Technology Strategies for the U.S. Glass Industry

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ABSTRACT

The American glass industry has taken important steps to define its future in response to changing market and business conditions. The industry faces exciting new opportunities but also serious competitive challenges. For the first time, U.S. glass manufacturers have come together to develop technology strategies to solve their most critical energy and environmental problems. At the heart of their technology strategy is a commitment to cooperate on precompetitive research that can create a competitive advantage for U.S. glass manufacturers. Advanced glass technology can lower production costs and create high-profit, innovative products to compete with other materials and foreign competitors. However, the complexity of new products and the intensity of global competition require that glass producers adopt new strategies for developing and applying innovations.

Profile of the U.S. Glass Industry

Glass is an integral part of the American economy and everyday life. It is essential for food and beverage packaging, for lighting homes and businesses, for high-speed communications, and for the construction of all types of buildings, from hospitals to high-rises. Glass is used for a myriad of consumer products ranging from ordinary cookware to televisions, and is an essential component in automobiles and trucks. The unique attributes of glass (transparency, chemical durability, optical properties, low cost, total recyclability) and the abundance of raw materials from which it is made account for the ubiquity of glass products in our society and ensure its continued success.

The U.S. glass industry generates more than 21 million tons of consumer products each year with an estimated value of $25 billion. Just over 150 thousand people are employed by the four segments of the industry, which include container, flat, fiber, and specialty (pressed and blown), or by firms manufacturing products of purchased glass. Their hourly average wage is $14.50, which is above the manufacturing average of $12.97 per hour (DOC 1998a).

Glassmaking is one of the most energy-intensive processes in U.S. industry. In theory, about 2.2 million Btu of energy are required to melt a ton of glass, but in reality, it takes twice that much because of inefficiencies and losses. Direct annual energy consumption is about 250 trillion Btu, and glass manufacturers spend about $1.37 billion (1996) on energy purchases annually (EIA 1997 and DOC 1998a). These energy expenditures account for about 11% of the industry's total production costs. As a percentage of sales, energy costs are roughly four times the manufacturing average: 7.4 percent versus the manufacturing average of 1.8 percent (DOC 1998a).

Environmental regulations restricting air emissions have had a strong impact on the glass industry over the past few decades. Although 80 percent of the fuel used in glass furnaces is relatively clean natural gas, emissions of NO_x, SO_x, and particulates continue to be an issue (EIA

1997). Equipment has been added and processes modified to meet increasingly stringent requirements. In the past decade, manufacturers have made great strides in increasing furnace efficiency and reducing the environmental consequences of fuel combustion in glass furnaces. For example, the introduction of oxy-fuel firing, in which gas is burned in a pure oxygen environment, has reduced emissions of greenhouse gases and critical air pollutants such as NO_x by about half. The industry spent a total of $285 million on pollution abatement (capital and operating costs) in 1994 (DOC 1996).

Although there are many commonalities in the processes that transform raw materials into molten glass, the chemistries of the glass as well as the fabrication methods vary significantly among the four major segments of the glass manufacturing industry. The different products, processes, and pressures in each of these industry segments have historically kept them somewhat isolated from each other.

The container sector produces the most tonnage with 9.2 million tons of production per year. It is a significant energy user that produces bottles and other containers that compete with plastic, aluminum, steel, and paper. Four main companies dominate this sector as a result of past mergers and consolidation. This segment includes128 furnaces with a typical output of 250 tons per day. Most furnaces are regenerative furnaces (102 furnaces); 24 furnaces are oxy-fuel fired (Ross 1998).

The flat glass industry is dominated by five major firms that produce 4.6 million tons of glass per year. Products are used mainly for windows in buildings and automobiles and for architectural features. This segment consists of 36 regenerative furnaces with a typical output of 600+ tons/day. The first oxy-fuel furnace went into operation in April 1998 (Ross 1998).

