The Development of a Next Generation Melting System for Glass Production: Opportunities and Progress

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ABSTRACT

Energy currently accounts for about 15% of glass production costs, and the majority of energy consumed in the glass industry occurs in the melting and refining of glass. A next generation melting system for glass production must facilitate a new business model, with significant improvement in investment returns, that would allow the U.S. glass industry to better compete in world markets and continue to offer products with the unique properties of glass. This system would reduce energy consumption, reduce capital requirements as well as overall production costs, and at the same time maintain and improve glass quality and environmental stewardship. Achieving such a system will be challenging and will require significant resources and collaboration.

Recently, the U.S. glass industry, through the Glass Manufacturing Industry Council (GMIC), has collaborated with the U.S. Department of Energy (DOE) to examine the potential for developing a next generation glass melting system. Collaborative efforts to date include: conducting a technical workshop for next generation melting technologies, creating a task force to develop technical criteria for next generation melting systems, and preparing a technical and economic assessment of past technology improvement efforts and current melting processes. In addition, DOE has solicited proposals for innovative bench-scale approaches to glass melting as well as general research and development efforts.

The objective of this paper is to highlight the approaches and strategies that have been taken and the results obtained to date on the development of a next generation melting system for glass production. The results obtained to date represent the contributions of many companies and individuals, both domestic and foreign. Included in the paper will be preliminary highlights from the technical and economic assessment, a reference document that will help guide the development path.

Background

The glass industry technology roadmap, published by the Glass Manufacturing Industry Council (GMIC), identified priority research and development (R&D) needs by time horizon in four key areas: production efficiency, energy efficiency, environmental issues, and innovative uses for glass. The key research priorities for the near and mid term included advanced sensors and controls, furnace and emissions modeling tools, longer-life refractories, and improved recycling. Long-term research priorities included the development of next generation melting systems, improved materials for operations, new glass compositions and raw materials, and advanced processing techniques for novel glass product applications. The roadmap also defined the roles that various stakeholders can play in implementing the needed research.

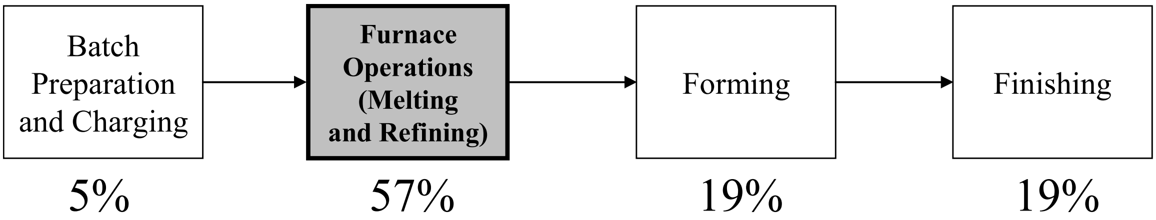
The roadmap stated that while the majority of technical priorities focus on melting and refining, in the long term, the glass industry is convinced that a more radical improvement in the melting and refining process will be needed to solidify the competitive position of the industry. As such, a significant commitment from the industry will be needed to undertake such high-risk efforts, and considerable time and research funding will be required to develop and implement such technology (GMIC 2002).

Potential Impact

Glass production is inherently an energy-intensive process. On average, about 15% of the direct cost of production for glass comes from energy requirements. The majority of this energy use is used in the furnace, where raw materials are melted and refined into molten glass. In 1998, an estimated 250 trillion Btu were consumed by the U.S. glass industry during the production of approximately 20 million tons of glass products. Figure 1 depicts estimated consumption for each major process step during glass production (DOE 2002).

