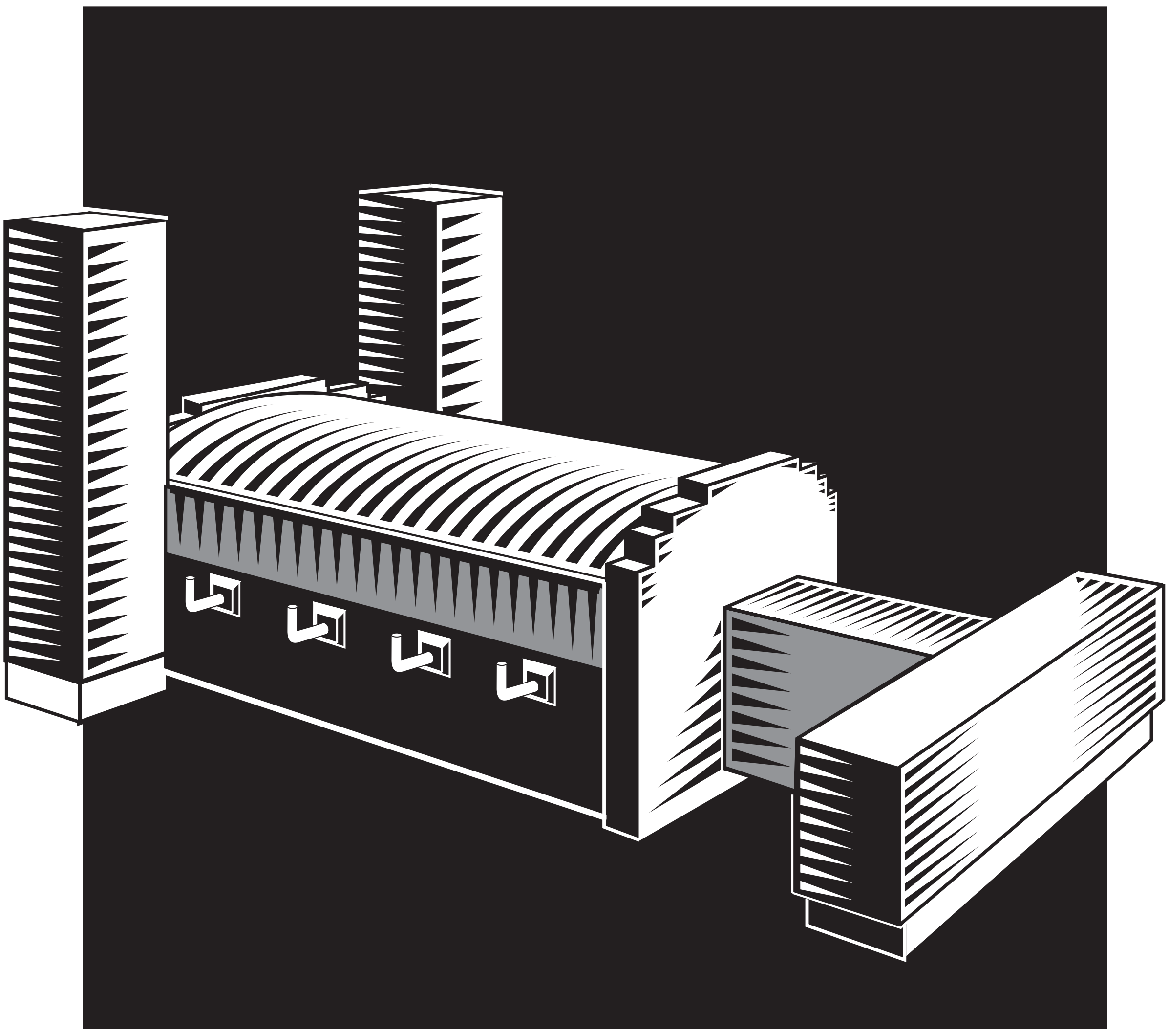
Glass Industry of the Future

Quarterly Status Reports

As of December 31, 2008



U.S. DEPARTMENT OF ENERGY

02-GA50113-03

Glass

Industry of the Future

Quarterly Status Reports

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Glass Projects

Rapid Conditioning for the Next Generation Melting System 1
Gas Technology Institute
GO16010

Rapid Conditioning for the Next Generation Melting System

Gas Technology Institute

GO16010

QUARTERLY PROGRESS REPORT

Project Title	Rapid Conditioning for the Next Generation Melting System
Covering Period	October 1, 2008 through December 31, 2008
Date of Report	February 17, 2009
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

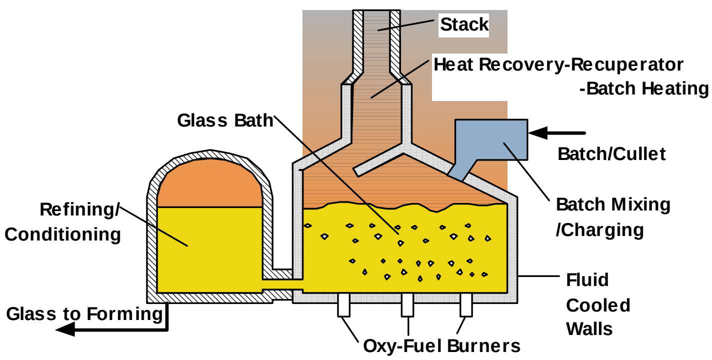
Background

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.

