materials Laboratory to develop techniques to assist all glass manufacturers with their glass defect problems.

Project Participants

- Techneglas, Pittston, PA: William J. Horan (570-883-2861)
- Oak Ridge National Lab: Arvid Pasto (865-574-5123), Larry Walker (865-574-5339)

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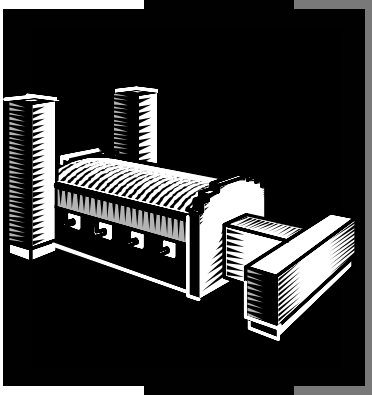
Glass Manufacturing Industry Council

GPLUS Current Project

Glass Coating Enhancement

Project Objective and Background

Presently, glass marbles are being coated with Tetraisopropyl Titanate (TIPT) to enhance the marbles esthetics. The process incorporates heating of the substrates followed by room temperature aspiration of the TIPT on to the heated substrates. The heating is presently the rate limiting step, it is not fully characterized, and in some instances, the substrates crack upon heating. This work will involve fully characterizing the heating and coating process at Marble King, in the field.



Potential Benefits and Impacts

The Glass Technology Roadmap identifies the following needs; " increase yield/decrease rejection rate of product ", " us of process heat ", and " increase throughput and waste minimization ". When completed and implemented, this work will result in decreased energy usage through optimization of heating, heating technology, and reduced scrap.

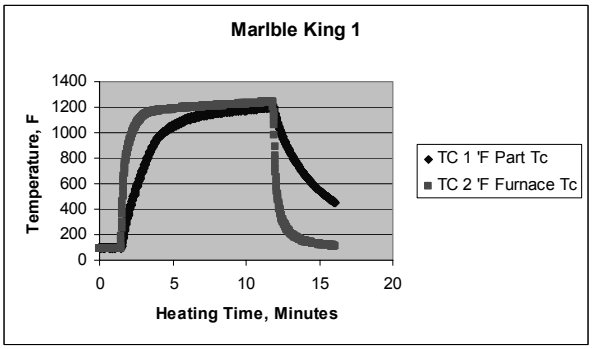
Information/Technology Transfer Potential or Plans

Following the full analysis of the process, a design/procedure will be developed for implementing changes in the present process to increase energy efficiency, throughput and decrease scrap.

Project Participants

- Marble King, Paden City, WV (Beri Fox)
- Oak Ridge National Laboratory, Oak Ridge, TN (Dr. Craig A. Blue)

Shown below are the present glass marble heating and coating process and thermal profiles. Work at ORNL has shown that the heating can be achieved in half the time with no cracking of product while increasing energy efficiency.



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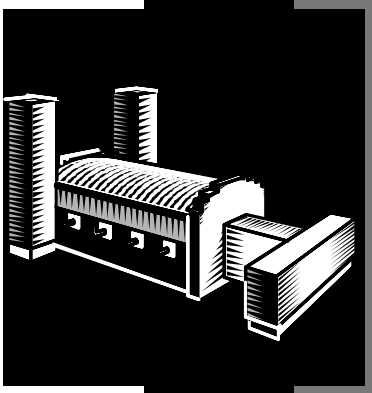
Glass Manufacturing Industry Council

GPLUS Current Project

Analysis of Gases in Blisters in Amber Glass



Project Objective and Background

Blisters in glass can result in significant losses in production efficiency, requiring additional energy to reprocess the rejected glass. Currently available analytical techniques require special sample preparation and results are usually not available for at least two days. A process to determine the gaseous constituents early in the manufacturing process, i.e., shortly after forming, would allow for timely corrective action.

Potential Benefits and Impacts

Development of a technique for real-time analysis of the gas content of blisters could provide information to correct deviations in the melting and conditioning process which cause blisters, reducing losses, thereby improving production efficiency.

