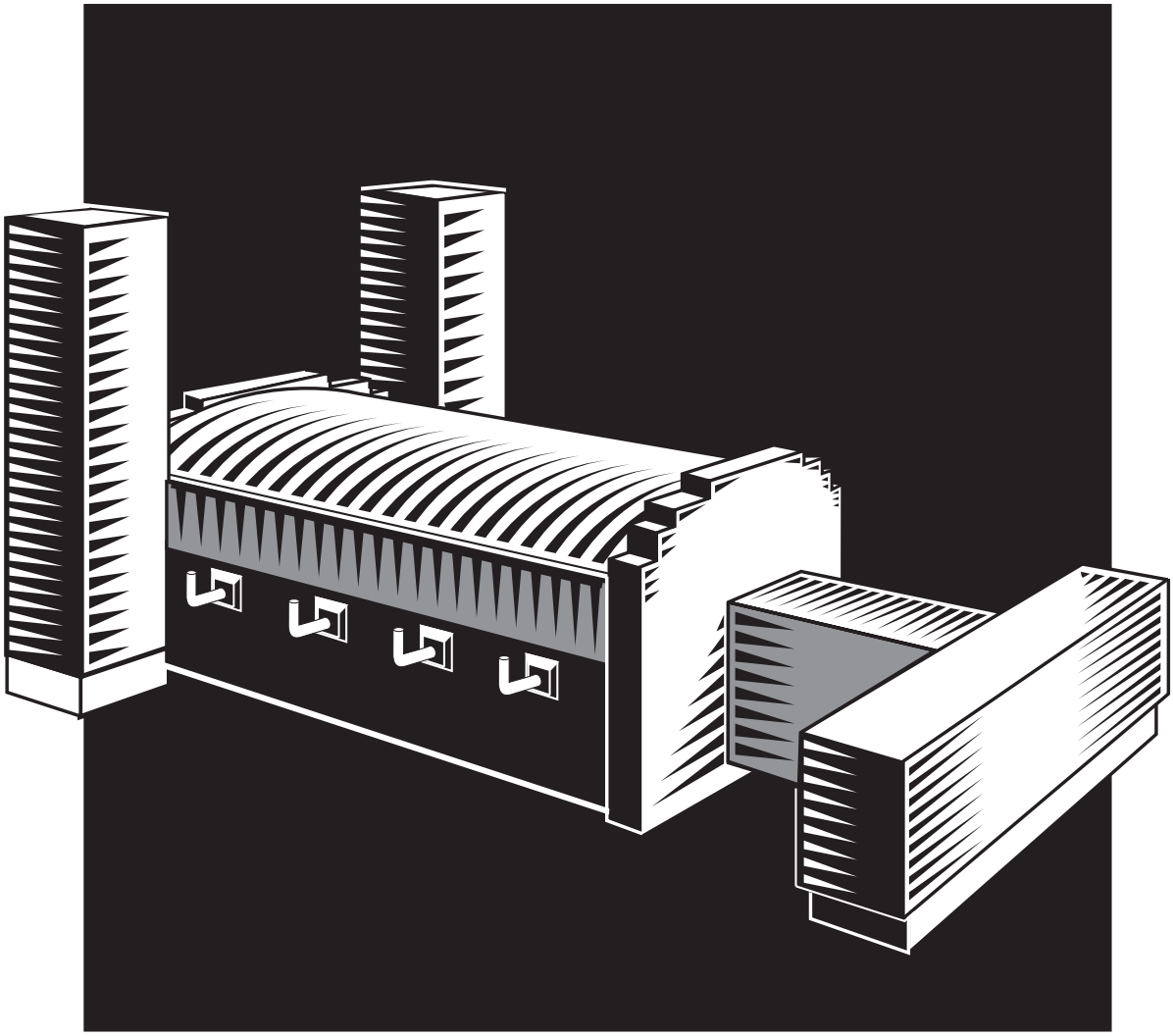
Glass Industry of the Future

Quarterly Status Reports

As of September 30, 2004



U.S. DEPARTMENT OF ENERGY

02-GA50113-03

Glass

Industry of the Future

Quarterly Status Reports

As of September 30, 2004

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Glass Projects

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Advanced Oxy-Fuel Front-End System

Mighton: Owens Corning

GO13091, CPS#14233

Quarterly Progress Report

Project Title: Development/Demonstration of an Advanced Oxy-Fuel Fired Front End

Covering Period: June 15, 2004 to Sept 30, 2004

Date of Report: October 30, 2004

Recipient: Owens Corning
Columbus Rd., Rt. 16
Granville, Ohio 43023

Award Number: DE-FC36-03G013091

Industrial Partners: Eclipse/CombustionTec, Dan Wishnick, Kevin Cook
BOC, Neil Simpson, Greg Prusia
Osram Sylvania, Tim Jenkins

Contacts: Steve Mighton, P. Eng. (740) 321-7633

Project Team: Elliot Levine (DOE Glass Industry Liaison)
Brad Ring (DOE Project Officer)
Carrie Capps (Project Monitor)
Beth Dwyer (DOE Contract Officer)

Project Objective:
The goal of this project is to develop and demonstrate an oxy-fuel combustion system for the front end of a fiberglass melter that will reduce fuel consumption by approximately 70% creating an operating savings of approximately 40% and significantly reduce NOx and CO2 emissions.

Background:
Glass melters have successfully used oxy/fuel burners to reduce emissions and operating costs. Glass melter front ends, consisting of refractory channels that deliver glass to the forming process have traditionally used air/gas burners. Conventional front end air/gas combustion systems supply an air/gas mixture to the burner. Due to safety concerns, the mixture is not preheated as is done for air in recuperative or regenerative melter combustion systems. As a result, a significant portion of energy is required just to heat nitrogen in the air to the temperature of the combustion space. Use of oxy/fuel burners in a front end eliminates the need to heat the nitrogen and generates a hotter flame that radiates energy with a shorter wavelength resulting in improved transmissivity

characteristics. These factors create a more efficient radiant heat transfer into the glass and create the potential for improved thermal homogeneity.

Background: cont'd

The resulting efficiency of a front end oxy/fuel combustion system is approximately 55% vs. only 15 to 30 % for an air gas system. In terms of gas consumption, an oxy/gas burner will use 65% to 70% less gas than an air/gas burner for the same heat input to the glass. As CO_2 emissions are directly proportional to the amount of gas combusted, the reduction in CO_2 emissions is the same (65 to 70%). Elimination of nitrogen in the combustion space results in much lower NOx levels as well.

The hurdle to implementation of oxy/fuel burners in a front end is two fold and relates to the fact that front ends are relatively long, narrow troughs of glass that require a large quantity of closely spaced burners (< 1' apart, both sides) to distribute the energy evenly.

a) Overheating: Front end burners with outputs of 0.04 - 0.1 MM Btu/hr do not have the large flows of oxygen and gas (compared to melter oxy burners with outputs of 2-5 MM Btu/hr) for cooling of the burner. As an oxy/fuel burner has a flame temperature of ~5000 F, vs. ~3500 F for an air gas burner, overheating, soot formation and degradation of the burner or the burner block material can result.

b) Capital Cost The close spacing of side fire burners in a front end system results in a large capital cost for upgrading to oxy/fuel burners if existing burners and blocks are substituted on a one for one basis. Side fire oxy/fuel burner systems are commercially available and have been successfully supplied for trial in the past by others (Eclipse & BOC/BFH).

This project involves installation of burners in a top fire configuration, parallel to centerline of the channel, as opposed to the traditional side fire configuration in which burner alignment is perpendicular to the centerline of the channel. This allows one top fire burner, with higher flow, to replace 10 to 20 air/gas burners.

Status

Phases 1 and2 of the original project task list were substantially complete as of June 04 and were summarized in the June 04 quarterly progress report. Tasks included:

Phase 1
1.0 Develop conceptual designs of the oxy-fuel front end burner system
2.0 Perform computer modeling of the burner and block designs
3.0 Conduct single burner tests on a lab forehearth system
4.0 Develop oxy-fuel combustion systems to be integrated into front end
5.0 Perform computer modeling on combustion system integration
6.0 Conduct multi-burner tests on a lab forehearth system
Phase 2
7.0 Conduct field test of a single burner operation
8.0 Conduct field tests of multi burner operations
9.0 Conduct field evaluation of a production forehearth/channel

Project activity for the 3rd quarter is summarized below:

Phase 3
10.0 Design, engineering and system integration for field demonstration
11.0 Perform computer modeling on performance and glass quality
12.0 Prepare demonstration site for system installation
13.0 System installation and shakedown on a fiberglass melter front end.

Engineering for the installation was coordinated with the larger project of rebuilding the melter in Jackson, Tennessee.

Check Out
Prestart up check out identified the following three issues:

- 5 % of the individual burner gas and O2 drops were located too far away from the burner location for the flex hose length. Piping was modified accordingly.
- Rough handling of burners prior to installation by the piping contractor resulted ~20% of the burner gas tubes, which project beyond the O2 nozzle, being bent. Straightening was required.
- Burner centering lugs were lengthened to improve burner to block centering

Commissioning

Commissioning occurred in July. Light off of the 108 burners occurred over a 3 day period once temporary heat up burners had raised the front end temperature above the auto ignition temperature. Other installation problems identified at this point included:

- hose tension due to not enough slack in the hoses causing burners to start to unseat over time
- flow measurement inaccuracy of O2 and gas on individual burner drops was found to be widespread when the total of individual flows was compared to the flow reading at zone skids. The causes identified were:
  - poorly blown out lines resulted in a film of pipe thread cutting oil on gas drop orifice plates
  - incorrect orifice plate component assembly by the mechanical contractor on individual burner drops:
    - components were found to be installed upside down
    - components were found to be swapped between O2 and gas drops

    Due to the resulting individual burner flow measurement inaccuracy, zone skid flow measurements for the total flow for up to 8 burners on a manifold were used to ensure a lean ratio was maintained and zones were set up with an oxygen/gas ratio of 2.6 vs. 2.4 to compensate for any burner to burner differences in flow until the issue could be corrected

- Linkage adjustments to the zone skids and oxygen supply pressure dips caused several short periods in which rich ratio conditions occurred.

Photos of equipment in operation

View of top fire burners located on the centerline of a channel.

View of individual burner sitting on cover tile

Energy Savings - Preliminary Results

Condition	Front End Nat. Gas Used DT/h [kW]	Reduction in Energy [%]
Target Nat. Gas Energy Reduction		**65-70**
Computed (normalized for process differences)		
Air/gas, before conversion	16.5 [4836]	
Oxy/gas, after conversion	6.3 [1846]	62
Computed, including electricity		
Air/gas, before conversion	16. 7 [4894]	
Oxy/gas, after conversion	6.8 [1997]	59

If process differences are factored in, a 62% reduction in natural gas consumption is being achieved, compared with the predicted 65- 70%.

When energy consumption is calculated factoring in:

a) electricity to run a blower for the air/gas combustion system

b) electricity to generate oxygen for the oxy/gas combustion system

the net energy reduction is 59%.

Based on a 59% reduction in energy consumption, the annual energy savings achieved by the conversion of the front end to oxy/gas firing is 86724 DT/yr.

Plans for next 2 quarters

Consortium partner Eclipse will be modifying their side fire burner for use in a top fire configuration. If bench trials are successful, 8 Eclipse burners will be installed in one forehearth to compare to the OC burners for resistance to high temperature scaling and block glazing over the long term.

Consortium partner BOC will support the project through the collection and analysis of forehearth exhaust emissions and development of a N2/O2 mixer suitable for supplying artificial (oil free) air as a back up to provide cooling to the burners if the natural gas supply was lost for an extended period of time, in which case, either pure N2 or pure O2 would not be an ideal cooling gas due to safety reasons.

Patents

OXYGEN-FIRED FRONT END FOR GLASS FORMING OPERATION
US application published October 9, 2003 as 2003/0188554
PCT application published October 16, 2003 as PCT/2003/084885

LOW HEAT CAPACITY GAS OXY FIRED BURNER
US application filed June 9th 2004

Publications/Presentations

An update on the project was made to the project consortium members on August 5, 2004. No publications or other presentations have been made.

Budget Data

Total project spending (Yr 1 + Yr2) is anticipated to be $ 1,756,000 vs. the approved budget of $1,776,000 (rounded to closest thousand).

			Approved Spending, $K			Actual Spending, $K		
Phase / Budget Period			**DOE Amount**	**Cost Share**	**Total**	**DOE Amount**	**Cost Share**	**Total**
	From	To						
Year 1	9/30/03	9/30/04	585	585	1170	765	765	1530
Year 2	10/01/04	10/01/05	303	303	606			
		Total	888	888	1776	765	765	1530

Energy Efficient Glass Melting: The Next Generation Melter

Rue: Gas Technology Institute

GO13092, CPS#14231

QUARTERLY PROGRESS REPORT

Project Title	Energy-Efficient Glass Melting - The Next Generation Melter
Covering Period	July 1, 2004 through September 30, 2004
Date of Report	October 31, 2004
Recipient	Gas Technology Institute 1700 S. Mt. Prospect Rd. Des Plaines, IL 60018
Award Number	DE-FC36-03GO13092
Subcontractors	A.C. Leadbetter and Son, Inc. Fluent, Inc. Praxair, Inc.
Other Partners	NYSERDA – project sponsor GTI Sustaining Membership Program (SMP) – project sponsor Gas industry through FERC funding – project sponsor CertainTeed Corp. Corning, Incorporated Johns Manville Owens Corning PPG Industries, Inc. Schott Glass Technologies, Inc.
Contacts	David M. Rue Manager, Industrial Combustion Processes Gas Technology Institute 847-768-0508 david.rue@gastechnology.org
Project Team	Elliott Levine Glass Team Leader U.S. Dept. of Energy OIT, EE-20 1000 Independence Ave., SW Washington, DC 20585-0121 202-586-1476 elliott.levine@ee.doe.gov Brad Ring Project Monitor U.S. Dept. of Energy Golden Field Office 1617 Cole Blvd. Golden, CO 80401 303-275-4930 brad.ring@go.doe.gov Beth H. Dwyer Reports Monitor Golden Field Office 1617 Cole Blvd. Golden, CO 80401 303-275-4719 Beth.dwyer@go.doe.gov

Project Objective

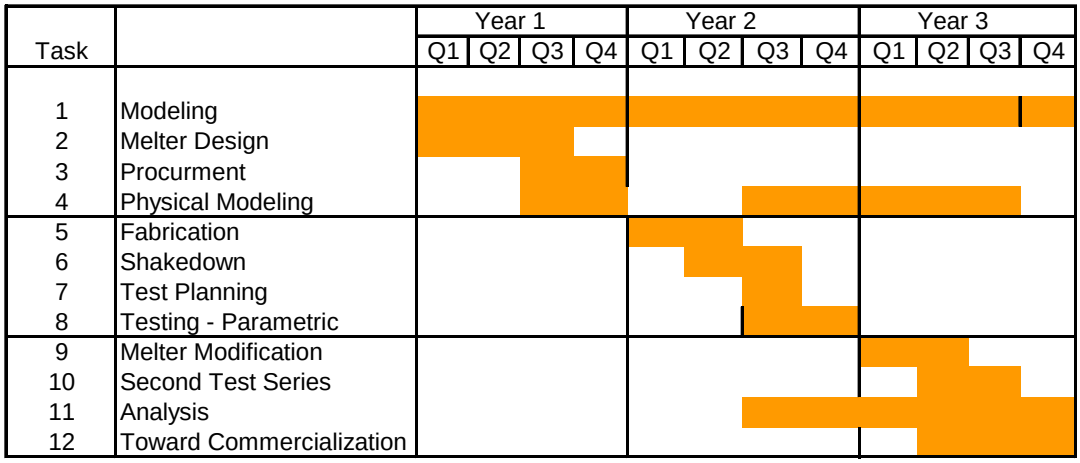
The objective of this project is to demonstrate a high intensity glass melter, based on the submerged combustion melting technology. This melter will serve as the melting and homogenization section of a segmented, lower-capital cost, energy-efficient Next Generation Glass Melting System (NGMS). After this project, the melter will be ready to move toward commercial trials for some glasses needing little refining (fiberglass, etc.). For other glasses, a second project Phase or glass industry research is anticipated to develop the fining stage of the NGMS process. Overall goals of this project are:

- Design and fabrication of a 1 ton/h pilot-scale submerged combustion glass melter,
- Extensive melting of container, fiber, flat, and specialty glass formulations,
- Detailed analysis of the product glasses,
- Preparation of a Fluent-supported CFD model of the melter to be used in parallel with further development of the NGMS technology,
- Physical modeling of the NGMS process to determine energy savings, cost savings, environmental improvements, and use of waste heat for production of needed oxygen,
- Development of a commercialization plan and timeline for further, needed components and integration of the NGMS technology.

The Work Breakdown Structure and schedule are presented below. The project team recognizes that further work will be needed after this project to bring the critically-needed NGMS into industrial use. To expedite that development, the work in this project will focus in three areas needed to demonstrate the melting and homogenization steps of the NGMS technology and to prepare for further work to commercialize NGMS. These work areas are:

- Design, fabrication, and operation of a pilot-scale melter with analysis of product glass,
- Supported CFD modeling on the melter that is available to all users,
- Physical modeling and energy balances for the full NGMS with specific planning for further steps leading to commercial implementation.

Work in each project year is divided into Tasks with milestones at the end of many of the Tasks. The integrated Task Schedule enables project team members to assign labor appropriately and to follow a critical path to reach all milestones and objectives toward the overall goal of design, modeling, demonstration, and analysis of this melting technology.



Milestones are placed at the end of many project Tasks to help sponsors and team members evaluate project technical progress on time and financial tracking. The milestones shown below will serve throughout the project as a gauge to successful completion of the work.

Year 1 Milestones	• Complete CFD model to be used by team members to design pilot scale melter • Design pilot scale melter • Procure all equipment and components for the melter in preparation for fabrication
Year 2 Milestones	• Fabricate and shake down of the pilot scale melter • Prepare test plan including compositions of glasses to be melted • Finish all pilot scale melting tests and collect samples for analysis • Complete detailed analyses of product glass properties and quality
Year 3 Milestones	• Modify melter, as needed, for second test series • Finish second test series, including at least one long term test, and all glass analysis • Finalize CFD model of the melter usable by all CFD operators • Finish physical material and energy balance model of next generation melting system (NGMS) process including utilizing waste heat for oxygen production • Complete plan for commercialization, including needed developments and stages

Go-no-go decision points are placed at the end of the first and second years of the project. At these times, the project team and sponsors have the opportunity to assess project progress and decide on continued work in the next phase (or year) of the project. The project team has every confidence that all project technical targets and milestones will be reached.

- The Year 1 go-no-go decision point criteria for continuing work will be design of the pilot scale melter and procurement of equipment and components on schedule and budet.
- The Year 2 decision point criteria for continuing work will be completion of pilot scale testing with glass formulations from all four industry segments and analyses of the product glasses.

