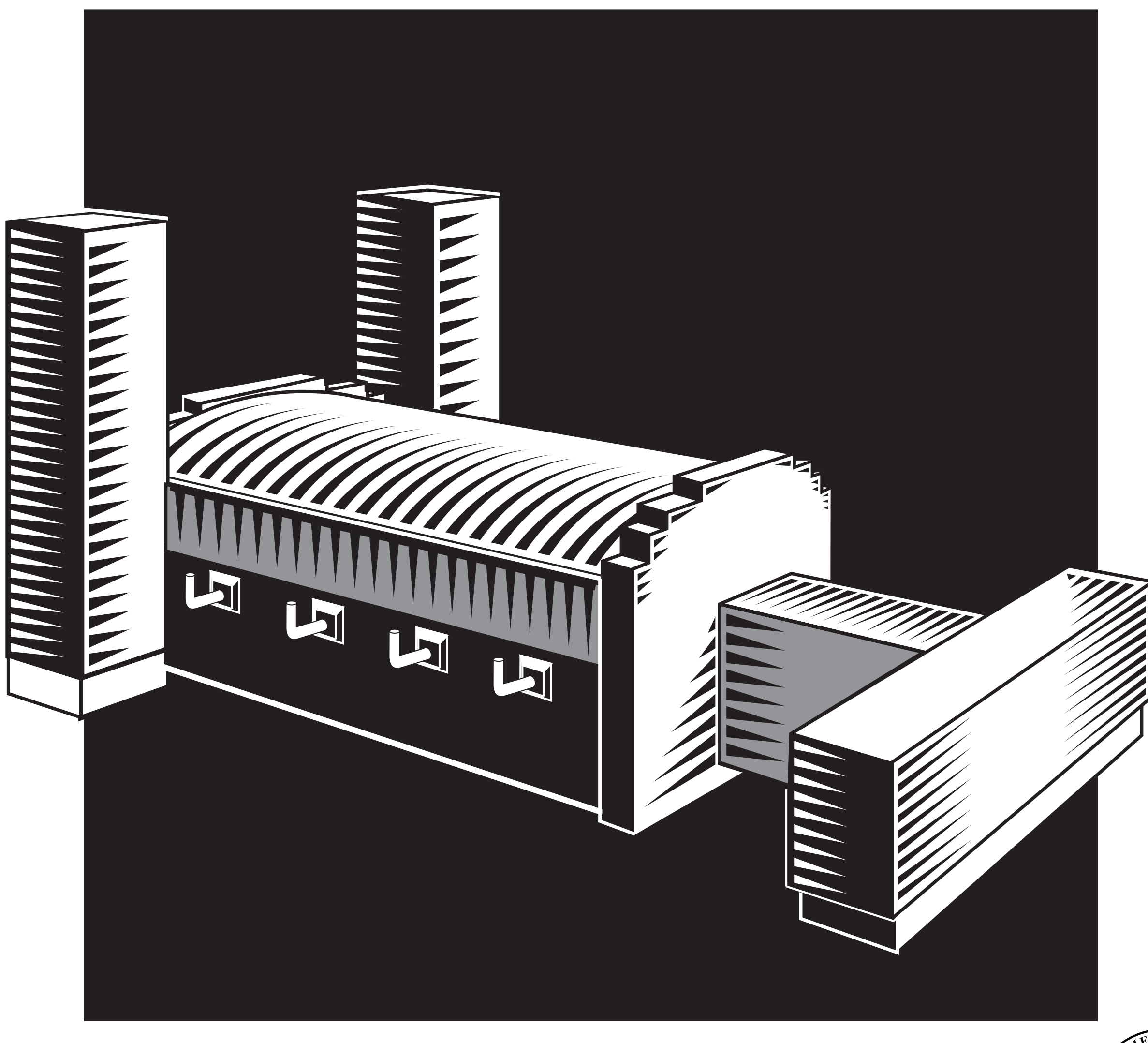
Glass
Industry of the Future

Quarterly Status Reports

As of September 30, 2006



U.S. DEPARTMENT OF ENERGY

02-GA50113-03

Glass

Industry of the Future

Quarterly Status Reports

As of September 30, 2006

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Glass Projects

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

Lottes: Argonne National Laboratory (w/ Techneglas)

Agr id:04895

QUARTERLY PROGRESS REPORT

Project Title:	Glass Furnace Model (GFM) Technology Transfer Program
Covering Period:	1 July 2006 through 30 September 2006
Date of Report:	30 October 2006
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):	Steven Lottes 630-252-7014 slottes@anl.gov Michael Petrick 630-252-5960 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 a 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 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 31 December 2004, nineteen 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 6/06)

Technical support and ongoing development responsibilities for GFM were taken over by S.A. Lottes in March 2005. In the transition all pieces of the GFM package were reviewed, and areas where significant improvements could be made to increase marketability were identified. Major “ease of use” improvements and a new automatic cycling capability were reported in the April through June 2005 quarter. In the July through September 2005 period, new problems in robustness and numerical stability in both the melt space and combustion space components were identified and automated program state data collection and plotting was implemented to speed up isolation and resolution of problems. In the October through December 2005 period the new GFM monitoring capabilities were used to identify and initiate resolution of performance issues with the radiation heat transfer scheme in the combustion code, revamp the high level combustion space algorithm to speed up the computation, isolate and resolve a variety of minor combustion space problems, such as loss of solution precision on restart. The monitoring tools were also employed to identify a number of weaknesses in the melt code. Removal of a constraint requiring a positive heat flux into the melt over the entire melt surface yielded a pattern of oscillatory instability in cycling boundary conditions between melt and combustion space computations. A set of tasks was formulated to resolve or substantially improve GFM performance with respect to these issues.

In the January to March 2006 quarter, a major effort was completed to resolve the most significant technical issues that were preventing convergence of the new automatic coupled cycling mode between the combustion and melt spaces. This effort involved all of the GFM components, but focused on improving numerical convergence in the melt and developing a cycling control and relaxation algorithm that would damp large oscillations in the melt and combustion space coupling conditions and lead to successful convergence of a coupled, cycling furnace simulation.

In the April to June 2006 quarter, new GFM documentation was written and a number of additional refinements and improvements were implemented to resolve issues that arose in testing GFM upgrades completed in the previous quarter.

DOE funding for GFM development and support was exhausted in June 2006.

In the July to September 2006 quarter, minor improvements and all upgrades since March 2005 were consolidated into a new GFM version (4.0), ANL-SF-01-030c, and documentation for the new version was completed and linked into the GFM user interface program menu system.

GFM 4.0 is a major new version of GFM. It includes a large number of new software modules and capabilities. The size of the GFM package in terms of lines of code has nearly doubled. The new version has been tested on the International Congress on Glass (ICG) TC-21 committee round robin test 4a (RRT4a).

Plans to complete the GFM development effort have been formulated and are being carried out. The plans include the following:

- Copyright for GFM 4.0 will be asserted as part of the GFM series.
- A six month trial license and installation package for GFM 4.0 will be sent to all previous trial license holders.
- A trial license will be provided to the Glass Manufacturing Industry Council (GMIC) with notification that trial licenses for GFM 4.0 are available to all GMIC members.
- A developer to continue work on GFM will be sought. The best candidates appear to be universities where student projects and thesis work could yield improvements in algorithms and new models that could be added to Argonne's version.
- GFM 4.0 will be offered for licensing on Argonne's software shop web site; a lower license fee is under consideration.
- Argonne will provide technical support as needed on a cost recovery basis.

Task 5: Periodic meetings of CUG held to discuss code usage and results (05/04 to 01/05) In view of the change in personnel and the extensive improvements being made to the GFM code, the initial meeting of the CUG (Core User Group) has been delayed. The meeting date will be set during the next quarter.

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

Plans for Next Quarter:

Plans enumerated above for the new GFM version 4.0 will be completed..

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 and upgrades provided to code users	11/04		Ongoing

Budget Data: (as of 6/30/06): 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	45.0	42.4
2005	January	March	10.0	n/a	10.0	110.0	8.9
2005	April	June					2.2
2005	July	Sept.					45.4
2005	Oct.	Dec.					55.0
2006	Jan.	March				75.0	73.1
2006	April	June					38.0
		Totals	250.0		250.0	480.0	477.1

*Program started officially 01/01/04.

Energy Efficient Glass Melting: The Next Generation Melter

Rue: Gas Technology Institute

GO13092

QUARTERLY PROGRESS REPORT

Project Title	Energy-Efficient Glass Melting - The Next Generation Melter
Covering Period	July 1, 2006 through September 30, 2006
Date of Report	November 10, 2006
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 Corning, Incorporated Johns Manville Owens Corning PPG Industries, Inc. Schott Glass Technologies, Inc.