Information/Technology Transfer Potential or Plans

Plan is to develop technology which requires a low capital investment yet is robust enough to provide accurate results in a plant environment. Emphasis will be on development of methodology for use by non-specialists.

Project Participants

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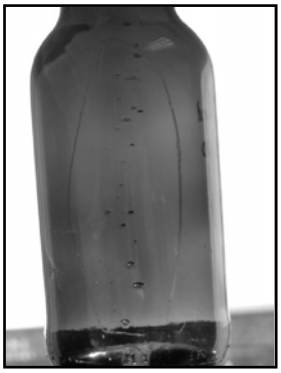
Erik M. Helin
G+ Project Manager
Project Engineer, Glass Technology
Saint-Gobain Containers



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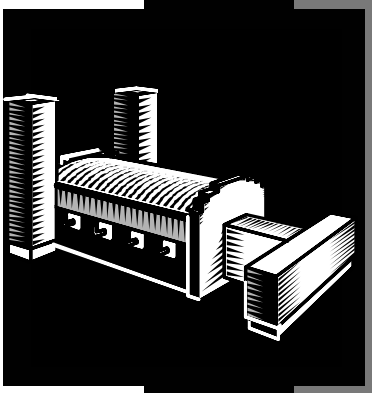
GMIC Glass Manufacturing Industry Council

GPLUS Current Project

Analysis of Refractory Metal Needles Formed During Quartz Tube Extrusions

Project Objective and Background



Quartz tubes for lamp applications are formed by melting high purity silica in a vertical refractory metal container that is then extruded through a refractory metal orifice and mandrel as a continuous quartz tube. Once in operation, the major cause of furnace shutdown occurs when the quartz tube becomes scribed or out of round. Scribing happens when large metallic crystals growing on the bottom of the orifice or on the skirt below the orifice (see figure below) intercept the extruded molten quartz tube.

Osram Sylvania and ORNL previously studied crystal origins in one refractory metal melter. Alternate designs are being tested at Osram and materials performance will be evaluated at ORNL.

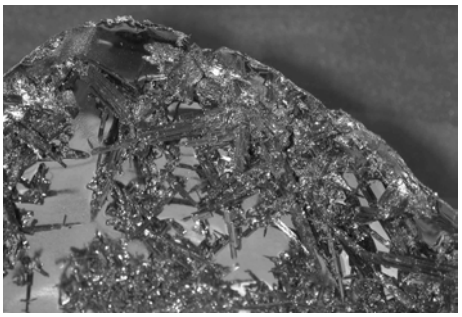
The objective of the GPLUS project is to characterize refractory melter components after operation along with any metallic needles present to determine the source of crystal production. Optical microscopy, scanning electron microscopy, x-ray diffraction, and thermodynamic modeling will be used to determine the crystal chemistry, growth habit, and the materials transport mechanism that supports the crystal growth.

Potential Benefits and Impacts

The reduction or elimination of crystal growth would greatly extend the lifetime of a quartz melter by reducing or eliminating a major cause of defective tube formation and melter shutdown. The reduction of defective tubes would result in a substantial saving of both energy and capital investment needed for the construction of a new refractory metal container, orifice and mandrel.

Information/Technology Transfer Potential or Plans

A project report will summarize the materials characterizations and thermodynamic calculations being performed.



Project Participants

- Mark Fieldsend, Osram Sylvania Inc, Glass Technologies, Exeter, New Hampshire
- Camden Hubbard, Evan Ohriner, and Roberta Peascoe, Metals & Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

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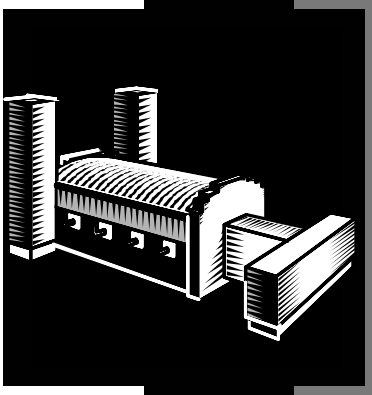
Glass Manufacturing Industry Council

GPLUS Current Project

High Temperature Thermocouple Degradation Study

Project Objective and Background



Glass manufacturers use precious metals thermocouples as the primary temperature sensors throughout the manufacturing process. It is well known that thermocouples degrade (drift) over time at high temperatures, but very little has been published that quantifies and characterizes this loss of accuracy at real operating temperatures over long periods of time.