The fiber glass sector produces about 3 million tons of product per year and is dominated by five large manufacturers. Products include a variety of insulation materials and textile products. Of the furnace population that is 75-100 tons/day, about half are unit melters (non-regenerative furnaces with only modest waste heat recovery) and about one-quarter are oxy-fuel. Of the furnaces with output of 100-150 tons/day, about half are oxy-fuel and about half are unit melters (Ross 1998).

The specialty or pressed and blown segment encompasses a broad variety of products ranging from tableware, cookware, lighting, scientific products, and television tubes. This segment produces about 2 million tons of glass products per year. Typical furnace size is 75 tons/day. Oxy-fuel furnaces represent roughly 35 percent of the furnaces in this segment (Ross 1998).

Since 1945, the container and flat glass segments of the industry have become more streamlined – a result of competition from other materials, excess capacity, and rising costs for labor, energy, and environmental compliance. At the same time, new glass markets have opened up in the specialty glass segment with the advent of fiber optics and other new products. The industry is now more efficient and closely aligned with customer needs and increasingly dependent on new and improved products.

Although market opportunities are expanding, all of the glass sectors must increasingly compete with various materials (e.g., plastics, aluminum) that may offer lower cost, lighter weight, better strength or other competitive advantages. In the future, glass companies must be able to provide superior products with unique properties that make them more desirable than products made from other materials. These new glass products will require the development of novel process technologies that reduce production costs and enhance desirable characteristics.

Innovations in glass composition and glass properties will be needed to increase the value of glass to consumers and support its expansion into completely new markets.

To remain competitive in the future, the glass industry must develop strategies and technology to address its critical energy, environmental, and economic concerns. However, few glass company can devote sufficient financial resources to accomplish the necessary research and development (R&D). Capital is in short supply, as one might expect in such a mature industry with low margins; profits per dollar of sales are around 4.3 cents compared with 10.6 cents in the chemicals industry or 6.3 cents for all manufacturing (DOC 1998b). The glass industry spends only about one percent of sales on research, whereas the average for all of U.S. industry is three percent (NSF 1996). Since industry alone cannot individually pursue the new strategies and technologies vital to remain competitive, the industry must consider research partnerships and cooperative funding efforts to achieve its goals.

Collaboration in a Competitive Environment

Until recently, competition and segmentation within the glass industry prevented its members from effectively partnering on technology research and development issues. Although the glass industry is sometimes viewed as resistant to change, they have shown an ability to quickly adapt if a solution addresses a clear need. Oxy-fuel firing of furnaces is a case-in-point. The technology for oxy-fuel, which lowers NO_x emissions and increases throughput for a given furnace footprint, was first introduced around 1990 and in a span of eight years, 24 percent of the glass industry had converted over to this new technology.

The current combined pressures from alternative materials, foreign producers, and thinly stretched R&D resources have prompted the glass industry to seek a collaborative solution. Such a solution presented itself when the Department of Energy's Office of Industry Technologies (OIT) offered to partner with the domestic glass industry to help increase energy efficiency, reduce waste, and increase productivity as part of its Industries of the Future strategy.

The Industries of the Future model is simple and flexible. First the industry as a whole is asked to anticipate the challenges it is likely to face in the future. It then develops a unified strategic vision of where it needs to be in 20 to 25 years to remain globally competitive. Based on the broad goals identified in this vision, the industry then develops a technology agenda or "roadmap" that specifies the steps necessary to achieve the vision. Finally, the strategy is implemented through collaborative partnerships composed of private companies, suppliers, trade associations, research organizations, and government agencies. The resulting Glass Industry of the Future will maximize the limited glass company R&D resources, allow an industry-wide response to energy and environmental issues, and gain streamlined access to federal scientific resources.