Background

Any new melter must perform at least as well as refractory melt tanks by all technical, cost, operability, and environmental criteria while providing tangible benefits to the glass maker. A partial list of this daunting set of criteria, by category is shown below.

Criteria Category	Specific Criteria
Technical	High thermal efficiency, ability to make any glass formulation, can handle needed temperatures and oxidation conditions, meet glass quality requirements, integrates with batch handling and forming processes
Cost	Low melter cost, low maintenance cost, low energy cost, inexpensive environmental regulation compliance
Operability	Scalable from 25 to 700 ton/day, reliable, stable operation, easy to idle, ability to start and stop, ease of access and repair, fast change with glass formulation and color, no moving parts to be abraded by the glass
Environmental	Low air, water, and solid waste, recycle-friendly

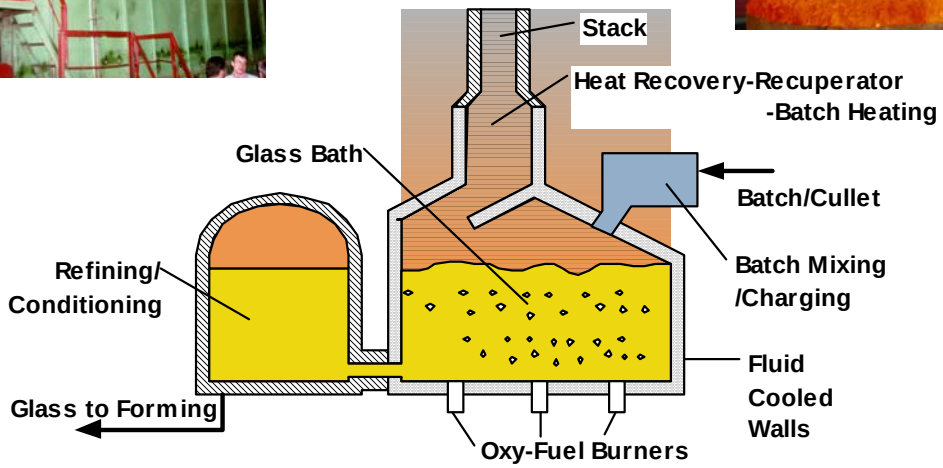
The search for a lower-cost glass melter has led technologists to suggest a segmented melting approach in which several stages are used to optimize the melting, homogenization, and refining (bubble removal) instead of the current practice of using a single, large tank melter. In this segmented approach, separately optimized stages for high-intensity melting and rapid refining are expected to reduce total residence time by 80 percent or more. This approach to melting has come to be known as the Next Generation Melting System (NGMS).

The project team has identified submerged combustion melting (SCM) as the ideal melting and homogenization stage of NGMS. This is the only melting approach that meets and exceeds all the performance characteristics of refractory tanks and also provides large capital and energy savings to the glass industry. Submerged combustion melting is a process for producing mineral melts in which fuel and oxidant are fired directly into the bath of material being melted. The combustion gases bubble through the bath, creating a high heat transfer rate to the bath material and turbulent mixing. Melted material with a uniform product composition is drained from a tap near the bottom of the bath. Batch handling systems can be simple and inexpensive because the melter is tolerant of a wide range in batch and cullet size, can accept multiple feeds, and does not require perfect feed blending.

SCM was developed by the Gas Institute (GI) of the National Academy of Sciences of Ukraine and was commercialized a decade ago for mineral wool production in Ukraine and Belarus. Five 75 ton/day melters are in operation. These commercial melters use recuperators to preheat combustion air to 575°F. All melters operate with less than 10 percent excess air and produce NO_x emissions of less than 100 vppm (at 0 percent O_2) along with very low CO emissions. A photo of a commercial SCM unit in Belarus is shown below.

In SCM (shown below), fuel and oxidant are fired directly into the molten bath from burners attached to the bottom of the melt chamber. High-temperature bubbling combustion inside the melt creates complex gas-liquid interaction and a large heat transfer surface. This

significantly intensifies heat exchange between combustion products and processed material while lowering the average combustion temperature. Intense mixing increases the speed of melting, promotes reactant contact and chemical reaction rates, and improves the homogeneity of the glass melt product. The melter can handle a relatively non-homogeneous batch material. The size, physical structure, and especially homogeneity of the batch do not require strict control. Batch components can be charged premixed or separately, continuously or in portions.



A critical condition for SCM operation is stable, controlled combustion of the fuel within the melt. Simply supplying a combustible fuel-oxidant mixture into the melt at a temperature significantly exceeding the fuel's ignition temperature is insufficient to create stable combustion. Numerous experiments conducted on different submerged combustion furnaces with different melts have confirmed this. Cold channels are formed that lead to unstable combustion and excessive melt fluidization. A physical model for the ignition of a combustible mixture within a melt as well as its mathematical description show that for the majority of melt conditions that may occur in practice, the ignition of a combustible mixture injected into the melt as a stream starts at a significant distance from the injection point. This, in turn, leads to the formation of cold channels of frozen melt, and unstable combustion. To avoid this type of combustion, the system must be designed to minimize the ignition distance. This can be achieved in three ways: 1) by flame stabilization at the point of injection using special stabilizing devices, 2) by splitting the fuel-oxidant mixture into smaller jets, and/or 3) by preheating the fuel/oxidant mixture.

Several types of multiple-nozzle air-gas burners that meet these requirements have been designed and operated industrially by the GI Ukraine. The burner is attached to the bottom of the bath with the main body outside the furnace. Only the surface around the exhaust of the slotted combustion chamber is in contact with the melt. Based on the research data available on thermal and fluid dynamic stability of the combustion chamber, a model for calculating the design parameters of submerged burners has been developed. GTI has extended this work to

oxy-gas burners and found them to be stable during lab-scale melting of several materials including mineral wool, sodium silicate, and cement kiln dust.

Material in the SCM melt chamber constantly moves against the walls. A typical refractory surface would rapidly be worn away by the action of the melt. To address this, the melting tank is constructed of fluid-cooled walls that are protected by a layer of frozen melt during operation. This frozen layer is constantly formed and worn away during operation. The industrial SCM units used water-cooled walls. The project team intends to use high temperature fluids for cooling to allow useful heat to be recovered from this coolant. The heat flux through the frozen melt layer is determined by the properties of the processed material and the temperature and turbulence of the melt. It is, therefore, undesirable to superheat the melt because this increases the heat flux through the walls. Also, heat flux is lower with oxy-gas firing because melt turbulence is greatly reduced. Under normal operating conditions for silica melts, the oxy-gas heat flux is 7700 $Btu/ft^2 \cdot h$, equal to 2×10^6 Btu/h heat loss for a 75 ton/day melter. These values are relatively independent of the temperature of the coolant as any increase or decrease in the coolant temperature is accompanied by a compensating change in the thickness of the lining. Heat flux for a refractory tank is lower at 1800 $Btu/ft^2 \cdot h$, but with much greater surface area, the refractory tank loses more heat (2.55×10^6 Btu/h).

Special care must be taken to minimize fluidization of the melt which creates a large amount of droplets. These droplets, especially small ones which are formed when bubbles split, can be thrown out of the melt to a significant height. Consequently, the exhaust ducting must be protected from being covered by the frozen melt. In our design, this issue is resolved by removing combustion products through a special separation zone. In the separation zone, exhaust gas is forced to change direction and drop all liquid carryover droplets. The roof of this zone is sloped so droplets can easily be returned to the melter. This approach also reduces the necessary fluid-cooled surface area around the melting zone.

GTI holds the exclusive, world-wide license to SCM outside the former Soviet Union. Recognizing SCM's potential, GTI has operated a laboratory-scale melter with oxy-gas burners and produced several melts. Evaluation of the process has shown its potential for glass production when combined with other technologies for heat recovery, batch handling, refining, and process control. The photo above shows melt collection from GTI laboratory SCM testing.

Waste heat recovery is critical to reach high energy savings with NGMS. Adaptation of Praxair's Oxygen Transport Membrane (OTM) technology to the melter will be evaluated in this project. Praxair has been the world leader in the development of oxygen transport membrane (OTM) technology. The OTM technology is based on a class of ceramic materials that, when operated at temperatures above 500ºC, can separate oxygen from air with infinite selectivity. Because of the high temperature of operation, opportunities exist for integrating OTM oxygen production with the glass melting process to utilize waste heat. This integration is expected to result in increased energy efficiencies, reduced oxygen costs and emissions, and potential carbon dioxide sequestration.

Praxair's efforts will focus on developing and simulating OTM processes that would be ideally suited for glass melting furnaces. A multitude of process configurations will be designed. Of these processes, the top two or three configurations will be selected based on process efficiency, emission levels, simplicity, and level of integration. A preliminary economic analysis then will be performed on the selected process cycles.

The Glass Industry Technology Roadmap cites the need for a less capital intensive, lower energy cost, and cleaner way to melt glass. Incremental changes to current melting practices will not stop the loss of furnaces, jobs, and companies to the competition from alternative materials and international glass makers. The Roadmap sets high strategic goals of 20 percent cost reduction, six sigma quality, 50 percent decrease in the gap between actual and theoretical energy use, and 20 percent decrease in air emissions. At the same time, the Energy Efficiency technical area calls for 'New Glass melting technologies'. This project addresses the following Needs expressed in the Roadmap:

- Accurate validated melter model (Energy Efficiency) – developed and supported by Fluent
- Improved thermal efficiency (Energy Efficiency) – the gap between actual and theoretical energy use is decreased by 50 percent
- Superior refractory materials (Energy Efficiency) – over 80 percent of refractory is eliminated because refractory walls are replaced with fluid-cooled walls with heat recovery
- Lower production cost (Production Efficiency) – melter cost at 55 percent lower, energy cost 23 percent lower, and glass production cost (capital, labor, and energy) 25 percent lower
- Decrease air emissions (Environmental Performance) – 20 to 25 percent decrease in air emissions from higher efficiency while NO_x is reduced over 50 percent (to under 0.35 lb/ton)

This project will demonstrate that the submerged combustion melter is ideally suited for technical and cost reasons, and better suited than any other melting approach, to be the melting and homogenization stage of an NGMS process. Also, the quality of glass produced and the flexibility of the melter to integrate with other processes will expedite development and commercial application of the full NGMS process. After this project, the melter will be ready to move to commercial trial for fiberglass and other glasses needing little or no refining. For other glasses, glass industry research or a Phase II project is expected to demonstrate rapid glass refining and to integrate the NGMS melting and refining stages.

Development of a new glass melting technology is a challenging undertaking, and no attempt to replace refractory tank melters has succeeded in the last 100 years. SCM, however, has been operated as an industrial-scale mineral wool melter for the last decade and has proved highly reliable. The industrial units are air-gas fired, but GTI has demonstrated smooth operation of oxy-glass burners on a 300 lb/h melter with several siliceous melts. This experience provides a solid basis for extending SCM to industrial-glass production.

A number of hurdles must be overcome to develop SCM into the NGMS melter and to develop the full NGMS process. The wide glass making, combustion, modeling, and engineering knowledge and experience of the project team assure the technical feasibility of this technology. No other project in recent memory has captured the commitment of such a large portion of the glass industry. This strong support makes clear that there is a great need for a revolutionary new melting technology and that these glass industry experts believe the melting technology to be demonstrated in this project is technically feasible and meets all the cost savings, energy reduction, emissions reduction, and operability needs of the glass industry.

Status – Work This Quarter

Work this quarter included 1) continued pilot melter design, hardware selection, and ordering, 2) pilot melter system assembly, 3) preparation for physical modeling of the submerged

combustion melter, 4) mathematical and computer CFD modeling, and 5) finalization of project subcontracts and the glass company consortium agreement.

Mathematical modeling

Mathematical modeling this quarter included initiation of CFD work by Fluent and several calculations that are summarized below.

Fluent modeling was begun with developing CFD code to describe the mixing and flow patterns in the air-fired mineral wool melters in Ukraine and Belarus. This route was chosen to provide a reasonable baseline for future CFD modeling of the oxy-fired glass melting undertaken in this project. By the end of this quarter, preparations were underway for CFD modeling, and the following work was completed

1. The modeling of bubble formation with convective flow and heat transfer is in progress with plans for validation with physical modeling.
2. The modeling of combustion and gas diffusion in the bubbles, which will provide information about the flame shape, is in progress.
3. The DO radiation model has been coupled to the VOF multiphase model.
4. The coupling of the DO model with the Eulerian multiphase model is in progress.
5. Infrastructure for batch melting model and mass transfer in and out of gas bubbles is in place.

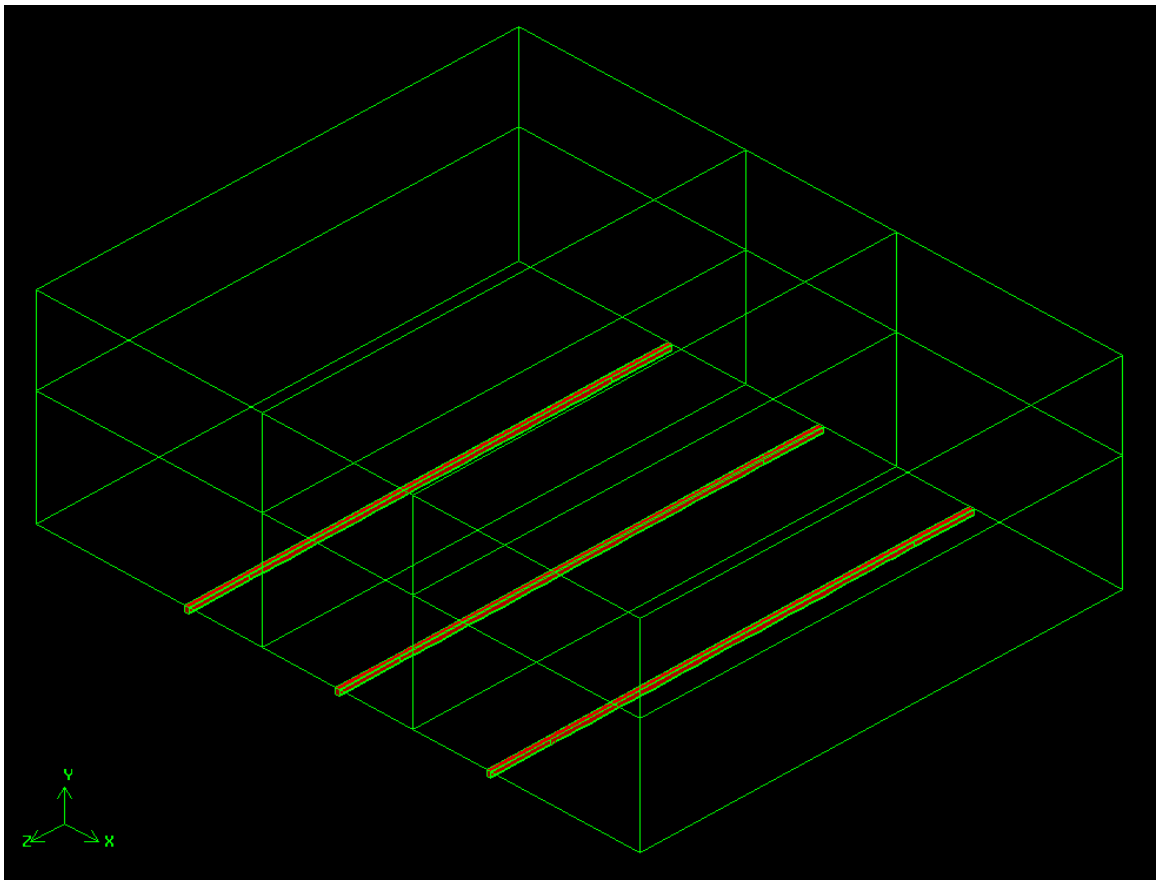


Figure 1: Air/Gas Melter Domain

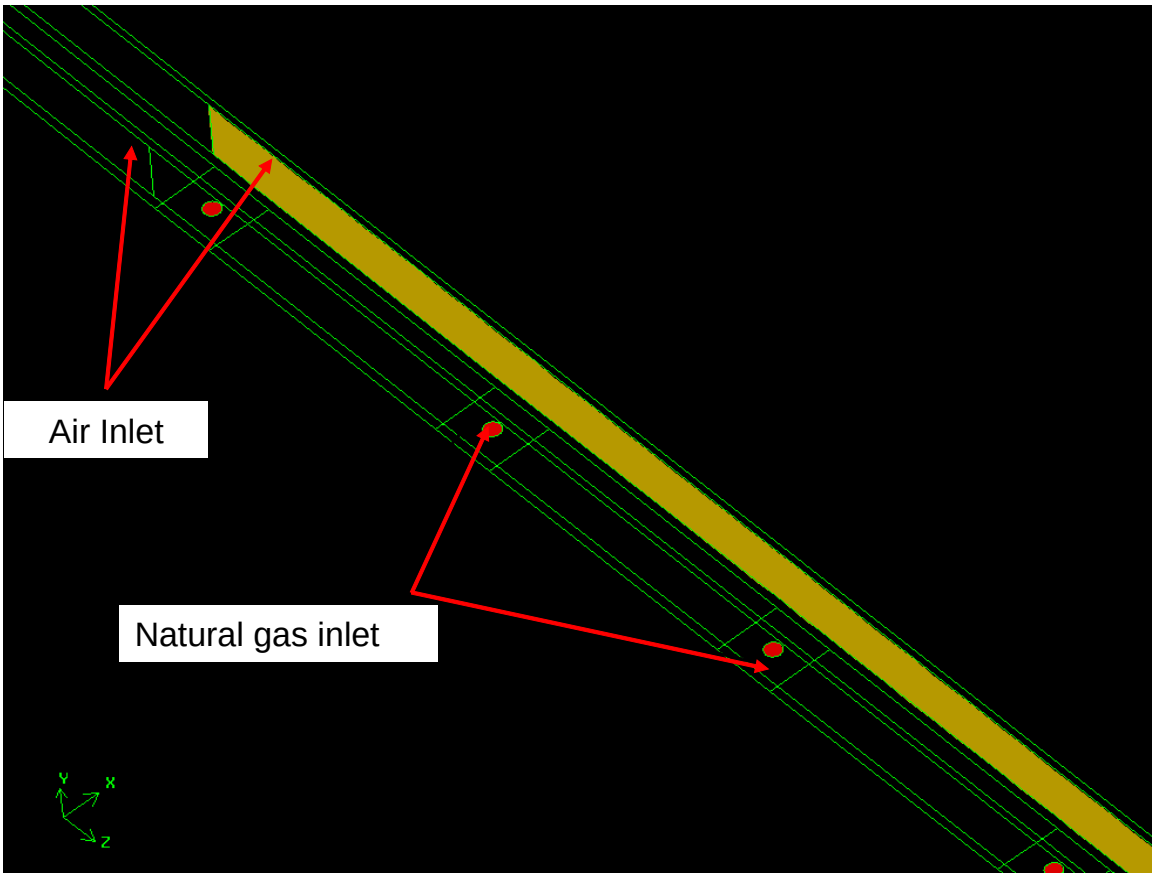


Figure 2: Close-up of burner area

Two Mathematical studies were conducted. The first was a determination of the impact of tangential sidewall jets on mixing in an SCM unit containing molten glass. The determination was that such jets could create a mixing pattern, but the level of mixing created is still unknown. Also, firing from the side walls, even if practical, in combination with externally-cooled walls, leads to non-uniform and decreasing temperatures in the bottom of the melter.