Figure 1. Estimated Energy Use by Process Step

Total = 250 Trillion Btu

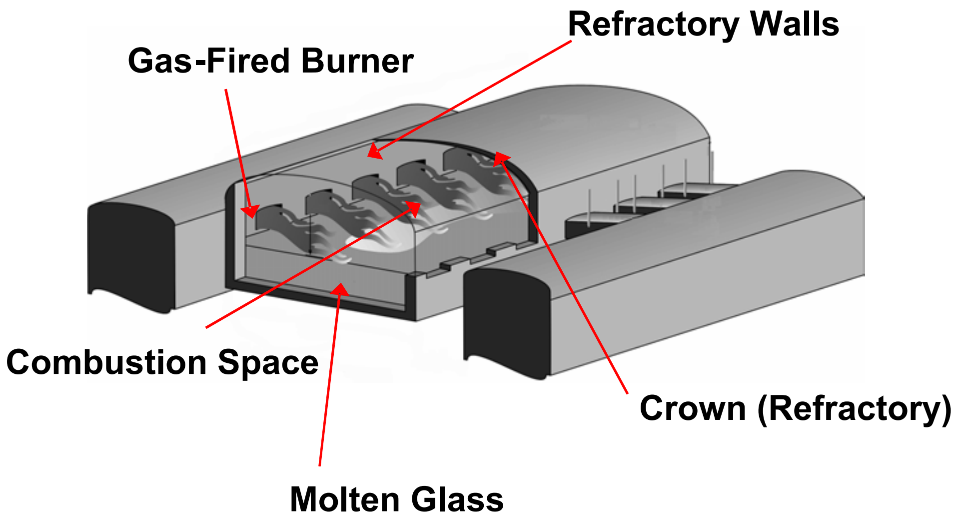


In theory, only 2.2-2.7 million Btu/ton are required to melt a ton of glass, depending on the composition of the glass. Energy is required for the heat of reaction and enthalpy of glass and gases emitted. However, inefficiencies cause the process to consume considerably more energy than is theoretically required, as much of the heat is lost through furnace walls and exhaust gases. In practice, two to three times the theoretical minimum is consumed during the melting and refining of glass. Table 1 shows the theoretical minimum and average consumption for melting and refining in the major glass sectors, and Figure 2 shows a glass furnace. With 1998 glass production levels, the amount of energy consumed above the theoretical minimum in glass melting and refining was around 85 trillion Btu. While it is not practical to believe that theoretical minimums can be achieved, it gives some idea of the magnitude of the opportunity (EC 2000).

Table 1. Theoretical Requirements and Average Energy Consumption Per Ton

	Million Btu/Ton Glass
Glass Composition Theoretical Energy Requirement	
Soda-Lime	2.7
Borosilicate and Crystal	2.25
Glass Sector Average Energy Consumption, 1998	
Flat Glass (Soda-Lime)	8.6
Fiber Glass (Borosilicate)	8.4
Pressed and Blown Glass (Various)	7.3
Container Glass (Soda-Lime)	5.5

Figure 2. Depiction of a Glass Furnace



While all glass product sectors have melting in common, there are both real and perceived differences in which different types of melting satisfy their individual business needs, such as production rate and compositional flexibility. Another key attribute is glass quality, and requirements vary from sector to sector. The most significant quality parameter between sectors is the amount of small gaseous inclusions, called seeds, which are allowed to remain in the molten glass. Seeds influence the aesthetics and service performance of glass products. For example, customers would not tolerate bubbles in auto windshields, but would not care about imperfections in residential insulation fiberglass. An illustration of the allowable seed content by sector is depicted in Table 2 (Ross 2003).

Table 2. Seed Quality by Sector

Glass Market	Seeds/Oz.	Relative Seed Quality
LCD Display		10x better than TV panel glass
TV Panel		10x better than float glass
Float/Flat		1,000 to 10,000x better than container glass
Textile Fiber		100x better than container glass
Tableware	< 2	10x better than container glass
Lighting Glass	~ 25	2x better than container glass
Container	10-20	10x better than funnel glass
TV Funnel	~ 200	2x better than wool insulation fiberglass
Insulation Fiber	~ 400	

The Approach

The glass industry has approached the development of a next generation melting system with several major efforts. Some of these have been conducted in a sequential manner, while others have been overlapping:

2001

- A workshop to discuss previous and current issues
- Establishment of a task force

2002

- Solicitation of feasibility studies for innovative melting ideas
- A technical and economic assessment
- Solicitation of advanced melting and refining technology development

Melting Workshop

With a growing segment of glass professionals believing that gradual improvements will not enable the industry to reach its goals and sufficiently enhance its competitive position, an effort was undertaken to explore radically different, more efficient ways to melt glass.

