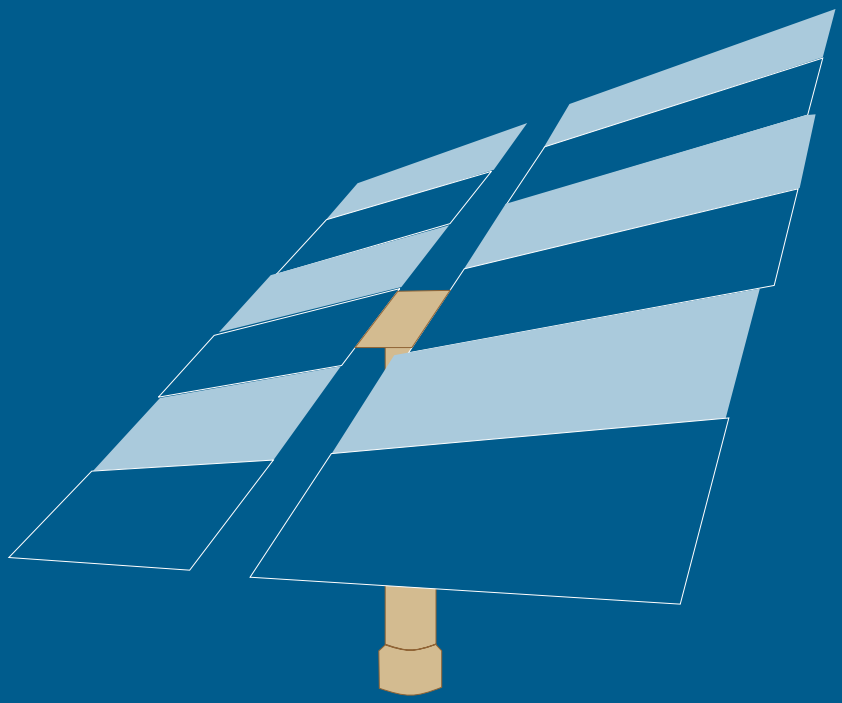
INDUSTRIAL TECHNOLOGIES PROGRAM

GLASS TECHNOLOGIES

The Legacy of a Successful Public-Private Partnership



U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Mission

Enhancing the nation's energy security, competitiveness, and environment by transforming the way U.S. industry uses energy.

Vision

American industry leads the world in high-impact, clean, efficient, and flexible energy technologies and practices.

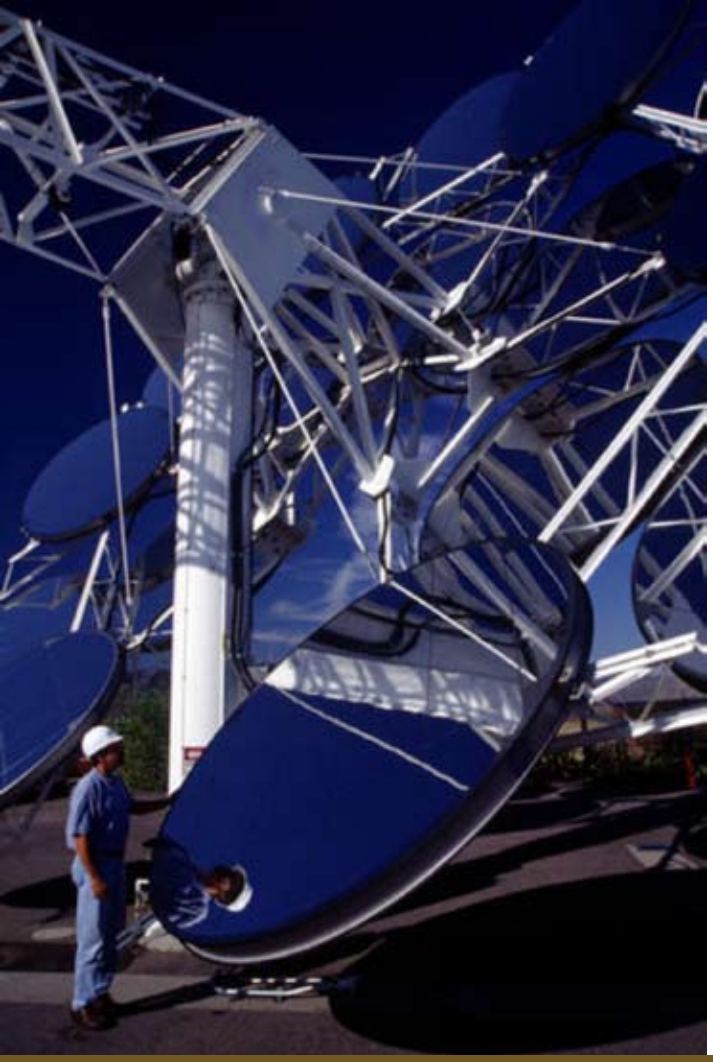
About the Industrial Technologies Program

The Industrial Technologies Program (ITP) is the key federal program addressing industrial energy consumption, and is part of the Department of Energy's Office of Energy Efficiency and Renewable Energy. Together with our industry partners, we develop real-world energy solutions that lift industrial energy efficiency and flexibility to new levels. Our technological breakthroughs catalyze changes in industrial processes, reducing demand for energy in ways the market alone can not achieve.

ITP plays a critical role in our nation's efforts to:

- **Save energy**
- **Increase fuel flexibility**
- **Reduce emissions and waste**
- **Promote economic growth and competitiveness**

ITP's Glass research partnership has worked with the Glass Manufacturing Industry Council and other industry partners to provide technology solutions that have broad applicability and high energy savings impacts. As a result, innovative technologies are boosting the energy productivity of the U.S. glass industry.



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Executive Summary

This document discusses the highlights and accomplishments of the glass-focused energy efficiency activities conducted by the U.S. Department of Energy's (DOE's) Industrial Technologies Program (ITP) since the mid 1990s. These activities include cost-shared research, as well as technology planning, partnership development, and analytical studies. The document will also provide information on continuing opportunities for improving energy efficiency in glassmaking operations, in order to facilitate technology transfer.

Background

ITP is the sole DOE program focused on reducing industrial energy demand. ITP has been engaged in reducing industrial energy consumption through the development of advanced technologies since the late 1970s. Of particular interest to the glass industry was work sponsored by ITP (then known as the Office of Industrial Programs) in oxy-fuel combustion during the 1980s, which helped the eventual commercial development of this technology which is now used extensively throughout the glass industry.

In the mid-1990s, ITP (then known as the Office of Industrial Technologies) began a planning effort known as Industries of the Future (IOF). The glass industry was one of nine industries selected to participate in IOF efforts, due to the glass industry's high energy intensity and significant energy consumption – the U.S. glass industry consumes around 250 trillion Btu of energy annually. Significant efforts were conducted in planning and analysis to ensure that Federal investments provided significant energy savings and met technical priorities for the glass industry. These efforts also built on research funded by ITP prior to the IOF effort on oxy-fuel firing, oxygen-enriched air staging and an advanced temperature measurement system, which became commercial technologies.