Several commercially available, Type "S", Type "B", and Pt 20% Rh vs Pt 40% Rh, precious metals thermocouples were exposed to temperatures of 1400°C and 1600°C for a period of several months. Pre-test calibration, data trending, post-test calibration and metallurgical analyses will be used to quantify the degradation.

Potential Benefits and Impacts

By providing quantitative information on the degradation of thermocouples, this project will increase the understanding of how and why thermocouples change while in use at high temperatures.

Information/Technology Transfer Potential or Plans

This information will be published to help the glass industry to improve and make better use of these common temperature sensors.

Project Participants

- Schott Glass Technologies Inc. (SGT)
- Idaho National Engineering and Environmental Laboratory (INEEL)
- Engelhard-CLAL

For more info, contact:

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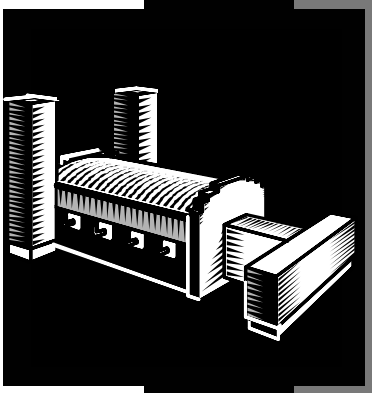
GMIC Glass Manufacturing Industry Council

GPLUS Current Project

Optical Probe and Software Improvements

Project Objective and Background



In order to increase the utility and versatility of the Laser-Induced Breakdown Spectroscopic (LIBS) instrument we are expanding our previous collaboration. This work will include efforts to improve software capability, laser beam delivery and emission collection. An optical probe has been designed and constructed that will allow for a more portable instrument that can be easily transported and set up in the field. A second goal will be to develop operating software for the spectrometer that will provide the command structure and versatility that will be useful in a variety of industrial and research environments. Currently, the spectrometer is operated using a limited demonstration program provided by the manufacturer. Development of customized control software will be the first step towards integrating instrument operation, data collection, and data analysis into one piece of software for near real-time analytical measurements.

Potential Benefits and Impacts

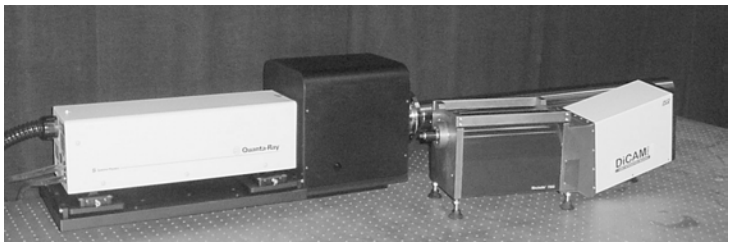
The creation of customized control software for this spectrometer will increase the range and utility of the LIBS instrument and prepare it for further software integration. The new optical probe and hardware will provide a rugged, field-portable instrument for analysis, optimization, and control in a real-time, quantitative manner of a wide variety of process flows in the glass industry. Measurements can be made on a wide variety of systems ranging from R&D bench-scale reactors to full-scale industrial production lines. The Corning and Sandia teams need to establish familiarization with the project since both teams have undergone complete personnel changes during the past year.

Information/Technology Transfer Potential or Plans

The control software will be tested by both Sandia and Corning on their respective LIBS instruments. The final version will be delivered to Corning for use on their instrument as well as kept at Sandia for use on other Glass Industry relevant projects. The field ready optical probe and hardware will be sent to Corning. The final report generated will be available to other glass companies.