The second mathematical study was focused on examining ways to minimize heat transfer to the walls while simultaneously preventing metal contamination to the molten material. Results of this analysis include:

The objectives of this analysis includes: formulating the mathematical model of heat transfer through the cooled refractory taking into account the most important parameters affecting the heat loss and the frozen glass layer thickness: the refractory thermal resistance, the intensiveness of cooling, and the glass melt velocity near the refractory; to reveal the primary correlations between the parameters listed above and the heat loss and the frozen glass layer thickness; and to word the objectives for the next stages of physical and mathematical modeling.

The mathematical model takes the influence of the refractory thermal resistance, the intensiveness of cooling, and the glass melt velocity near the refractory on the heat loss and the frozen glass layer thickness into account. The structure of the model includes the glass melt

viscosity's temperature curve as well as the glass melt heat conductivity's and heat capacity temperature curves.

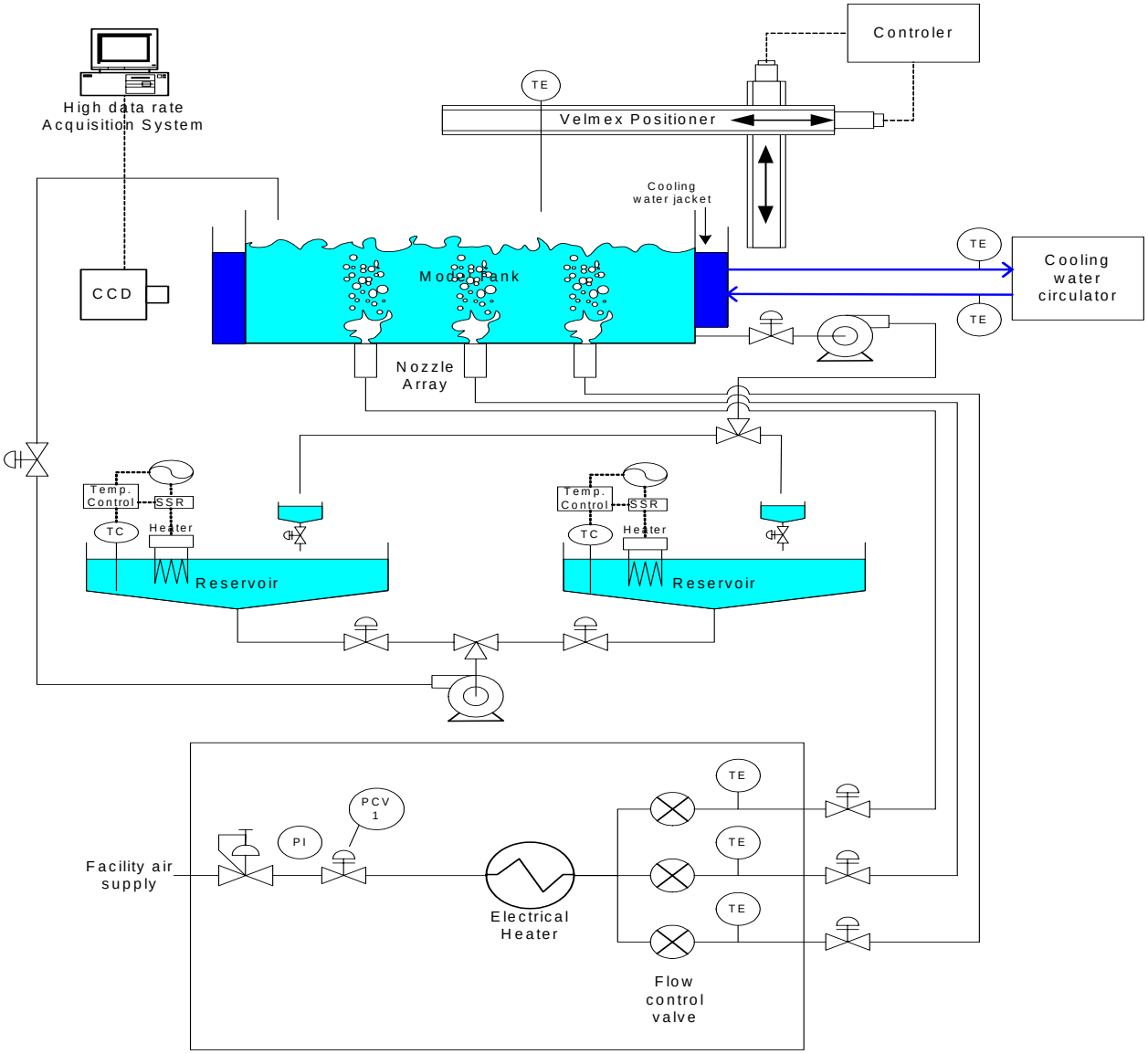
Based on the numerical experiments, the following conclusion were reached:

- There are two regimes of cooling: with and without the frozen glass layer. The boundary between them corresponds to the refractory thermal resistance approximately equals to 0.02 $\frac{m^2 \cdot {}^0C}{W}$.
- The minimum obtained value of the frozen glass layer thickness corresponds to the glass melt velocity of 0.5 $\frac{m}{s}$. The value of 0.5 $\frac{m}{s}$ is the possible upper limitation for the glass melt velocity near the walls. The possibility of compromise between the limitation on the glass melt velocity near the refractory and the need of the intensive mixing in the rest of the bath should be examined via the physical and the CFD mathematical modeling.
- Submerged melting with the glass melt velocity of 0.5 $\frac{m}{s}$ leads to an increase in the convective heat flux through the wall in about eight times and to the increase of the heat loss in about 2.5 times in comparison with the conventional class melting furnaces. It also leads to the decrease of frozen glass layer thickness in about 10 times. These results are the subjects for verification via the CFD mathematical modeling.
- The increase of the intensiveness of cooling from the intensive water-cooling to evaporative cooling does not affect the heat loss and the frozen glass layer.

Physical Modeling

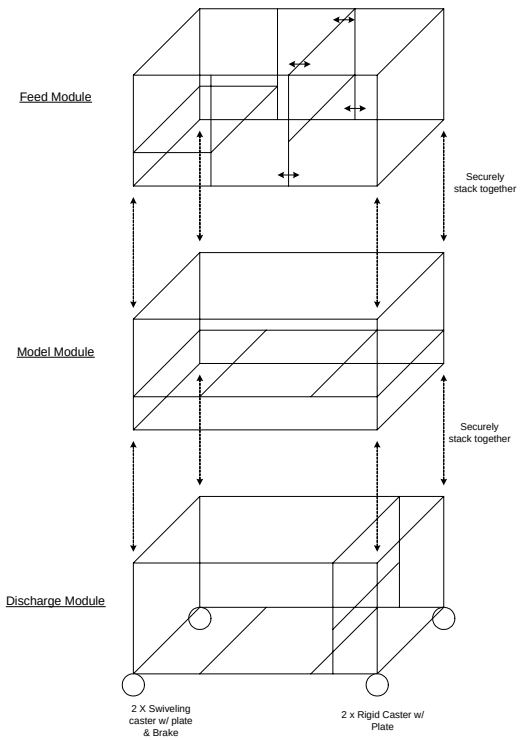
Physical modeling work moved into fabrication this quarter. The unit will simulate flow and mixing patterns using a dimensionless-group analysis approach. Tests are scheduled for next quarter. The first tests will simulate the commercial air-fired mineral melters in Ukraine and Belarus (the same approach being used for CFD modeling). After completion of these tests, the pilot-scale and full-scale oxy-gas fired glass melters will be simulated. Work this quarter included the following:

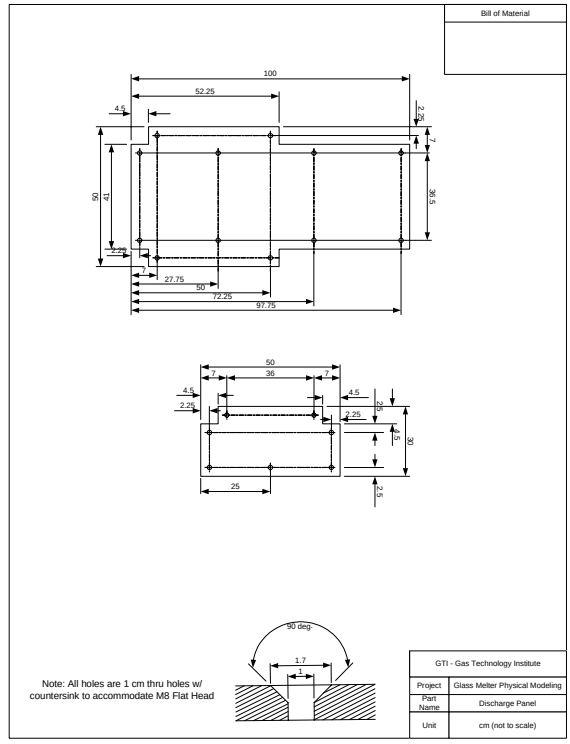
- Reviewed and discussed with consultant to finalize the model scale, model liquid selections, dimensionless groups to be included in analysis, and potential engineering problems we might face with different scenarios. Current conclusions are to include two dimensionless groups in the testing. One of the two is the equality of Re and We, the other is the equality of Gr, and Re. Former scenario will result in a higher than desirable viscosity range in the targeted temperature ranges and might complicate the system design. The later scenario will be realistic and will be the major focus in the physical modeling development at this time. The necessary apparatus to reduce the first scenario to practice will be investigated in parallel.
- The physical modeling experimental apparatus was laid out as shown in the following figure.



External Air Supply Module

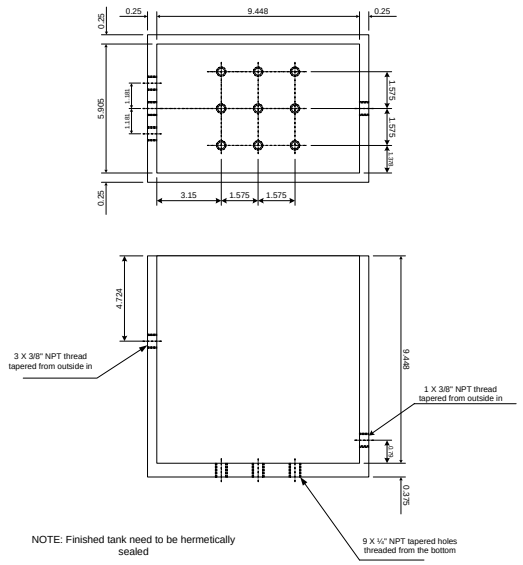
- Designed, fabricated, and integrated the custom modular framings and panels for the physical model. Sample design drawings are shown as follows,





- Designed, fabricated, and integrated the shakedown version of the physical model (top left), model anchor (top right), water tank (bottom left), and supply receive tank (bottom right).

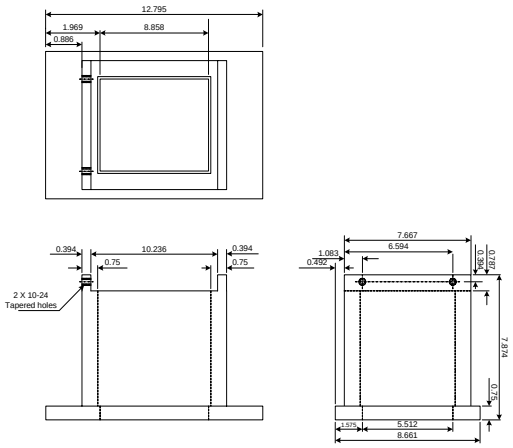
Bill of Material
Clear Lexan



NOTE: Finished tank need to be hermetically sealed

GTI - Gas Technology Institute	
Project	Glass Melter Physical Modeling
Part Name	Model-1
Unit	Inch (not to scale)

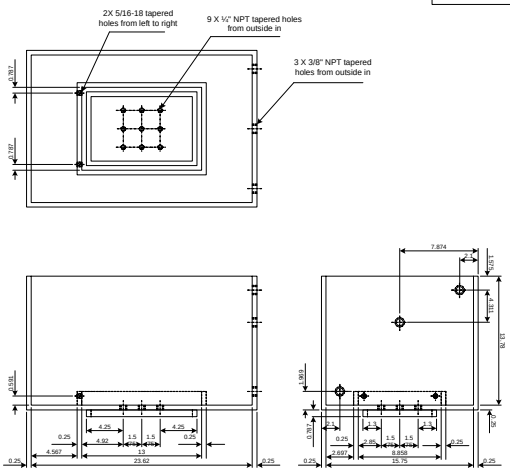
Bill of Material
Clear Lexan



Note: Taper holes every 2" along all adjoining edges/surfaces to reinforce the strength. Holes to accommodate flat head 10-24 at 1-½" length. Recess so all flat heads are flush to the surfaces. Apply silicon/adhesive on all mating surface before bolting together.

GTI - Gas Technology Institute	
Project	Glass Melter Physical Modeling
Part Name	Model Anchor
Unit	Inch (not to scale)

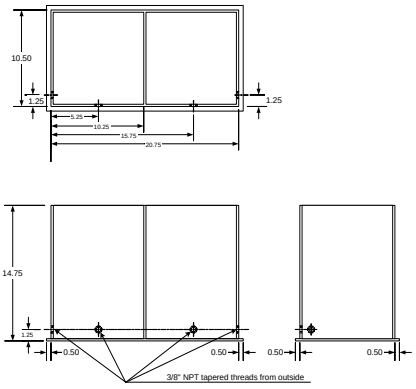
Bill of Material
Clear Lexan



Note: Taper holes every 2" along all adjoining tank edges/ surfaces to reinforce the strength. Holes to accommodate flat head 10-24 at 1-½" length. Recess so all flat heads are flush to the surfaces. Apply silicon on all mating surface before bolting together. Final product need to be hermetically sealed.

GTI - Gas Technology Institute	
Project	Glass Melter Physical Modeling
Part Name	Water Panel Tank
Unit	Inch (not to scale)

Bill of Material
All plates are ¼" thick SS 304



GTI - Gas Technology Institute	
Project	Glass Melter Physical Modeling Supply/Return Tank
Part Name	
Unit	Inch (not to scale)

Pilot-Scale Melter Assembly

The project team devoted significant effort this quarter to the installation of the pilot scale melter. Design of the system was completed last quarter, and design of the larger 1 ton/h melter is on going. The initial system will use the smaller, 200 lb/h melter in the system. The building annex to house the melter was completed last quarter. Photographs of the exterior and interior of this annex at the end of quarter are presented below. All magor peripheral equipment around the melter along with the steel frames and supports has been installed. The photographs show the melter and combustion control panel on t their stands and the roof deck with the baghouse, exhaust fan, and feed system in place.

Orders have been issued for installation of all remaining equipment and services. These include, among other items:

- poser and control wiring, piping for gas, air, nitrogen, and water,
- mechanical piping, exhaust duct installation,
- oxygen service (liquid storage, vaporizer, piping),
- heating and lighting,
- melt tap heating section,
- bag installation.

All of these remaining items are scheduled to be completed next quarter. The shakedown of the unit and the first melt tests are planned now for the end of the next quarter. Glass company engineers will join GTI engineers and technicians for testing, sampling of molten glass, and glass analysis.

Subcontracts and Consortium Agreement

The subcontracts between GTI and Fluent (for CFD modeling) and with Praxair (for Oxygen Transport Membrane assessment) were completed this quarter. Most issues regarding intellectual property, ownership, and cost sharing have been resolved for the glass company consortium agreement. GTI expects to complete the glass company consortium agreement next quarter and to initiate efforts immediately to place contracts in place with the six glass company partners.

Project work continued this quarter with A.C. Leadbetter and Son, Inc. engineers for design and fabrication of the pilot-scale melter. Leadbetter and GTI engineers are working together to complete design and fabrication of the pilot-scale melter. This teaming arrangement will continue through operation of the melter during the second year of the project.

Project managers put a sub-contract in place at the start of the project with Prof. Leonard Pioro, the developer of the SCM technology. In meeting with him in December 2003, engineers discussed melter operation, melter components, and melter shape. The melter can have a round cross section. This offers several potential advantages, including lower heat losses through the walls and better control of batch charging and exhaust gas removal. At this time, however, the round cross-sectioned melter is unproven. The decision was reached to build the pilot melter based on the proven rectangular shape. CFD modeling and physical modeling of the melter will both include rectangular and well as round cross sectioned SCM units. Dr. Pioro's work this quarter focused on burner design and evaluation of the potential for evaporative cooling to reduce water use and cut heat loss to the walls.

A meeting was held in late June at GTI with representatives of the six glass company partners. At that meeting, details regarding the course of project activities were outlined, discussed, modified, and agreed to. Abhi Dutta of Fluent, Inc. was at this meeting for first hand discussion of the CFD modeling approach. The multi-step modeling approach remains the preferred approach to CFD modeling of the SCM process. With the Fluent contract in place, the CFD will begin next quarter, with GTI and the glass companies providing melter and glass property data, respectively. By the end of year one (September, 2004), an initial model will be developed and evaluated by the project team.

Another glass company consortium meeting was held the last day of the quarter at GTI. Progress was reviewed. Efforts to model the melter were strongly encouraged. Discussions included the topics of melt collection, obtaining a stable melt stream, acquiring graphite molds, selecting the order of testing, and planning on support needed during testing and analysis.

Communications and education are important to the success of this project. A website (www.glassmelting.com) was established for faster communication and project-related discussions of important topics between project team members, sponsors, and interested parties. This site will be maintained by GTI with links to all member organizations. The website has a public section discussing SCM and the technology's development as well as password protected discussion sections for the project team members.

Plans for Next Quarter

Work will be carried out next quarter on a number of project activities. First, the final agreement that was completed this quarter will be signed by members of the glass company consortium. Fluent (for CFD modeling), and Praxair (for OTM evaluation) agreements work will continue next quarter. With these agreements finalized, all project Tasks are fully active. Work will be conducted in the following areas.

Modeling. Both physical and CFD modeling will be conducted. Physical modeling will be carried out by GTI with strong support from consultants and the glass industry partners (particularly Corning engineers). A consultant, Dr. Grigory Aronchik, at GTI is conducting mathematical support for both physical and CFD modeling. All parts for the physical model were received next quarter. Assembly was begun this quarter and will be completed next quarter. Shake-down tests are planned for next quarter. The first tests will simulate the air-fired mineral wool metlers in operation. Later tests will simulate the oxy-gas glass melter. The SCM melter will be simulated with an emphasis on optimizing flow and mixing patterns while avoiding any by-passing or batch volatilization. Physical modeling will be carried out based on dimensionless group scaling using glycerine-water mixtures having room temperature viscosity-temperature curves similar to molten glasses. Flow patterns will be monitored optically by adding dyes or fine particles to the field liquid mixture and tracking the streamlines produced.