Since the inception of the Glass IOF program in the mid 1990s, ITP has funded about 35 glass research projects, resulting in both commercial and emerging technologies; two R&D 100 awards, and significant in-

tellectual property in the form of patents and copyrights. The program has helped the glass industry supplement their limited research funding for process technology, especially in light of the reduction in research staffing and funding at many glass companies which has occurred over the past decade. Also, by sharing the risks and costs associated with developing new process technology, ITP allows technologies to be investigated that otherwise may not be funded.

Partnership

From the beginning of the IOF partnership efforts, ITP realized that there was no single organization that represented the technology needs for the glass industry. To maximize the potential for collaboration, ITP encouraged the glass industry to form an umbrella organization to represent its interests. As a result, the Glass Manufacturing Industry Council (GMIC) was formed in 1998. From the original seven founding members, GMIC has grown into a vibrant organization representing around 40 glass companies and other organizations.

To formalize the partnership between GMIC and ITP, a compact was signed by GMIC and ITP in February 1999. This voluntary agreement expressed the intentions of the parties to pursue collaborative efforts through the identification and performance of research, development, and technology demonstrations of mutual benefit to U.S. glass companies and the Nation. Additionally, an Allied Partnership agreement was signed between DOE and the GMIC in June 2003. This agreement formalized a relationship that will lead to the implementation of numerous energy improvement technologies and techniques across the glass industry.

Major Research Projects

In the period between 1996 and the present about 35 major research projects were conducted. The majority of these projects were focused on improving the energy efficiency of furnace operations, which is common to virtually all glass sectors and usually accounts for the largest proportion of energy consumption. Efforts included furnace modeling, refractory corrosion, and alternative melting techniques – technologies that could be applied to multiple glass sectors. Additional research and development included: efforts on sensors and controls, extending oxy-fuel technology, and preheating of batch and cullet.

The glass industry cost-sharing on these projects averaged around 35% of total project costs. The vast majority of these projects were selected through competitive solicitations, and annual review meetings were conducted to ensure that projects were on track to meet their technical objectives and to encourage technology transfer. Brief summaries of commercialized, knowledge-based, and emerging technologies are presented, and a full list of projects is included.

Conclusions

Over the past decade, ITP has successfully partnered with the glass industry. Overall, the ITP program has made a significant difference to the glass industry by:

- Providing new knowledge such as the high-temperature glass properties database.
- Developing new technology including four ITP-sponsored commercial technologies: oxy-fuel firing, oxygen-enriched air staging, advanced temperature measurement system, and high-luminosity low-NO_x burner. Several other technologies have the potential to emerge into the marketplace.
- Solving technical barriers and problems through the research and development of technology.

- Providing energy savings and energy saving protocols though the application of commercial technologies and protocols in the marketplace.
- Developing new learning tools such as a distance learning class under development to share knowledge of energy efficiency opportunities to plant personnel in the glass industry.
- Encouraging new collaborations by providing the requisite framework and helping the GMIC establish itself as a major agent for broad collaboration within the glass industry.
- Identifying future efficiency opportunities through the development of the technology roadmap and energy bandwidth documents.

However, ITP realizes that technical success alone will not ensure market acceptance of technologies developed. Increased efforts are required to ensure that adequate business planning is conducted, the value proposition is appropriate for end-users, and that there are champions for the technology. Otherwise, the value of the technology will not be maximized.

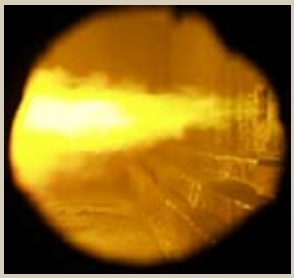
Finally, to ensure the legacy of the ITP glass program, a dedicated website has been developed to archive research findings, program documents, and other results. The URL for this website is http://www.osti.gov/glass. This website will be a valuable repository of knowledge for the entire glass community.

Commercial Technologies

Four technologies funded by ITP are currently being used by the U.S. glass industry. A brief description and ITP's role in the development of each technology are described below.

Oxy-Fuel Firing

Oxy-fuel Combustion Saves Energy and Reduces Emissions



Oxy-fuel firing uses oxygen instead of air in the high-temperature combustion process employed in glass melting furnaces. Burners specifically designed for oxy-fuel firing are employed to provide maximum efficiencies. Oxygen is provided to glass manufacturers by one of three primary technologies, depending on the economics for each glass facility. Glass manufacturers are using this process in all major glass sectors. ITP sponsored research exploring the technical and economic feasibility of using oxygen in the combustion process for industrial applications during the mid and late 1980s, including burner testing and combustion modeling. ITP also co-funded a demonstration project of the technology with Praxair at Gallo Glass. This technology, commercialized in 1990, is used in about one-third of U.S. glass furnaces.

Benefits:

- Reduced fuel use by 15-45%
- Reduced NO_x emissions up to 90%

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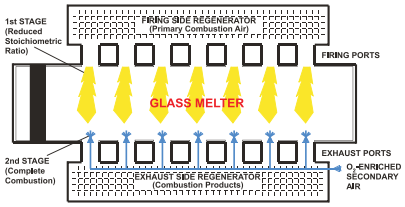
Oxygen-Enriched Air Staging

NO_x Emissions Reduced for Glass Furnaces



This technique controls NO_x formation and improves heat transfer in air-gas glass furnaces without interrupting furnace operation or adversely affecting product quality. The system stages combustion by holding back a portion of the combustion air normally provided during the earliest stages of combustion and flame development. The resulting flame is hotter and more luminous. Glass manufacturers can employ this technique in existing endport and sideport regenerative glass furnaces. ITP co-sponsored the first commercial demonstration of this technology, developed by the Institute of Gas Technology, at an Owens-Brockway facility in 1996. Licensing of the technology to Combustion Tec (now part of Eclipse), a major burner supplier for the glass industry, led to commercialization of the technology in the late 1990s.

Benefits:

- NO_x levels reduced 40-70%
- Cost-effective method to meet emission reductions

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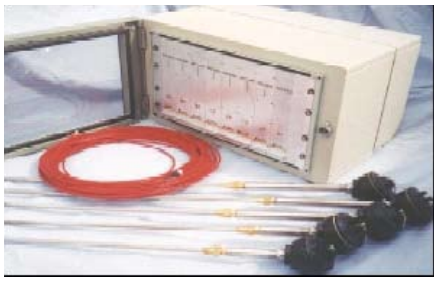
Advanced Temperature Measurement System

New Materials Lead to Development of Improved Monitoring Equipment



This temperature measurement system uses a calibration reference matrix built into the sensor and an associated remote signal processor and signal analysis software. A proprietary dielectric material used in the sensor helps avoid the normal failure mechanisms of other sensors. The sensor system performs real-time signal processing of the matrix data to provide accuracy in sensor readings. Glass manufacturers can use this sensor in their high-temperature melting furnaces. ITP sponsored the development of this sensor system by AccuTru in the late 1990s, and the technology was demonstrated in a Corning facility. AccuTru has been marketing this technology since its introduction in 2000, and continues to research further advancements for the technology.