Project Participants

- Corning, Inc.
- Sandia National Laboratories



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GMIC
Glass Manufacturing Industry Council

Appendix E

EERE Program Posters

GLASS FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

BUILDINGS

Windows of Opportunity in Energy-Efficient Buildings

In 2000, Americans spent approximately $265 billion for energy for buildings. This energy use is responsible for 35% of the nations's CO_2 emissions, 47% of SO_2 emissions, and 23% of NO_x emissions. These emissions are expected to increase by more than 25% between now and 2010. In 2000, buildings consumed more primary energy in the U.S. than either the industrial or the transportation sector, and buildings consume over twice as much electricity as the industrial sector.

The EERE *Building Technology Program* has three strategies to improve building energy efficiency:

- Research and development;
- Building codes, appliance standards, and guidelines; and
- Technology transfer and financial assistance.

The R&D strategy includes support for advanced research to develop new energy-efficient technologies for windows, building envelopes, and lighting. DOE has developed a technology roadmap for each of these glass-related building product areas. In addition, the Solar Program is pushing development of other glass-using technologies in its Zero Energy Building Initiative.

FACTOID

Commercial and residential window sales total 1.2 billion ft^2 ($7 billion) annually.

TECHNOLOGIES

LED light bulbs: just one of many new efficient lighting technologies for buildings.

LIGHTING RESEARCH PRIORITIES

- **Optical fibers**
- **Light Pipes**
- **LEDs, LEPs and ceramics**
- **Incandescent and flourescent bulbs**
- **Light Panels**
- **Daylighting**
- **Area Panels**

BUILDING ENVELOPE RESEARCH PRIORITIES

- Variable R-value insulating materials for glazings
- Glass and opaque double-envelope systems with integral energy collection and distribution
- Roof and/or wall assemblies that collect and supply energy to the building envelope
- Wall systems that integrate photovoltaics, similar to new roof shingles
- Simple, mass-producible wall and roof systems that can act as solar thermal collectors
- Daylighting system that has almost no heat gain and distributes light evenly

BUILDING WINDOW RESEARCH PRIORITIES

- **Imaging:** displays, holograms, electrochromics
- **Energy Production and Supply:** PV panels (clear, colors, thin film, coatings, environmentally benign materials), integral wind power
- **Light Transmission:** electro-, photo-, and thermochromics; holograms; low-e coatings; interior lighting; and daylighting rating
- **Insulation:** aerogels, monolithic transparent insulating materials, vacuum glass, gas retention, insulating coatings and alternate glazing materials
- **Analytical Tools:** thermal modeling, life-cycle analysis, solar heat gain
- **Manufacturing:** laser imprinting, recyclability, markets for process waste
- **Design:** stronger sealants, high security, glass-frame ratio, blast resistance, fire-rated, sun-screening, modular windows, ventilation
- **Electronics:** integral wiring, communications protocols

Large-area, thin-film PV modules used in a building facade.

CONTACTS

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GLASS FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

SOLAR-THERMAL

Concentrator Solar Power
The EERE *Solar Energy Program* supports a range of applications including large-scale power production, on-site electricity generation, and thermal energy for space heating and hot water.

Concentrating solar power is on the brink of commercial viability, and U.S. industry is actively seeking several commercial project opportunities where financial incentives are being offered to buy down the cost of early systems. Over the last decade 354 MW of parabolic trough solar power plants installed in the 1980s operated successfully in the Southern California desert. These plants used 20 million square feet of mirrored glass reflectors.

Based on a recent report to Congress, U.S. industry has developed a plan for deploying 1,000 MW of concentrator solar thermal power in the Southwest. Industry indicates that 250 MW could be installed by 2006 with contracts to be signed for an additional 750 MW by that time.

Solar reflecting mirrors require special manufacturing to meet reflectivity, specularity, and durability requirements. U.S. glass companies have an opportunity to work with U.S. solar manufacturers to develop a strong position in the domestic and international markets for solar thermal power systems.

FACTOID

100 megawatt solar thermal power plant = About 8 million ft^2, 14.4 million pounds of glass

TECHNOLOGIES

Parabolic Trough Concentrators
Parabolic trough concentrators are most suitable for larger applications ranging from electricity generating systems delivering 50 kW to 160 MW, to industrial applications with 1,000 m^2 to 15,000 m^2 of collector area down to commercial applications as small as about 80 m^2. Arizona Public Service Company has solicited proposals for a one megawatt trough organic Rankine cycle power system to comply with State portfolio standard requirements for solar power.