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Project Objective

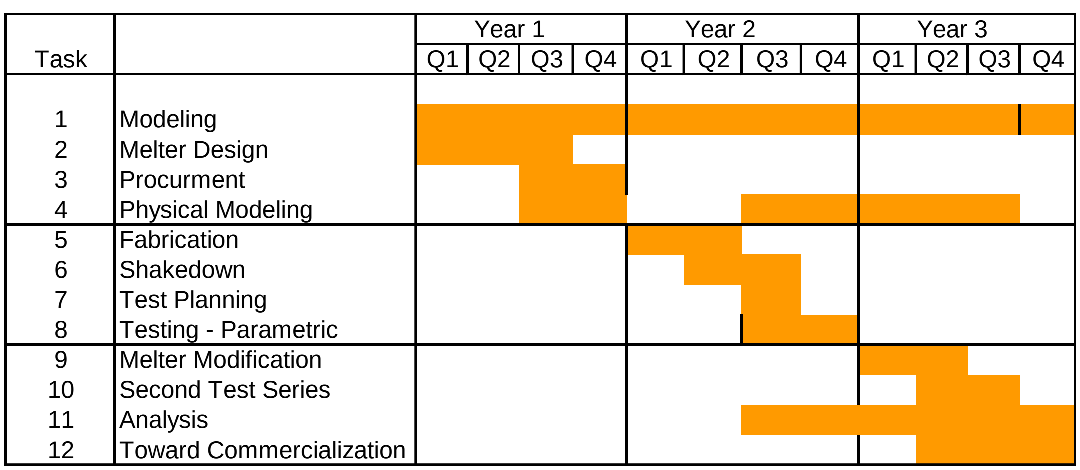
The objective of this project is to demonstrate a high intensity glass melter, based on the submerged combustion melting technology. This melter will serve as the melting and homogenization section of a segmented, lower-capital cost, energy-efficient Next Generation Glass Melting System (NGMS). After 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 budget.
- 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

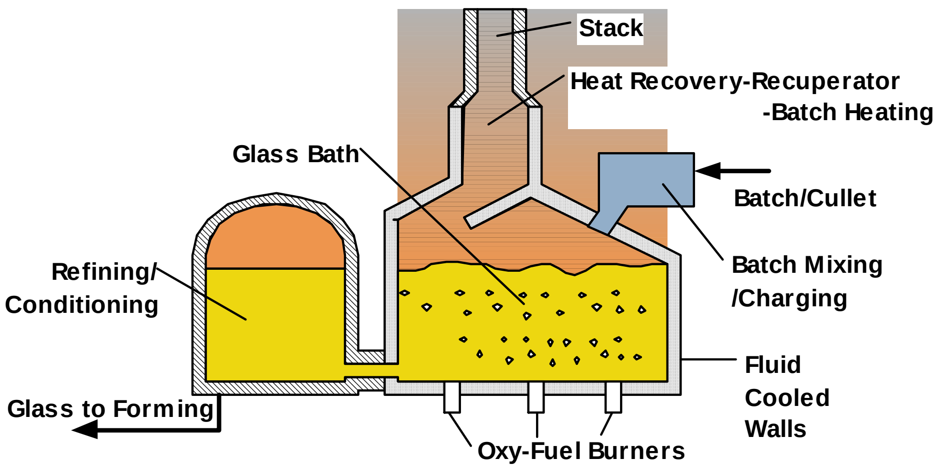
Operability	Scalable from 25 to 700 ton/day, reliable, stable operation, easy to idle, ability to start and stop, ease of access and repair, fast change with glass formulation and color, no moving parts to be abraded by the glass
Environmental	Low air, water, and solid waste, recycle-friendly

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 carried out this quarter was focused on CFD modeling and pilot SCM unit fabrication. This quarter was the third quarter in Year 3 of this three year project. There is a 6-month time extension, leaving three more project quarters. Areas of most attention this quarter included

- Final review of pilot melter design including instrumentation,
- Ordering final components for the pilot-scale melter, finish of melter panel fabrication, preparation for melter panel refractory work, and initial test cell wiring and piping preparations.
- Mathematical and computer CFD modeling including hydrodynamics and heat balances with a focus on means to reduce wall heat losses,
- Revision of the work scope for the Praxair OTM work on the project,
- Attendance at Glass Problems Conference to present project status,
- Plans for November consortium meeting with glass companies to plan first tests in the pilot melter.

The glass company consortium agreement has served well as a basis for all parties including GTI, Corning Incorporated, Johns Manville, Owens Corning, PPG Industries Inc., and Schott North America, working well together. With GTI taking the lead in testing and modeling and a smaller role in analysis of samples, the other consortium members have focused on:

- Corning - LCD batch provider, fabrication of platinum tap piece (twice), analysis of LCD glass,
- Johns Manville - E glass and fiberglass scrap provider, sample analysis,
- Owens Corning - Advantex glass provider, provider of transformer and power pack for tap piece, sample analysis, CFD modeling,
- PPG - CFD modeling support for the melter and for new tap piece designs,
- Schott North America - Tap piece design, tap piece shake-down testing, sample analysis,

Along with consortium member direct support, all members have attended meetings, reviewed analyses, discussed pilot SCM design, and provided financial support.

The Praxair Oxygen Transport Membrane (OTM) work has been delayed because Praxair analyses showed that OTM would not be a good fit for SCM. Further review has shown that the initial intended OTM application may not be attractive, but other applications may provide energy and cost benefits. A re-scaled OTM effort, with NYSERDA support was evaluated last quarter and initiated this quarter.

Mathematical modeling

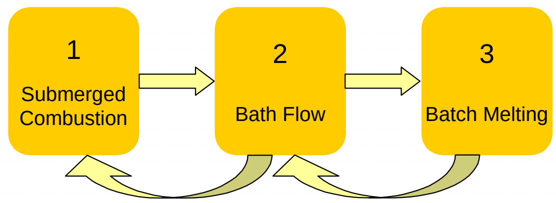
Mathematical modeling this quarter included continuation of CFD work by Fluent and continued hydrodynamic calculations of melt flow patterns, but mainly heat loss calculations.

Fluent modeling was begun with development of CFD code to describe the mixing and flow patterns in the oxy-gas fired SCM unit. Originally, work was to focus initially on the air-fired mineral wool melters, but this route was determined to not provide a reasonable baseline for future CFD modeling of the oxy-fired glass melting undertaken in this project. During this quarter, CFD modeling was underway, and the following work was completed. An important note is that Fluent is focusing on improvements to the CFD code to provide a better tool for SCM modeling. The project team, including engineers at GTI, Owens Corning, and PPG, is carrying out the modeling of specific SCM cases.

Fluent Modeling Developments

Concept Simulation

Research on the FLUENT model of the GTI pilot melter continued this quarter. With reference to the three-step analysis strategy presented in Figure 1, the Step 1 methods are already established, further Step 2 runs were completed, and the initial research on Step 3 methodology was conducted.



- A pragmatic approach to balance cost and fidelity
- Reduce compute expense by decoupling time scales
- Allows manual iteration among stages as needed

Figure 1. Top-level CFD analysis strategy (previous)

Miscellaneous modeling items suggested by the CFD Committee at the June 21 meeting were investigated. These included a correction to the Step 1 glass conductivity: since radiation is now being modeled explicitly with the P-1 model, the preliminary Step 1 simulation was re-run with the glass thermal conductivity reduced from 12.5 to 1.5 W/m-K, effectively removing the Rosseland equivalent-conduction radiation contribution.

The Step 2 source terms are based on time-averaging 30 seconds of Step 1 simulation results for a single axisymmetric burner. It should be noted that these runs continue to be based on a preliminary Step 1 inflow boundary condition at the outer circumference of the burner region, which is artificially held at a temperature of 1300 K, pending future adjustment based on baseline Step 2/3 results.

In this conversion process, the equivalent momentum source in the burner region was enhanced by adding a radial component to the previous vertical component. The intent is to generate a more realistic radially-inward acceleration of the liquid glass, particularly near the melter floor, as the melt is entrained by the large rising combustion bubbles.

Preliminary Step 3 simulations were performed with the glass batch represented wholly by a single chemical species field within the liquid melt. (In this approach, described in our 3Q05 quarterly report, the "species" mass fraction at any point is equated with the degree of conversion of unmelted batch.) E-glass particle size distribution data provided by Johns

Manville were incorporated. The effective average heat of fusion was assumed to be 565 kJ/kg. Interphase density differences were neglected. Several findings emerged from this initial exploration, as follows:

- The relatively small particle size (Figure 2) allows the entire batch to be represented accurately in FLUENT with the species approach, rather than the Discrete Phase Model (DPM) approach, because the trajectories of such small particles will generally not deviate from the liquid pathlines.
- The thermal effect of the melting “reaction”, including heats of fusion of individual batch constituents, has a first-order effect on the Step 2 velocity and temperature fields (Figure 3).
- For the two preceding reasons, the batch melting physics can and should be incorporated into Step 2 on a steady-state-operation basis.
- The Step 3 transient particle tracking that is needed to assess melter residence time and output glass quality can be done using a fixed flow field from the enhanced Step 2 analysis.

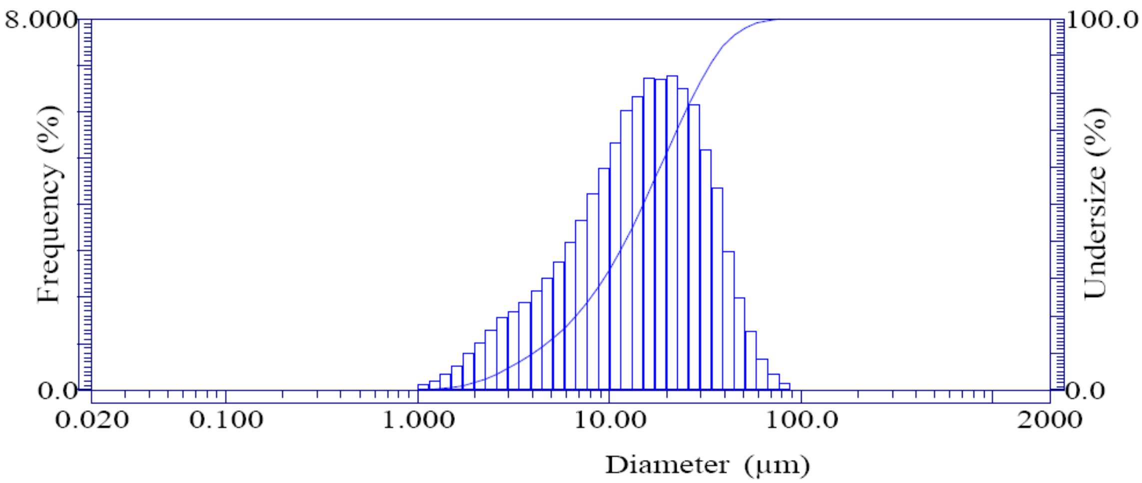


Figure 2. E-glass silica batch particle size distribution [1]

