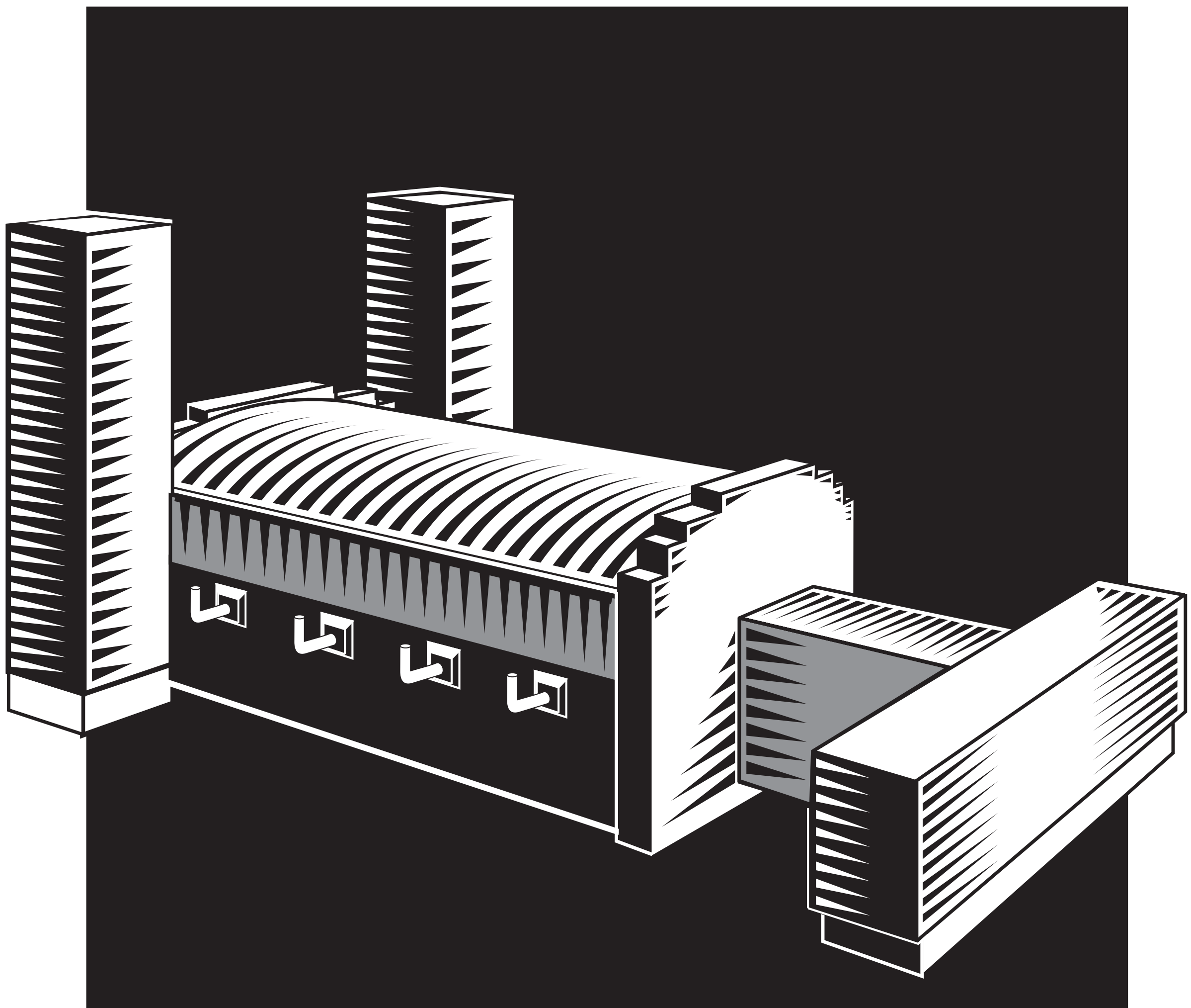
Glass
Industry of the Future

Quarterly Status Reports

As of September 30, 2008



U.S. DEPARTMENT OF ENERGY

02-GA50113-03

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Glass Projects

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	July 1, 2008 through September 30, 2008
Date of Report	November 7, 2008
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

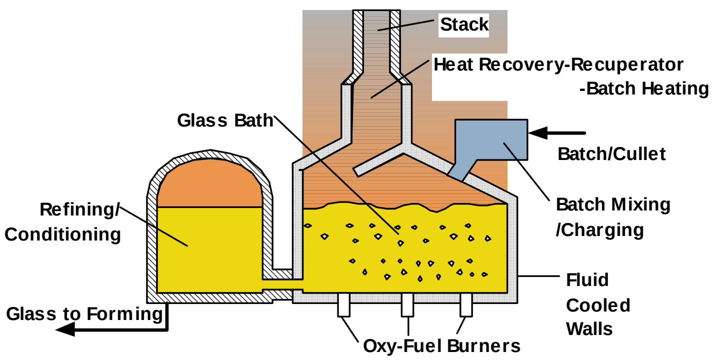
Background

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.