In January 1996, the glass industry outlined its long-range vision for maintaining and building its competitive market position in the document *Glass: A Clear Vision for a Bright Future* (Glass 1996). Later that year, the industry reaffirmed its commitment to the goals contained in this vision by signing a compact with Secretary of Energy Hazel O'Leary. This partnership enables the industry and the federal government to align their R&D efforts to meet common goals. The glass industry will reap the benefits of technology development that can enhance its worldwide industrial competitiveness while at the same time contribute to the Nation's energy efficiency and environmental quality.

Table 1. Glass Industry Goals

1. Reduce unit production costs by at least 20% below 1995 levels
2. Recycle 100% of all glass production wastes back into the manufacturing process
3. Reduce by 50% the gap between current process energy use and the theoretical minimum
4. Reduce air and water emissions by at least 20% through environmentally sound practices
5. Recover, recycle, and minimize 100% of available post-consumer glass where consumption is greater than 5 lbs/capita
6. Achieve 6 sigma quality through automation, process control, optimized glass composition and strength, and computer simulation
7. Create innovative products that broaden the marketplace
8. Increase supplier and customer partnerships in the areas of raw materials, equipment, and energy improvements.

The glass industry vision recognizes the importance of past technological achievements and the potential of future technological advances to accomplish a variety of glass industry goals. These goals, listed in Table 1, will be instrumental in guiding glass technology priorities among glass manufacturers, government technology programs, and research performers within universities and national laboratories.

Following publication of the glass vision, four subcommittees were formed to begin developing a *technology roadmap.* When complete, the roadmap will provide a comprehensive blueprint of the research necessary to achieve the market, business, and technology goals identified in the glass vision. Each subcommittee addressed one of the four critical research areas outlined in the vision:

- Production Efficiency
- Energy Efficiency
- Environmental Protection and Recycling
- Innovative Uses for Glass.

Determining Technology Priorities

Recognizing the importance of technology planning to market success, the U.S. glass industry held a *Glass Technology Roadmap Workshop* in April 1997 (Eisenhauer et al. 1997). This collaborative workshop brought together experts from the glass industry, universities, and the national laboratories to help identify key targets of opportunity, technology barriers, and research priorities in the glass industry. The workshop addressed the needs of the entire glass industry, including the flat, container, specialty, and fiber glass sectors.

Workshop participants explored in detail the critical research needs in the areas of production efficiency, energy efficiency, environmental protection and recycling, and innovative uses of glass.

Production Efficiency. Improving the efficiency of glass production, including improved manufacturing processes and new techniques that maximize glass strength and quality, will allow industry to increase quality product yield as well as reduce energy consumption, waste generation, and production costs.

Energy Efficiency. Development of more energy-efficient manufacturing processes and technologies will help the industry save significant energy and improve the competitiveness of glass products. Since the majority of energy consumption in the glass industry occurs in the melting and refining processes, research should focus on technology advancements in those areas.

Environmental Protection and Recycling. Environmental Protection and Recycling focuses on challenges and opportunities to reduce emissions and waste in the glass industry through leaner and cleaner processing as well as increased recycling.

Innovative Uses of Glass. To meet the challenges of the future, the U.S. glass industry must broaden the use of glass in existing markets and support research to create completely new and innovative uses for glass by investigating new glass compositions, developing a better understanding of glass properties and interactions, and modifying and improving essential glass making processes.

During the workshop, participants identified over 130 specific research needs in the four areas, of which about half were considered to be priority. These research ideas were analyzed to determine the time frame in which each research activity is expected to have an impact in a commercial application or product: near (0-3 years), mid (3-10 years), and long (beyond 10 years). In addition, some research is expected to continue over all time periods and produce valuable results in each. The result of this process was an agenda of selected high-priority research needs organized by time frame that will serve as a guide for creating a robust glass industry R&D portfolio. This research agenda is illustrated in Table 2 (Eisenhauer et al. 1997).