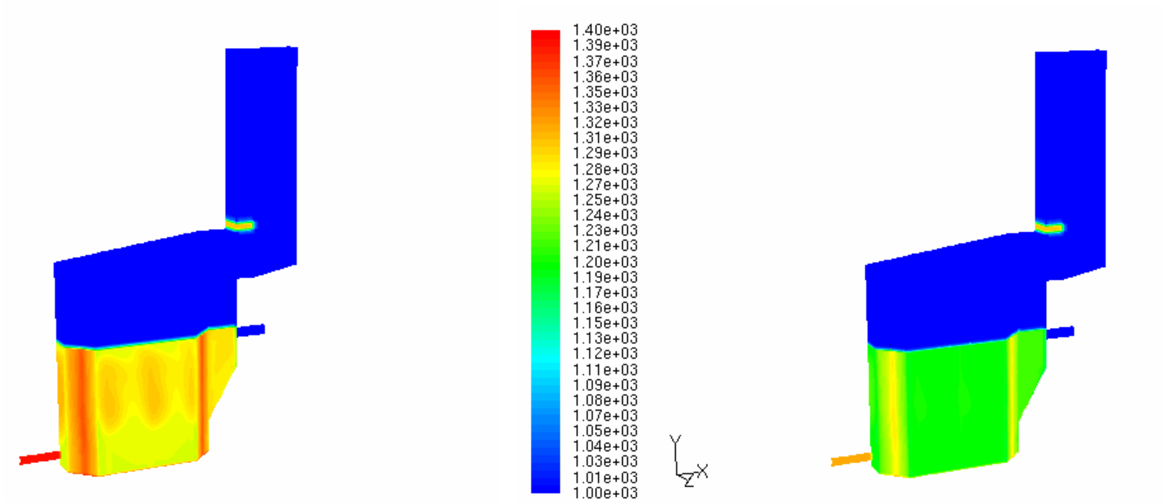


Figure 3. Predicted fluid temperatures at melter inner walls (K)
(L – without batch melting; R – including melting effects)

Even with the improved realism from the endothermic melting "reaction", the predicted wall temperature range of 1200-1300 K adjacent to the melt may not yet be realistic, given that the model is intended to explicitly represent the so-called frozen layer of slow-moving molten glass at the refractory wall. The results do not yet exhibit the expected velocity and thermal boundary layers at the walls. This issue remains under investigation.

Figure 4 shows schematically how this latest research has evolved the analysis strategy, building all the essential physics into Steps 1 and 2, with a simplified and non-iterative Step 3 used only for residence time distribution (RTD) and product homogenization estimates. In practice, this transient integration can actually be invoked in the same FLUENT run as Step 2 – although within FLUENT it will be accomplished as a separate, sequential operation after steady-state convergence. There is no need for an artificial mass split between the species and DPM representation of the batch, as had been previously anticipated. However, further research is needed to select between the two Step 3 alternatives presented in Table 1, based on the factors listed.

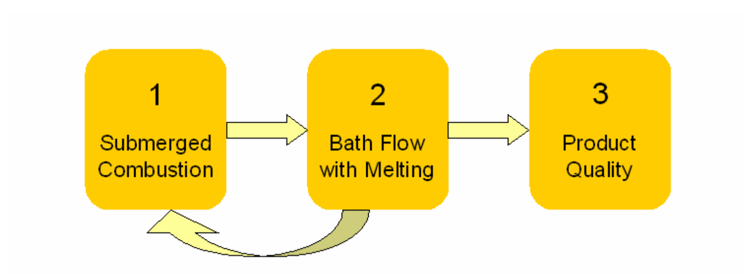


Figure 4. Top-level CFD analysis strategy (revised)

Table 1. Alternative Methods for Product Quality Analysis (Step 3)

Option	Description	Advantages
A) Species approach	Introduce a second, inert (tracer) species at batch feed region. Integrate to predict residence time distribution curve. Deduce stones content in product outflow from melting progress variable of Step 2.	• Smoother (continuous) RTD • Much simpler set-up • Lower computational cost
B) DPM approach	Introduce a distribution of discrete particles at batch feed region. Integrate to predict residence time distribution curve. Include particle melting model to assess risk of stones in outflow.	• Clearer prediction of batch particle-size effects • Able to account for particle density and inertial effects if significant • More options for modeling particle-turbulence interaction if significant • Readily extended to handle entrained bubbles

Simulation Tool Research and Development

As FLUENT 6.3 approached commercial readiness, CFD software R&D this quarter transitioned into final Quality Assurance (QA) testing of the project-related features already developed. This activity was leveraged, but not charged to the project, since the QA team is separate and not using the melter model directly.

Project Management

The analysis efforts proceeded slowly this quarter as the team focused on completion of the pilot melter and preparations for the first tests. There were no formal meetings of the overall project team or CFD Committee. A key committee member, Guosheng Kang, resigned from PPG during the quarter.

The cumulative ANSYS (formerly Fluent) efforts on this project as of the end of the quarter are summarized in Table 2 in terms of labor hours. The average ANSYS level of effort this quarter was about 14% full-time equivalent (FTE), primarily provided by Raj Venuturumilli. An Excel spreadsheet file is being submitted to GTI along with this report that provides additional information, prior period data, and graphical charts. Based on the extended period of performance through January 2007, the ANSYS sub-project was 88% complete by schedule at the end of this reporting period. Cumulative costs were reasonably proportional to that status, at 86% of budget.

Table 2. ANSYS task status as of 9/30/06

SOW	Task Description	Staff	Budget hours	Actual hours
A.1a	Develop an initial model of the SCM and evaluate performance based on information provided by GTI	AT, RV	150	272
A.1b	Study design alternatives based on direction from team		50	0
A.2	Refine and re-run model as more mature design information becomes available	RLC, RV	50	108
A.3a	Support FLUENT use by team members	AT, RV	100	140
A.3b	Administrative support: contracting, provide FLUENT licenses, etc.	ERF	0	7
A.3c	Conduct two-day SCM-focused training workshop at mutually agreed venue	AT	50	33
A.4a	Using enhanced tool from Task B, conduct final CFD analysis of melter, validate with operating data from GTI.		200	0
A.4b	Investigate scale-up to production scale, optimization of design details		100	0
B.1	Identify and prioritize CFD technology gaps and FLUENT enhancements	AD, RLC	80	70
B.2a	Investigate cost/accuracy trade-off; extend and calibrate Eulerian method to represent SCM conditions	HL	100	236
B.2b	Prepare SRS with cost estimates, review with team, finalize and integrate with FLUENT development cycle	AD, ERF, RLC	50	56
B.3a	Implement new SCM features in FLUENT prototype (development version)	AKV	1990	2683
B.3b	Verification testing and draft documentation	RV	300	12
B.3c	Port to team members' platforms and distribute prototype		50	0
B.3d	Obtain suggestions and defect reports from team usage, process validation results from A.4, and incorporate improvements in software		100	0
C.1	Participate in team telecons and 2 one-day team meetings per year	AD, RLC, JAK, RV	100	251
C.2	Quarterly technical reports, final report, and technical paper contributions	ERF, AD, RLC	200	131
	TOTALS		**3670**	**3999**

Issues and Resolution

Table 3 summarizes the remaining important issues and our plans to resolve them. While a few prior issues were resolved this quarter, an unexpected and puzzling Stage 2 result persisted that is increasing the urgency for conducting a careful overall "audit" of the model inputs to help ensure realistic material properties and other assumptions. The main new issue (#3 in the table below) arose due to the additional delays in melter construction. With the first pilot melt now targeted for mid-November, the originally-envisioned post-test analysis activities, including the essential step of model validation, are becoming increasingly compressed. While the proposed resolution is confined to the project period, in practice these activities may be possible for GTI or others to accomplish after the formal end of the project if desired.

Table 3. Summary of outstanding CFD issues and resolution plans

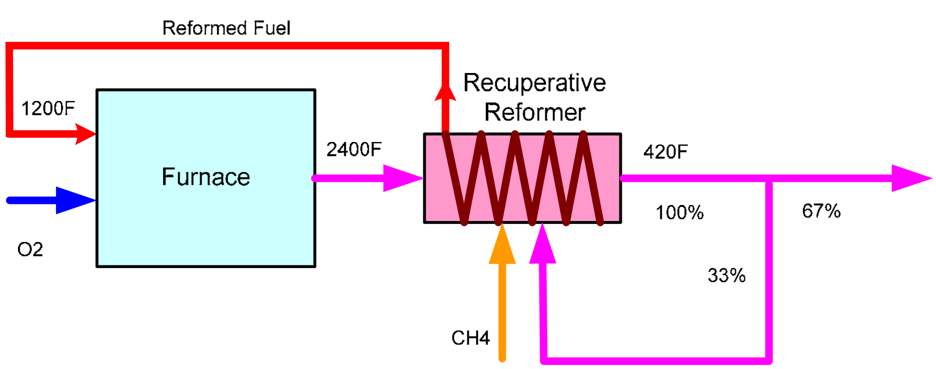
Issue	Proposed resolution
1. Step 2 results do not show expected momentum and thermal and boundary layer	Perform an audit of boundary conditions and material properties; make adjustments as required.
2. Temperature at combustion bubble surface may be high enough to induce some glass vaporization and/or new reactions.	Conduct further research to assess the likelihood, and if it occurs, how to approximate in the model.
3. Some planned CFD activities are contingent on having pilot test results and are getting squeezed by the associated schedule slippage.	Omit the analysis of different glass types, scale-up sizes, design optimization, energy efficiency verification, etc., that were originally planned.