Benefits:

- Improved fuel efficiency
- Improved process yield
- Extended equipment life

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PrimeFire 400: High-Luminosity, Low-NO_x Burner

High-efficiency Burner Lowers Cost and Emissions in Oxy-fuel Glass Melters

The PrimeFire 400 is an advanced flat flame burner designed for oxy-fuel glass furnaces which can be fitted into existing control schemes. This burner improves performance by modifying the fuel prior to combustion and then forming and burning soot in the flame. The PrimeFire 400 comes in four sizes with maximum capacities of 2MM, 4MM, 10MM and 20MM Btu/hr. All models can be fired using natural gas or fuel oil. Glass companies employing oxy-fuel glass furnaces can utilize this technology. ITP sponsored the development of this burner by the Gas Technology Institute. Begun in the late 1990s, the project included design, fabrication, and testing of both laboratory and pilot scale burners. Scale-up and plant demonstration testing followed at an Owens Corning facility, and subsequently at PPG Industries (separately funded by a DOE National Industrial Competitiveness through Energy, Environment, and Economics program grant). Licensing of the burner technology to Combustion Tec (now part of Eclipse), a major burner supplier for the glass industry, led to commercialization of the technology in 2004.

Benefits:

- Thermal efficiency increases up to 20%
- Reduces NO_x by up to 50%
- Extends furnace life

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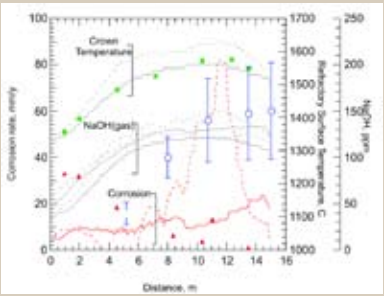
Knowledge-Based Results

Three projects funded by ITP have contributed to the scientific understanding and improvement of glass-making operations. A brief description and ITP's role in the development of each project are described below.

Modeling of Refractory Corrosion in Oxy-Fuel Glass Furnaces

Reduced Corrosion Leads to Increased Refractory Life and Furnace Efficiency



The use of energy efficient oxy-fuel firing in glass melting furnaces requires refractories that are more resistant to corrosion than those used in traditional air-gas melting. Researchers gathered experimental data, determined corrosion factors, and developed mathematical models to predict corrosion rates in several types of refractories. The results of the modeling work have been published in trade journals and incorporated in commercial furnace model codes, and thermodynamic data is available online. The results can be used to identify furnace conditions, furnace designs, and refractory compositions that lower corrosion rates. This project, funded by ITP and performed by Sandia National Laboratories, was completed in 2004.

Benefits:

- Increased energy efficiency and productivity
- Improved refractory life and product quality

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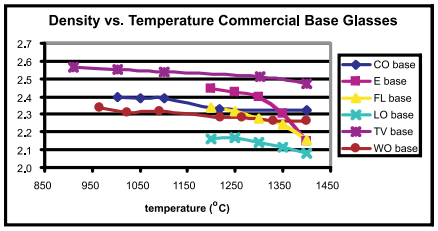
High-Temperature Glass Melt Property Database

Published Database Enables Improved Product and Process Modeling



The database, published in a 290 page book available for sale through the American Ceramic Society, contains information on many key glass melt properties for several glass compositional families. This data can be used by the entire glass industry to improve modeling capabilities, which will ultimately improve glass melting and forming processes. Accurate, improved modeling can also eliminate the need for costly experimental melts to test for proposed process changes. ITP sponsored the Center for Glass Research at Alfred University to develop this database. Data measurements for this multi-year project were completed in 2003, and the book providing the results was published in 2005.

Benefits:

- Improved efficiency
- Increased yields
- Reduced environmental impacts

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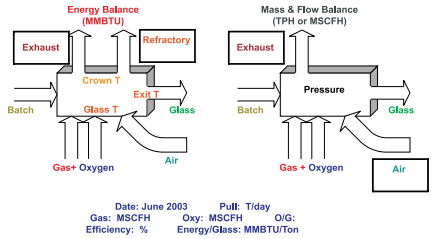
Oxy-Fuel Protocol

Detailed Process Evaluation Identifies Efficiency Improvement Opportunities



By better monitoring and characterizing oxy-fuel furnace operations through advanced measurement techniques and mass and energy balances, operational inefficiencies can be identified and energy saving changes can be recommended. This best practice was developed by Mississippi State University in cooperation with Eclipse Combustion and PPG Industries. PPG evaluated the protocol at one of their facilities and is exploring opportunities for additional technology transfer. ITP sponsored Mississippi State University to develop this energy-saving methodology. The protocol was completed in 2004.

Benefits:

- Improved efficiency
- Reduced environmental impacts

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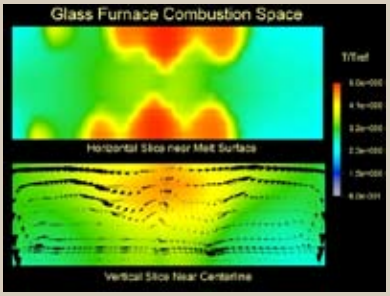
Emerging Technologies

Eight projects funded by ITP have the potential to provide significant benefits to glassmaking operations if they are adopted by the glass industry, and may become commercially available in the next two to three years. A brief description and ITP's role in the development of each project are described below.

Coupled Combustion Space Modeling



A three-dimensional combustion space/melt tank/batch melting model using real-world furnace data and conditions has been developed in order to better regulate heat flux distribution on the batch and glass melt surfaces both in existing and new glass furnaces. Argonne National Lab has led an industrial consortium, including several glass manufacturers, in the development of this model. Industrial consortium members are evaluating and validating the model for potential application.

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Submerged Combustion Melting

An innovative method injects the combustion flame directly into a pool of hot glass melt, yielding intense combustion, direct-contact heat transfer, and turbulent mixing. The Gas Technology Institute (GTI) is leading an industrial consortium including five glass manufacturers and other industry suppliers in the development and demonstration of this technology. GTI is testing glass melts in its pilot-scale melter.

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High Intensity Plasma Melting

An innovative, modular glass melter utilizes electric-based plasma melting and increases torch life and process stability. Plasmelt Glass Technologies, LLC is developing this technology; AGY and Johns Manville also contribute. Plasmelt is conducting exploratory glass melting trials on a wide variety of glass compositions and is continuing to improve process parameters in its pilot-scale melter.