Parabolic Dish Concentrators
Single parabolic dish systems with thermal engines, most often Stirling cycles, can produce 10 to 25 kW of electricity in stand-alone applications, or many dishes can be co-located to provide megawatts of power for distributed generation or village power systems. Several next-generation dish/Stirling systems are scheduled to be installed in Nevada next year.

Central Receivers
Central Receiver Systems will be installed in units of 100 $MW_{electric}$ and larger. U.S. companies Boeing and Nextant (Bechtel) are participants in fabricating a new system in Spain with a 45 MW–solar array and rated capacity of 15 MW_e due to the addition of 16 hours storage for round-the-clock operation.

MARKETS

Utility Scale Power Systems
Remote Electric Power Systems
Small Grid –Connected Power Systems
Industrial and Commercial Thermal Systems

Projected Near-Term Market for Concentrator Solar Power
To begin to meet the current 1,000 MW installation goal for solar themal power in the southwestern United States, parabolic trough systems will be the most likely technology to be deployed in the first stage. LUZ International was installing 80 MW-parabolic trough plants in 12 to 15 months in the late 1980s and a large portion of the first 250 MW of capacity is expected to be trough systems. Dish/Stirling fields in megawatt increments should be ready to be deployed as the project advances. In addition, companies developing U.S. central receiver technology overseas could organize a follow-on project in the U.S. as the cost of replication declines.

CONTACTS

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GLASS FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

TRANSPORTATION

Lightweight Window Glazing Alternatives for Vehicles

The EERE *Freedom Car and Vehicle Technologies Program* is supporting development of lightweight glass for vehicles. The objective is to develop new glazing that helps meet a 30% weight reduction target for a next generation of more fuel-efficient vehicles.

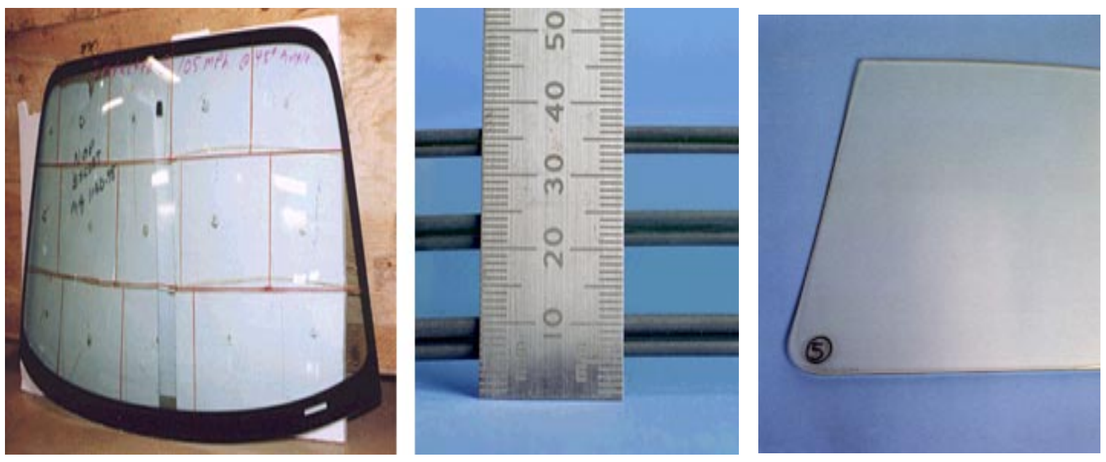
Current production vehicles have an average of 150 pounds of window glass. The key to development of a new glass product is to maintain structural integrity of the vehicle while cutting the weight of windows as much as 50%. A Cooperative Research and Development Agreement with glass industry companies and the Pacific Northwest National Laboratory has produced a new glazing with thin glass layers and asymmetric construction. To date, windshield and side-body glasses have been made that are 30% lighter than conventional glazing.