Mathematical Modeling for the Pilot-Scale SCM

Efforts on CFD modeling this quarter continued to focus on mathematical modeling and optimization of heat loss and heat balances of submerged combustion melters. The estimates of maximum expected thermal efficiency of glass melters, the related minimum expected heat loss, and the optimum firing rate distributions have been analyzed. This was studied for the pilot-scale SCM unit and for larger proposed melters. Results of calculations will be presented at the Glass Problems Conference.

Calculations were made of using thermo-chemical recuperation (TCR) as a means to recover exhaust gas heat for return to the melter. In TCR natural gas is partially reformed to hydrogen and carbon monoxide in an endothermic reaction and preheated, all before being returned to the melter. The TCR process is currently under testing and development at GTI. The calculations were carried out to show the potential for improved SCM thermal efficiency. The project team recognizes that TCR is only one of a number of possible methods for recovering waste heat to improve the thermal efficiency of the SCM technology.

Submerged Combustion Pilot Melter with TCR Reforming
Nominal parameters: pull rate – 1 tonn/hr, firing rate 9 MMBtu/hr, dimensions – 4.5 ft x 3 ft x 5 ft.
(The thermal efficiency is 39%, reduced fuel and oxygen consumption is 16%)

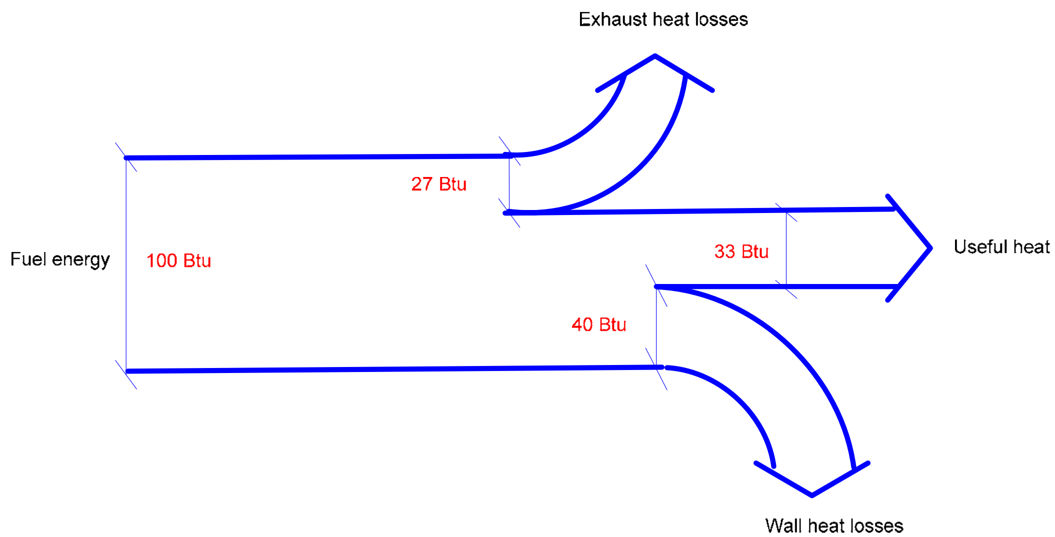


PARAMETERS OF REFORMER

Energy capacity, MMBtu/hr	Furnace exhaust temperature, F	Reformer exhaust temperature, F	Reformed fuel temperature, F	Heat transfer area, ft^2	Dimensions (4-passes heat exchanger)		
					Width, ft	Height, ft	Length, ft
1.4	2400	420	1200	346	2	2	7

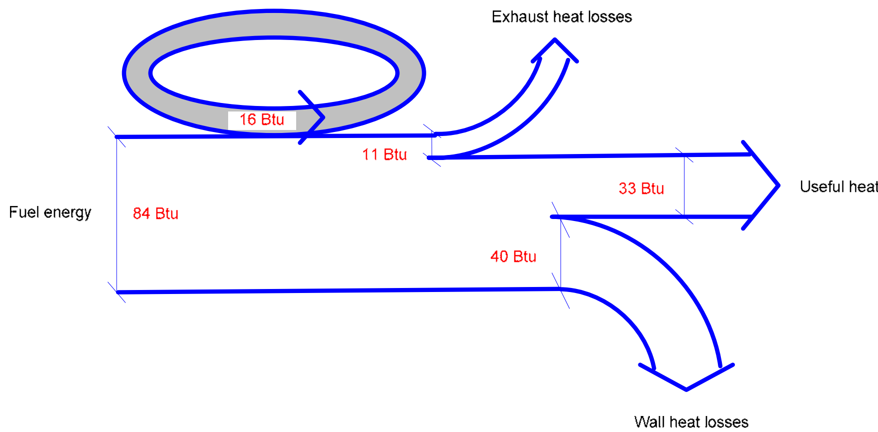
Sankey Diagrams for SCM without TCR and with TCR are shown below. The diagrams clearly show the potential for overall energy savings by combining TCR with an oxy-gas melter such as the SCM unit. Overall energy savings of 16% are calculated for the baseline case selected.

Without TCR
(The thermal efficiency is 33%)



With TCR reforming

(The thermal efficiency is 39%, reduced fuel and oxygen consumption is 16%)



Pilot-Scale Melter Fabrication and Assembly

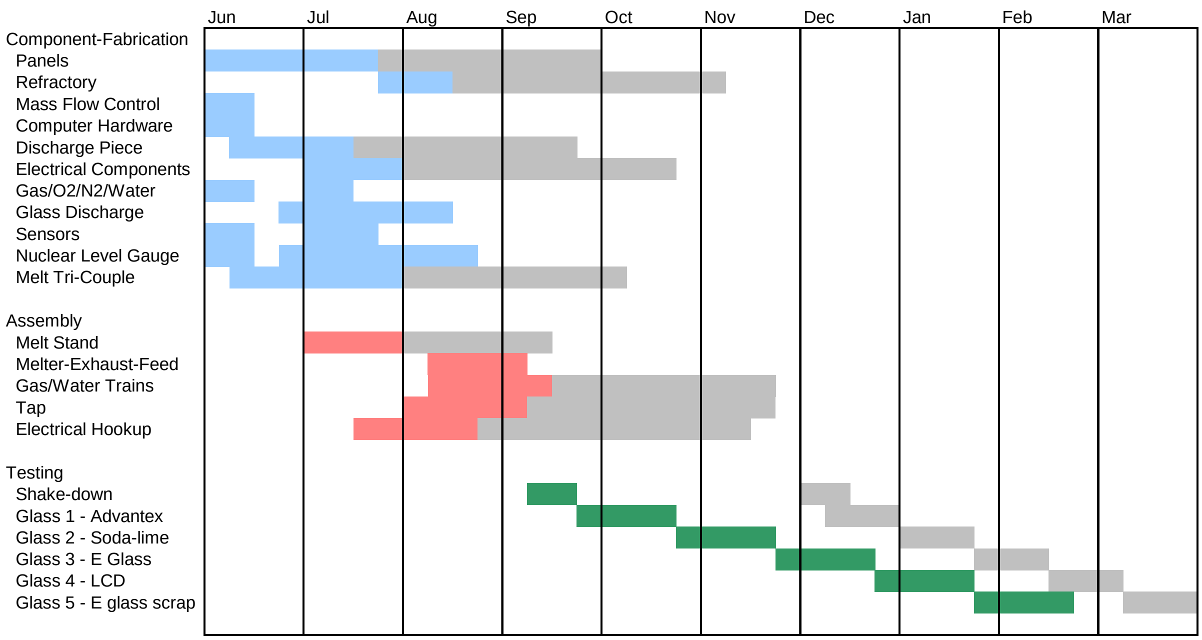
No melting tests were conducted this quarter. Instead, all efforts were focused on preparing for installation and operation of the pilot-scale melter later this year. The project team has agreed to focus all pilot-scale melt tests on three glass types and four compositions:

- Soda-lime glass (flat glass composition provided in batch by PPG)
- E glass
    - borosilicate glass batch provided by Johns Manville
    - Non-boron Advantex batch provided by Owens Corning
- LCD glass (no alkali glass batch provided by Corning)

A project consortium team meeting was held last quarter (early June, 2006) at GTI in Des Plaines, IL. At that time, all project team members had the opportunity to review the pilot-scale melter design and instrumentation package. Melt test planning was initiated, and assignments were made to acquire needed glass batch and to schedule glass company engineers to attend tests and participate in operations and sampling. The schedule for assembly and testing with the pilot-scale melter is presented below.

The schedule below has been modified (in gray) to show delays encountered. These delays are primarily related to melter panel assembly and refractory installation. At the end of this quarter, all panels were fabricated. Work remaining for assembly includes panel leak testing, refractory installation, and final melter assembly.

Table 6. Pilot-Scale 1 ton/h SCM Assembly and Testing Schedule



<u>Pilot Melter Design and Assembly</u>

The project team collected all available information from physical modeling, CFD modeling, lab SCM testing, and Ukrainian experience to provide input for the continuous, pilot SCM design. The consortium team members met last quarter and previous quarters to review preliminary pilot melter designs and to make final modifications. The objective is to design and fabricate a highly flexible 0.5 to 1.0 ton/h SCM unit with continuous feed and continuous melt discharge. The analysis was completed and the final design was selected. Details of the design will be provided after patent applications have been filed. Presented below are the primary design parameters selected and the rationale for those selections. Design concept work was completed last quarter, and work was begun on the detailed engineering drawings. The design was intentionally selected to utilize all existing support components installed with the lab-scale SCM unit. The feed system, the exhaust gas system (with fans and baghouse), the utilities supplies (gas, oxygen, electricity, and water), and the data acquisition systems will all be used with only minor modifications. This will simplify and speed installation of the new pilot-scale SCM unit.