As a first step to explore innovative approaches to melting glass, the GMIC and DOE planned and conducted a full-day workshop titled "Glass Melting Technology of the Future" on February 22, 2001. Over 150 glass makers, vendors, engineers, and scientists from over 15 countries attended the workshop held in Washington, DC. This workshop brought together experts from industry and academia to discuss a variety of issues relating to glass melting technologies, past, present, and future. Speakers provided presentations on advanced rapid melting, rapid fining, plasma technologies, microwave melting, submerged combustion melting, and expert system control. At the conclusion of the workshop, a task force was established to actively move the process forward.

Next Generation Melting System Task Force

The Next Generation Melting System task force, created by employees of GMIC member companies, is composed of approximately 20 representatives from glass companies in all four major sectors, plus universities and suppliers. The task force has been instrumental in gathering opinions and guiding development criteria for a next generation melting system. The task force has developed benchmarks of current technologies and performance criteria to evaluate new ones. Sample benchmarks include capital cost/ton of glass produced, energy efficiency (million Btu/ton of glass), operating cost/ton of glass produced per year, and energy cost/ton of glass produced per year.

Inventions Solicitation

While the task force was establishing criteria, another activity was undertaken to solicit new ideas for melting technologies. On January 2, 2002, the Department of Energy, Office of Industrial Technologies issued a solicitation requesting applications for innovations and inventions from small businesses, academic institutions, and individual inventors. A special portion of the solicitation was devoted to feasibility studies for new and innovative technologies to be employed in melting glass, which would provide up to four, $40,000 grant awards. Responsive proposals were to demonstrate the feasibility of substantially reducing energy requirements and capital cost per unit of glass, while maintaining glass quality and producing equal or lower emissions compared to traditional methods. The solicitation closed on March 4, 2002, and three feasibility study awards for glass melting were announced on June 5, 2002. The award titles and participants are as follows:

- Selective Batching for Improved Commercial Glass Melting. This project, proposed by Alfred University, is examining whether adding different materials to the batch could in itself lower the temperature required for melting.
- Monitoring of Refractory Wall Recession Using Radar Techniques. This project, proposed by University of Missouri-Rolla, is evaluating a method to determine whether a furnace campaign can be extended.
- Monitoring of Refractory Wall Recession Using High Temperature Impact-Echo Instrumentation. This project, proposed by the University of Dayton, is also evaluating a method to determine whether a furnace campaign can be extended.

Activities on these three projects began in August 2002. However, results from these efforts will not be available until September 2003 (DE-PS36-02GO90014 and I&I).

Technical and Economic Assessment

In order to better understand the technical challenges, past technology improvement efforts, and current melting processes within the glass industry, DOE contracted with the GMIC in the spring of 2002 to conduct a technical and economic assessment. The technical and economic assessment provides a starting point in formulating approaches to overcoming technical hurdles. The document created will be an invaluable reference document for the industry as a whole and provide insight into today's state-of-the-art technology, and will document recent, significant development efforts.

The assessment has separated the components of glass melting into key elements, and will describe: the current understanding of chemical and physical processes; how current melting technologies are compatible with optimizing each process; what barriers exist which limit optimization or commercialization; what alternative melting technologies have learned about overcoming the barriers; how the economics of glass production could be impacted; and which areas will be most significant in defining projects for the development of a next generation melting system.

The principal investigators for the assessment, Philip Ross and Gabe Tincher, have engaged key experts, conducted in-depth literature and patent searches, assessed technological, environmental, and economic barriers, approaches, opportunities for improvements and barriers. In addition, for several technology approaches that had been previously pursued, basic principles, achievements, reasons for non or incomplete implementation, and areas for possible additional work were identified. The principal investigators also held a facilitated workshop with 15 well-recognized experts in glass melting where scenario analysis was conducted - on significantly higher energy costs; much more stringent environmental pressures; and both higher and lower cost of capital - to gain insight into how significant changes in drivers would affect technology options (Ross and Tincher 2003).