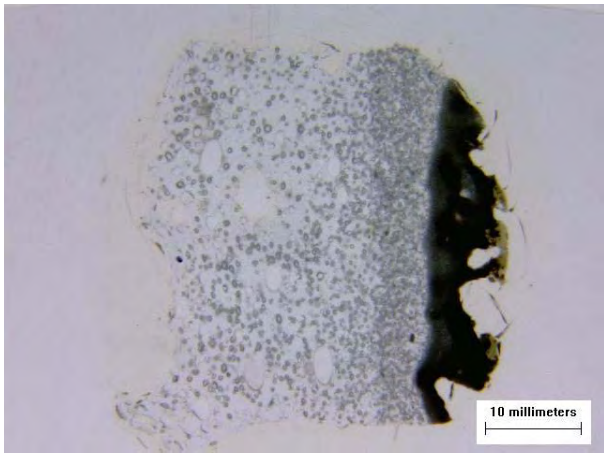
The U.S. Department of Energy is supporting collaborative efforts to develop a Next Generation Melting System (NGMS) that will produce glass of needed quality to the forming step of each glass industry segment. The submerged combustion melting technology, licensed and controlled by the Gas Technology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

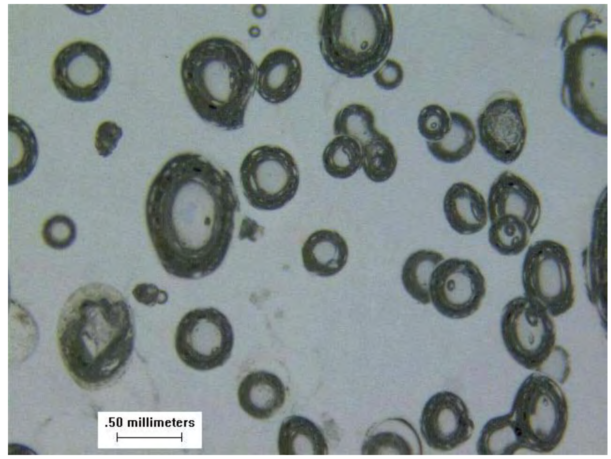
In SCM (shown below), fuel and oxidant are fired directly into the molten bath from burners attached to the bottom of the melt chamber. High-temperature bubbling combustion inside the melt creates complex gas-liquid interaction and a large heat transfer surface. This significantly intensifies heat exchange 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 have shown that 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 that will 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 fabrication of this refining section for continuous tests. Construction of the new front end section was essentially completed this quarter, in September, 2008. This new front end section will allow the project team to study glass refining in tests next quarter, starting in October, 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 the use the 'front end' 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 2008.

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.

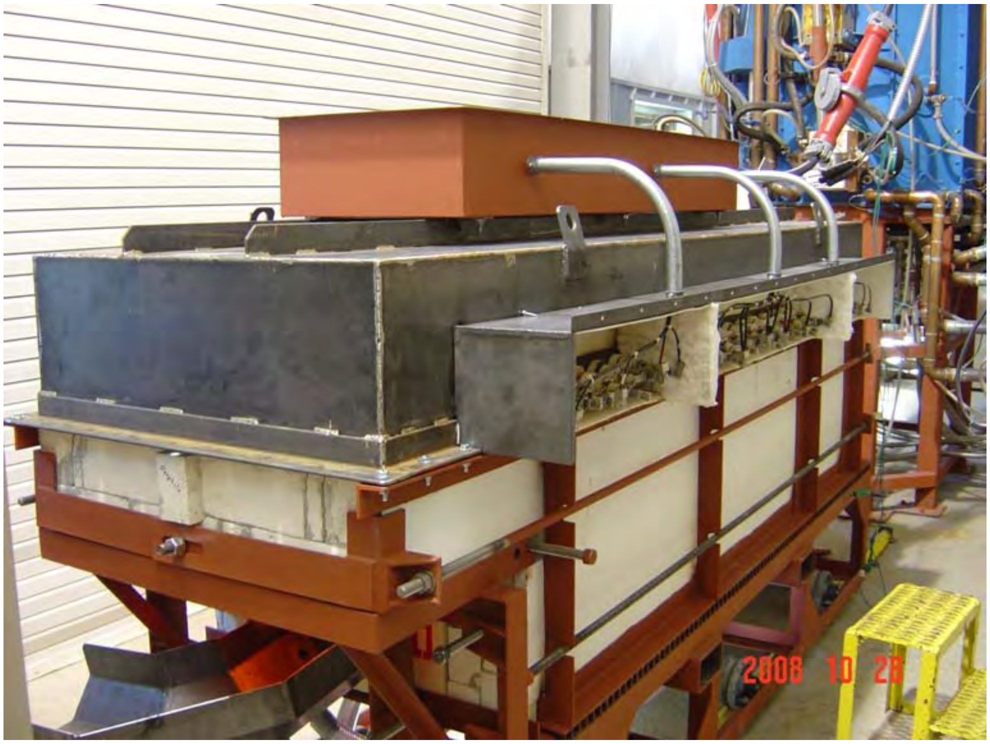
Two tests with molten glass from the SCM have confirmed that the great majority of moderate to large bubbles can be removed from SCM product glass by holding the glass at a constant refining temperature for periods of up to 60 minutes. This short residence time is considered practical on an industrial scale and can be achieved by discharging molten glass from the SCM directly into a 'front end' or forehearth type channel. The residence time is very short because the number of bubbles is very large. As the biggest bubbles rise quickly through the glass, they carry a large fraction of the smaller bubbles to the surface at the same time.