CFD modeling began this quarter with GTI providing information to Fluent and Fluent staff starting model construction. The first work is to construct appropriate 2D and 3D mesh designs. Calculations of flow patterns along with heat and mass transfer will be conducted and two and three dimensions before the full CFD model will be developed. Then a complete combustion model will be incorporated. Because forced convection controls heat and mass transfer in the SCM and heat transfer to the walls, instead of natural convection that controls in a traditional tank melter, the model must be designed to incorporate the proper material heat transfer and flow behavior. This development will parallel work on physical modeling and testing. The 2D flow modeling will be completed next quarter and 3D modeling work will continue.

The project team has decided to also evaluate the Argonne Glass Furnace Model (GFM) as a comparison with the Fluent model. A copy of the GFM code was obtained this quarter, and work will begin next quarter at GTI to determine the strengths and weaknesses of the Argonne model. Argonne staff have agreed to provide basic training. Initial feelings are that the GFM models radiation heat transfer well but may not have sufficiently robust hydrodynamic modeling to describe submerged combustion melting. Any opportunity to improve the GFM will be utilized to produce a reliable CFD model that can be used to model SCM processes.

GTI and A.C. Leadbetter have completed initial design of the pilot melter system. Work is underway to design the larger 1 ton/h melter. That work began last quarter and will continue next quarter with a completion date planned before the end of the year. The peripheral units (batch hopper, feeder, baghouse, melt removal, sample collection, etc.) were installed this quarter and are being used with the smaller 200 lb/h SCM unit at GTI. The smaller, existing pilot melter will be used for tests during the next two quarters. The 1 ton/h melter is being designed, fabricated, and installed for much more extensive testing in 2005.

Data collection will continue. This will include collection and/or translation of relevant SCM papers and publications, further discussions with Prof. Pioro, calculations and designs by Prof. Pioro and by Dr. Olabin of the Gas Institute of Ukraine. Dr. Olabin will continue the 1 ton/h melter design work that he began this quarter. Articles related to compatible rapid refining techniques will also be collected and reviewed. Calculations will be completed next quarter to assess the optimum wall design (with and without refractory) to minimize heat loss and to determine the pluses and minuses of rectangular and round melter footprints.

Peripheral questions will be outlined, and work started to evaluate them. These include determining any potential for devitrification in the SCM unit and assessing the possibility of metal contamination of the glass by melt reaction with the melt chamber walls. Literature will be reviewed. Experts will be consulted. Lab experiments, if needed, will be set up and carried out, probably by the glass company partners.

Testing. The pilot melter system with complete feed, discharge, sampling, exhaust gas cleaning, baghouse, and control will be completed next quarter using the smaller 200 lb/h melter. Shakedown tests will be conducted, followed by the first melting tests with glass batch material. The work plan calls for melting a container glass batch first, next quarter. Tests after that, in subsequent quarters, will focus on E glass and 'hard' glass compositions.

Patents

GTI holds world-wide rights to the submerged combustion melting technology outside the former Soviet Union. GTI also holds a patent covering portions of the technology. A new patent covering the combustion system used for oxy-gas firing was completed this quarter including all needed signatures. The patent application was submitted this quarter with the U.S. Patent Office early in April.

The project team has formed a consortium to develop the NGMS technology. GTI has agreed to provide the glass company members of this consortium royalty-free rights to submerged combustion melting for glass production. In return, the glass company consortium members have agreed to support the project with cash, man-hours, testing assistance, modeling, and technical support. Other companies will be able to license the technology from the developing consortium. This arrangement is considered the most efficient means to rapidly develop, commercialize, and disseminate the NGMS and submerged combustion melting technology. The consortium agreement was not yet signed this quarter. Lawyers for team members were resolving final points and are expected to sign the agreement next quarter. This consortium represents the first time such a large segment of the U.S. glass industry has worked together on a project, and a number of issues must be clarified to avoid legal concerns in the future.

Publications/Presentations

A number of presentations and papers have been published regarding submerged combustion melting and the NGMS technology. A presentation was made at a GMIC workshop held after the 7th International Conference on Glass Fusion in Rochester, NY held in July, 2003.

A paper was presented at the second Natural Gas Technology Conference in Phoenix, AZ in February, 2004. Additional papers will be published throughout 2004. A presentation was made at the DOE ITP project review meeting in June, 2004. An introductory presentation was also made at the DGG, Germany Glass Society, meeting in Nurenmurg, Germany in June 2004. A presentation is planned for the American Ceramic Society (ACerS) Glass and Optical Materials Division (GOMD) in Port Canavreal, FL in November, 2004.

Milestone Status Table

This project is divided into twelve Tasks over a three-year period. Tasks 1 through 4 are scheduled for Year 1 (Phase I). Tasks 5 through 8 are scheduled for Year 2 (Phase II). Tasks 9 through 12 are scheduled for Year 3 (Phase III). Project work began this quarter and is completed covered within Year 1. Thirteen milestones have been defined covering the full project. Progress toward milestone completion is shown below.

Mile-stone	Milestone Description	Planned Completion	Actual Completion	Comments
1	Initial working CFD model written and tested	Sept. 2005		Continued this quarter
2	Design pilot scale melter	June 2004		Continued this quarter
3	Procure equipment for pilot scale melter	Sept. 2004		Continued this quarter
4	Fabricate pilot scale melter	March 2005		Started this Quarter
5	Prepare test plan	March 2005		Started this Quarter
6	Complete pilot scale melting tests and collect samples	July 2005		
7	Complete all sample analyses	Sept. 2005		
8	Modify melter as needed	Dec. 2005		
9	Complete second test series	June 2006		
10	Finalize CFD modeling and physical modeling	Aug. 2006		
11	Complete OTM analysis	June 2006		
12	Complete development plan	Sept. 2006		

Budget Data

The DOE contract was dated September, 2003, and work began in Oct. of 2003. The NYSERDA contract for co-funding was finalized last quarter. Gas industry co-funding through FERC funds for $700,000 are in place, and the SMP portion of gas industry co-funding will be put in place during years 2 and 3 of the project. The glass industry consortium finalized the consortium agreement this quarter. This agreement will be in place next quarter. At that time, GTI will enter into identical contracts with each of the six glass company partners. The overall

project budget, and spending to date, is shown below. Only cash funding is shown. In-kind cost-sharing by Praxair, Fluent, and the six glass company partners is not shown.

			Approved Spending, $K			Actual Spending, $K		
Phase / Budget Period			**DOE Amount**	**Cost Share**	**Total**	**DOE Amount**	**Cost Share**	**Total**
	From	**To**						
Year 1	**10/03**	**9/04**	**1311**	**850**	**2161**	**1192**	**178**	**1370**
Year 2	**10/04**	**9/05**	**1335**	**300**	**1635**			
Year 3	**10/05**	**9/06**	**1186**	**300**	**1486**			
Total			**3833**	**1450**	**5283**	**1192**	**178**	**1370**

High Intensity Plasma Glass Melter

Gonterman: Plasmelt

GO13093, CPS#14232

QUARTERLY PROGRESS REPORT

Project Title: High-Intensity Plasma Glass Melter

Covering Period: 07/01/04 to 09/30/04

Date of Report: October 23, 2004

Recipient: Plasmelt Glass Technologies, LLC
2845 29th Street
Boulder, CO 80301

Award Number: DE-FC36-03GO13093

Subcontractors: James K. Hayward
InnovaTech Services, Inc.
N.Sight Partners, LLC
Laboratory of Glass Properties, LLC
Integrex Analytical Laboratories
Dr. Scott Parker
Robert Kirkland

Other Partners: AGY
Johns Manville

Contact(s): J. Ronald Gonterman, 270-524-5110, Ron@plasmelt.com
Michael A. Weinstein, 303-530-2727, Mike@plasmelt.com

Project Team: Elliott Levine (DOE Glass Industry Liaison)
Brad Ring (DOE Project Officer)
Carrie Capps (Project Monitor)
Beth Dwyer (DOE Contract Officer)
Matea McCrav (DOE Technical Analyst)

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

Background: The purpose of this project is to demonstrate the energy efficiency and reduced emissions that can be obtained with a dual torch DC plasma transferred arc-melting system. Plasmelt Glass Technologies, LLC was formed to solicit and execute the project, which will utilize a full-scale test melter system. The system is similar to the one that was originally constructed by Johns Manville, but Plasmelt has added significant improvements to the torch design and melter system. The original JM design has been shown to achieve melt rates 5 to 10 times faster than conventional gas or electric melting, with improved energy efficiency and reduced emissions. The Project began on 7/28/2003.

EXECUTIVE SUMMARY

As of 9/30/04, significant progress has been made in understanding the process conditions required for a stable melter setup and a stable multi-hour "hands-off" glass melting operation. Torch designs and the torch operation have significantly improved to the point where a torch with greater than 10 hours of in-service life has been demonstrated, and is still in operation. The process definition that is required to define a stable startup procedure is not yet finalized and work is on going. Damage to the torch tip, torch-housing materials, and to the moly orifice have occurred when the startup procedures were too aggressive. More gentle startup procedures have shown the possibility of having a near-zero negative impact on torch condition from this startup.

Assessments of the initial glass cullet quality are underway. The cursory glass samples show glass quality that ranges from batchy-frothy-scummy with abundant heavy seeds/stones/cords to a relatively clean, lower-seed batch-free glass. Contamination by molybdenum and copper also has occurred, which we believe to be related to adverse operating conditions. Efforts are underway to fully understand and correct these contamination issues.

Process efficiencies have not yet been given a high priority. Currently, we have demonstrated efficiency numbers of ~ 7 MM BTU/ton of glass vs. a goal of 4.1. Process definition work must first be completed to define completely the conditions under which a stable operation and a stable glass quality can be routinely produced. Efficiency experiments, which are planned for late 2004 and early 2005, will be conducted after the process definition work has been completed and the process has been stabilized.

All milestones are on schedule, with the exception of the demonstration of a stable 500 #/hr process, which has been shown albeit for only brief periods. The maximum throughput demonstrated thus far has been ~350 #/hr. The pursuit of a stable process that is capable of producing 500 #/hr of glass cullet continues to be our NO.1 Goal.

Much work remains but no "fatal flaws" have thus far been identified.

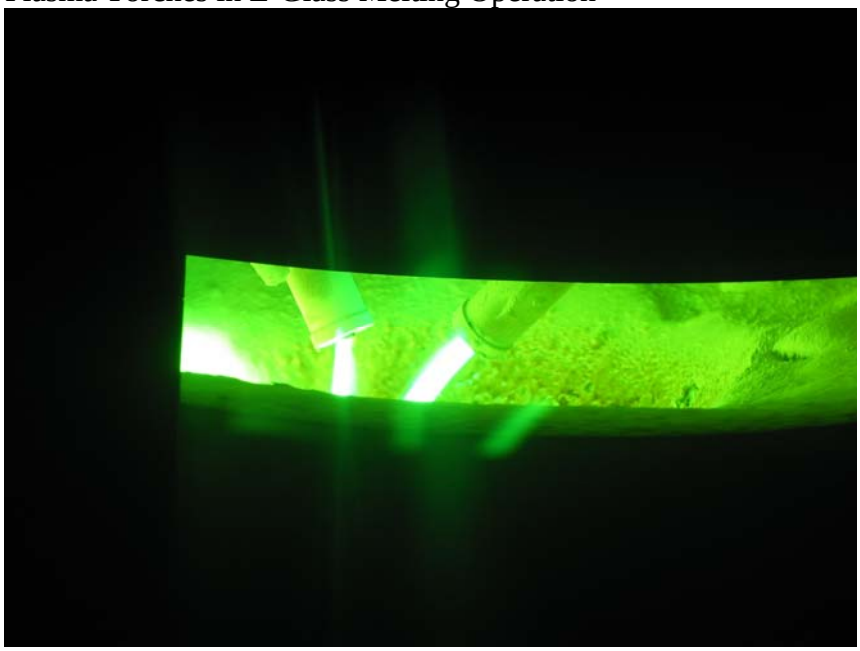
- TECHNICAL CHALLENGES

  From the previous Johns Manville work, several critical technical obstacles were known to exist with the plasma based glass melting process:
  - Torch life
  - Torch stability
  - Glass Quality
  - Maximum throughput of the melter system
  - Energy efficiency

Torch Life and Stability

Torch lives are influenced by both design and operation. We have placed high priority on testing and conducting trials of various and sundry torch designs in order to define quickly those exhibiting the most potential. More than 50 design iterations have thus far been evaluated in the first few months of the melting work. The intensive screening process has yielded a design for a 5/8" diameter torch that shows good promise. This design has been designated the "standard 5/8 torch" and is now being used for all glass melting experiments. High potential has been shown for this design to be capable of producing up to approximately 250 #/hr of E-glass. Based on trial results, higher glass melting throughputs up to 500 #/hr will likely require modifications to a larger diameter torch. A new design 3/4 inch torch has been initially tested. Although it shows promise in its early stage of development, there is still much work to be done to fine tune this design. The current melting operation using the baseline torch designs is shown below:

Plasma Torches in E-Glass Melting Operation



Initially, a goal of 100 hours of torch life was established for the project. Thus far, incremental improvements to design and major improvements to the operation have currently evolved to a torch with a demonstrated life of more than 10 hours. The torch was still in good operating condition when it was removed from service. Many of the life improvements made thus far relate to the operation of the torches. Several process configurations have been identified that can significantly shorten the torch life and cause premature failures. We continue to improve our understanding of the relationship between this torch operation and energy efficiency, heat transfer, batch bowl configuration, proximity of the torch tips to the batch pile, separation of the torches from each other, and the power settings. Even with our improved understanding, there remains a significant

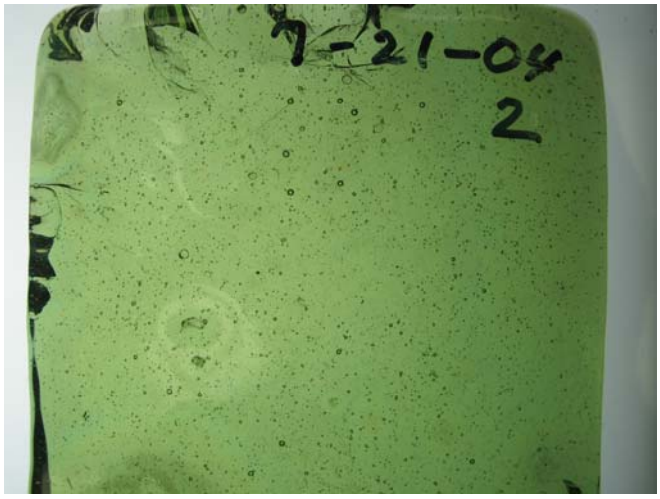
technical challenge to reach the 100-hour goal. However, at this time, we do not foresee any fatal flaws related to torch design and operation that would cause us to recommend a "No Go".

Glass Quality

Certainly, one of the most important technical challenges of this program is to demonstrate the potential for producing the best quality glass from the plasma melting process without the need for downstream refining and processing. The development of further refining processes is beyond the scope of this project.

Glass quality is the challenge that most glass scientists/technologists deem to be the most significant fundamental barrier of this project. The amazingly short dwell times of the plasma melter, which range from 5 seconds to 5 minutes, play a direct role on the quality and consistency of the glass that is produced. Although we certainly agree that this short dwell time is a major barrier by traditional standards, our initial optimism still remains. Other than the Manville work and some early work by British Glass, there are no documented processes (of which we are aware) that have investigated the glass batch reactions and glass homogeneity at the elevated temperatures involved in plasma melting aimed at high quality glassmaking. And, we know of no commercial plasma-based high quality glassmaking operations in existence globally. The temperatures involved in plasma melting are too high to effectively measure and we are left to postulate on the thermal history of the glass itself. Actual measurement of glass melting temperatures continues to be a high priority task in the project and activities are on going that may soon shed some light on this issue. To achieve the highest quality possible, the glass dwell time is being maximized through operational controls such as a glass flow control on the bottom orifice, which will be used to meter the glass throughput. We believe this to be a key factor in achieving the highest potential for glass quality. Our optimism is, in part, based on a 21 July experiment in which the glass was melted in the plasma melter for 20 minutes without glass flow from the exit. A photograph of this glass is shown below:

E-Glass Held in Plasma Melter for 20 Minutes



The glass produced in this experiment was a better quality than any produced in any experimental thus far in the program. Therefore, the quality demonstrated by this “20-minute glass” sample has become our quality target and will be achieved through the operational controls available in this process.

Although a thorough assessment of glass quality is in our milestone plans and is scheduled for four months hence, a preliminary assessment of the cullet has already been done. The overall chemical analyses of the glass show that the glass is essentially on-composition for E-glass. All major oxides, except boron, were within their normal range as compared to glass melted in conventional production glass melting furnaces. The boron loss was slightly higher than traditional melters. Table 1 shows these results.

Molybdenum contamination has shown to be a more significant barrier than originally thought. Certain conditions can results in large quantities of molybdenum being contributed to the glass. In the most egregious examples, black glass has been produced, although the more common manifestation is with reddish/brownish/grayish streaks in the otherwise green E-Glass (See Photo Below). While there is certainly a maximum service temperature beyond which molybdenum melts, there appears to be a much lower temperature than its 2600°C published melting temperature where the moly breaks down and causes streaking in the glass. This maximum service temperature is not yet known and is being investigated. The roles of glass chemistry, glass viscosity, and glass redox on the maximum molybdenum service temperature are likely important and are being investigated. This moly service life issue has slowed progress toward our goal of fiberizing the plasma-produced glass. This goal has now been changed from December, 2004 to February, 2005.

E-Glass with Reddish Moly Streaks

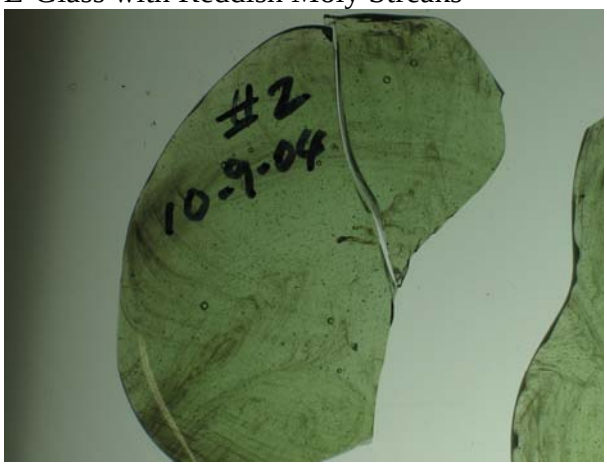


TABLE 1 -- Chemical Analyses of Glasses Produced in the Plasma Melter

All values are expressed as Weight %.