Assessment Results and Findings

More than 525 technical literature articles and nearly 300 patents were identified during the course of the assessment. The analysis of these articles and patents has been grouped into 18 technical and economic issues associated with glass melting technology improvements, as depicted in Table 3.

In addition, over 75 companies and institutions were interviewed. Observations from these interviews revolved around eight key themes, as follows:

- Quality requirements to be competitive often justify capital and operating costs for melting
- Energy savings are driven only by net cost savings
- Higher operating costs may be acceptable if higher throughput and capital productivity can be realized
- Glass industry technical and economic horizon is short-term
- All traditional glass segments are adverse to technical and economic risk

Table 3. Technical and Economic Issues

Issue	Description
Glass quality improvement	Defined by quantified values representing a number of physical properties
Manufacturing flexibility	Ability to address operating variables such as glass chemistry, glass color, throughput rate and product quality
Raw material oxide source selection	Oxide source selection influences physical properties of final glass product
Raw material beneficiation	Processing to improve the quality of the minerals used as raw materials for glass
Recycled cullet use	Glass production with increased utilization of recycled glass cullet not only reduces raw material requirements and reduced landfilled waste, it also reduces energy requirements in melting by about two to three percent for each ten percent increase in cullet usage (EC 2000)
Batch preparation/agglomeration	Methods to prepare batch materials to promote the melting process
Batch/cullet preheating	Preheating batch materials to reduce melting energy requirements in the furnace
Enhanced heat transfer	Increasing convective or radiative heat transfer to speed the glass fusion process
Waste heat recovery	Technology to recover and utilize combustion gases from the glass furnace
Fusion (sand solution) process	Drive the rate of solution of batch components
Zonal separation	Separation of each phase of the melting process into distinct zones
Refining (seed removal)	Removal of gaseous inclusions (seeds) from the glass
Chemical and thermal conditioning	Conditioning of molten glass to ensure thermal and chemical homogeneity
Process controls	Instrumentation that provides meaningful measurements to control the melting process
Environmental compliance	Technologies that address air emissions and solid waste disposal
Lower capital cost	Reducing capital investment per unit of glass production
Lower operating cost	Reducing operating labor, material, and energy costs per unit of glass production
Lower environmental compliance cost	Reducing costs to meet regulated environmental requirements

- Although melting concerns, particularly environmental issues, are common to most glass producers, perceived differences between segments limit interest in collaboration
- There is no significant interest in a large-scale melting initiative unless key drivers change
- A clearer view of future energy, capital, and environmental costs could provide drivers to change melting practices, melting development and interest in collaboration

Many of these observations are not unique to the glass industry, but are common to the basic materials and process industries. In most of these industries, energy accounts for a relatively high portion of total operating costs. Glass is somewhat different since there are multiple, distinct segments that compose the glass industry.

Additionally, the assessment provides detailed information about several key development efforts that have occurred. Table 4 depicts several of the more significant efforts that are highlighted (Ross 2003).

Although the technical and economic assessment has not been published yet, presentations on the results have been shared at the DOE Industrial Technologies Glass Project Review in September 2002 and at the Glass Problems Conference in October 2002, and an article has been published in the January 2003 edition of the American Ceramic Society Bulletin (Ross and Tincher 2003).

Glass Solicitation

On August 5, 2002, the Department of Energy, Industrial Technologies Program issued a solicitation requesting applications for cost-shared research, development and demonstration of innovative glass technologies that will reduce energy consumption, reduce environmental impacts, and enhance economic competitiveness in the U.S glass industry. This solicitation contained two topics of particular interest to next-generation melting. These two topics were:

- Technologies for innovative glassmaking (melting) - Development of innovative glassmaking (melting) technologies that significantly reduce the gap between theoretical and actual energy usage. These technologies will have improved combustion efficiency and/or improved heat recovery.
- Advanced refining - Development of more energy-efficient processes for refining and delivery of glass to the forming machines. Refining may be through thermal, mechanical, or chemical means.