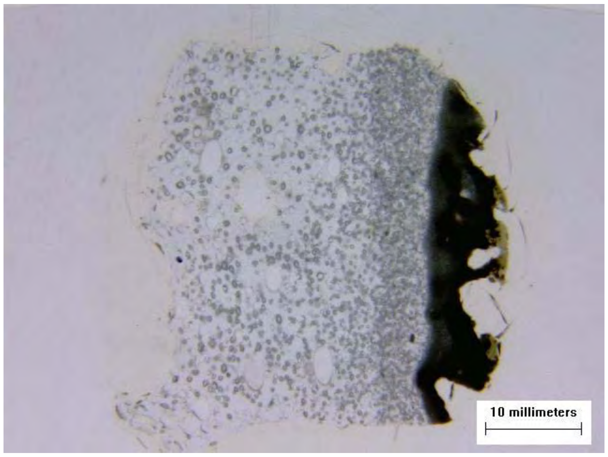
The U.S. Department of Energy is supporting collaborative efforts to develop a Next Generation Melting System (NGMS) that will produce glass of needed quality to the forming step of each glass industry segment. The submerged combustion melting technology, licensed and controlled by the Gas Technology 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.

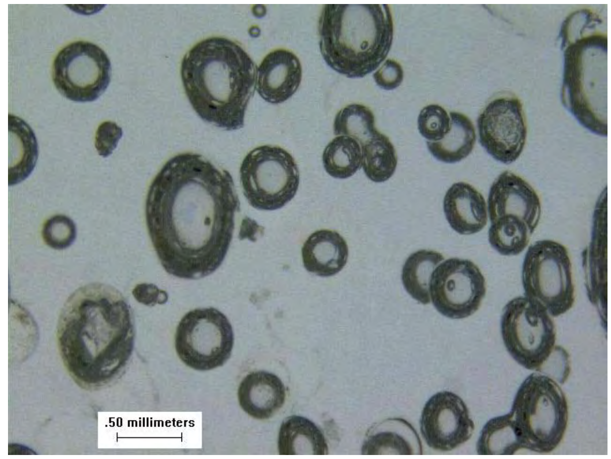
In SCM (shown below), fuel and oxidant are fired directly into the molten bath from burners attached to the bottom of the melt chamber. High-temperature bubbling combustion inside the melt creates complex gas-liquid interaction and a large heat transfer surface. This significantly intensifies heat exchange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

Status – Work This Quarter

The final contract was signed with DOE (2006) and approved by NYSERDA (2008 signing). A test was conducted in October 2007 in which SCM product glass was refined in crucibles in an electric oven. Observations of refined samples showed the SCM glass can be refined in a relatively short time of 20 to 40 minutes. With this data in hand, work has proceeded in two directions. First, a refractory trough or 'front end' has been designed and built to take SCM product glass and hold it at temperature for 20 to 60 minutes during continuous operation of the melter. All project efforts this quarter were focused on final shakedown of this refining section for continuous tests and conducting the first test. Construction of the new front end section was essentially completed last quarter, in September, 2008.

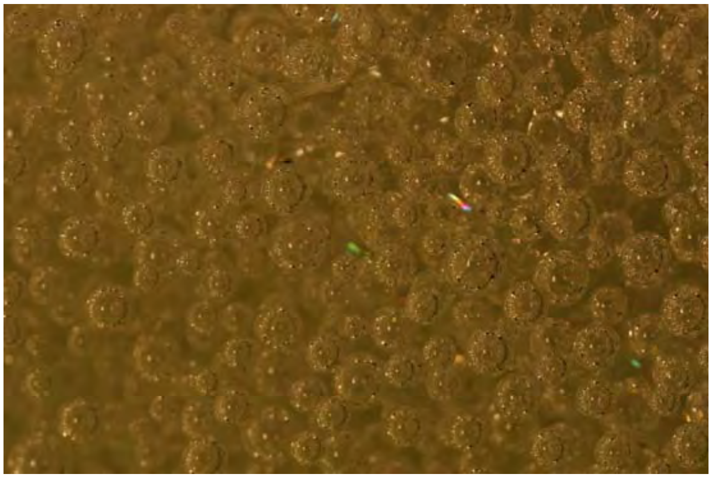
The second direction involves laboratory study of bubble behavior and removal from viscous liquids. High viscosity silicone oil simulating glass was initially used for this work. Work with silicone oils having viscosities similar to molten glass allows for easier evaluation of possible refining approaches. The overall approach being followed is to use the 'front end' section to remove the great majority of bubbles from the molten glass and then to use a 'polishing' step to remove the remaining bubbles down to the level required for commercial glass. These concepts will be tested separately and together in 2009.