Contact:

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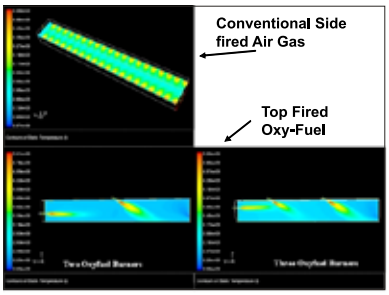
Advanced Oxy-Fuel-Fired Front-End System



Oxy-fuel-fired front-end technology provides significant improvements in energy consumption by replacing air-gas burner systems and optimizing heat transfer distribution. Owens Corning has developed this technology in collaboration with Eclipse Combustion and BOC Gases. Full-scale testing of the front-end system is underway in one of Owens Corning's fiberglass plants.

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Measurement and Control of Glass Feedstocks

A lased-induced breakdown spectroscopy (LIBS) instrument measures the chemical make-up of glass batch materials in order to detect contaminants and batch nonuniformity. Energy Research Company developed the technology and the associated analyzer. A long-term plant demonstration of the commercial instrument is ongoing at a PPG Industries facility.

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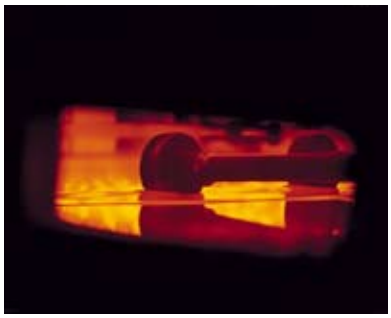
Model of On-Line Coating of Float Glass



A computational model of tin oxide deposition by chemical vapor deposition predicts growth rates on a float-glass line as a function of process parameters. Sandia National Laboratories and PPG Industries developed this model and tested it using data from laboratory experiments and measurements in a pilot-scale coating reactor at PPG's Glass Technology Center. The model, together with kinetic data describing the decomposition of the tin precursor and thermodynamic information for gas-phase species present during growth, can be obtained from Sandia.

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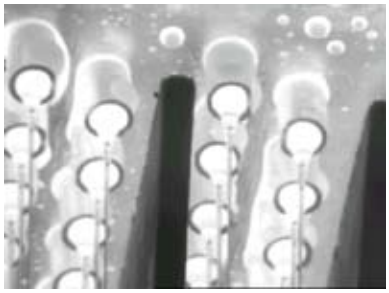
Improving Yield in Fiber Drawing



Through modeling and improved process control techniques for glass fiber drawing, reductions in break frequency for fiber drawing can be reduced by a factor of four. Cleveland State University, in conjunction with PPG Industries and Johns Manville, has led an industrial consortium in developing these improvements. The pilot-scale drawing tower has successfully demonstrated only one break in a four-hour period; technology transfer to the plant floor is being pursued.

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Monitoring and Control of Batch Carryover and Alkali Volatilization

A high-temperature laser-induced breakdown spectroscopy (LIBS) sampling probe measures the time-dependent batch carryover and alkali concentrations in the exhaust of glass furnaces. Sandia National Laboratories developed and tested the LIBS probe, in collaboration with the University of Alabama-Birmingham, and the Gallo Glass Company. A conceptual design has been developed for a low-cost, low-maintenance LIBS probe sampling system.

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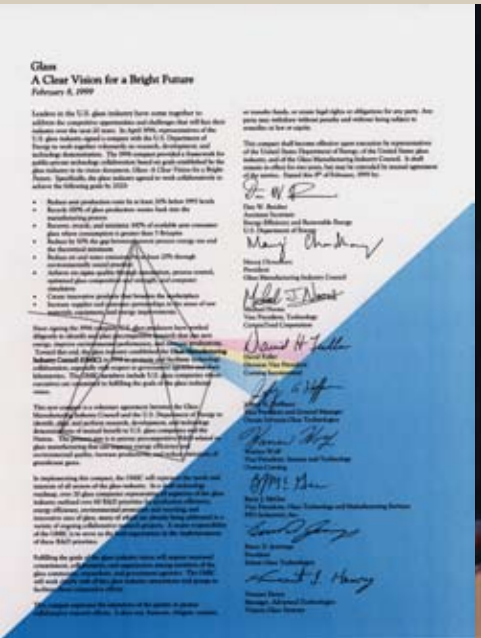
Partnership with the Glass Industry

To maximize the potential for collaboration, ITP encouraged the glass industry to form an umbrella organization to represent its interests, since no single organization represented the entire glass industry. As a result, the Glass Manufacturing Industry Council (GMIC) was formed in 1998. From the original seven founding members, GMIC has grown into a vibrant organization representing around 40 glass companies and other organizations.

A compact was signed by GMIC and ITP in February 1999 to formalize this government-industry partnership. This voluntary agreement expressed the intentions of the parties to pursue collaborative efforts through the identification and performance of research, development, and technology demonstrations of mutual benefit to U.S. glass companies and the Nation. The GMIC also served as an advisor during ITP solicitations – providing technology developers a connection with potential industrial partners.

Furthermore, an Allied Partnership agreement was signed between DOE and the GMIC in June 2003. This agreement formalized a relationship that will lead to the implementation of numerous energy improvement technologies and techniques across the glass industry. As part of these efforts, GMIC hosted or arranged several energy efficiency training workshops in subjects such as process heating and compressed air. The GMIC remains a primary conduit for ITP in providing technology solutions to the U.S. glass industry.

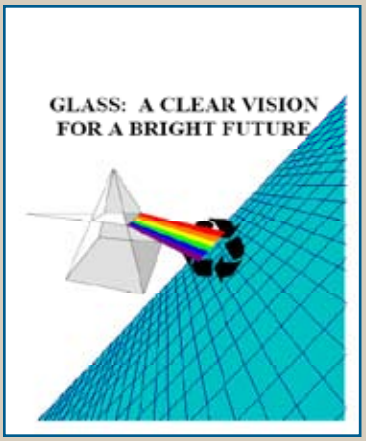
Through its interactions with the glass industry, ITP has been able to attract major industry players to participate in research and planning activities. Approximately 100 participants throughout the Nation have partnered with ITP over the past decade. Participation ranged from conducting research and providing specialized technical knowledge to providing cost-sharing assistance and facilities for demonstration testing. Participants include large glass manufacturers, niche glass manufacturers, industry vendors and technology suppliers, academic institutions, national laboratories, and other partners. A listing of known partners and participants is shown on page 24.


Glass
A Clear Vision for a Bright Future
February 8, 1999

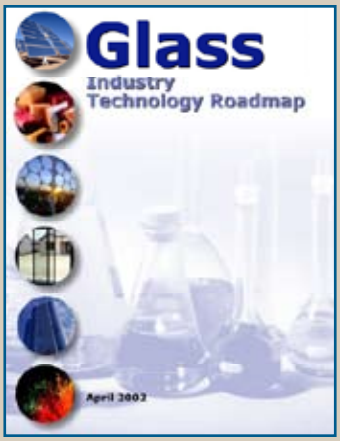
Technology Planning

Technology planning activities identified the highest priority needs in the glass industry and guided R&D efforts conducted by ITP, and included the development of the glass industry vision and technology roadmap – which ITP helped facilitate and the glass industry provided input. The glass vision document, "Glass: A Clear Vision for a Bright Future," was published in January 1996. This document spelled out primary goals and priorities, including a goal of reducing the gap between actual energy use and the theoretical minimum by 50% by the year 2020. A technology roadmap workshop was conducted in 1997, which ultimately led to the publishing of the "Glass Industry Technology Roadmap" in April 2002 by the GMIC. The roadmap identified technical barriers and priority research needs in four technical areas: production efficiency, energy efficiency, environmental performance, and innovative uses.