The Glass Manufacturing Industry Council

The success of the roadmapping workshop led many glass industry leaders to recognize the value of working together to solve the tough challenges the future would hold. However, pursuit of the priority technology areas would require an increase in participation, collaboration, and organization among all members of the glass community, something that the industry had historically failed to do. No existing association represented the interests of all sectors of the industry. To address this problem, key representatives of glass producers met in November 1997 and expressed the need to create an umbrella organization to serve as a focal point for technology collaboration. They approached the American Ceramic Society (ACerS) for help in creating such an organization. In 1998, the glass industry established the Glass Manufacturing Industry Council (GMIC), under the auspices of ACerS, to promote the interests of glass manufacturers (see insert). The GMIC provides a unified voice for the industry, facilitating cooperation and leveraging resources to address issues of common concern.

> **GMIC Mission**
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> To facilitate, organize, and promote the interests of the entire glass industry through cooperation in the areas of technology, productivity, and the environment

The primary purpose of the GMIC is to develop, select, and oversee a precompetitive R&D portfolio with the ultimate goal of strengthening the competitive position of the U.S. glass

Table 2. Selected High Priority Research Needs for the Glass Industry

Time Frame	Production Efficiency	Energy Efficiency	Environmental Protection and Recycling	Innovative Uses for Glass
NEAR (0-3 Years)	• Produce coupled models that simulate combustion space and the glass melt	• Establish test facility for model verification	• Develop and evaluate refractories for melting systems	
MID (3-10 Years)	• Develop intelligent control of production and fabrication processes • Develop integrated process control strategies		• Develop predictive emission modeling tools • Develop cost-effective separation and sorting techniques for post-consumer glass • Develop durable, high-temperature sensors for flow temperature, and gas composition • Develop integrated control systems to link production with emissions • Develop more efficient, lower-cost oxygen production	• Conduct research to increase understanding/ model surface modifications, surface interactions, surface chemistry, and reactions at the glass interface • Explore use of microwaves and ultrasonic waves for control of glass shape and other process parameters
LONG (10+ Years)	• Develop longer-lasting non-refractory materials	• Explore new alternative glassmaking technologies - alternative melting methods - new, large-volume processes - revolutionary small-scale glassmaking processes • Design and develop non-traditional refining techniques		
ALL (0-10+ Years)	• Determine corrosion mechanisms of refractory composition • Improve hot glass contact materials (e.g., molds and rolls)	• Develop accurate, validated melter models that include batch melting, combustion, and glass flows • Conduct research to improve refractories		• Develop more effective sensors for measurement and control of temperature, viscosity, redox reactions, gas velocity, and colorants

industry in materials markets[1]. This focus distinguishes the GMIC as the only central organization for advancing the technology and efficiency of glass manufacturing in areas of mutual benefit to all glass producers. Toward that end, in February 1999, the GMIC signed a compact with the U.S. Department of Energy reaffirming the industry's commitment to pursue precompetitive R&D related to glass manufacturing that can improve energy efficiency and environmental quality, increase productivity, and reduce emissions of greenhouse gases.

A major responsibility of the GMIC will be to serve as the "portfolio manager" for the glass industry's research agenda and to actively shape DOE's glass research portfolio. The Council will help shepherd glass research throughout the R&D process from proposal selection to the development of results ready for commercialization. In its efforts to guide and oversee the glass R&D portfolio, the GMIC will:

- identify technology priorities
- help evaluate R&D proposals
- guide R&D projects
- facilitate R&D projects between companies
- negotiate Cooperative Research and Development Agreements (CRADAs)
- determine intellectual property rights.

The Glass Industry R&D Portfolio

The technology priorities established by the industry allow it to move forward in its pursuit of mutually beneficial collaborative research opportunities. Many of those opportunities are cost-shared projects funded by the Department of Energy. The 1999 DOE OIT glass technology portfolio has a budget of $4.3 million dollars, allocated to 18 projects, all of which address priorities from the industry research agenda. A representative sample of these ongoing, collaborative research projects is presented in Table 3.