Experiments have shown that refining of glass from a high-intensity melter such as the SCM can productively be carried out in two stages. For the sake of discussion, they can be referred to as the coarse refining stage and the fine refining stage. To study the coarse refining stage, the project team elected to construct a forehearth channel to allow continuous refining of SCM product glass for 20 to 60 minutes at various temperatures.

Construction of the forehearth channel was completed last quarter. A photograph of this completed device is presented below. Note that the forehearth section is mounted on rails to facilitate easy movement of the device up to and away from the melter. Shakedown testing of all sub-systems for the SCM and the refiner were completed in the first several weeks of this quarter.

The first continuous SCM-refining test was conducted this quarter with a non-boron E glass. In this test, molten E glass was continuously fed to the forehearth at differenct flow rates. These varying flow rates were supposed to produce refiner residence times for the glass of 20 to 60 minutes. Glass samples were collected from both before and after the refiner during each steady state period. These glass samples were vertically sectioned and analyzed.

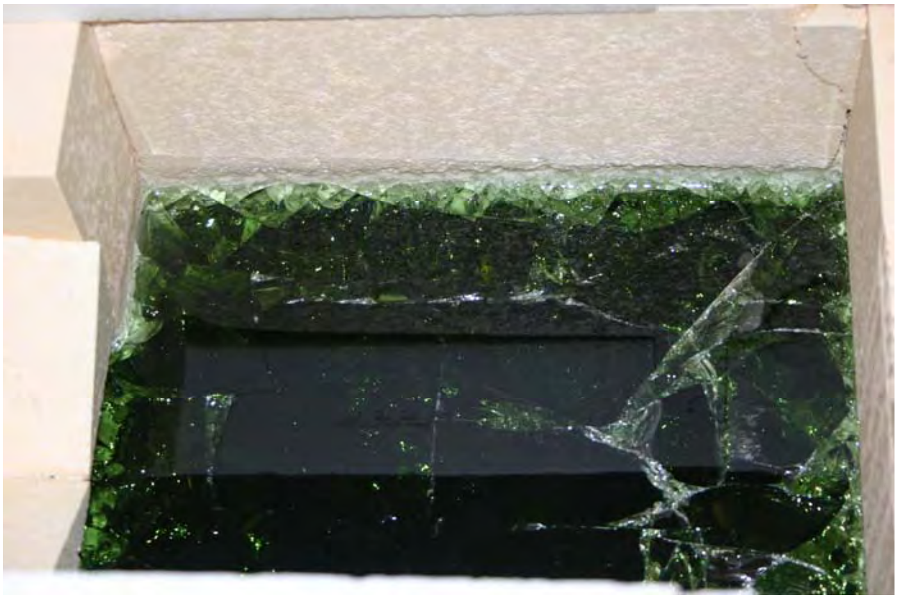
The test did not proceed as planned. The glass passed through the refining section much faster than planned, and the glass exiting the refining section did not show a significant decrease in bubbles. Review of the test revealed that the glass entering the refining section was too cold to flow uniformly. This led to the refining section filling with glass to the discharge level. Then the next glass charged 'floated' on top of the highly viscous glass already in the refining section. This process short circuited the refining step. The pictures below are extreme close-ups of the glass removed from the refining section after the test. The bottom sample indicates that refining began, but that the glass was too cold and viscous to fully refine. The glass surface sample shows that bubbles do rise to the surface and break there.



Bottom of Refining Section

Glass at Surface of Glass in Refining Section

While the first effort to conduct continuous refining was not successful, the project team sought ways to address the problems encountered. The first thing the team did was to heat the glass left in the refining section and let that glass refining for two days. The photograph below shows that this operation demonstrated that glass will definitely refine in this unit. After this was shown, the glass was emptied from the refining section in preparation for the modifications and further testing next quarter.



SCM-Melted E Glass in Refining Section After Two Days at Temperature

The project team felt the first test went well operationally, but the results were poor since the glass was not hot enough either entering or exiting the refining section. The project team, with assistance of Owens Corning engineers, has designed a ceramic feed chute to link the SCM and the refining section more closely. This component will help keep the glass hot and at the desired low viscosity entering the refining section.