	Sample #5 06/16/04 9:00PM 45 min ET	Sample #7 06/16/04 9:28PM 73 min ET	Sample #9 06/16/04 9:48PM 93 min ET	Sample #11 06/16/04 10:18PM 123 min ET	Average	Typical E-Glass	Typical E-glass minus Plasmelt chem. average + means more loss in Plasmelt process - means less loss in Plasmelt process
SiO2	54.08	53.86	53.75	53.85	**53.89**	**53.55**	-0.34
Fe2O3	0.271	0.274	0.274	0.277	**0.27**	**0.26**	-0.01
FeO	0.161	0.171	0.172	0.169	**0.17**	**0.09**	
TiO2	0.56	0.56	0.57	0.56	**0.56**	**0.58**	0.02
Al2O3	14.91	14.92	15.04	14.93	**14.95**	**14.78**	-0.17
Cr2O3	0.007	0.007	0.008	0.008	**0.01**		
CaO	22.73	22.66	22.86	22.77	**22.75**	**22.35**	-0.40
SrO	0.166	0.166	0.167	0.165	**0.17**		
MgO	0.56	0.54	0.57	0.55	**0.55**	**0.52**	-0.03
Na2O	0.46	0.47	0.49	0.50	**0.48**	**0.64**	+0.16
K2O	0.06	0.06	0.08	0.07	**0.07**		
Fluorine	0.37	0.37	0.40	0.40	**0.39**	**0.64**	+0.26
B2O3	5.85	5.97	6.04	6.07	**5.98**	**6.94**	+0.96
MoO3	0.016	0.013	0.015	0.012	**0.014**		
CuO	0.009	--	--	--			
VISCOSITY	2195.2	2183	2186.8	2181.8		2165.00	

Maximum Throughput of the Melter

All of the initial melting trials have been conducted in the 200 #/hr range. The method used for establishing throughput is by hand collecting patties, annealing, then weighing. These patties are collected for known times in the 15 second to 45 second range. Pull control is generally established by the diameter of the opening of the fixed orifice and by the viscosity of the glass. Since most runs have been made with E-glass with a fixed batch chemistry, the only indirect control on glass flow rate through the orifice is by controlling temperature of the glass near the orifice.

Early trials have established the ability of the process to deliver exit glass with temperatures as high as ~3100°F. These conditions are achieved by some combination of power level through the torches, torch proximity to the batch / glass, and the torch-to-torch spacing. Batch feed-rate also has some influence, albeit a secondary one within the throughput range that is being used in this process thus far.

At this time, a "hands-off" process has been demonstrated in excess of 4 hours on two occasions. Both trials had glass throughputs of approximately 200 #/hr. Numerous short runs have been successfully completed, but no other longer runs have been attempted. Although the automatic data logging equipment was not installed, hand data was collected during these trials. Temperature monitoring was provided with a Mikron I.R. detector. This sensor was entrained on the glass stream at the bottom of the moly orifice support cylinder. From experience, we know that this sensor reads a too-low temperature compared to the actual temperature within the glass stream. In large part, this is due to the glass stream being composed mostly of large glass droplets that are separated by as much as 12 inches of air space in between. The sensor is averaging the air/glass temperature. More accurate temperatures have been sensed by entraining the Mikron on the glass ladle as it fills with hot glass. Often, the ladle glass is +200 to +400°F hotter than the temperatures sensed on the stream itself. Recently, we have shown that the orifice temperature on the cold face can be monitored by using the Mikron and a mirror entrained on the orifice itself. This innovation now gives us the ability to have a more accurate temperature monitor loop that relates to the glass temperature in glass stream.

We have demonstrated that throughput control can be achieved by moving the torch positions from a central position, i.e. the anode centered over the orifice, to "off-center" positions. Quite dramatic reductions in temperature and therefore glass throughput have been achieved by changing these positions. However, this temperature reduction has a serious downside of reducing the temperatures within the glass pool, increasing dramatically the seed/batch stone content of the glass, and makes it even more difficult than normal to achieve a good quality glass. We now believe that, for improved glass quality, it is crucial to be able to de-couple the temperatures within the glass bath from temperatures in the orifice so that flow control can be independently controlled. Ideally, we strive for relatively long dwell times at very high temperatures with a regulated and controlled glass throughput from the orifice.

Work has been commissioned to develop an independent orifice glass flow control device that will allow the very high temperatures to be achieved in the glass bath to attempt to reach the maximal glass quality, and simultaneously, allow flow control to be changed from zero flow to 500 pounds of glass per hour. Currently, we believe this flow control to be the key element that will allow larger orifices to be used in conjunction with high batch feed rates and very high glass bath temperatures. These capabilities will likely be critical to achievement of the 500 #/hr goal.

Energy Efficiency

The stated goal of the program is to achieve a melt rate of 4.1 MBTU/hr melting efficiency. That number was selected as an improvement over the previously demonstrated work completed at Manville.

Based on this previous work, it is known that the increased power efficiencies will be achieved at higher throughputs. The increased efficiencies at the higher throughputs are primarily due to the ohmic heat transfer mechanism that is realized by the amperage and torch position. It is only possible to operate in these positions at the higher feed rates. Further testing in October and November will validate this statement.

The runs completed to date have primarily been at 200 pounds per hour. For the operation at this level, the average operating conditions are:

- 305 Volts
- 700 Amps

These numbers will vary by +/- 15% during a typical run. However, these are good averages for typical operation. To calculate the energy used per pound of glass:

$$Power = Volts \times Amps = 305v \times 700a = 213{,}500 watts = 213.5kW$$

$$kW / Pound\ of\ Glass = \frac{213.5kW}{200 lbs/hr} = 1.0675 \frac{kW}{lbs/hr}$$

$$1kW = 3412.4 BTU/hr$$

$$1.0675 \frac{kW}{lbs/hr} * 3412.1 \frac{btu}{hr} = 3642.4 \frac{btu}{lbs} \Rightarrow 7.285 MBTU/ton$$

This power is 77% over our stated goal for the program. All efforts in this program to date have been devoted to torch life and glass quality. Now that torch life is not the predominant factor in operation, effort can be devoted to increasing the glass quality and power consumption. Being 77% over the stated goal is not surprising considering the program focus for the first year.

For the last quarter of 2004, the following items will be investigated to determine the effect on power consumption:

- Operation at 500 pounds per hour
- Reduced exhaust volume

- Increased torch separation which increases the amount of ohmic heating and reduces radiant heating
- Reduce shell cooling

Based on the significant improvements achievable with these improvement areas, we are confident the power consumption can be significantly reduced.

ACCOMPLISHMENTS

Without elaboration, below is a list of program accomplishments to date.

1. All lab infrastructure has been installed including the glass melter, batch feed system, exhaust gas system, plasma torch system, all electrical power and control systems, cullet handling, and process monitoring.
2. More than 50 torch designs have been evaluated. A standard 5/8 torch has been designed that is in routine use and has allowed the process to run in a stable hands-off mode for > 4 hours.
3. A process has been demonstrated that is capable of melting glass in the 200 to 250 pounds per hour for several hours.
4. The standard 5/8 inch torch has been used to operate the process at pull rates of ~ 350 #/hr.
5. Brief runs have been conducted in excess of 500 pounds per hour, but these were not stable and in-control operations. We have concluded from these experiments that a larger torch is required and work has been initiated on a 3/4 inch torch.
6. Preliminary chemical analyses of glass, which was collected on 6-16-04, show that overall, the analyzed glass samples were essentially on-composition, with somewhat higher losses of boron and fluorine.
7. Several preliminary assessments have been made of several E-Glass patties produced during trials. These generally show a very high seed count, some cord, and occasional un-melted batch stones.
8. The best glass quality was demonstrated on a glass sample that was melted for 20 minutes with no flow from the exit orifice. This samples has been selected as our target glass quality.
9. Torch lives have improved dramatically from a few minutes on the initial designs to several hours on the current standard 5/8 torch. The torch with the longest service life thus far is > 10 hours.
10. Energy consumption has on average been about 7MM BTU/ton. This efficiency is much worse than the target 4.1 MM BTU/TON of glass, but is primarily related to our low throughputs thus far in the program.
11. The environmental impact of the process has not yet been assessed, but the dustiness of the initial system is known to be high. Significant work is planned for later in the program to focus on reducing the particulate emissions.
12. A market study has been completed. Candidate early adopters have been identified. Discussions are on-going with these companies.
13. One melting trial has shown that the system is capable of melting 200 #/hr of S-2 Glass.

14. We have developed a preliminary understanding of the process settings and how these may relate to the ability to maintain a stable melting operation.
15. The design has been completed for a refractory glass delivery channel that will transport the glass from the melter exit orifice to the processing area.
16. A patty-making machine has been located and integrated into the design. An option to lease this machine has been signed.
17. Several preliminary methods for glass flow control have been identified and two such designs are actively being investigated.

BUDGET/FINANCIAL

- The project finished Year One under budget with total DOE expenditures of $792,986 vs. a DOE budget of $956,198.
- Cost share contributions for Year 1 totaled $269,016.
- We filed a project revision with DOE, which was approved, to extend the 12-month program to a 24-month program with full support from the cost share partners.
- DOE has approved a 24-month budget of $1,732,356 (including cost share contributions) to support this revised plan.

UNDERSTANDING THE PROCESS RELATIONSHIPS AND LIMITS

Although much progress has been made during the project to understand the relationship between the critical process variables and the important process outputs, much work remains to develop a quantitative understanding of these relationships and their limits. In order to achieve the process setup that can give the highest glass quality at the lowest energy consumption with the least environmental impact, and at the longest torch lives, data collection must and will be put in place to allow statistical analyses to be performed. Both AGY and Plasmelt will perform these data analyses in order to help define the specification and limits for each process variable that will ensure that a resultant stable efficient process can be operated.

The installation of the automatic data monitoring system is not yet complete. Upon completion, the important variables that will routinely be logged include:

1. Power supply output
2. Batch feed-rate
3. Shell rotation speed
4. Glass stream temperature
5. Melter orifice temperature
6. Melter shell temperature
7. Video output of batch pile
8. Video output of glass stream
9. Anode angle
10. Cathode angle
11. Anode in/out
12. Cathode in/out
13. Water supply temp

14. Anode electrode return temp
15. Anode nozzle return temp
16. Cathode electrode return temp
17. Cathode nozzle return temp
18. Power supply return temp
19. Shell water supply temp
20. Shell water out temp
21. Exhaust temp

This list will further evolve as data are analyzed and conclusions drawn.

EPILOGUE:
At this time, we continue to see significant technical challenges toward the achievement of the program goals, but do not see any fatal flaws in the program and are actively proceeding with the project as a "GO" for Year 2.

Budget Data (as of 9/30/04): The actual spending should reflect the money actually spent on the project in the corresponding periods.

Project Spending and Estimate of Future Spending							
Quarter	**From**	**To**	**Estimated Federal Share of Outlays***	**Actual Federal Share of Outlays**	**Estimated Recipient Share of Outlays***	**Actual Recipient Share of Outlays**	**Cumulative**
	Start	9/30/04	Note 1	$856,828	Note 1	$365,391	$1,222,218
4Q04	10/1/04	12/31/04	$106,650	Note 4	$40,500	Note 6	$ 147,150
1Q05	1/1/05	3/31/05	$106,650		$40,500		$ 147,150
2Q05	4/1/05	6/30/05	$106,650		$40,500		$ 147,150
3Q05	7/1/05	9/30/05	$ 35,578		$33,109		$ 68,688
4Q05	10/1/05	12/31/05					
1Q06	1/1/06	3/31/06					
2Q06	4/1/06	6/30/06					
3Q06	7/1/06	9/30/06					
4Q06	10/1/06	12/31/06					
1Q07	1/1/07	3/31/07					
2Q07	4/1/07	6/30/07					
3Q07	7/1/07	9/30/07					
4Q07	10/1/07	12/31/07					
Totals			**$355,528**	$856,828	**$154,609**	$365,391	$1,732,356

* Update quarterly

General Note: DOE Laboratory partner spending should not be included in the above table. If a DOE Laboratory is a partner, report their spending and spend plan information in the table below (use separate tables if multiple DOE Laboratories are involved):
Note 1: Leave blank. Only the actual DOE/Cost Share amounts spent through 6/30/04 are needed.
Note 2: Amount for this quarter and subsequent quarters should be updated as necessary on a quarterly basis. Estimates need to be provided for the entire project. If spending for a given quarter is different than estimated, then the remaining quarter's estimates should be updated to account for the difference. Total DOE and Cost Share amounts should be the same as the Award amount.

Note 3: This should match the amount on the SF269A section 10.c. Column III (10.j. Column III on the SF269).
Note 4: This should match the amount on the SF269A section 10.c. Column II (10.j. Column II on the SF269).
Note 5: This should match the amount on the SF269A section 10.b. Column III (10.i. Column III on the SF269).
Note 6: This should match the amount on the SF269A section 10.b. Column II (10.i. Column II on the SF269).
Note 7: This should match the amount on the SF269A section 10.a. Column III (10.d. Column III on the SF269).
Note 8: This should match the amount on the SF269A section 10.a. Column II (10.d. Column II on the SF269).

Plans for Next Quarter:

- Resolve the molybdenum service temperature problem that is resulting in moly streaks in the glass.
- Continue to develop the glass flow control meter concept
- Evaluate any and all other methods of protecting moly from the hot glass
- Conduct our BASELINE GLASS QUALITY ASSESSMENTS on E-glass and S-glass to relate the process variables to glass quality.
- Produce patties to be used for fiberization trials at AGY
- Conduct 500 #/hr trials on E- and S-glass
- Conduct optimization work to improve energy efficiency

Patents: N/A

Publications/Presentations:

A presentation was made at the Crystal City, VA DOE Project Review. A copy of that presentation is filed with this report.

Milestone Status Table: This should be a complete list of project milestones, anticipated completion dates and actual completion dates. The milestone identification number should correspond to the task numbers in your agreement to aid in tracking (example below).

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
M 1	Project Startup: Establish WBS and Schedule, operating agreements, IP terms, subcontract agreements	10/31/03	10/31/03	Complete
M 2.1	Melter Design: Develop Project Request Documents, specifications, materials lists, engineering packages	10/31/03	10/31/03	Complete
M.2.2	Laboratory Preparation: Identify candidate facilities, sign lease agreements, establish environmental permits	12/31/03	10/31/03	Complete. Notification of environmental Exemption Letter received from Colorado DPHE
M.2.3	Construct Melter: Subcontract fabrication and construction, install melter at site	12/31/03	2/29/04	Most of the delay due to major change in the building electrical system upgrade by Xcel Energy. Melter construction and fabrication are now complete.
M 3	Market Survey	5/31/04	5/31/04	Work is complete.
M 4	Melter/Process Test Program: Startup and operation at 500 #/hr rate [GO/NO GO DECISION], preliminary energy balance, preliminary report	7/27/04		Although 500#/hr has not yet been achieved on a routine basis, this work is ongoing. Long stable runs have been achieved at 200 #/hr but not at 500 #/hr. A report was issued to our team-members documenting our "GO" decision.
M 5	Assess Glass Quality: Patty Making Installation, Patty Production, and Fiberizing Testing [GO/NO GO DECISION]	1/31/05		
M 6.1	Optimization: Process refinement, energy balance updates [GO/NO GO DECISION]	6/30/05		
M 6.2	Final Reporting to DOE	7/27/05		

Measurement and Control of Glass Feedstocks

Weisberg: Energy Research Company, ORNL

ID14030, CPS#01609

QUARTERLY PROGRESS REPORT

Project Title: Measurement and Control of Glass Feedstocks

Covering Period: July 1, 2004 through September 30, 2004

Date of Report: October 28, 2004

Recipient: Energy Research Company
2571-A Arthur Kill Rd.
Staten Island, NY 10309

Award Number: DE-FC36-01ID14030

Subcontractors: Oak Ridge National Laboratory

Other Partners: PPG Industries
Fenton Art Glass

Contact(s): Arel Weisberg, Ph.D.
(718) 608-0935
aweisberg@er-co.com

Project Team: DOE-HQ Contact: Elliot Levine
Contract Specialists: Brad Ring, Beth Dwyer

Project Objective: Energy Research Company (ERCo) is developing an on-line sensor for controlling the quality of glass feedstocks, both batch and cullet. In the case of batch, the sensor can determine whether or not the batch was formulated accurately, and serve as part of a feedback loop in the plant to control glass quality. In the case of cullet feedstocks, the sensor can serve as part of a system to sort cullet by color and ensure that it is free of contaminants.

Background: The Glass Industry Technology Roadmap[1] emphasizes the need for accurate process and feedstock sensors. Listed first under technological barriers to increased production efficiency is the "Inability to accurately measure and control the production process." ERCo's LIBS sensor addresses this need by giving plant operators critical knowledge of their batch composition. In plants where cullet is used in glass production, the LIBS sensor can provide color sorted cullet free of contaminants,

[1] Available at: http://www.oit.doe.gov/glass/pdfs/glass2002roadmap.pdf

including those contaminants that are not detectable using current optical based color sorters.

LIBS utilizes a highly concentrated laser pulse to rapidly vaporize and ionize a small amount of the material being studied. As the resulting plasma cools it radiates light at specific wavelengths corresponding to the elemental constituents (e.g. silicon, aluminum, iron) of the material. The strengths of the emissions correlate to the concentrations of each of the elemental constituents. This technology has been successfully demonstrated in ERCo's LIBS laboratory for both batch analysis and cullet sorting. In the upcoming year, designs of prototype sensors for installation at the program's industrial partners will be developed.

Status:

1. **Executive Summary**

A significant goal of this program was reached this quarter upon installation of ERCo's rapid batch analyzer in PPG's Chester, SC fiber glass plant. It will remain there for extended testing by plant personnel. Results from in-plant testing are summarized in Table 1 and presented in full in the sections below.

During the 2nd quarter of 2004 ERCo tested the sensor in PPG's plant and found that changes were necessary for regular use by plant personnel. These changes as well as several improvements were completed in this reporting period, resulting in an analyzer capable of operating reliably in the plant without aid from ERCo. The benefits of these improvements are seen in the far right column of Table 1, where the reduction in the average discrepancy between the measured and reported values is shown.

With this installation, the R&D program has reached its goal of developing an accurate, reliable, and user friendly LIBS batch analyzer for plant use.

Table 1: Comparison of Mining Company and ERCo Batch Analyzer Ulexite Concentrations (all results are in relative % except trace element differences which are in absolute %)

Element	Ulexite Component	Average Discrepancy Between Reported and Measured Values	Average Discrepancies From Prior Quarter	Percent Discrepancy Reduction
Boron	Major	**0.35%**	0.54%	**35%**
Calcium	Major	**0.50%**	1.51%	**67%**
Sodium	Major	**1.83%**	2.57%	**29%**
Silicon	Minor	**4.03%**	4.98%	**19%**
Magnesium	Minor	**2.52%**	4.06%	**38%**
Strontium	Trace	**0.027%**	0.026%	**-4%**
Aluminum	Trace	**0.007%**	0.007%	**0%**
Iron	Trace	**0.002%**	0.003%	**33%**

2. Analyzer Hardware

The hardware for the analyzer was repackaged into an instrument cabinet suitable for the lab environment where the sensor is used. Figure 1 contains a photograph of the analyzer cabinet in the plant, and Figure 2 contains a photograph of the analyzer with the cabinet doors open, displaying its hardware components.