Vision Goals (2020)



- Operate with production costs at least 20% below 1995 levels;
- Recycle 100% of all glass products in the manufacturing process;
- Reduce process energy use from present facility levels by 50% toward theoretical energy use limits;
- Reduce air/water emissions by a minimum of 20% through environmentally sound practices;
- Recover, recycle and minimize 100% of reasonably available consumer glass;
- Achieve six sigma quality through automation, process control, optimized glass composition/strength, and computer simulation;
- Create innovative products that broaden the marketplace;
- Increase supplier and customer partnerships in raw materials, equipment, and energy im provements.



Strategic Goals

- 20% cost reduction
- 100% glass recycle in manufacturing
- 6 sigma quality

- Reduce the gap between actual and theoretical energy use by 50%

- 20% reduction in air and water emissions
- 100% post consumer recycling where consumption >5lb/capita

- Broaden market with new products

Technology Challenges

- Efficient Thermal Transfer
- Process Characterization and Modeling
- Process Measurement and Control
- Materials Limitations
- Functional Glass Properties
- Cost Reduction

Production Efficiency

- Advanced Process Control Systems
- Advanced Measurement Techniques
- Process Improvements
- High Temperature Materials
- Process Design

Energy Efficiency

- Integrated Furnace Models
- Improve Thermal Efficiency
- New Glassmaking Technologies
- Refractory Materials
- Glass Melter User Facility

Environmental Performance

- Emissions Characterization and Modeling
- Emissions Measurement and Control
- Pollution Prevention
- Process Modifications
- Post-Market Recycling

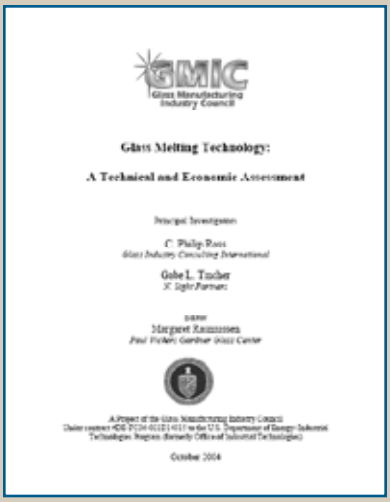
Innovative Uses

- Communications and Electronics
- Structural Uses
- Novel Uses
- Surfaces and Coatings
- Advanced Processing and Control

Other efforts in technology planning included several technology workshops. Sandia National Laboratories led an effort to produce a roadmap for glass coatings. Two workshops were conducted that focused on oxy-fuel firing, and another workshop focused on next generation melting – which served to define the level of industrial interest in collaborating in this area.

Analysis

Analytical studies were conducted by ITP to help identify opportunity areas and provide baseline data. These studies helped overcome the lack of benchmarking data in the glass industry. The "Energy and Environmental Profile of the U.S. Glass Industry" provides an analysis of energy consumption by process, and an overview of various processes used in the glass industry. "Glass Melting Technology: A Technical and Economic Assessment" provides insights on previous efforts for advanced melting technologies conducted both in the United States as well as many that have been investigated overseas. And the "Industrial Glass Bandwidth Analysis" provides an assessment of potential energy savings from implementing state-of-the-art technology as well as potential technology improvements. A second-stage bandwidth effort will take a closer look at the potential impacts of individual technology improvements and applications. These publications not only provide insight into glass manufacturing technology, but provide a sound basis for the pursuit of individual research topic areas.



Best Practices: Glass

ITP's Best Practices program has conducted many activities devoted to using existing technology to improve energy efficiency, and developed numerous resources for industrial use including software tools and publications. The glass industry has actively participated in many of these activities and utilized these resources.

For example, ITP has developed software tools that can help industry identify opportunities to save energy in several areas. A listing of ITP software tools and typical training topics are listed on page 23. Furthermore, ITP developed a series of glass-specific "Cost Reduction Now" factsheets for the following areas: Combined Heat and Power, Compressed Air, Industrial Assessment Centers, Motors, Process Heating, Pumps, and System Management.

ITP's Best Practices program has also provided limited financial assistance for identifying energy saving opportunities. Smaller facilities that qualify participate in ITP's no-cost Industrial Assessment Center program. Larger plants have competed for cost-shared assessments; glass plants selected for these assessments include:

- Anchor Glass (Warner Robins, GA and Jacksonville, FL)
- Corning (Greenville, OH)
- Johns Manville (Waterville, OH)
- Osram Sylvania (Exeter, NH)
- Visteon (Nashville, TN)

More recently, 10 glass company facilities were selected to participate in the first round of DOE's Save Energy Now Energy Saving Assessments program. Save Energy Now is part of a national campaign, "Easy Ways to Save Energy," initiated by DOE in 2005. The plants selected include:

- AFG Industries (Church Hill, TN)
- Anheuser-Busch Packaging Group (Houston, TX)
- Automotive Component Holdings, LLC (Tulsa, OK)
- Cardinal Glass Industries (Portage, WI)
- Corning Incorporated (Canton, NY)
- Osram Sylvania Products (Towanda, PA)
- Owens Corning (Jackson, TN)
- PPG Industries (Carlisle, PA)
- Saint-Gobain (Kansas City, KS)
- World Kitchen (Charleroi, PA)

Awards and Intellectual Property

ITP strongly encourages developers of promising technologies apply for prestigious awards, including R&D 100 awards named annually by R&D Magazine. Since 1990, ITP sponsored technologies have garnered 39 of these awards, including two for glass technologies:

- Oxygen-enriched Air Staging
- Coupled Combustion Space Modeling

ITP also encourages their project partners to protect potential intellectual property as a result of work conducted, including the filing of patent and copyright claims. During the past decade, over 150 patents have been directly attributed to technologies sponsored or advanced by ITP, including 10 patents for glass technologies:

Patent Title	Patent Number	Organization	Year Awarded
Apparatus for measuring the concentration of a species at a distance	7,027,150	Sandia National Laboratories–CA	2006
High-heat transfer low-NOx combustion system	6,939,130	Gas Technology Institute	2005
System and method for glass processing and temperature sensing	6,796,144	Battelle Memorial Institute (PNNL)	2004
Apparatus and method for in situ, real time measurement of properties of liquids	6,784,429	Energy Research Company	2004
Molybdenum disilicide composites	6,300,265	University of California (LANL)	2001
Molybdenum disilicide composites	6,197,247	University of California (LANL)	2001
Raining bed heat exchanger and method of use	5,992,041	Thermo Power Corporation	1999
Self-verifying temperature sensor	5,887,978	AccuTru International	1999
High-heat transfer, low-NOx oxygen-fuel combustion system	5,725,366	Institute of Gas Technology	1998
Self-verifying temperature sensor	5,713,668	AccuTru International	1998

ITP also encourages licensing agreements so that a broader portion of industry can utilize technologies developed.