The design philosophy behind the pilot-scale SCM unit is:

- Maximum ‘flow element’ path length with no bypass to discharge - Burners must be spaced far enough apart so that convective flow paths form around them and particles (flow elements) do not pass around any of the burners.
- Minimized surface to volume ratio - Since heat is lost from the water-cooled walls and the viscosity is high along the cooled walls (giving poorer mixing zones), the amount of wall surface area is to be a small as possible. This is addressed by choosing the length to width ratio of the tank appropriately.

- Avoidance of ‘corners’ or stagnant zones that concentrate unmelted or poorly melted batch and may serve as sites for devitrifidcation of some glasses - A cylindrical melt tank design is not preferred because particle flow path optimization and heat distribution can not both be optimized. Therefore, a rectangular tank with no 90 degree corners is preferred. This means no 90 degree corners along the sides or where the sides meet the bottom of the melt chamber.
- Maximized symmetry - Symmetry has been shown in both physical and CFD modeling to be a key parameter in optimizing flow patterns in an SCM unit. For that reason, burners will be placed in designed, optimized patterns in the melt chamber, and options will be provided to study different burner patterns as desired.
- Minimized convective heat loss to walls - Convective heat loss is maximized by higher velocity melt close to the melter walls. At the same time, placing burners too far from the walls leads to poor uniform of temperature across the chamber. To balance these two undesirable conditions, burners must be placed at appropriate distances from the walls, not too close and now too far away. The CFD modeling work is guiding this design parameter.
- Short, intense oxy-gas flame - Oxy-gas flames provide preferred heat transfer when flames are short and very stable. For that reason, burners will be used that meet this criterion. This ensures the combustion is completed in the bottom of the melt, and combustion gases have the needed opportunity to transfer heat to the melt as they pass upward toward the melt surface. Also, stabilized flames prevent burner pulsing and serve as an added feature to prevent melt flowing downward into the burners. Multiple burners are used so that heat is distributed uniformly through the melt, surface area between combustion products and melt is maximized, and kinetic energy of each burner is in the desired range. If kinetic energy is too low, melt particle flow patterns are not established around the burners. If kinetic energy is too high, how spots are created and excessive melt surface disturbance and splashing occurs.

The pilot-scale SCM will have the following features:

- Capacity of 1000 to 2000 lb/h - capacity will vary for different glass compositions and different melt depths
- Continuous feed - using two different feed systems, one based on dropping batch into the melter and the other based on pushing batch through a horizontal pipe or slot into the melter
- Continuous discharge - using newly designed platinum discharge pipe. The discharge pipe used in the lab-scale SCM tests will be redesigned and rebuilt for the pilot-scale unit so larger flows and more uniform discharge pipe temperature profiles are achieved.
- Operation with wide range of glass batch and batch compositions. The intention is to used three glasses - soda-lime, E glass, and LCD glass as the baseline glasses. Scrap fiberglass, which is of particular interest to the consortium will also be melted.
- Water-cooled walls lined with 1 to 2 inches of high-alumina rammed refractory - with refractory thickness designed to minimize heat loss and to enable a frozen layer of glass to form on the walls during operation

- Fully instrumented with data collection - operation to be in manual mode with data collection to be in automatic mode. Instrumentation includes all flows, voltage and amps to the tap piece, temperatures (including melt temperature), pressures, and med level.
- Burner firing rate up to 9 MMBtu/h divided among 6 burners - with the tank bottom designed to be removal so that alternative burner patterns can be studied
- Flexibility
    - Multiple feed options
    - Two discharge positions
    - Melt depth from 2 to 4.5 ft
    - Burner pattern of multiple burners
- Full data collection and control through National Instruments Labview interface - extension of the system already in place for the lab-scale SCM unit
- Sensors - A list of the wide range of sensors to be installed on and around the melter is presented below. All data will be digital collected using Labview software.

Gas and oxygen flow	Into all 6 burners
Gas and oxygen pressure	Into each burner
Water flow	Into each melter panel
Differential pressure	At melter flue exhaust
Melt temperature	Internal thermowell
Temperatures	Gas, oxygen, water, tap, exhaust gas, refractory
Nuclear level gauge	Average bed height
Digital cameras	Melt surface and tap
Voltage, amps	Tap transformer control
Weights	Batch feed rate

Pilot-Scale Melter Fabrication

The new melter will be built from a number of water-cooled panels joined together. Once assembled, a 1.5 in. layer of high alumina castable refractory will be applied in a monolithic layer on all surfaces. Work was begun in the last two quarters on the panel assembly, and the quote has been received for the refractory work to be conducted when all panels are fabricated and assembled. Panels were fabricated this quarter and assembled for fit and for leak testing. Fit and leak tests were positive, and the panels were disassembled for refractory installation next quarter. Shown below are the floor panel with the burner ports and the assembled melter with no refractory installed.

The lab-scale melter was removed from the test cell. A new floor drain was installed, and underground piping laid for removal of higher volumes of discharge water. The team considered using a chiller instead of once-through water, but consideration of the number and length of tests vs. cost led to the decision to go with once-through water. The design of the flow control systems for gas, oxygen, and nitrogen to six burners instead of two was completed and all components ordered. The water flow system was also designed. All of the components needed for metering, flow, valving, piping, and instrumentation are now on site. All data will be collected through Labview data acquisition modules. These modules have now been ordered, and the software modifications were initiated this quarter.

Several special systems must be properly designed and built for a melter producing up to 1 ton of glass per hour. These include the six burners (fabricated last quarter), a new platinum discharge pipe (fabricated this quarter at Corning and now at GTI), an in-bed thermocouple (fabricated at Corning) to directly read melt temperature, and a safe, practical melt collection system. A design for the melt removal conveyor was completed last quarter, and the unit was ordered with delivery this quarter in time for use with the first melt tests. One of the burners (with a zirconia coating on the tip) and the melt collection system are shown below.

Glass companies consider the platinum discharge pipes they use to be proprietary. Therefore, the pipe designed for the lab-scale SCM was intentionally designed to not conflict with known, proprietary designs. The pipe consisted of an outer shell with an inner platinum pipe. The inner pipe extends through the outer pipe in a horizontal position leaving the melter. The inner pipe then undergoes a 90 degree bend and extends downward to a nozzle. Two flanges are used, one against the melter wall and one above the nozzle. The tap piece is set in castable refractory and then encased in insulating bricks held in a steel frame. The pipe is designed for flows up to 660 lb/h. This is sufficient for lab-scale tests.

After successful operation, a new pipe was designed for flows up to 2000 lb/h when used with the new pilot-scale SCM unit. This new pipe is straight instead of having a 90 degree bend. The pipe diameter will be increased to 60 mm. Carsten Weinhold of Schott is again designed this piece, and the Corning metal shop again fabricated the platinum pipe. Owens Corning is providing the power pack and transformer to operate the platinum pipe. This work was completed this quarter and final refractory installation and wiring will be completed next quarter.

Collecting up to 2000 lb per hour of molten glass requires careful operation to avoid unsafe situations. The team considered a number of methods to handle this rate of glass flow and spent considerable time looking at water channels with belts and chains. These systems are used industrially and would work well. However, they are large and costly and were considered to be excessive for the pilot-scale melter tests. The final design was simple and robust for testing and met with the available budget and timing. The WHM Co. of Cincinnati built the discharge unit.

Burners for a submerged combustion melter should maintain a very stable, short flame. The project engineers felt a modified burner design could improve the stability of the flame and produce a shorter flame. A shorter flame allows more time for combustion products to heat the melt, and are therefore more desirable. Several new burner designs were modeled for mixing patterns, and a reliable, simple design was selected. Detailed engineering drawings were made of this new burner design, and the drawings were sent out for fabrication. The new burner design was tested in the lab-scale SCM unit before the last melt tests. The main feature of the new burner design is to provide faster and more uniform gas-oxygen blending. Results found that the burner produced a very loud combustion process and no real benefit toward a shorter flame. Testing, did however, indicate ways in which mixing can be improved and the flame can be shortened. A new burner modification was completed and sent out for fabrication bids. This second burner modification was fabricated this quarter and will be tested next quarter.

The six burners for the pilot-scale melter are based on the stable, proven burner already used in the lab-scale SCM. If the new burner design proves superior, future burners will incorporate some of those design features. One modification explored this quarter for the burners is the concept of applying a plasm-deposited zirconia coating on the top face of the burner. This should improve burner life and reduce potential for metal contamination of the glass. Talks with Sulzer-Metco engineers revealed this is possible, and a shop was found to do this work. The burner tops are now zirconia coated in preparation for testing.

Oxygen Transport Membrane (OTM)

Engineers from Praxair and GTI met in December, 2005 to discuss Praxair's analysis of applying their OTM technology to the NGMS process. After careful technological and economic analysis, Praxair has concluded that OTM is not a competitive means to produce oxygen for SCM or the NGMS process. Other oxygen production methods are more reliable and cost effective. Praxair is preparing a report describing their analysis procedures and results. This report will be completed next quarter. Upon further analysis, Praxair engineers now feel that the OTM technology may offer some important advantages for the NGMS process. They are now tasked with this analysis and providing a full report over the next two quarters. The report from Praxair is expected by the end of 2006 and will be submitted to both DOE and NYSERDA.

Industrial Bandwidth Analysis

GTI, with support from consultant Warren Wolf, completed a report titled, "Industrial Glass Bandwidth Analysis" this quarter. The full report will be made available this quarter through both DOE and GMIC.

This Industrial Glass Bandwidth Analysis has been prepared as a guide to determining places in the glass-making process where energy can be saved and means by which energy can be saved. This has been accomplished by reviewing available literature, discussions with industry experts, and several rounds of questionnaires sent to industry experts. The glass industry is often reluctant to reveal detailed energy data for proprietary reasons. For this reason, public data has been used as much as possible and affiliations of industry experts have been left out of the references. The authors trust that this approach has improved the quality of the reported information without detracting from the credibility of the sources. Energy use data is often not collected directly but is embedded in the price of materials, utilities, or oxygen. Other times, energy data is available but only for the combination of several process steps. Efforts have been made to examine energy use alone in this report.