Table 4. Key Technology Development Efforts

Technology	Summary
Submerged Combustion	A process in which fuel and oxidant are fired directly into the bath of material being melted. A high heat transfer rate is accomplished by turbulent mixing of the bath materials. The technology is being used in Ukraine for mineral wool manufacture. Development activities to extend the technology to other applications are continuing.
PPG Industries' P-10 Process	A segmented approach in which the glass fusion process was optimized for each step. The technology was developed and employed in the 1980s (two development units and one commercial unit), and while technically successful, high operating costs forced PPG to stop production using this process. PPG retains proprietary rights to much of the technology developed.
Gas Research Institute's Advanced Glass Melter	A process based on suspension heating of the batch material and thin-film glass fining. A demonstration unit was developed in the 1980s for fiberglass production, but technical challenges limited the run to less than 10 days.
Batch and Cullet Preheating	Several techniques have been developed to utilize waste heat from the furnace, and a few units have been installed in Europe. The most recent development advancement entails the use of an electrostatic batch preheater system. This effort, led by BOC Gases, has successfully conducted a pilot-scale demonstration.
Plasma Melting	A process where electrical plasma-arc torches melt glass. Small-scale units have successfully demonstrated the concept for a few applications. Development activities to extend the technology to larger scales and other applications are continuing.
Thermochemical Recuperator (TCR) Reformer	An option for waste gas heat recovery.
Oxy-Fuel Firing	A process where oxygen replaces air in the glass furnace. Over one-quarter of the U.S. glass industry has adopted the technology. Efforts continue to optimize the process.

The solicitation closed on January 7, 2003 (DE-PS07-02ID14308). DOE has selected two proposals for negotiation that have advanced melting components, as follows:

- Energy Efficient Glass Melting: The Next Generation Melter. In this effort, the Gas Technology Institute of Des Plaines, Illinois will lead nearly a dozen partners including glass manufacturers PPG Industries, Owens Corning, Johns Manville, Corning, CertainTeed, and Schott Glass Technologies, to design and develop a high intensity glass melter based on submerged combustion melting technology. If successfully developed, fuel savings in excess of 20% over current technology and a significant reduction in capital costs are expected.

- High-Intensity Plasma Glass Melter. Plasmelt Glass Technologies of Boulder, Colorado, in collaboration with Johns Manville and Advanced Glassfiber Yarns, will develop and demonstrate a modular, high-intensity plasma melter. This novel approach uses an electric, dual-torch plasma transferred arc heating system and rotating reactor to melt a wide variety of glass formulations. Significant improvements in energy efficiency and capital productivity are expected if successful.

Coalition Building

A significant development in the glass industry in the last few years has been the opening up of communications between and within sectors. This has led to a new willingness to collaborate on common challenges whose solutions promise to yield significant improvements for the whole industry. The partnership between the DOE and the GMIC has facilitated this process. The "Energy Efficient Glass Melting – the Next Generation Melter" project mentioned earlier is a perfect example of this trend: six companies representing three glass sectors who compete amongst themselves, have come together to pursue a technology of common interest to each of them, overcoming their differences in the hopes of achieving progress that will truly make a difference. Without such cooperation, such a project would not likely be undertaken by any individual company on its own. This increasing willingness to work together is the true measure of progress in this industry.

Summary

While significant efforts have been undertaken to date in analyzing and planning a next generation melting system for glass production, much remains to be done towards the actual development of a system that will use energy more efficiently. In the past, many sharp minds and industrial companies have tried to develop advanced melting technologies on their own, with limited success. This paper describes attempts over the past two years to facilitate the glass industry working together to enable dramatic reductions in energy intensity. To date, achievements include technical workshops, establishment of committees, a technical and economic assessment, collaborative efforts, and submission of project proposals. These efforts are hopefully the start of the next big step in reducing energy requirements for glass melting.

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