This program has also developed new numeric models to study behavior of automotive glass under impacts and performance and reliability as a structural element in a vehicle.

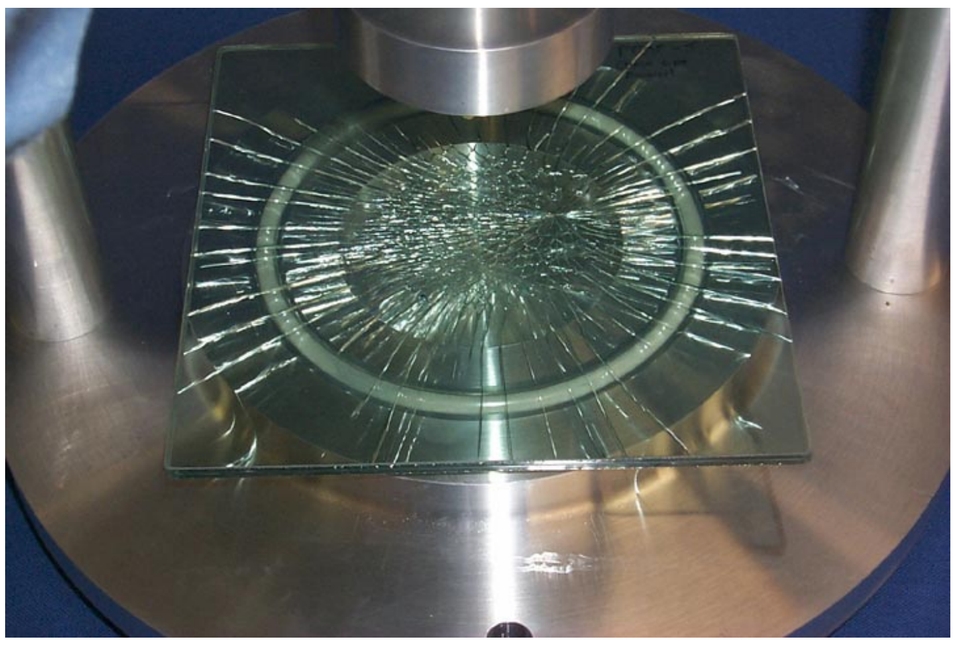
FACTOID

Current production automobiles contain an average of 150 pounds of glass.

TECHNOLOGIES

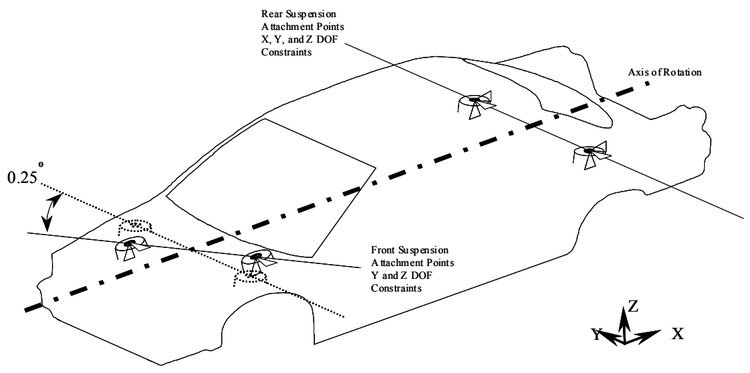


The plies used to fabricate conventional auto glass range between 2.4 and 2.6 mm thick. DOE has fabricated windshield glass using plies of 1.6 to 2.1 mm thick. It is also working on hardening coatings and studying asymmetric constructions. Results to date have reduced weight by 30%.



DOE developed a unique ring-on-ring testing apparatus to test strength of curved glass segments. The tests created a tool for determining failure probabilities as a function of design, thickness, service life, and temperature.

Torsional Loadcase



Structural Rigidity and Strength Characterization are two key factors supporting work on glass and lighter weight vehicles. Working with Ford Motor Company, DOE has modeled torsional rigidity of a particular car design and found that reducing glass thickness by 50% should only lower torsional rigidity a small amount.

CONTACTS

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