In order to insert a sample into the sensor, the cabinet doors must be opened, however they may be closed during a measurement.

See the prior quarter's report for a complete description of the components.

Figure 1: The Sensor Cabinet in the Fiber Glass Plant

Figure 2: The Sensor Cabinet with Doors Open Displaying the Hardware Components of the Sensor
Top Shelf: Monitor, Keyboard and Mouse
Middle Shelf from left to right: Windows PC, UPS, Laser Power Supply, Sample Chamber
Lower Shelf from left to right: Spectrometer, Dedicated Spectrometer PC

3. User Interface

ERCo's LIBS software interface, described in the prior quarter's report, was upgraded with some functionality improvements, but otherwise remains the same. One important upgrade included better computer control and monitoring of the laser performance as well as laser safety interlocks.

4. Results

Over 50 samples were analyzed during the installation to ensure that the analyzer was ready for regular use by plant personnel. During this period, PPG employees prepared samples and were trained on using the machine. An operating manual was also provided to the plant personnel. Figure 3 contains a photograph of Phil Gibson, the plant batch house supervisor preparing a ulexite sample for analysis. Figure 4 contains a photograph of plant production manager Kevin Streicher placing a ulexite sample in the sample chamber for analysis.

Figure 3: PPG Batch House Supervisor Phil Gibson Prepares a Ulexite Sample for Analysis

Figure 4: PPG Production Manager Kevin Streicher Placing a Ulexite Sample in the Sample Chamber for Analysis

The results for the analyses done in the plant are given in the figures below. In each figure caption the average relative difference between the mining company results and the LIBS analysis +/- one standard deviation is given. The actual concentrations are proprietary PPG data, and are therefore blocked out.

It should be noted that minerals have a natural variability, therefore perfect correlation between the mining company results and the LIBS results should not be expected. The mining company pulled one sample from a multi-ton shipment while we used a different sample pulled from the

shipment for the LIBS tests. The accuracy and precision of the LIBS batch analyzer results should be viewed in light of this fact.

The major constituents of ulexite are boron, calcium, and sodium. The first three graphs, Figures 5, 6, and 7, demonstrate the accuracy of the LIBS analyzer for these large percentage constituents. The average difference for these elements was no greater than 1.83%

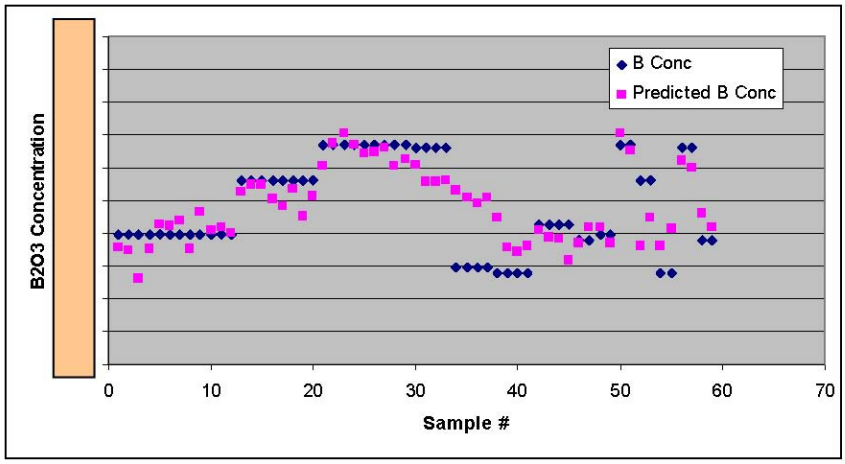


Figure 5: Boron Average Difference: 0.35% +/- 0.31%

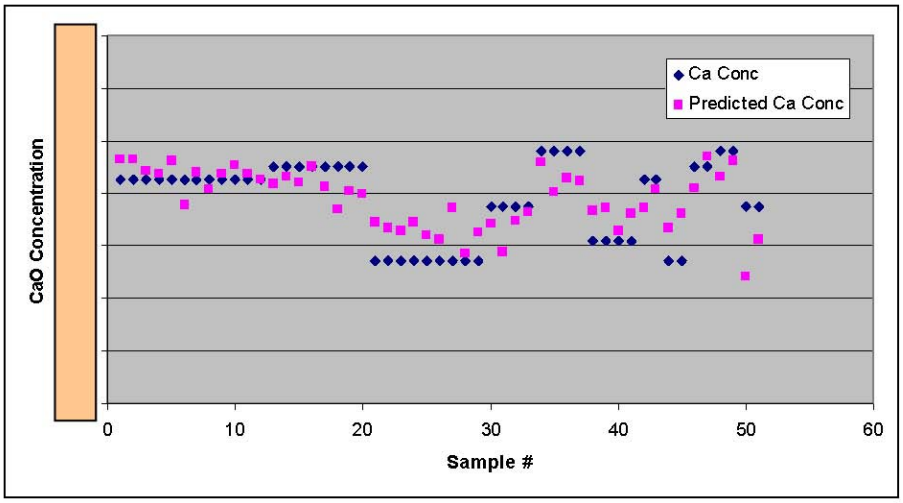


Figure 6: Calcium Average Difference: 0.50% +/- 0.32%

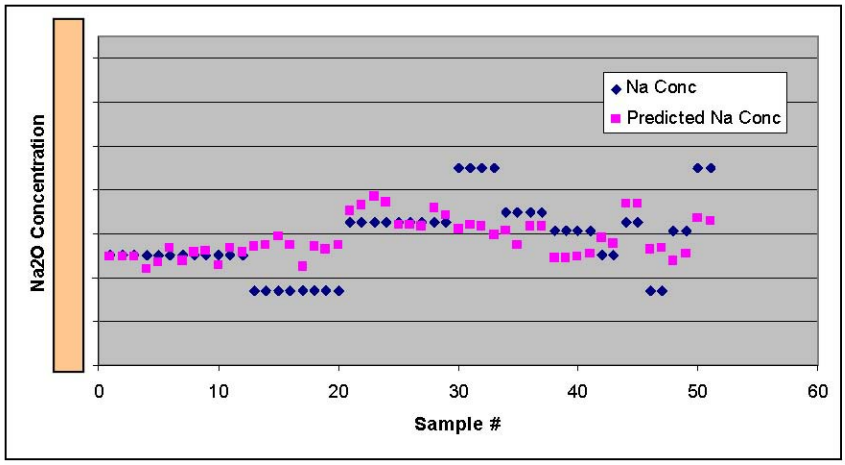


Figure 7: Sodium Average Difference: 1.83% +/- 1.42%

Silicon and magnesium are present in much lower concentrations. As in the case of the major constituents, the LIBS analyzer closely tracked the reported data for these elements, shown in Figures 8 and 9. The average difference for these minor elements was no greater than 4%.

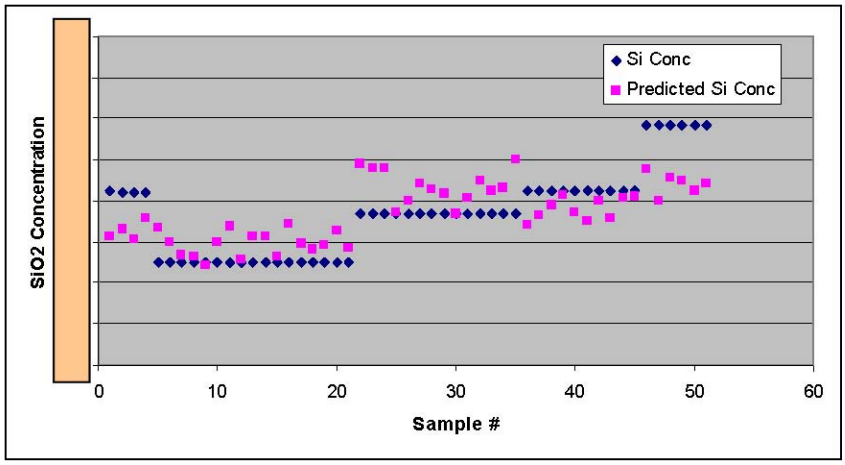


Figure 8: Silicon Average Difference: 4.03% +/- 2.64%

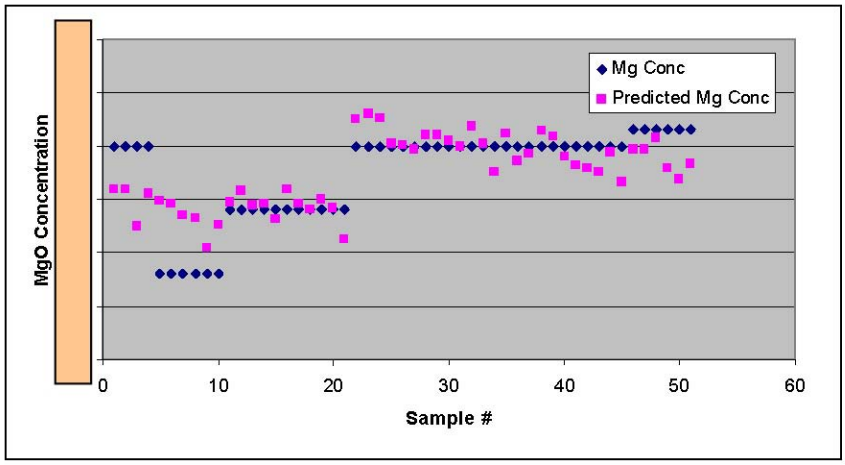


Figure 9: Magnesium Average Difference: 2.52% +/- 2.27%

The last three elements, shown in Figures 10, 11, and 12, are all present in trace quantities. At these much lower concentrations, the LIBS analyzer was able to match the mining company data as well. Since the concentration percentages for these elements are so small, the absolute differences between the mining company values and the LIBS analyzer values are relevant, more so than the relative values. Therefore, the percentage difference is reported as absolute percent for these elements, and was no greater than 0.027%.

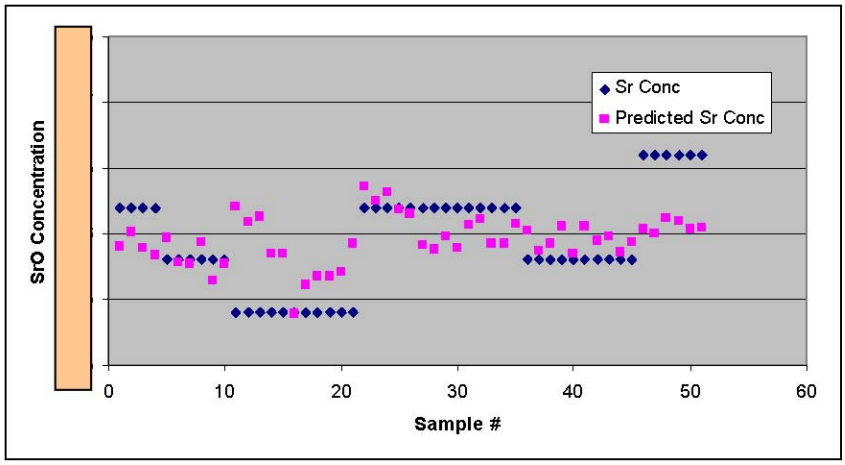


Figure 10: Strontium Average Difference: 0.027% +/- 0.020%

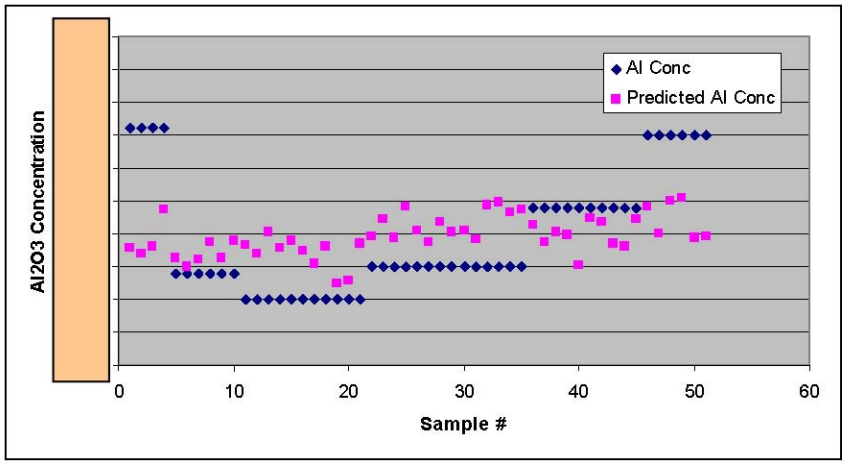


Figure 11: Aluminum Average Difference: 0.007% +/- 0.004%

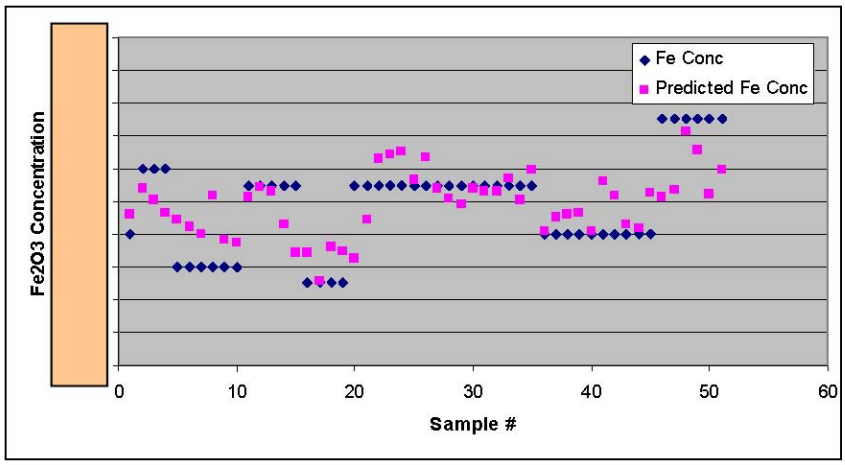


Figure 12: Iron Average Difference: 0.002% +/- 0.001%

Following these tests, the ERCo personnel left the plant and PPG personnel took over the operation of the analyzer. Four new shipments of ulexite arrived at the plant in September, and multiple samples from each shipment were analyzed with the LIBS analyzer.

Presented below in Table 2 is the repeatability in our measurements for the elements in ulexite. Aluminum and iron are omitted from the table as the standard output of the software has too few decimal places to track the repeatability of these elements (it was below 0.01%).

Table 2: Repeatability of Measurements Taken by PPG Personnel on New Ulexite Shipments
Values are Relative Standard Deviation (σ/μ)

Shipment	Boron	Calcium	Sodium	Silicon	Magnesium	Strontium
1	0.16%	0.38%	0.25%	2.39%	1.70%	1.00%
2	0.21%	0.50%	0.37%	1.80%	2.72%	0.00%
3	0.21%	0.50%	0.37%	1.80%	2.72%	0.00%
4	0.13%	0.20%	0.09%	0.16%	0.00%	1.14%

These values are well within the requirements for PPG, and demonstrate the high repeatability that the LIBS analyzer achieves with plant personnel operating the machine.

Only boron concentrations for the shipments are available. A comparison of the measured and reported boron values are in Figure 13. With the exception of the last set of data, the results matched very well, with an average discrepancy of 0.8% (relative). While the discrepancy in the last set is larger (4.07%), the values reported by the LIBS analyzer for that set are very nearly within the total range reported. As mentioned above, there is a natural variability in any mineral. It is possible that the samples analyzed in the LIBS analyzer had a different average value than the sample analyzed by the mining company, as they are both two small samples pulled from tons of material.

Furthermore, most of the samples analyzed in the prior tests had their concentrations verified by an outside laboratory. Some of the laboratory results on those samples varied from the mining company results by a similar amount to that seen in Figure 13.

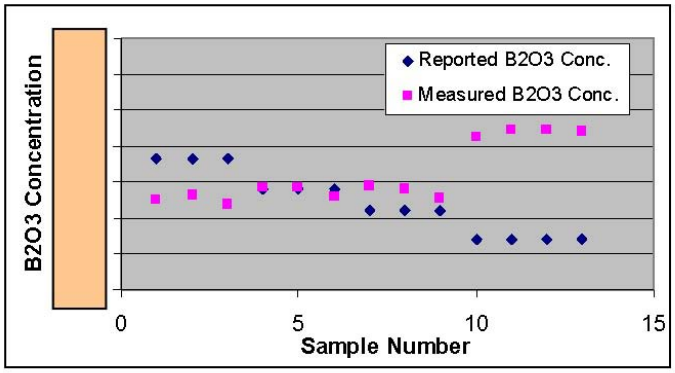


Figure 13: Results of Ulexite Analyses by PPG Personnel on New Shipments

5. Conclusion

This installation of the LIBS analyzer at PPG has been completed, and the analyzer will remain in the plant for extended testing and use by plant personnel. All tests to date have been successful, and the analyzer continues to operate accurately and reliably.

Plans for Next Quarter:

ERCo will enhance the utility of the sensor to PPG by adding the ability to measure elemental concentrations in limestone residue from the plant's exhaust scrubbers. The modifications necessary for this capability will be built into a new sample chamber (Figure 2) which will then replace with the existing sample chamber in PPG. Related software changes will also be made. The remainder of the sensor hardware and packaging will remain the same.

Patents: N/A

Publications/Presentations:

N/A

Milestone Status Table:

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
1	Laboratory Development			
1.1	Facility Modification	9/30/01	9/30/01	
1.2	Testing	3/31/02	2/28/02	
1.3	Initial Software Development	3/31/02	3/31/02	
1.4	Performance Evaluation	3/31/02	3/31/02	
2	Sensor Fabrication			
2.1	Facility Construction	9/30/02	8/31/02	
2.2	LIBS Testing	8/31/03		Ongoing to add capabilities
2.3	Modifications to PPG Facility	12/31/03	3/31/04	Not necessary
2.4	Procure System	6/30/04		Ongoing to add capabilities
3	Sensor Testing			
3.1	Testing at PPG	2/28/05		Commenced in 6/04
3.2	System Integration	12/31/04	8/24/04	

Budget Data (as of date):

Project Spending and Estimate of Future Spending							
Quarter	**From**	**To**	**Estimated Federal Share of Outlays***	**Actual Federal Share of Outlays**	**Estimated Recipient Share of Outlays***	**Actual Recipient Share of Outlays**	**Cumulative**
	Start	6/30/04	Note 1	904,873.18	Note 1	784,137.42	1,689,010.60
3Q04	7/1/04	9/30/04	Note 2	1,109,175.19	Note 2	784,137.42	1,893,312.61
4Q04	10/1/04	12/31/04	1,127,725.19		984,137.42		
1Q05	1/1/05	3/31/05					
2Q05	4/1/05	6/30/05					
3Q05	7/1/05	9/30/05					
4Q05	10/1/05	12/31/05					
Totals				**Note 3**		**Note 5**	**Note 7**

* Update quarterly

General Note: DOE Laboratory partner spending should not be included in the above table. If a DOE Laboratory is a partner, report their spending and spend plan information in the table below (use separate tables if multiple DOE Laboratories are involved):
Note 1: Leave blank. Only the actual DOE/Cost Share amounts spent through 6/30/04 are needed.
Note 2: Amount for this quarter and subsequent quarters should be updated as necessary on a quarterly basis. Estimates need to be provided for the entire project. If spending for a given quarter is different than estimated, then the remaining quarter's estimates should be updated to account for the difference. Total DOE and Cost Share amounts should be the same as the Award amount.
Note 3: This should match the amount on the SF269A section 10.c. Column III (10.j. Column III on the SF269).
Note 4: This should match the amount on the SF269A section 10.c. Column II (10.j. Column II on the SF269).
Note 5: This should match the amount on the SF269A section 10.b. Column III (10.i. Column III on the SF269).
Note 6: This should match the amount on the SF269A section 10.b. Column II (10.i. Column II on the SF269).
Note 7: This should match the amount on the SF269A section 10.a. Column III (10.d. Column III on the SF269).
Note 8: This should match the amount on the SF269A section 10.a. Column II (10.d. Column II on the SF269).