The objective of the Bandwidth Analysis is to provide a current benchmarking of glass industry energy use. When benchmarking energy use in the glass industry, each of the major glass segments must be considered separately in order to reach useful energy use profiles. Also, to provide guidance on where the largest energy savings are possible, the energy use in each glass industry segment has been presented two ways: 1) by process step, and 2) in current average, state of the art, practical minimum, and theoretical minimum. Details of the project approach are presented in the appendix of the Final Report for reference.

Plans for Next Quarter

Work will be carried out next quarter on a number of project activities. The primary focus will be on final installation of pilot-scale melter components and on continued CFD modeling.

Modeling. Model refinement activities will continue next quarter as the time of the first pilot tests approaches. The pilot melter reference model and solution method has been extended as summarized in the Table below, based on the guidance from the CFD Committee. The immediate next step is to develop step 3 now that the team has finalized Step 2 and worked to set up iteratation back to Step 1. The FLUENT development work will target those enhancements that can aid the chosen simulation approach. Commercial release of FLUENT 6.3 (the beta version of which is being used by the project team) is targeted for 2007.

Model input audit	Oct
Method development and finalization	Oct-Nov

Baseline simulation and validation using test data	Dec
Model documentation and deployment	Jan

Physical modeling work has been halted as the project team focuses on fabrication of the pilot-scale SCM unit, CFD modeling, and final testing in the pilot-scale SCM unit. The results from physical modeling have been confirmed by CFD calculations. Additional physical modeling work will be conducted if additional data is needed to confirm design decisions or to validate results from CFD work.

A consultant, Dr. Grigory Aronchik, at GTI is conducting mathematical support for both physical and CFD modeling. CFD modeling will be the main focus of the modeling effort next quarter. The emphasis will be on developing better understanding of wall heat losses, modeling bubbles and combustion chemistry, and improving understanding of heat transfer mechanisms. Cases will be expanded to incorporate hydrodynamics, glass temperature-viscosity properties, heat balances, temperature profiles, and limited combustion. Temperature-viscosity modeling will be included in the cases for preferred configurations. This modeling will provide important insights into the final configuration of the 2000 lb/h pilot-scale melter (burner positions, exact dimensions, tap discharge location, burner firing rates, etc.). Specific work next quarter in CFD modeling will remain the same as last quarter and will include:

- Solution of combustion kinetics and incorporation of these results into the overall SCM model
- Work with FLUENT to complete a working model of the full SCM unit that incorporates hydrodynamics, combustion, heat transfer, radiation heat transfer, and turbulence.
- Preparations to use the CFD model to compare calculations with experimental results in the fourth quarter when pilot-scale tests are planned with multiple glass compositions.

The model will be modified to allow the user to change some of the boundary conditions and material properties. An attempt will be made to capture the effect of radiation using the optically thick assumption (Rosseland approximation).

Pilot SCM Melter Assembly. GTI and A.C. Leadbetter designed and constructed the supporting components for the pilot melter system. This system was adapted to work originally with the smaller lab-scale SCM unit. The larger 1 ton/h melter design concept work has been completed and all CAD fabrication drawings were completed. All components have been ordered and pilot melter panel fabrication continued. Pilot-scale SCM erection is planned for next quarter. This will include

- Assembling the melter
- Installing a 1.5 inch layer of high-alumina castable refractory
- Installing the burners and combustion control system
- Installing all oxygen, natural gas, nitrogen, and water lines and flow control systems
- Installing all sensors and data acquisition equipment
- Completing the electrical hookups for the full unit
- Installation of an improved platinum discharge pipe at Corning followed by shakedown
- Installing the rebuilt tri-plex platinum thermocouple fabricated at Corning through the melter floor up into the melt chamber

- Hook-up of the water trough conveyor system to collect and remove product glass for storage and disposal.

Shake-down testing of the complete pilot-scale SCM unit is scheduled for the end of next quarter, and pilot-scale SCM tests are planned for the following quarter.

The platinum discharge pipe and the triplex melt thermocouple were tested on the lab-scale melter. The tap worked well but needed to be redesigned and re-built for higher pilot-scale SCM flow rates. The triplex thermocouple was replaced with a new triplex platinum sheathed thermocouple coming up from the floor. The peripheral units (batch hopper, feeder, baghouse, melt removal, sample collection, etc.) were installed last year and have been used in tests with the smaller 300 lb/h SCM unit at GTI. All major support systems, including the oxygen, water, gas, water, electricity, and Labeiew data collection are now installed and operational. These systems are being expanded for the pilot-scale melter.

Peripheral questions continue to be evaluated. 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. Devitrification can be minimized by decreasing 'corners' in the melter where glass in not at high temperature and is not moving. The pilot-scale melter design will minimize 'corners' by eliminating all 90 degree angles.

Testing. The lab-scale melter (300 lb/h) system with complete feed, discharge, sampling, exhaust gas cleaning, baghouse, and control system has been removed from the test cell. Shake-down testing with E glass batch is planned for the next quarter after the pilot-scale melter is assembled. Tests will be made in the first quarter of 2007 with the new pilot-scale melter and new tap piece. Glass compositions will include soda-lime, LCD, E glass (containing boron and boron-free), scrap continuous fiber, and scrap matt glasses. All data will be collected via Labview software. Samples of product glasses will be analyzed by GTI and several glass company partners (Corning, Owens Corning, Johns Manville).

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 and submitted with the U.S. Patent Office in April, 2004. This can be found under the U.S. Patent Office Application 20050236747. A new patent application covering SCM design and operation is planned for the next quarter.

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 is a blueprint for multiple parties to work together on a technology of value to each of them. Lawyers for team members resolved final points and the agreement is signed and active. 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 have been 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 held in Rochester, NY in July, 2003. A paper was presented at the second Natural Gas Technology Conference in Phoenix, AZ in February, 2004. A presentation was made at the DOE ITP project review meetings in June, 2004 and September, 2005. An introductory presentation was also made at the DGG, Germany Glass Society, meeting in Nurenburg, Germany in June 2004. A presentation was made at the American Ceramic Society (ACerS) Glass and Optical Materials Division (GOMD) in Port Canavreal, FL in November, 2004.

Presentations were made in the first quarter of 2006 to the management and senior technical staffs of three of the five glass consortium member companies as well as to project managers at NYSERDA. Presentations to the other two glass company partners (Johns Manville and Schott) were made the next quarter. These presentations were made at the glass companies (not at GTI) to focus attention on the project and to expand support for continued NGMS development after completion of this project.

A report titled, "Industrial Glass Bandwidth Analysis", was completed last quarter and was made publicly available through DOE and GMIC last quarter. This document is based on extensive review of published data and discussions with many glass industry professionals regarding energy use in the U.S. glass industry.

A presentation on submerged combustion melting status was made at the end of the quarter. Status of this project, both the NGMS and the bandwidth activities, will be presented to DOE and GMIC for review at the start of next quarter.

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 on the Year 3 effort and is expected to be complete on time and budget. 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		On-going but complete
2	Design pilot scale melter	June 2004	June 2005	Completed
3	Procure equipment for pilot scale melter	Sept. 2004		Continued this quarter
4	Fabricate pilot scale melter	March 2005		Continuing next quarter for larger pilot melter

5	Prepare test plan	March 2005	March 2006	Completed
6	Complete pilot scale melting tests and collect samples	July 2005	Nov. 2005	Completed
7	Complete all sample analyses	Sept. 2005	Dec. 2005	Completed
8	Modify melter as needed	Dec. 2005		Complete this quarter
9	Complete second test series	June 2006		Next quarter
10	Finalize CFD modeling and physical modeling	Aug. 2006		
11	Complete OTM analysis	June 2006		
12	Complete development plan	Sept. 2006		
13	Complete Bandwidth Report	Feb. 2006	June 2006	Completed

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. The SMP portion of gas industry co-funding is in place during years 2 and 3 of the project. The glass industry consortium has finalized the consortium agreement and billings are continuing based on the planned schedule. GTI has entered into identical contracts with each of the five 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 five 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**	**1376**	**637**	**2013**
Year 3	**10/05**	**9/06**	**1281**	**300**	**1581**	**1147**	**37**	**1184**
Total			**4076**	**1450**	**5526**	**3715**	**850**	**4565**

References

1. Rose, J.W., and Cooper, J.R., eds. (1977), *Technical Data on Fuels*, New York: Wiley, 7th Edition.

2. Seward, T.P., and Vascott, T., eds. (2005), *High Temperature Glass Melt Property Database for Process Modeling*, Westerville, Ohio: American Ceramic Society, ISBN 1-57498-225-7.

Rapid Conditioning for the Next Generation Melting System

Rue: Gas Technology Institute

GO16010

QUARTERLY PROGRESS REPORT

Project Title	Rapid Conditioning for the Next Generation Melting System
Covering Period	July 1, 2006 through September 30, 2006
Date of Report	November 10, 2006
Recipient	Gas Technology Institute 1700 S. Mt. Prospect Rd. Des Plaines, IL 60018
Award Number	DE-FC36-06GO16010
Other Partners	NYSERDA – project sponsor GTI Sustaining Membership Program (SMP) – project sponsor Johns Manville Owens Corning

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Project Objective

The objectives of this project are to 1) test and evaluate the most promising approaches to rapidly condition the homogeneous glass produced from the submerged combustion melter, and 2) to design a pilot-scale NGMS system for fiberglass recycle. Techniques to produce higher quality glass from the melter will be investigated, and external fast conditioning approaches will be analyzed. The add-on rapid conditioning techniques evaluated through modeling and limited testing will rely on sonic energy, steam, and time discharge to speed conditioning

Statement of Objectives

The objectives of Budget Period One are to:

- Evaluate furnace operating parameters on glass quality. These parameters include burner firing patterns, melt temperature, glass residence time, etc.
- Conduct initial tests to evaluate the improvements achieved in glass quality using sonic refining
- Analyze product glass quality using advanced techniques for both on-line and off-line measurement of seed count and size
- Model other promising rapid conditioning techniques adaptable to the SCM
- Develop the engineering requirements for a Next Generation Melting System designed to recycle scrap fiberglass.