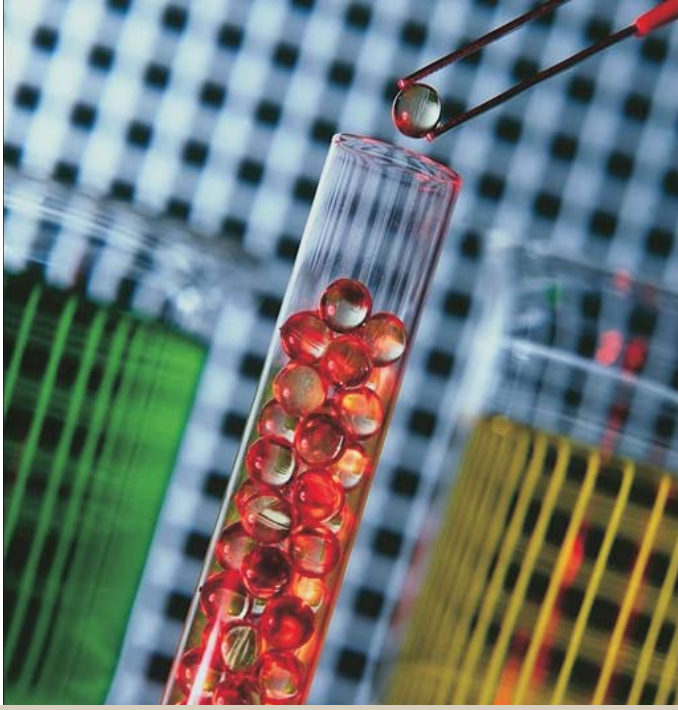
Other ITP Glass Research Projects

The table below depicts other ITP research projects that were not discussed previously. Some of these projects were technically successful, but are unlikely to move further forward into the marketplace without additional development efforts.

Energy Efficiency Performance Improvements	
Furnace Modeling	• **Glass Furnace Combustion and Melting User Research Facility:** This project designed a state-of-the-art user facility for researchers. The objective was to provide diagnostic tools, measurements, and analysis of the flows and chemical reactions, for purposes of improving combustion control, product uniformity, and refractory life. However, the facility was never constructed. (2002) • **Development, Experimental Validation, and Application of Advanced Space Models:** Researchers developed combustion space models for both air-fuel and oxy-fuel furnaces. Experimental data was generated and validated in float furnace operations, and the model was used to improve the efficiency of a float furnace during the rebuild process. (2000)
Materials-Related	• **Molybdenum Disilicide Composites for Glass Processing Sensors:** Scientists evaluated the production of molybdenum disilicide hybrid composite tubes and coatings for thermocouple sheath applications. Advantages of molybdenum disilicide tubes over conventional materials include: electrically conductive, stronger than ceramic refractory materials, and chromium-free. Plasma-spray forming techniques were established and optimized for creating these tubes. (2001)

Materials-Related	• **On-Line Chemical Vapor Deposition for Composites:** Researchers used a research reactor to determine identities and amounts of gaseous phase species present during chemical vapor deposition (CVD). The purpose was to investigate the CVD process used to coat float glass to determine the source of some present difficulties, to optimize the process, and to develop new coatings. (1999) • **Synthesis and Design of Intermetallic Materials:** Researchers developed processing methods for molybdenum disilicide ($MoSi_2$) based materials, such as plasma spraying/ spray forming and electrophoretic deposition. Activities also included development and characterization of $MoSi_2$-based high temperature structural materials with focus on $MoSi_2$-based composites, and plasma sprayed $MoSi_2$ materials and microlaminate composites. (1998)
Batch and Cullet Preheating	• **Electrostatic Batch Preheater System:** Researchers developed an advanced technology to preheat mixed glass batch and abate emissions from the waste gases of an oxy-fuel fired furnace. A full-scale demonstration of the technology was planned, but demonstration host site difficulties resulted in early termination of the project. (2002) • **Integrated Batch & Cullet Preheater System:** This project attempted to demonstrate the technical viability, system reliability, and economic benefits of batch and cullet preheating using raining bed preheating technology for both conventional preheated air and oxygen-fuel combustion. Demonstration host site difficulties resulted in early termination of the project. (2000)
Non-Furnace Operations	• **Enhanced Cutting and Finishing of Handglass Using a Carbon Dioxide Laser:** Scientists developed laser-enhanced cutting and finishing methods to dramatically decrease waste and improve productivity in the manufacture of handblown glass. A bench-scale prototype system was constructed using a sensor-controlled, moderate-power, CO_2 laser to precision-cut the glass and produce a finished edge. The portable prototype was demonstrated in industrial facilities. (2002) • **Integrated Ion Exchange Systems for High-Strength Glass Products:** Researchers evaluated integrated ion-exchange systems for soda-lime based composition in which strengthening times could be reduced by at least a factor of 2, and up to a factor of 5. Large potential markets exist in architectural, automotive, and specialty applications, but remain untapped due primarily to the high cost of chemical strengthening. (2001)

Sensors and Process Control	• **Advanced Process Control for Glass Production:** Scientists developed and implemented an advanced process control system that should increase the amount of high-quality product from the initial manufacturing step. The system integrated: (1) a model that relates process parameters (e.g., temperature, deformation, cooling rate) to final product quality; (2) a suite of novel, 3-D stress and temperature sensors for measuring process parameters; (3) a system for integrating and analyzing data from a wide range of sensors; and (4) cognitive control software for adjusting the process parameters to maintain product quality. (2002) • **Auto Glass Process Control:** This project developed a novel non-contact stress measurement method for improving quality control of automotive glass. A patent has been submitted for the method. In addition, a computer code for glass product forming was validated. Pacific Northwest National Laboratory is working with a software vendor to include the code in their commercial software program. (2002) • **On-Line Sensor System for Monitoring the Cure of Coatings on Glass Optical Fibers and Assemblies:** Scientists worked on developing a continuous, non-contact sensor to monitor coating cure at line speeds of up to one kilometer per minute. This sensor uses infrared spectroscopy to inspect 100% of the polymer coatings to assure proper curing. The information could be used to create a visual display, sound an alarm, or activate a feedback loop for process control. (2000) • **Dynamic Expert Systems Control for Optimal Oxy-Fuel Melter Performance:** Researchers attempted to develop an innovative dynamic expert system of controls for oxygen-enriched glass melting plants. Novel, non-intrusive laser-based diagnostic methods for temperature measurement were investigated. (2000) • **Redox State Sensor Technology in Glass Melts:** Researchers attempted to develop a robust sensor for reliably measuring the ratios of various redox components in a melt during processing. A redox sensor could then be integrated with a thermochemical model for predicting glass properties based on the chemistry of the melt and a control strategy for adding reductants or oxidants during glass production to improve the final product. (2000)
Environmental Performance	• **Development of a Process for the In-House Recovery and Recycling of Glass from Glass Manufacturing Wastes:** This project evaluated a separation technology for purifying and upgrading glass waste streams. Researchers studied imperfections and tested thermal and chemical methods to purify and upgrade the waste glass. An economic evaluation was conducted to ensure that the most technically efficient and cost effective method is chosen for further process development. (2003)



Glass Project Laboratory User Services (GPLUS)

The GPLUS program, which started in 2000, enabled many glass manufacturers to conduct small-scale scoping studies in collaboration with any of the DOE national laboratories – facilitating access to the vast technical capabilities and technologists found in the DOE national laboratories. The program was cost-shared by ITP and the glass manufacturer, and results have been provided to the GMIC to encourage technology transfer.