DOE Laboratory Spending Table (if applicable):

DOE Laboratory Partner Spending and Estimate of Future Spending					
Quarter	**From**	**To**	**Estimated DOE Lab Amount***	**Actual DOE Lab Amount**	**Total**
	Start	6/30/04	Note 1	155,000.00	155,000.00
3Q04	7/1/04	9/30/04	Note 2	0	0
4Q04	10/1/04	12/31/04			
1Q05	1/1/05	3/31/05			
2Q05	4/1/05	6/30/05			
3Q05	7/31/05	9/30/05			
4Q05	10/1/05	12/31/05			
1Q06	1/1/06	3/31/06			
Etc.					
Totals				**155,000.00**	**155,000.00**

* Update quarterly

Developing the Glass Industry Vision and Roadmap

Greenman: Glass Manufacturing Industry Council

ID14315, CPS#01034

DOE F 4600.6
(10-94)
Replaces EIA-459F
All Other Editions
Are Obsolete

U.S. Department of Energy

OMB Control No.
1910-0400

FEDERAL ASSISTANCE PROGRAM/PROJECT STATUS REPORT

OMB Burden Disclosure Statement

Public reporting burden for this collection of information is estimated to average 47.5 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Office of Information Resources Management Policy, Plans, and Oversights, Records Management Division, HR-422 - GTN, Paperwork Reduction Project (1910-0400), U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, DC 20585; and to the Office of Management and Budget (OMB), Paperwork Reduction Project (1910-0400), Washington, DC 20503.

1. Program/Project Identification No.	2. Program/Project Title	3. Reporting Period
DE-FC36-02ID14315	Promotion of the U.S. Glass Industry	07/1/04 to 09/30/04

4. Name and Address	5. Program/Project Start Date
Michael Greenman Glass Manufacturing Industry Council PO Box 6136 Westerville, OH 43081	4/01/02
	6. Completion Date 3/31/05

7. Approach Changes

No changes since last reporting period.

8. Performance Variances, Accomplishments, or Problems

The Technical and Economic Assessment: a major project of the GMIC/DOE collaboration over the past two years, was completed this period. It will be printed and distributed in October. This will be a document of fundamental value to current and future glass industry professionals and researchers as it establishes a basis for understanding the past, present and likely future evolution of the industry as it moves towards greater energy efficiency and environmental responsibility. Copies are available from the GMIC and on line from GMIC and DOE.

Achieve Goals and Priorities outlined in the Glass Industry Vision and Roadmap Documents: GMIC Subcommittee work is moving into new areas of major importance: the Production Efficiency Subcommittee is developing a technical foundation for identifying future refining requirements to achieve optimum process efficiency. The Environmental Subcommittee is initiating a process whereby it will be able to collaborate with the EPA with the objective of improving energy efficiency in glass plants in future rebuilds and new plant permitting.

Project Review: Council finalized the technical evaluation of the progress on research programs pursuant to the June Project Review meeting and submitted to the DOE for transmittal to Principal Investigators. Several minor recommendations were submitted but no major concerns were identified. And,
Distributed second quarter quarterly reports to glass industry evaluators for comments.

Provide information to DOE and guidance to GMIC members: Council and members are providing input to the Stakeholder Engagement Tool established by ITP Liaison, Elliott Levine. Several communication channels were established to encourage interaction between DOE and the industry. The GMIC will be monitoring responses and coordinating resulting action recommended by contributors. We have also publicized the availability of this tool to entire industry.

Collaboration with other environmental entities: GMIC participated in an E-Glass Recycling Workshop with EPA intended to develop an optimum system for recycling obsolete cathode ray tubes and other electronic glass items that are expected to enter the waste stream as landfills reject these items and technology moves to other methods. Recommendation was made to consider Submerged Combustion Melter technology being developed in DOE funded research as means to separate glass from potential polluting products.

Encourage collaborative opportunities between Industry and the National Laboratories: GMIC is investigating methods with the Argonne National Lab to provide ongoing support for the DOE funded Glass Furnace Model to ensure it is effectively introduced and maintained as development period ends and implementation/application moves forward.

9. Open Items

GMIC is entering into phase with the DOE of considering need to update the Technology Roadmap in 2005. This valuable tool was started in 1997 and completed in 2002.

10. Status Assessment and Forecast

Six new members have joined the GMIC since the beginning of the year: three glass companies one national lab and two suppliers.

11. Description of Attachments

12. Signature of Recipient and Date	13. Signature of U.S. Department of Energy (DOE) Reviewing Representative and Date
Michael Greenman – 10/27/04 (by e-mail)	

Improvement of Performance and Yield of Glass Fiber Drawing Technology

Sanger: State of Ohio

ID14347, CPS#none

NINTH QUARTERLY PROGRESS REPORT

Project Title: Improvement of Performance and Yield of Glass Fiber Drawing Technology

Covering Period: July 1, 2004 through Sep 30, 2004

Date of Report: Oct 10, 2004

Recipient: State of Ohio, Office of Energy Efficiency
77 S. High Street
Columbus, OH 43215-6108

Award Number: DE-FC07-02ID14347

Subcontractors: Cleveland State University

Other Partners: PPG Industries Inc
Johns Manville
U.S. Borax

Contact(s): Dr. Simon M. Rekhson – Principal Investigator
(216) 687- 5283
s.rekhson@csuohio.edu

William L. Manz -Business Manager
(614) 466- 7429
WManz@odod.state.oh.us

Project Team:

DOE-HQ Team Leader:	Elliott Levine
DOE Regional Team Leader:	Brian Olsen
DOE Project Manager:	Glenn Doyle
DOE Contract Specialist:	Tom Reynolds

Project Objective: Investigate the basic science of continuous glass fiber drawing and use that information to improve the drawing process: 1) demonstrate reduced break frequency on a state of the art fiber-drawing machine from 1 break per hour to 1 break per 4 hours, 2) reduce fiber diameter variation, 3) drive toward six-sigma* quality through process control and computer simulation.

Background: Fiber breakage is the single most important process variable in the drawing of continuous glass fibers limiting fiber quality and production throughput and resulting in over 500 10^9 BTU of energy wasted annually. Continuous glass fiber drawing in "state of the art" glass industrial facilities is accomplished in the simultaneous drawing of up to 5000 filaments from a single bushing. The perturbation caused by the breaking of one filament, which typically occurs once per hour, quickly propagates toward disruption of all 5000 filaments. During the recovery time of 5-10 minutes, the glass is continuing to ooze through the bushing holes. Over 67,000 tons of unrecyclable glass annually and all the energy invested in the melting and forming of this wasted glass is lost. To address this problem, this project will apply six sigma quality methodology combined with fundamental glass science to reduce breakage, increase throughput and improve the quality of glass fiber.

Status: The drawing tower continues to run beautifully having accumulated 1140 operational hours of tests and 14700 lbs of glass drawn. The break-o-meter passed initial validation tests of its ability to show the site of a likely breakout and predict the approximate break rate. This quarter we ran a definitive test of our process design and drawing tower's performance against our commitment on this project. The drawing tower ran for ~53 continuous hours at a break rate of 0.17 breaks/hr. This performance achieved on a 200 tip bushing compares very well with our commitment to demonstrate 0.25 breaks/hour using a smaller 100 tip bushing. We had two conference calls and one visit with our PPG and JM partners.

Task 1 Build and Install Glass Fiber Drawing Tower

The drawing tower shows excellent performance and our partners are very supportive with our maintenance needs. Per our request JM sent us two craters – 6200 pounds – of marbles. We also purchased three quartz windows to conduct tests on controlling entrained air affecting performance of front rows of tips.

Task 2 Develop diagnostic Instrumentation

Last quarter we completed our development work on cone imaging using the Panasonic CCD camera and on automatic conversion of this data to a cone width. Upon further mathematical

manipulation the cone width yields cone length and, coupled with the tip temperature data from the IR spot pyrometer, it yields tip_temperature/cone_length ("eta/L") ratio that was found to be a key parameter for predicting the break rate. The break rate is calculated using our theoretically derived transfer function. This quarter we tested the break-o-meter, see Fig. 1.

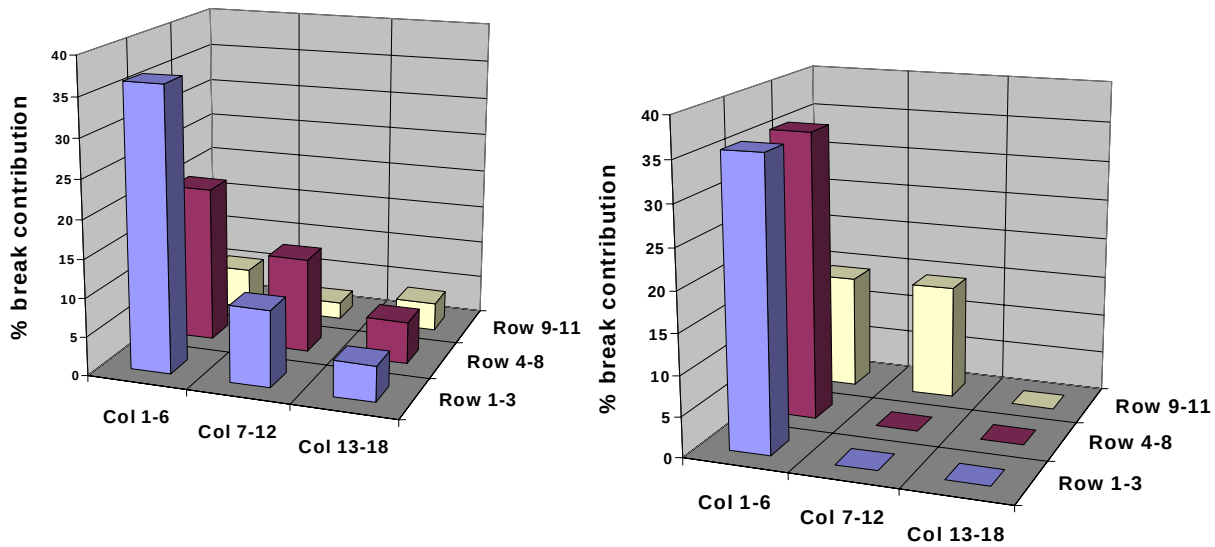


Fig. 1 Break contributions by nine bushing segments of 22 tips each per break-o-meter data (left) and direct count (right).

We experienced difficulties in validating our break-o-meter when we used the quartz window to block air entrainment by the front row of our bushing. As the quartz window refracted some of the radiation, the temperature data taken on the window side were undervalued. Taking cone images was similarly more difficult because of viewing issues.

Task 3 Develop simulation models

Last quarter's report offered a narrative outlining our computations that we now present in Fig. 2. In our discussion we stated that one can draw a 10 mkm filament at various combinations of winder speed and set point (i.e. average bore) temperatures, see the "10 mkm" curve. This raised a question of where to center the process. Through calculations we determined that depending on the choice made the break rate may differ by a factor of ten (!), see numbers directly on top of the

10 mkm curve. These calculations suggested that by pushing the process toward higher temperatures and winder speeds we may be able to reach a break rate of 0.3 per hour. We pointed out that this key finding was largely analytical and computational and needed to be validated.

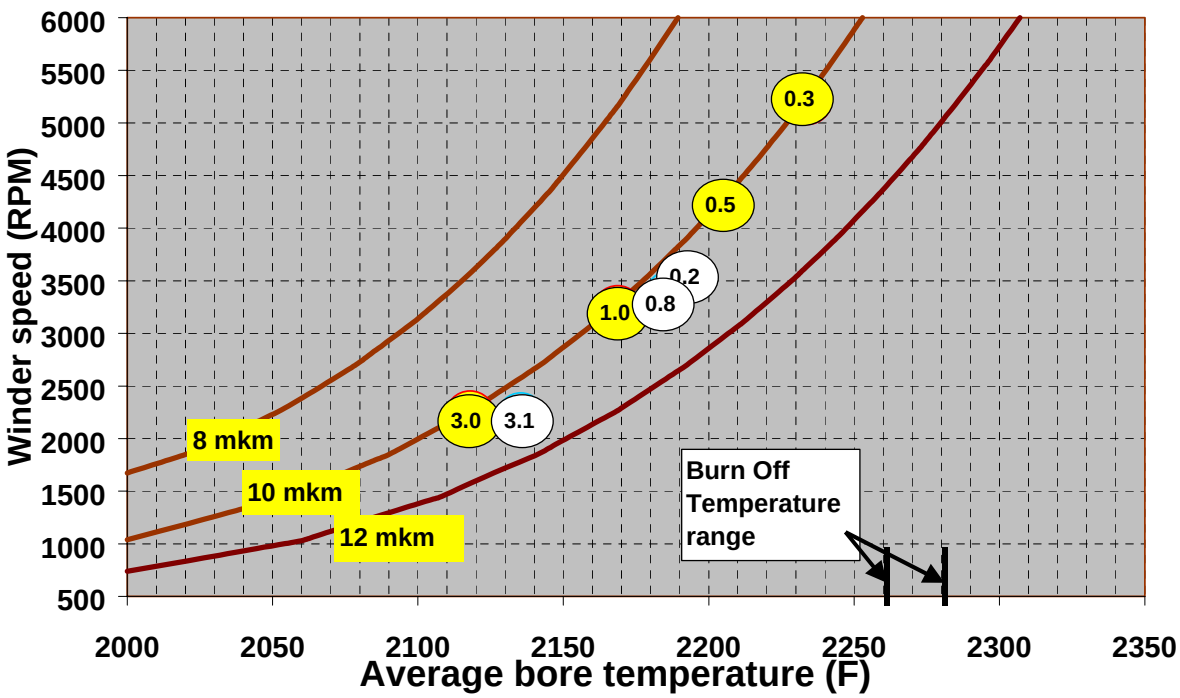


Fig. 2. Filament diameter (lines) and break rate (yellow circles) computations vs tests (white circles) on a CSU Gen II bushing.

Task 4 Optimize Glass Drawing Process

The experimental data are shown in Fig. 2 by white circles. The 3.1 and 0.8 brks/hr data were obtained in January-February of 2004 and used for model calibration. Whereas the theory was pushing the process toward higher temperatures, the "burn off" temperatures limited us to the set point of 2225°F (bore T = 2190 F) and winder speed of 3538 RPM, which resulted in making a 10.25 micron fiber. The "0.2" data point shown was obtained during the week of 7/12-

16/04 in a continuous 52 hr 30 min run, which averaged at a break rate of 0.17 breaks/hr. This exceeds our commitment we made in our proposal to DOE, which was to demonstrate the break rate of 0.25 breaks/hour for a 100 tip bushing vs. a 200 tip bushing we use.

Why did our test show a better performance than predicted by the model? This is because we continued to improve our piloting fiber drawing unit after the model validation was complete. For instance, we found the first three rows of tips exceedingly contributing to breakage because of chilling effect of entrained air. Similarly the finshield manifold chilled back rows of tips. We used fiberfrax gasket to protect the affected tips, and indeed, our pyrometer registered up to 50°F rise in tip temperatures.

Plans for Next Quarter:

The strength of glass, which is the key property as far as break rate is concerned, has been treated as an adjustable parameter in this study. As our process is fully defined and our model validated we can now attempt and answer the question about the numerical value for the strength of glass. We plan to answer this question next.

Publications/Presentations:

- Presentation to DOE Glass Project Review in Oct 2002
- Presentation to DOE Glass Project Review in September 2003
- Presentation to the 2003 Glass Problems Conference, October 28, 2003
- Presentation to DOE Glass Project Review in June 2004
- We were invited to write a chapter titled *Attenuation in Glass Fiber Forming* for the volume “GLASS FIBERS - SCIENCE AND TECHNOLOGY.”
- We were invited to give an invited talk titled "Process Design of Glass Melt Attenuation Combining Physics, Statistics, and Validation’ at the spring meeting of the Am. Ceram. Society in Baltimore, MD, April 2005.
-

Milestone Status Table:

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
1	**Build and Install Drawing Tower**			
1.1	Install tower	1/10/03	3/20/03	
1.2	Complete debug process	05/15/03	4/20/03	
1.3	Install new design of bushing	11/15/03	8/30/2003	
2	**Develop diagnostic instrumentation**			
2.1	Install IR and high speed photo system	03/01/03	9/10/2003	
2.2	Implement dimensional characterization process	09/15/03		Develop simultaneous cone shape and tip temperature across the entire bushing
3	**Develop simulation models**			
3.1	Initiate testing of models	12/20/02	11/30/02	
3.2	Complete transfer function	04/16/03	4/30/03	
4	**Optimize process**			
4.1	Validation	07/30/03	03/15/04	
4.2	Demonstrate improved process	03/15/04		The process has been successfully validated to show 0.17 breaks/hr for a 200-tip bushing vs committed to 0.25 breaks/hr for a 100-tip bushing.
5	**Disseminate technology**			
5.1	Hold first tech transfer training session	10/30/02	10/30/02	
5.2	Start final partner implementation	05/30/04	02/23/04	
6	**Final Report**	01/31/05		

Budget Data (Till December 31, 2004):

			Approved Spending Plan			Actual Spent to Date		
Phase / Budget Period			DOE Amount	Cost Share	Total	DOE Amount	Cost Share	Total
	From	To						
Year 1	July 11, 2002	July 30, 2003	$554,014	$166,070	$720,084	$531,676	$255,952	$787,628
Year 2	August 1, 2003	July 30, 2003	$313,932	$122,525	$430,407	$330,220	$183,833	$514,052
Six month extension	August 1, 2004	December 31, 2004	$106,003	0	$106,003			
Totals			$967,899	$288,595	$1,256,494	$861,896	$439,785	$1,301,680

Development and Validation of a Coupled Combustion Space/Glass Bath Furnace Simulation

Petrick: Argonne National Laboratory (Techneglas)

CPS#01025

QUARTERLY PROGRESS REPORT

Project Title: Glass Furnace Model (GFM) Technology Transfer Program

Covering Period: July 1, 2004 through 30 September 2004

Date of Report: October 28, 2004

Recipient: Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

Award Number: *Follow-on Program to DE-SC02-97CH10875 and DE-SC02-00CH11037*

Other Partners: Techneglas, Libbey, Inc., Osram-Sylvania, Owens Corning, Visteon

Contact(s):

Brian Golchert	Michael Petrick
630-252-6518	630-252-5960
bgolchert@anl.gov	mpetrick@anl.gov

Project Team: *Elliot Levine, OIT DOE–HQ contact; Matea McCray, DOE-ID, Project Mentor*

Project Objective: The objectives of the program are to transfer the ANL-developed Glass Furnace Model (GFM) to the glass industry and to promote its widespread use by providing the requisite technical support to allow effective use of the code. Project objectives will be accomplished through the following actions. A brochure will be prepared that describes the capabilities of the code and the support that will be provided to the user. The brochure will be mailed to a broad spectrum of glass industry representatives. The GFM code will be placed in ANL's Software Shop on the internet and will be readily available for licensing on-line through the laboratory's Office of Technology Transfer. Technical support will be provided to the code users and a GFM code user group (CUG) will be established. Every licensee will automatically become a member of the CUG and will be entitled to receive technical support at no cost throughout the duration of the technology transfer program. The level of support provided is expected to allow the licensee (user) to become proficient in the use of the code. The CUG members will meet periodically to discuss their experience and the results derived from the use of the code. Further improvements in the code that evolve from the technical support activity will be incorporated into the source code. At the conclusion of this program, the CUG members will be expected to define a mechanism that they would implement for provision of any additional support they may need in the long term.