Continuing Partnership Activities

The U.S. glass partnership has created an umbrella for a variety of forward-looking activities to support technology development in the glass industry (see Figure 1). The partnership is guided by the industry vision and technology roadmap which outline priorities and direct activities. These activities include workshops, leveraging activities, the development of policy positions, project reviews, and portfolio development. As the GMIC builds its industry base, it will continue to play a larger role in leading partnership activities and responsibilities.

An integral part of the glass industry's technology development strategy is to leverage investments through collaborative partnership. Private companies, government agencies, and trade and professional organizations develop partnerships to share the risks and costs of research and create a larger pool of relevant expertise and facilities to help solve some of industry's toughest technical challenges. Partnerships also include the research community—the industrial research centers, universities, and national laboratories—that provide world-class scientific and

[1]Precompetitive R&D encompasses research and development activities up to the stage where technical uncertainties are sufficiently reduced to permit preliminary assessment of commercial potential and prior to development of application-specific commercial prototypes.

Table 3. Example Glass Industry R&D Projects

Project	Priority Research Need(s) Addressed
Improved Refractories for Glass As furnaces are converted to new firing processes, including oxy-fuel firing, refractories are exhibiting greater deformation and corrosion due to higher operating temperatures and severe environments. Researchers will test, analyze, and characterize a variety of refractory materials in an effort to develop refractories with superior corrosion and creep resistance, thus improving furnace efficiency, stability, and lifetime.	• Refractories for melting systems • Research to improve refractories • Corrosion mechanisms of refractory composition
Dynamic Expert Systems to Optimize Oxy-fuel Melter Performance Project partners will develop and demonstrate a dynamic system of automatic controls for the efficient operation of oxygen-enriched glass melting plants. By demonstrating improved production efficiency, reduced emissions, and extended refractory life, this new system may make the oxy-fuel process more attractive to a greater portion of the glass industry.	• Predictive emission modeling tools • Integrated process control strategies
Advanced Process Control System for Glass Production Project partners will develop and implement a process control system using by integrating four advanced technologies: a process parameter model; a suite of stress and temperature sensors; a data acquisition, analysis, and communications system; and a cognitive controls software package. Improved process control will reduce glass waste, cut energy consumption, boost production efficiency, and yield a higher-quality product.	• Integrated control systems to link production with emissions • Intelligent control of production and fabrication processes
Glass Furnace Combustion and Melting User Research Facility Project partners will design, build, and operate a state-of-the-art user facility where research and experimentation can be conducted to explore technology for improving combustion and furnace efficiency. In addition to addressing combustion issues, researchers at the facility can develop techniques for tighter control of the melting process, which in turn will lead to increased production efficiency and product quality for all industry segments.	• Test facility for model verification • Coupled models to simulate combustion space and glass melt • Validated melter models
Tougher Composites for Glass Processing Sensors Using plasma spray forming technology, this project team plans to develop hybrid composite tubes that can be used as protective sheaths and periscope sight tubes for advanced temperature sensors. The molybdenum disilicide-based composites to be used are stronger, more resistant to oxidation, friendlier to the environment, and less expensive than traditional refractory metals.	• Longer-lasting non-refractory materials • Durable, high-temperature sensors for flow temperature, and gas composition • Effective sensors for measurement and control of temperature, viscosity, redox reactions, gas velocity, and colorants
Integrated Ion-Exchange Systems for High-Strength Glass Products Although chemically strengthened glass has advantages over conventional, thermally tempered glass, its lengthy treatment time often makes it an uneconomical option for manufacturers. Project partners are developing integrated, ion-exchange systems for soda-limed-based compositions that will reduce strengthening times by a factor of two to five, increasing production efficiency and costs savings.	• Optimize chemical processing for high strength