Over the past several years, nearly 30 of these scoping studies – each roughly equivalent to one month's time in the laboratory – were conducted in a broad range of subject areas related to improving energy and production efficiency, including glass properties, process behavior, sensors and process control, and melting and modeling. A listing of GPLUS projects is provided in the table below:

Glass Properties	• Application of Strength Test Data to the Design of Automotive Glazing With and Without Holes • Glass Properties Determination • High Temperature Viscosity Measurements • Mechanical Strength Studies of Automotive Tempered and Annealed Glass with Holes • Strength of Tempered Glass with Holes Including Stress Corrosion Cracking • Thermal Conductivity Measurement of Fiberglass • Thermophysical Properties of Glass
Melting and Modeling	• Application of Furnace Model to Oxy-Fuel Furnace for the Production of Amber Glass • Improvement of Oxyfuel Burner Design and Operations • Pollution-Free Fiber Glass with Reduced Melting Temperature
Sensors and Process Control	• Construction and Performance of an Aerosol Generation System for Calibration of In-Situ Laser Induced Breakdown Spectroscopic Measurements • Development of New Control Software for Integration of an Echelle Grating Spectrometer for Use in Laser Induced Breakdown Spectroscopic Measurements • High Temperature Thermocouple Degradation Study • LIBS as a Glass Melt Monitor • Millimeter Wave Diagnostics for Glass Fiber Drawing • Spectral Analysis and Imaging of Colored Glasses

Process Behavior	• Analysis of Refractory Metal Needles Formed During Molten Glass Extrusion • Asymmetrical Windshield Construction • Batch Reactions of a Soda-Lime-Silicate Glass • Dependence of Boron and Sodium in Flue Gas from a Borosilicate Glass Melting Furnace on Oxygen to Natural Gas Ratio • Dependence of Boron and Sodium in Flue Gas from a Borosilicate Glass Melting Furnace on Conditions in the Caustic Spray Tower and Electrostatic Precipitator • Foaming of E-Glass • Glass Coating Enhancement • Reduction in Corrosion of Refractories Using Encapsulated Glass Additives • Sulfate Fining Chemistry in Oxidized and Reduced Soda-Lime-Silica Glasses • Using Colored Cullet for Making Beautiful Glassware

Snapshot of the Glass Industry

Economic Summary

Value of shipments (2005)	$29.1 billion
Employment (2005)	118,500
Average hourly earnings (2005)	$17.91
Capital expenditures (2005)	$1.34 billion
Trade balance (2005)	-$1.24 billion

Energy Summary

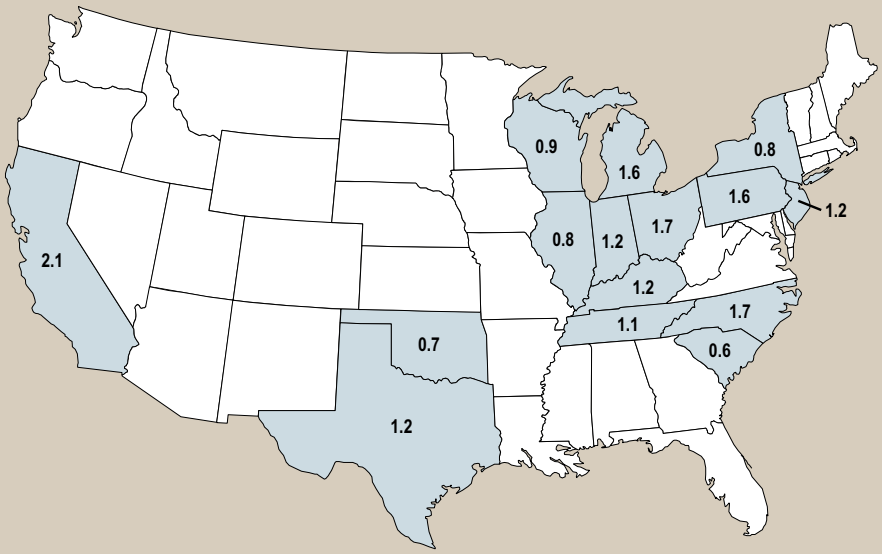
Net energy consumption (2002)	253 trillion Btu
Energy expenditure for heat and power (2005)	$2.49 billion

Sector Shipments (million tons)

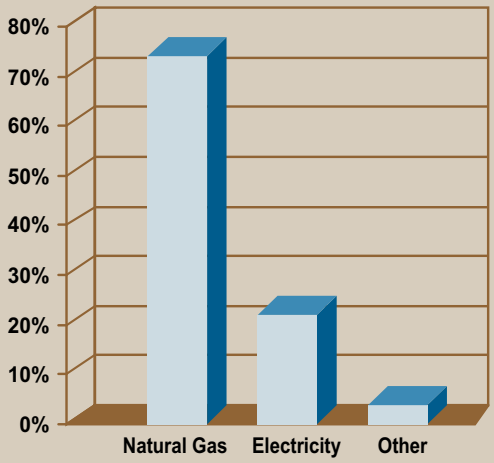
Container	9.4
Flat	5.3
Fiber	3.8
Specialty	1.7

Top 15 States Producing Glass Products

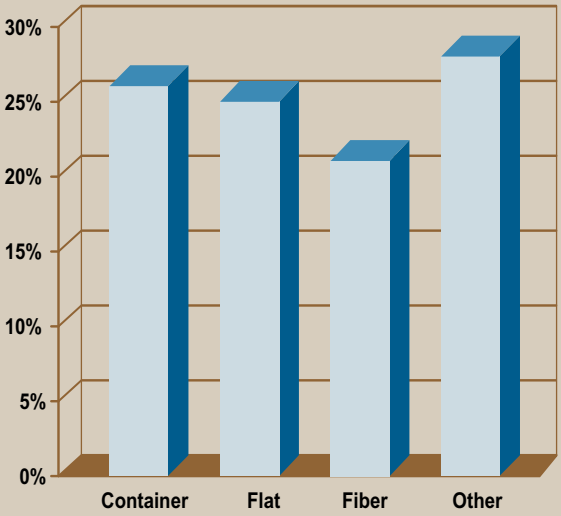
Value of Shipments in 2005 (Billions of Dollars)