The project team also is planning to brick in the discharge to the refining section. This will significantly reduce the amount of cold air induced into the refining section, and will help to decrease cooling of the product glass before that glass is removed from the refining section.

These two changes regarding the refining step of the glass-making process will be completed next quarter. The next overall continuous SCM-refining test will be conducted after these changes are carried out and when the weather is warm enough to allow for safe operations.

Tests of the fine refining step have conducted last quarter with molten soda-lime glass melted in a laboratory electric furnace. Bubbly SCM product glass was melted and passed through high-temperature resistant refractory beads to determine the ability of the surfaces to retain bubbles. The tests were unsuccessful because the flow rates, residence times, and velocities could not be controlled well enough. Some improvement in the bubble count was achieved, but nowhere near the level of control required for an industrial process. Future work will repeat this testing with better controls on velocity and residence time in place.

Plans for Next Quarter

Work will be carried out next quarter primarily on Task 2 activities. The current quarter marked the first attempts at continuous refining tests. There will be two primary areas of effort next quarter as described below.

The course refining approach will be pursued by conducting tests with glass from the pilot-scale SCM sent directly to the front end channel. This channel will allow SCM product melt to be held at a refining temperature for 20 to 60 minutes. The channel has been fabricated from refractory and is heated by electric elements below the lid. Since glass enters the channel in a molten state, the electric elements serve to balance heat losses and to adjust melt temperature. However, the electrodes can only make minor changes in melt temperature. The electric elements are being used for testing simplicity. In an industrial environment the make-up heat will likely be supplied by roof-mounted flat flame burners. Tests are planned for next quarter with different glass residence times and temperatures to assess the coarse refining step. Due to budget constraints, these tests will be limited to proof of concept and will be limited to one glass composition, probably an E glass similar to a composition produced by both Johns Manville and Owens Corning.

Before additional refining tests are conducted, changes will be made to both the transfer of molten glass from the SCM to the refiner and to the discharge of glass from the refiner. Glass was found to lose too much heat in these two transfer operations which made refining and glass movement difficult. To keep glass hotter entering the refiner, a refractory box with a channel will be fabricated. This will prevent large heat losses from the open transfer of glass from the melter carried out in the last SCM-refiner test. The second change will be to better enclose the discharge of the refiner. This section is presently open. During operation, this open area acts as a chimney, drawing cold air into the refiner. When this cold air comes in contact with the refined glass during discharge from the refiner, the glass becomes viscous and will not flow. The refined glass temperature must be kept hot enough to enable steady flow and collection of product glass from the refiner.

Further SCM-refiner tests will be conducted starting next quarter after the changes are made to keep the glass hot enough to flow easily. The tests will be conducted with the same glass batch and will cover the ranges of refiner temperature and residence times selected for evaluation of continuous refining with the SCM unit. These further tests will be conducted when weather is warm enough (March or April) in Chicago to enable the testing to be conducted.

The fine refining approach has been shown to work for high viscosity silicone oils, so a test series will be undertaken next quarter to find the range of operating conditions appropriate for removing all fine bubbles from molten glass under laboratory conditions. Ultimately, long term tests are envisioned to confirm that the approach can be developed into a commercial process. Other fine refining work, if budgets allow, will involve further lab tests in which molten glass with bubbles will be poured onto a filter bed at high temperature to evaluate the filtration of bubbles to produce a clarified glass.

In following quarters the selected rapid conditioning approaches will be assembled and tested in both surrogate liquids and in molten glass from the pilot-scale SCM unit. Product glass will be analyzed by the project team so that a complete understanding of the impacts of rapid conditioning approaches becomes available.

Publications/Presentations

There have been no publications or presentation yet related to this project. A patent application was prepared and has been submitted to the U.S. Patent Office. This patent application covers the approach being developed for refining of glass from high-intensity melters such as the SCM.

Milestone Status Table

This project is divided into three Tasks over a three-year period. This quarter began the year three effort. Work in Year Three will focus on refining tests with the pilot SCM unit and the new refining section that is now assembled

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.

			Approved Spending, $K			Actual Spending, $K		
Phase / Budget Period			**DOE Amount**	**Cost Share**	**Total**	**DOE Amount**	**Cost Share**	**Total**
	From	**To**						
Year 1	**7/06**	**8/07**	**109**	**100**	**209**	**15**	**0**	**15**
Year 2	**7/07**	**8/08**	**257**	**100**	**257**	**173**	**50**	**223**
Year 3	**7/08**	**8/09**	**6**	**150**	**156**	**156**	**50**	**206**
Total			**372**	**350**	**722**	**344**	**100**	**444**

Work will continue next quarter with refining tests with both surrogate liquids and molten glass. The pilot-scale SCM unit will be used for continuous melt tests focused on refining.

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