All work will be carried out using a single E glass composition. This approach will provide the largest impact of changing melter parameters and rapid conditioning conditions to be compared and analyzed.

Project Schedule

The project timeline is shown below. The first task will include the design and construction of the short heated discharge section and preparation of the sonic refining test setup and sampling methods. Task 1 will be nine months in duration. Task 2 will include all testing and analysis of samples and will also include modeling of other rapid refining approaches. It is anticipated that there will be up to 6 total melter tests performed over the 12 months of Budget Period One. Each melt will be 12 to 72 hours long and will include multiple experimental tests. These tests will incorporate evaluation of the impacts of changes in melter operation (pull rate, burner firing rate, burner patterns, etc.) along with evaluation of the sonic rapid conditioning method. The third task will be used to prepare for an engineering design and CFD model for a demonstration-scale NGMS process to melt scrap fiberglass. Task 3 will last 3 months. Quarterly reports and a Final Technical report will be prepared for all sponsors.

Task	Title	Budget Period One, months											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Preparation for SCM Glass Quality Tests												
2	Rapid Conditioning Tests and Analyses												
3	Engineering Design of NGMS for Scrap Fiberglass Recycle												

Performance Measures

Performance measures and go/no-go decision metrics are placed at the end of Year 1 of the project. Performance measures include the following:

Performance Measures

- Design, fabrication, and shake-down pilot SCM modifications including short refractory discharge zone and sonic refining equipment
- Completion of SCM tests with variations in operating conditions and with sonic refining following by glass quality analyses
- Initial modeling of other rapid refining techniques for the Next Generation Melting System
- Preparation of engineering design parameters for a Next Generation Melting System for

The performance measures for Budget Period One will lead directly into the go/no-go decision points for continued project work in Budget Period Two. The go/no-go decision points will refer to all activities as well as to which quality improvement approaches will be evaluated further or discontinued from evaluation. Go/no-go decisions are:

Go/No-Go Decision Points - at the end of Year 1

- Completed modifications to SCM pilot unit for testing with multiple approaches to glass refining and to glass quality measurement
- Conducted tests with sonic refining and shown significant glass quality

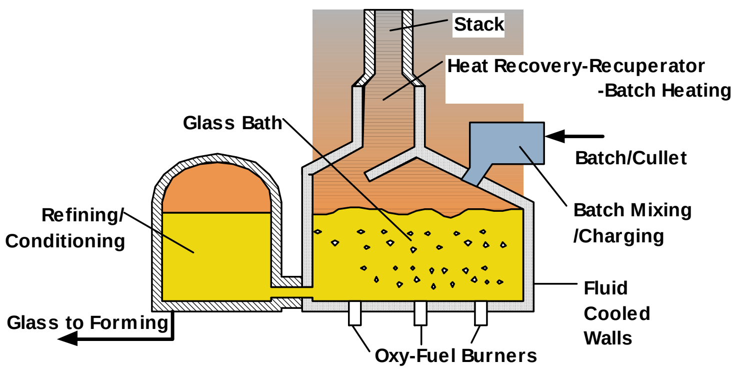
Background

Glass formation places heavy demands on the glass melting process. Quality requirements vary radically between industry segments, but all forming processes need a steady flow of molten, homogeneous glass of the chosen color (if not clear), with few to no unmelted sand grains (stones). This molten glass must be at a specific viscosity, with means temperature must usually be controlled to within several degrees. Along with all these requirements, each industry segment specifies molten glass must have the number and size of bubbles (seeds) for their product. In general terms, seeds must be below 0.1 mm in diameter, although optical glass demands are even stricter.

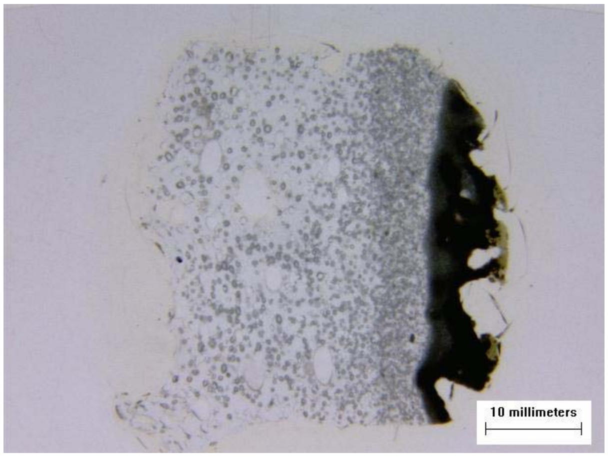
The U.S. Department of Energy is supporting collaborative efforts to develop a Next Generation Melting System (NGMS) that will produce glass of needed quality to the forming step of each glass industry segment. The submerged combustion melting technology, licensed and controlled by the Gas Technology Institute (GTI), is currently being developed by a GTI-glass industry consortium to serve as the melting and homogenization step of the NGMS process. NGMS envisions a segmented melting approach to achieve high energy efficiency, low emissions, and low capital cost. These goals are met by optimizing components of the melting process. SCM is particularly attractive because homogeneous, stone-free glass is produced while feed handling is less costly and simpler than for conventional furnaces, energy use is decreased, and emissions are lower, all with a far less expensive melter.

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.

The many features and requirements for SCM have been discussed elsewhere and will not be covered in detail here. The technology requires careful and appropriate design of combustion systems, and GTI has filed for a patent in this area. Oxy-gas firing is imperative so that heat input can be maximized while nitrogen bubbles are eliminated and total gas volume is minimized. Refractory walls will be worn away by moving glass, so walls must be built from externally cooled walls on which a frozen glass layer forms to protect the wall. GTI and a glass company consortium (Corning, Johns Manville, Owens Corning, PPG, and Schott) have been developing SCM for use as the NGMS melting and homogenization step. Soda-lime and E glass compositions have been melted to date in a lab-scale SCM unit (shown below), and work is underway to design a pilot-scale 1 ton/h melter.



Operation of SCM with a range of industrial glass compositions from soda-lime glass to LCD glass is verifying the melter's capacity to generate homogeneous, stone-free glass. Photomicrographs of soda-lime glass produced in the pilot SCM unit are shown below.



Results to date with SCM are highly encouraging. The product glass, however, must be of higher quality to meet many industrial needs. There are multiple means to improve the glass quality, and the proposed project will focus entirely on improving the quality of SCM product glass. Many of the techniques evaluated, particularly the external conditioning methods, are also applicable to conventional glass melters, as indicated above.

SCM Operations Improvements to Improve Glass Quality

SCM glass quality can be improved through a number of melter improvements, some in components and some in operating techniques. Component improvements include

- feeding systems systems that control batch introduction and minimize particle and volatile discharge
- modified burners and combustion systems to give desired combustion and heat transfer patterns to generate large easily refined bubbles
- Optimum discharge taps located to discharge high quality glass and to control melt flow rate

Improved operating procedures include burner locations and firing patterns, temperature control, residence time contro, and control of melter mixing patterns. All of these techniques have potential to increase the size of bubbles, decrease bubble concentration, and eliminate small bubbles (below 0.5 mm). All of the techniques mentioned will be tested and evaluate in this project.

External Conditioning Approaches

Along with improved SCM operation, external, rapid conditioning methods can improve glass quality. These techniques will be modeled in this project, and the most promising will be tested in a bench-top lab apparatus, and potentially on the pilot SCM unit. Glass refining is made difficult by the small size of bubbles (0.1-2.5 mm) that must be removed, the high viscosity of molten glass (often 100-150 poise), and limitations on materials chemically and physically compatible with molten glass.[2] The upward velocity of small bubbles in a liquid is characterized by Stokes Law.

$$V \;\alpha\; d^2 g \rho / \mu$$

which states a bubble's upward velocity (V) is proportional to the square of the bubble diameter (d), the gravitational constant (g), and to glass density (ρ) and is inversely proportional to the viscosity of the glass (μ). All refining approaches modify one or more variable to increase V. Refining time is controlled by the time it takes the smallest bubbles to reach the glass surface. Gas diffusion rates through glass vary, with nitrogen and carbon dioxide being the most difficult to remove. Current practice relies on time and chemical fining agents. Fining agents release gases such as oxygen that combine with bubbles of other gases. This produces larger, faster diffusing bubbles that shorten the refining time but also can contribute to air pollution. Fining agents are expensive and can alter glass chemistry, so their application is limited. Time can be turned into a refining ally by using a thin film or 'fining shelf' that shortens bubble distance to rise. Fining shelves are employed in some furnace designs, but care must be taken to maintain temperature uniformity and to minimize heat loss from the large surface of molten glass.

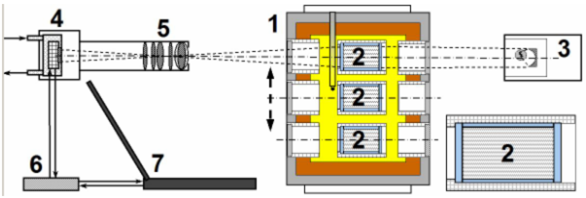
The NGMS process requires rapid conditioning to produce high quality glass from the high-intensity SCM unit. The most promising approaches will be modeled and analyzed in this project. The project team includes experts in water refining (Tomazawa), sonic refining (Spinosa), and other approaches such as vacuum (Wooley). Each rapid refining approach takes advantage of one or more variables in Stokes Law to accelerate the conditioning process. A list of the rapid conditioning approaches to be modeled and analyzed in this project is shown in the table below.