Background: A substantial effort in the previous project was expended to develop the state of the art furnace model (GFM) that can be used to predict furnace performance. This validated model has been used by the industrial participants of the project to perform extensive parametric studies on their furnaces. These studies indicated that computer modeling is a cost effective method for improving furnace performance. In an effort to improve the performance of furnaces throughout the industry, the ensuing technical transfer program has been initiated to promote the usage of the GFM in the glass industry.

Status: Program progress is presented in accordance with the work breakdown structures adopted for the program. A brief summary of progress in tasks pursued during the last reporting period follows. Those tasks in italics are not applicable to the current quarter.

Task 1: GFM brochure prepared and mailed to glass industry companies. (01/04 to 03/04) Completed.

Task 2: Licenses for GFM available on ANL's software shop website (04/04) As of 30 September 2004, eighteen licenses have been issued through ANL technical transfer. A CD with the GFM was mailed to the licensees once ANL technical transfer notified the code developers a license had been signed.

Task 3: GFM users group formed (05/04) Completed

Task 4: Technical support provided to GFM users (05/04 to 11/04)
To date, eleven users have been trained on the use of the code and two more training sessions are scheduled for the fourth quarter. During training, the users are instructed on the use of the code as well as the functions of the users group. Training is focused on helping the new users build functional models of a furnace of their choosing.

Task 5: Periodic meetings of CUG held to discuss code usage and results (05/04 to 01/05) Due to the limited availability of the members of the CUG, an interactive website was designed and built to facilitate communication between ANL and the CUG. Information concerning the codes (updates, FAQ's, user's manual, etc) will become available on the website. A mechanism is also in place on the website to allow asynchronous discussions concerning the long term support of the GFM.

Task 6: Long-term code support mechanism established by CUG membership (02/05)

Plans for Next Quarter:

Technical support of the GFM to licensed users will continue. An interactive webpage for the users group will also become active. Discussions will be held to determine the most viable option for long term support of the GFM.

Patents: The Glass Furnace Model software (GFM 1.0) was copyrighted (May 14, 2001).

The Glass Furnace Model software (GFM 2.0) was copyrighted (ANL-SF-01-030b) (May 17, 2002).

Milestone Status Table:

ID Number	Milestone Description	Planned Completion	Actual Completion	Comments
1	Brochure created and mailed	03/04	03/04	
2	Licensing becomes available via ANL software shop	04/04	04/04	
3	Technical support provided to code users	11/04		Ongoing

Budget Data (as of 9/30/03): The approved spending should not change from quarter to quarter. The actual spending should reflect the money actually spent on the project in the corresponding periods.

			Approved Spending Plan ($K)			Provided to Date	Actual Spent to Date
Year/Budget Period			DOE Amount	Cost Share	Total	DOE Amount	DOE Amount
	From	To					
2004	January	March	70.0	n/a	70.0	250.0	78.2
2004	April	June	60.0	n/a	60.0		77.9
2004	July	Sept	60.0	n/a	60.0		56.0
2004	Oct	Dec	50.0	n/a	50.0		
2005	January	March	10.0	n/a	10.0		
2005	April	June					
		Totals	250.0		250.0	250.0	212.1

*Program started officially 01/01/04

Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulates and Crown Corrosion

Blevins: Sandia National Laboratories (Gallo Glass Co.)

CPS#01608

The PI is currently writing the final report for the project and will not be submitting a quarterly report. The following is the most recent quarterly report submitted:

Quarterly Progress Report

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

Covering Period: April 1, 2004 to June 30, 2004

Date of Report: August 6, 2004

Laboratory: Sandia National Laboratories
7011 East Avenue
Livermore, CA 94550

FWP/OTIS Number: M1ID156-HA, EEW34126, ED1805000

Subcontractors: University of Alabama Birmingham

Other Partners: Gallo Glass Company, 605 South Santa Cruz Avenue, Modesto, CA 95354

Contacts: Christopher Shaddix
Phone: 925-294-3840
E-mail: crshadd@sandia.gov

Project Team: DOE-HQ Contacts: Elliott Levine

Industry Contact: John Neufeld
Gallo Glass Company, Modesto, CA 95354

Project Objectives: The objectives of the project are: (1) reduction of particulate matter emissions, (2) increase in length of furnace campaigns, and (3) improvement of melting efficiency, through simultaneous minimization of batch dust carryover, minimization of alkali volatilization, and optimization of oxygen-to-fuel ratio during glass melting and fining using wide flame oxy-fuel burners. The anticipated improvements in performance are to be achieved by reduction of alkali and particulate at its sources, reduction of unburned combustibles and waste heat losses, maximization of flame radiation through intelligent control of melting furnace conditions, and optimization of batch composition.

Background: Entrainment of batch particles in flue gas and vaporization of the alkali metals, sodium and potassium, from melting batch and molten glass are associated with a number of negative impacts on the glass melting process and melting tank performance. Among the negative effects are: (1) corrosion of superstructure and crown refractories, (2) plugging of regenerator checkers, (3) fouling and corrosion of flue ducts, (4) particulate matter emissions, and (5) loss of raw materials. The relative importance of these effects depends upon the type of glass being melted, the design and materials of construction of the furnace, and local emissions regulations. The causes of batch particle entrainment and alkali volatilization are, for the most part, well understood. However, alteration of batch composition and furnace conditions to minimize entrainment and volatilization may have negative impact on other aspects of furnace operation and glass quality. For example, volatilization could be reduced by distributing heat input so as to make the peak glass surface temperature lower and the distribution of surface temperatures more uniform, but this would suppress glass circulation in the melt and result in

poorer glass quality at a given pull rate. As another example, batch dusting could be reduced by minimizing heat input and gas velocity over the batch blanket, but the shift of fuel heat input away from the batch blanket toward the fining zone might increase batch coverage, result in poorer overall transfer of heat to the load, and would likely increase the glass surface temperature in the fining zone, leading to increased alkali volatilization and seeds in the product. Intelligent optimization of these conflicting requirements is the subject of the project. The great variability of the rates of refractory corrosion, particulate emissions, and heat requirements from furnace to furnace and the excellent performance of some furnaces suggest that an optimum set of furnace conditions exists and that significant reductions in emission and corrosion rates and improvements in the efficiencies of poorly performing furnaces are possible.

The method being used to measure carryover and volatilization is laser-induced breakdown spectroscopy (LIBS), a continuous monitoring technique for metals demonstrated in previous trials at Gallo Glass. By observing the correlation of metals concentrations with operating conditions over long periods, the batch properties and furnace conditions associated with batch carryover and alkali volatilization will be identified. Because the oxygen-to-fuel ratio is expected to be among the critical process variables, the work also includes simultaneous measurements of furnace efficiency, so that this measure of performance can be incorporated in the furnace optimization scheme.

The work has been greatly facilitated by the sooner-than-expected arrival on the market of echelle grating spectrometers, capable of recording signals from all of the elements in the LIBS spark simultaneously, permitting the identification of individual particle types and their sources or mechanisms of formation. The echelle grating instrument, originally planned for application to the problem in March 2003, was incorporated in the LIBS system during the first 5 months of the project and has been used in two sets of field trials at Gallo Glass. Though the echelle spectrometer has provided very useful data, it has not performed as well as expected. In the first round of measurements, in December 2001, the spectrometer was found not to have sufficient sensitivity for determination of element concentrations in individual laser sparks. This would preclude the determination of joint particle size-composition distributions. However, the apparent size distributions of individual elements can still be determined using the original Czerny-Turner spectrometer, so relatively infrequent large particles carried over from batch can be distinguished from the more uniform concentration of submicrometer particles formed from volatile species. During the most recent field test, in June 2002, both the echelle and conventional grating spectrometers were run side-by-side, for direct comparison of their performance.

Status: Extended measurement campaigns were conducted in May 2003, June 2002, and December 2001. Analysis of the data from these three test campaigns has been completed, pending resolution of LIBS measurement calibration issues in the glass furnace environment. This quarter, activity focused on preparations for and execution of a final field test at Gallo, from June 3-12, 2004.

During this latest test campaign, a limited set of LIBS measurements was performed at the base of the vertical flue downstream from the furnace exit on Tank #1. This location had demonstrated an unexpected decrease in the apparent Na concentration (from LIBS) in the May 2003 test campaign when the flue gas became fuel-rich. Subsequent analysis and laboratory measurements showed that this artifact resulted from absorption of the LIBS Na emission by sodium atoms in the high-temperature, fuel-rich gas stream. Consequently, most of the LIBS data in the current test campaign was collected at a downstream sample location in the exhaust duct, subsequent to spray cooling of the flue gas. A bifurcated fiber bundle allowed

simultaneous LIBS signal detection on an echelle cross-dispersion spectrometer system and a traditional Czerny-Turner spectrometer. The echelle data was used to characterize the average particle chemistry, focusing on sodium, potassium, and calcium content, whereas the Czerny-Turner spectrometer primarily focused on measurements of batch carryover particles, monitoring magnesium and silicon lines. For a limited period during the test, the Czerny-Turner spectrometer system measured sodium concentrations, to double-check the sodium measurement provided by the echelle spectrometer system.

In addition to the LIBS measurements, a portable gas analyzer was used to measure the concentrations of O_2, CO, NO, and SO_2 in the flue gas. Also, a micro-gas chromatograph (GC) with a thermal conductivity detector (TCD) was used to measure the concentrations of O_2, CO_2, and N_2 in the flue gas. Chemical analysis of the condensate collected in the water trap in the gas analyzer sampling line was used to provide a time-averaged measurement of sodium and potassium in the sampled flow. These gas composition measurements were primarily performed at the vertical flue sampling location, with occasional measurements performed in the downstream exhaust duct. The gas temperatures at both the vertical flue and the downstream exhaust duct were continuously measured and recorded.

The temperature of the cooling wind and the cooling wind velocity were measured during the test campaign in order to assess the variation in the effectiveness of the cooling wind and any impacts on furnace in-leakage that may be attributed to the cooling wind fans. Temperature was also measured in the doghouse to evaluate the influence of furnace pressure on in-leakage through the doghouse (influencing batch carryover). Pitot tube measurements of flow velocity at the doghouse were attempted but were only partly successful, because of the low flow velocities at that location.

During the test campaign, the pull rate varied from 270 to 338 tons/day and the oxygen to gas ratio (as recorded by the plant control system) varied from 2.00 to 2.13. Strong day-to-night ambient temperature variations, typical for this location during the summer, were present during the test period and resulted in variations in in-leakage of air into the furnace/flue, as seen during previous tests.

Preliminary results from the June 2004 test campaign were presented at the DOE Materials, Glass and Sensors Portfolio and Project Review, held in Alexandria, Virginia, on June 21-23. Based on the gas analysis provided by the GC measurements, total in-leakage at the sampling location at the bottom of the vertical flue amounted to ~ 25% of the furnace exhaust, with in-leakage at the doghouse amounting to an estimated 2-3% of the furnace exhaust. In general, the in-leakage tracked variations in the ambient temperature, with maximum in-leakage occurring when the ambient was coolest. The LIBS measurement of sodium was demonstrated to be insensitive to rich conditions in the flue gas when the measurements were performed at the exhaust duct sampling location, with moderate gas temperature (~ 700 K). This result confirmed the laboratory flow reactor experiments and equilibrium gas composition analysis that had been performed previous to the test campaign. The sodium content in the furnace exhaust was found to decrease with increasing excess oxygen, as measured at the sampling locations, and to increase with increasing ambient air temperature. These trends suggest that the measured sodium is sensitive to the dilution effect of air in-leakage into the furnace/flue. An increase in sodium concentration was apparent with increasing furnace temperature, which varied over the range of 2470-2570 °F (South Wall Temperature).

Measurements of batch particles with LIBS demonstrated that the batch particle loading increased by ~ 2-fold when the furnace pressure was controlled manually for a few hours and

fell to lower pressures than the typical setpoint (0.045-0.060 in. H_2O, compared to 0.066 in. H_2O). Also, it was determined that the sensitivity of LIBS to measuring batch carryover could be increased 10x by optimizing the temporal gating parameters used to measure the LIBS plasma emission.

Measurements of the cooling wind velocity showed that it was nominally constant with time. Consequently, the mass flow rate of the cooling wind varies inversely with the ambient temperature.

An analysis of the energy budget for Tank #1 during the test campaign shows larger energy use (~ 5 MJ/kg glass) in comparison to the test campaign in 2003 (~ 4 MJ/kg glass). The main culprit appears to be substantially lower cullet content this year, which increases the energy consumed in batch reactions and lost through heating of batch gases.

At the end of this quarter, Christopher Shaddix of Sandia took over as PI on this project, replacing Linda G. Blevins, who began a temporary assignment to the National Science Foundation in July, 2004. Peter Walsh of the University of Alabama Birmingham is a consultant on this project. Shane Sickafoose, Doug Scott, and Alejandro Molina of Sandia are the current project participants.

Plans for Next Quarter: Data reduction for the June 2004 field test will be completed during the next quarter. Laboratory research will focus on resolving calibration issues associated with using LIBS at elevated temperatures, with high Na loading, and in a gas mixture dominated by water vapor and CO_2. Towards the end of the quarter, the project work will conclude with the writing of a final project report.

Patents: none

Publications/Presentations:

Blevins, L.G., Molina, A., Sickafoose, S.M., Scott, D.D., Walsh, P.M., and Neufeld, J., “Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulate Emissions and Crown Refractory Corrosion in Glass Melting Furnaces,” DOE Materials, Glass and Sensors Portfolio and Project Review, Alexandria VA, June 2004.

Blevins, L.G., Molina, A., Scott, D.D., Sickafoose, S.M., Neufeld, J.W., Walsh, P.M., “Effect of Variations in Oxygen to Gas Ratio on Flue Gas Composition, Process Temperature and Alkali Metal Concentration in an Oxygen/Natural Gas Glass Melting Furnace,” Fall Technical Meeting, Western States Section of The Combustion Institute, Los Angeles, California, October 2003.

Blevins, L.G., Molina, A., Sickafoose, S.M., Scott, D.D., Walsh, P.M., and Neufeld, J., “Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulate Emissions and Crown Refractory Corrosion in Glass Melting Furnaces,” DOE Glass Industry Project Review, Golden, CO, September 2003.

Blevins, L.G., Shaddix, C.R., Sickafoose, S.M., and Walsh, P.M., “Laser-Induced Breakdown Spectroscopy in High-Temperature Industrial Boilers and Furnaces,” *Applied Optics*, V. 42, pp. 6107-6118, 2003. (Results featured on the cover of the journal.)

Walsh, P.M., Blevins, L.G., Sickafoose, S.M., Johnsen, H.A., Molina, A., Ottesen, D.K., Scott, D.D., Steinhaus, R.J., Christy, R.H., and Neufeld, J.W., "Laser-Induced Breakdown Spectrometry: Application to Measurement of Inorganic Particulate Emissions from Combustion in Engines and Furnaces," Third Mediterranean Combustion Symposium, Marrakech, Morocco, June 8-13, 2003.

Walsh, P., Allendorf, M. Nilson, R., Griffiths, S., Blevins, L., Sickafoose, S., Johnsen, H., Molina, A., Scott, D., Moore, D., Neufeld, J., Lemings, L., Brown, J., Wu, K.T., "Sodium Volatilization and Silica Refractory Corrosion in an Oxygen/Natural-Gas-Fired Container Glass Furnace," Hotbels Seminar, Lexington, KY, April 2003.

Blevins, L.G., Molina, A., Sickafoose, S.M., Walsh, P.M., and Neufeld, J.W., "Alkali Metal Concentrations in an Oxy-Fuel Glass Furnace Exhaust," presented at the 3rd Joint US Meeting of the Combustion Institute, Chicago, Illinois, March 2003.

Walsh, P.M., Sickafoose, S.M., Scott, D.D., Steinhaus, R., Johnsen, H.A., and Neufeld, J., "Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulate Emissions and Crown Refractory Corrosion in Glass Melting Furnaces" DOE Glass Industry Project Review, Livermore, CA, September 10, 2002.

Milestone Status Table:

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
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	9/30/02	
8	Conditions influencing sodium	4/30/02	9/30/02	
9	Maximum furnace efficiency	5/31/02	1/30/04	
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	01/15/03	
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	02/01/03	
17	Optimum stoichiometry	9/30/03	09/30/03	
18	Sodium and calcium monitor	1/31/04		
19	Control strategy	3/31/04		
20	Demo in melting research facility	4/30/04	cancelled	Melting research facility not constructed

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
21	Method for monitoring and control of volatilization and carryover	5/31/04		

*It has not been possible to collect data from the control room in real time; printouts of the data acquisition system records of furnace conditions are used instead. The furnace radiation, exit gas temperature, and flue gas composition data are, however, synchronized with LIBS.

Budget Data:

			Approved Spending Plan ($000)			Actual Spent to Date ($000)		
Phase / Budget Period			DOE Amount	Cost Share	Total	DOE Amount	Cost Share	Total
	From	To						
Year 1	6/01	5/02	350	350	700	350	350*	700
Year 2	6/02	5/03	350	350	700	350	350*	700
Year 3	6/03	5/04	350	350	700	250	250*	500
Totals			1,050	1,050	2,100	950	950*	1,900

*Sandia National Laboratories' estimate.

Index of HQ CPS and Award CID Numbers

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GO13092..... 2
GO13093..... 3
ID14030 4
ID14315 5
ID14347 6