A design concept for such a channel was developed and discussed among the project participants. Fabrication approaches have been evaluated, and a final detailed design was approved. Final fabrication drawings were completed last quarter. Care was taken to design and build a practical unit that can be moved in and out of position as required and that can handle the necessary temperature swings, types of glass, residence times, and temperatures to be evaluated. All needed refractories, heating elements, and steel frames and supports were ordered. The channel was fabricated and prepared for testing with molten E glass starting this quarter, in July, 2008. The channel has been built from standard high-temperature bricks and uses high temperature electric elements to control channel temperatures. A total of 42 kW of power is delivered from 24 Super Kanthal elements run with 480V, 3-phase power. Residence times will be controlled by the SCM pull rates. One challenge has been to devise a reliable means to continuously discharge molten glass from the SCM and to introduce the molten glass at high temperature into the refining channel. Initially, the project team felt the best way to transfer glass to the front end channel was with a diverter plate. Upon further analysis, the diverter plate has been replaced with a high-temperature stainless steel refractory guide to direct molten glass into the channel. This guide channel is at a steep 45-degree angle and is partially water cooled from behind to protect the steel while not adding water to the glass.

The final glass product will be removed from the bottom half of the channel using a skimmer block. The glass level in the channel will be controlled automatically by overflow of a weir block after the skimmer block. The team originally planned to use a heated bushing to control glass flow out of the channel, but this was deemed unnecessary when the overflow of glass into an oversized exit port was devised. The major criteria for the exit flow is to have sufficient heat to avoid freezing. This will be achieved by the use of additional electric heating elements placed on he walls and roof after the skimmer block at the end of the channel.

In summary, the forehearth channel sits on a steel frame and can be moved in and out of position relative to the melter. The forehearth is built of three layers of refractory selected for their high temperature thermal properties. An outside layer of high-temperature refractory board is also included. The foreharth section internal dimensions are approximately 12 inches wide by 72 inches long. Glass depth can vary and is initially set for 6 inches. The lid contains the inlet channel from the melter. A total of 24 electric elements are mounted horizontally in the lid and are operated in three groups (of six, twelve, and six elements). Nine SCRs supply three-phase 480V power to the elements, and a transformer is connected to the SCRs.

Construction of the forehearth channel was completed this 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 will be completed in the first several weeks of the next quarter. After nominal operation of all subsystems is demonstrated, the first test will be conducted. In the first test, molten E glass will be continuously fed to the forehearth at differenct flow rates. These varying flow rates will result in refiner residence times for the glass of 20 to 60 minutes. Glass samples will be collected from both before and after the refiner during each steady state period. These glass samples will be vertically sectioned and analyzed for composition and total seed count.



An approach to fine refining has been proposed by GTI, and a patent application has been filed. The coarse refining removes all bubbles down to under 1 mm. Fine refining takes this product glass and removes the remaining bubbles. Tests were conducted under laboratory conditions steady state conditions with high viscosity silicone oil serving as a surrogate liquid. These tests were positive in removing fine bubbles, but the rate is too slow for an industrial process. Initial efforts to increase the production rate were positive but lead to a rate that was still 2 to 3 times slower than desired for an industrial process. Parametric tests are underway with the surrogate liquid, and the project team believes the production rate can be improved to the desired industrial rate. Once this has been demonstrated, tests will be conducted with molten glass to verify the success of the fine refining approach.

Tests of the fine refining step were 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 end of fabrication and preparation for 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 will be heated by electric elements below the lid. Since glass enters the channel in a molten state, the electric elements will 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.

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 completes the year two 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	70	20	90
Total			372	350	722	258	70	328

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.

Index of Award CID Numbers

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