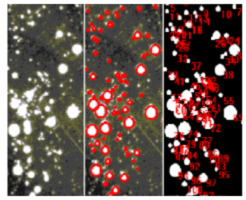
Rapid Conditioning	**Basis for Accelerated Conditioning**
Helium (inert gas)[3]	High solubility and high diffusion leads to scavenging of small bubbles into larger bubbles and fast bubble rise to surface (d_b is larger)
Water (steam)[4]	High solubility and high diffusion leads to scavenging of small bubbles into larger bubbles and fast bubble rise to surface (d_b is larger)
Sonic[5]	Vibrations lead to bubble consolidation and faster rise to the surface
Vacuum[6]	Decrease pressure leads to bubble expansion and fast rise to the surface
Centrifugal[7]	Gravitational constant changed from g to $r\omega^2$ which can greatly increase velocity

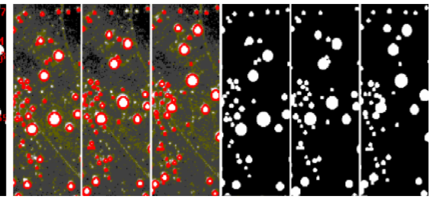
Bubble Characterization

Using optical techniques for bubble characterization, the project team will be able to routinely and rapidly determine the impact of changes in parameters on the quality of SCM product glass. By being able to see through a molten glass one is able to study the glass melting processes taking place. Consider two examples: light scattering connected with formation and evolution of bubbles at re-fining, and refraction of light connected with dissolution of cords at homogenization. Both phenomena can be studied using a high-temperature imaging system similar to that developed by the Laboratory of Glass Properties in 1998–2001. By taking images of the molten glass layer through sapphire windows using its own near-infrared radiation, diffused of directed backlight, one obtains all of the information necessary for analysis of small (~0.005” seeds) or large (~ 0.5” bubbles and thick cords) objects visible in the observation area.[8]

LGP support in the proposed project is based on 12-years experience in development of equipment for optical studies of molten glass at temperatures up to 3000ºF. Based on know-how developed in LGP, a stable and accurate high-temperature imaging system will be developed. The proposed system works as a stand-alone accessory, compatible with different refiner modules. The system includes: a) stabilized light source (3); b) CCD module consisting of 1 MP VIS-NIR matrix sensor (4) supplied with frigistor and water-cooler; c) zoom lens (5); c) imaging processor (6); d) portable computer (7). The following components designed in LGP will be used as prototypes: high-temperature optical cell (offered in 1994 and used without design changes until now), stable light sources, original large-aperture optical schemes, data acquisition systems and software, and others. A scheme of the system is presented below. The light source, CCD sensor module and image processor are drawn schematically. Real components are high-tech portable units, which will be developed using modern advanced technologies. The system allows still images to be taken at 1 fps or video at 24 fps. Image analysis software recognizes and numbers individual bubbles and assemblies, does bubble measurement, count, and determines their size distribution. The system is also capable in determining degree of non-homogeneity.







Scheme of high-temperature digital imaging system **Image numbering** **Observation of bubbles evolution**

Bubble #	X	y	d
1	0.0019	0.0217	0.0022
2	0.0039	0.1260	0.0022
7	0.0213	0.2575	0.0054

Development of the system for on-line monitoring of bubbles and cords in steady-state or flowing melt includes:

- Assembling a working prototype of the system, consisting of full-size light source, CCD module and imaging processor with reduced (lab-scale) high-temperature chamber plus initial version of image analysis software;
- Performing an initial set of experiments with commercial glass samples;
- Adjusting, customizing, and finishing the prototype to full-value registration ***system***;
- Developing the released version of image analysis software, to write user manual;
- Bringing the system, and all necessary software and documentation to an experimental facility of RC flexible laboratory melter, to install it and test with different types of glasses;
- Performing pilot-scale approbation of the system with the pilot-scale SCM unit;
- Providing technical support during the project period.

Status – Work This Quarter

This project started this quarter. The project team actually had only a month to conduct work after all contractual items were in place. Effort in this quarter focused on planning activities for next quarter.

The work next quarter will focus on planning for rapid conditioning tests. Conversations are planned with subcontractors related to ultrasonic refining and relating to molten glass and glass sample analyses. These talks will lead to initial designs for rapid conditioning and glass analysis tests. The first tests are planned for the third or fourth quarter of the project when the pilot SCM unit becomes available.

No work was performed on melter design for scrap fiberglass processing this quarter. This work is scheduled to begin toward the end of the first project year.

Plans for Next Quarter

Work will be carried out next quarter primarily on Task 1 activities. The primary focus will be on preparations for initial rapid conditioning testing. In following quarters the selected rapid conditioning approaches will be designed, assembled, and testing. Product glass will be analyzed by the project team so that complete understanding of the impacts of rapid conditioning approaches tested are available.

Publications/Presentations

There have been no publications or presentation yet related to this project. A brief introduction to the project will be provided at the DOE annual project review meeting to be held next quarter.

Milestone Status Table

This project is divided into three Tasks over a three-year period. A detailed schedule of project activities and completion dates will be prepared next quarter and included in the quarterly report.

Budget Data

The DOE contract was signed in June 2006 with an effective start date of July 1, 2006. The NYSERDA contract for co-funding will be finished in the next several quarters. Gas industry co-funding through GTI's SMP program is in place. The glass industry partners will be providing in-kind support to the project. The overall project budget, and spending to date, is shown below. Only cash funding is shown. In-kind cost-sharing by subcontractors and the two glass company partners is not shown.

Task	DOE Funding	Other Funding	Total Fudning
1	$109,000	$24,000	$133,000
2	$257,000	$56,000	$313,000
3	$6,000	$25,000	$31,000
Total	$372,000	$105,000	$477,000

No DOE or other funding was spent this quarter. Work will begin next quarter with planning for refining tests.

Measurement and Control of Glass Feedstocks

Weisberg: Energy Research Company, ORNL

ID14030

QUARTERLY PROGRESS REPORT

Project Title: Measurement and Control of Glass Feedstocks

Covering Period: July 1, 2006 through September 30, 2006

Date of Report: October 31, 2006

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

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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,

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[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:

A critical component for measuring fluorine in the LIBS analyzer was completed during this quarter, and drawings for the other components for the upgraded sample chamber were completed and delivered to the machine shop for fabrication. A photograph of the fluorine upgrade optical mount is shown below. Delivery of the remaining parts is scheduled for November. Testing of the upgraded chamber will then commence in ERCo's LIBS laboratory.

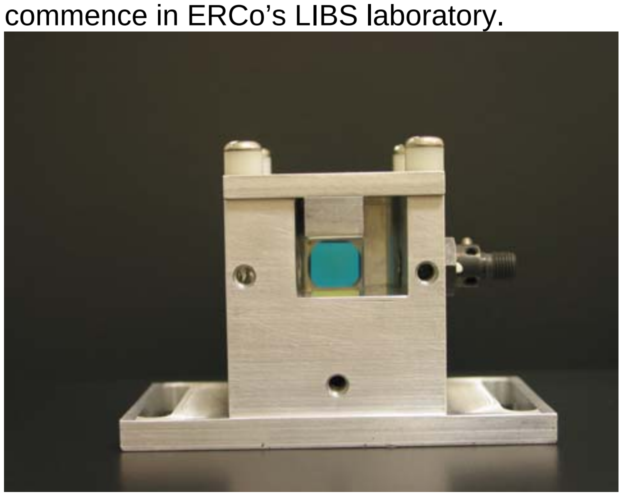

Figure 1: Custom Optical Mount for Fluorine Measurement
The mount includes fiber optic couplers (one is seen protruding at right) and a beamsplitting cube (blue). The mount allows for measuring both fluorine and the background light level simultaneously.

Plans for Next Quarter:

The in-plant shakedown and testing of the improved system will be scheduled following successful testing of the system in ERCo's LIBS laboratory.

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	
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	6/30/05	Note 1	1,179,178.00	Note 1	1,605,006.00	2,784,184.00
3Q05	7/1/05	9/30/05	Note 2	1,179,178.00	Note 2	1,605,006.00	2,784,184.00
4Q05	10/1/05	12/31/05		1,179178.00		1,605,006.00	2,784,184.00
1Q06	1/1/06	3/31/06		1,278,375.01		1,605,006.00	2,883,381.01
2Q06	4/1/06	6/30/06		1,278,375.01		1,605,006.00	2,883,381.01
3Q06	7/1/06	9/30/06		1,278,375.01		1,605,006.00	2,883,381.01
4Q06	10/1/06	12/31/06					
1Q07	1/1/07	3/31/07					
Etc.							
Totals				1,278,375.01		1,605,006.00	2,883,318.01

* 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).
General Note: The information in this table should be consistent with the information provided in section 10 of the quarterly financial status reports (SF269 or SF269A).
Note 1: Leave blank. Only the actual DOE/Cost Share amounts spent through 3/31/05 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.

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	6/30/05	Note 1	155,000.00	155,000.00
3Q05	7/1/05	9/30/05	Note 2	0	0
4Q05	10/1/05	12/31/05		0	0
1Q06	1/1/06	3/31/06		0	0
2Q06	4/1/06	6/30/06		0	0
3Q06	7/1/06	9/30/06		0	0
4Q06	10/1/06	12/31/06			
1Q07	1/1/07	3/31/07			
Etc.					
Totals				155,000.00	155,000.00

* Update quarterly

Index of Award CID Numbers

Index of Award CID Numbers