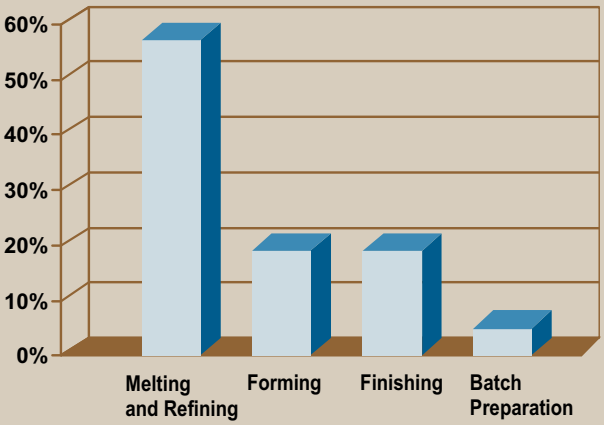
Energy Use by Fuel



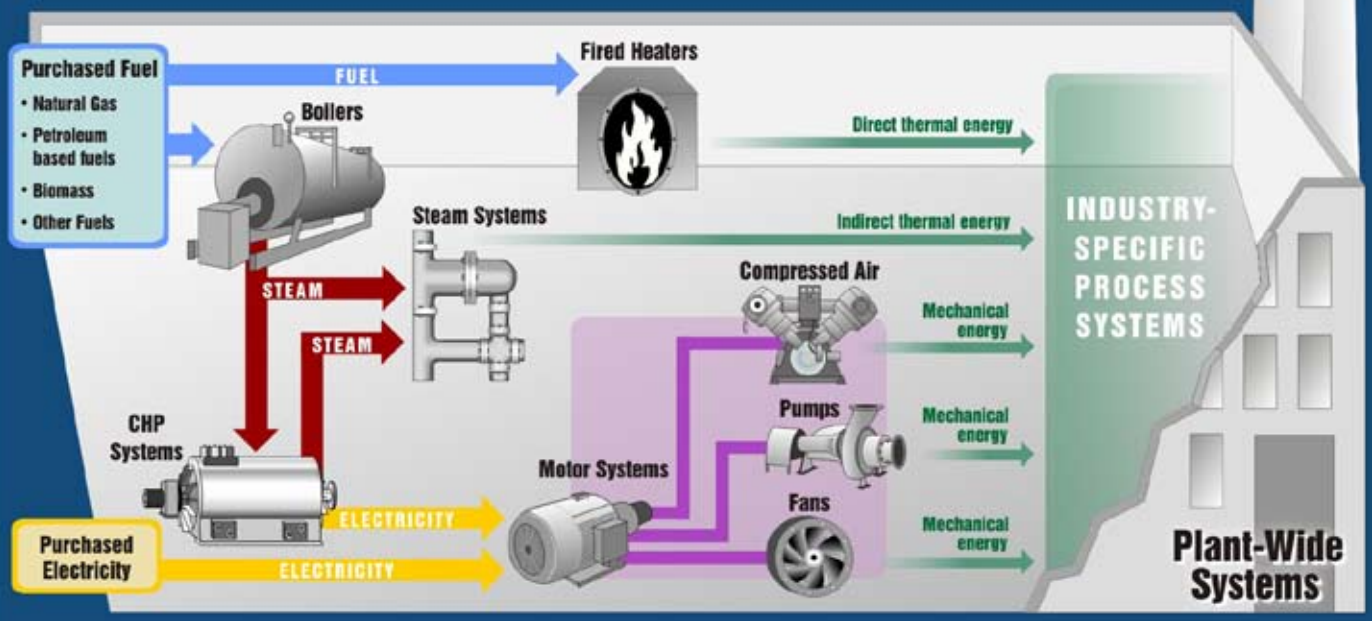
Energy Use by Sector



Energy Use by Glassmaking Process



To identify the top energy-saving opportunities, DOE offers free software tools and training.



ITP Software Tools are available to identify the best opportunities for saving energy and costs:

- AIRMaster+
- Chilled Water System Analysis Tool (CWSAT)
- Combined Heat and Power Application Tool (CHP)
- Fan System Assessment Tool (FSAT)
- MotorMaster+ 4.0
- MotorMaster+ International
- NO_x and Energy Assessment Tool (NxEAT)
- Process Heating Assessment and Survey Tool (PHAST)
- Pumping System Assessment Tool 2004 (PSAT)
- Quick Plant Energy Profiler (Quick PEP)
- Steam System Tool Suite

Training sessions provided by DOE help operators run plants and mills more efficiently. Sessions focus on effective use of system-wide and component-specific software tools. Training is available throughout the year and around the country.

Training Session Topics:

- Compressed Air Systems
- Steam Systems
- Process Heating Systems
- Pump Systems
- Fan Systems

DOE and industry partners periodically host one-day workshops to help plants and mills identify and implement energy and greenhouse gas savings opportunities.

Partners and Participants

Known partners and participants in the Glass IOF program are depicted below:

Glass Companies	• AFG Industries • AGY • Canandaigua Wine • Cardinal Glass • CertainTeed • Corning • Davis Lynch Glass • Emhart Glass • Fenton Art Glass • Fire & Light Originals • Gallo Glass • GE Lighting • Johns Manville • Kopp Glass • Leone Industries • Libbey • Longhorn Glass • Marble King	• Osram Sylvania • Owens Corning • Owens Illinois • Pilgrim Glass • Pilkington LOF • Plasmelt Glass Technologies • PPG Industries • Saint-Gobain Containers • Saint-Gobain Vetrotex America • Saxon Glass Technologies • Schott Glass Technologies • Sierracin • St. George Crystal • Techneglas • Thomson Consumer Electronics • Viracon • Visteon • Vitro
Industry and Technology Suppliers	• A.C. Leadbetter and Sons • AccuTru International • Advanced Control Systems Inc. • Air Liquide • Air Products and Chemicals • BOC Gases • Corhart • Eclipse/Combustion Tec • Engelhard • Energy Research Co. • Exotherm • Fluent • Gas Technology Institute • Laidlaw Drew • Lilja	• Maxon • McDermott Technologies • Merkle Engineers • Monofrax • NARCO/Harbison-Walker (now RHI Refractories) • New York Gas Group • Physical Optics Corp. • Plasma Processes • Praxair • Thermex • Thermo-Power • TransResources • U.S. Borax
Academia	• Brigham Young University • Center for Glass Research (Alfred University) • Clark Atlanta University • Cleveland State University • Georgia Institute of Technology • Mississippi State University	• Ohio State University • Penn State University • Purdue University • University of Alabama-Birmingham • University of Missouri-Rolla • University of Utah • West Virginia University

A STRONG ENERGY PORTFOLIO FOR A STRONG AMERICA

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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