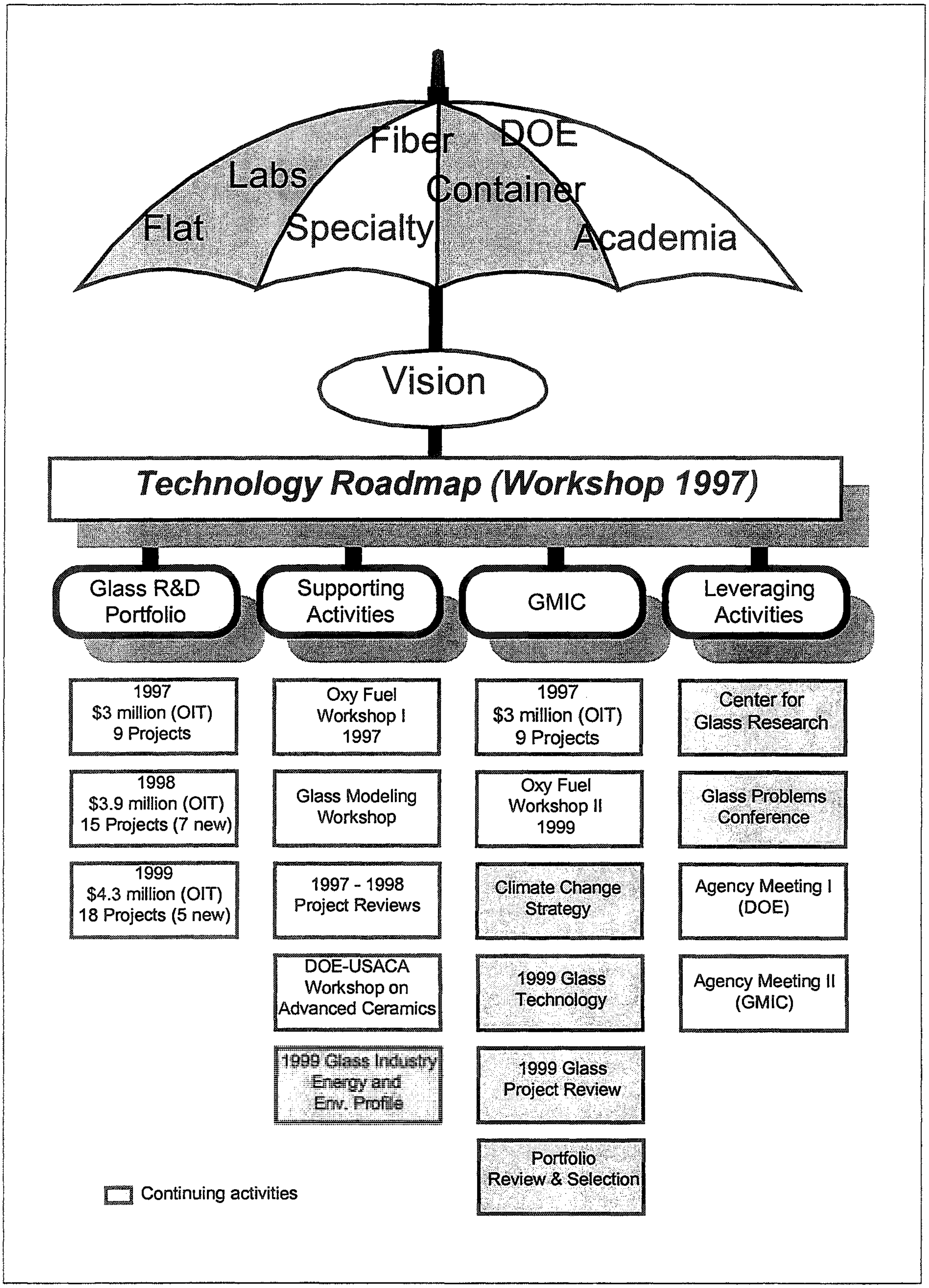

Figure 1. Glass Industry Partnership

engineering expertise and unique experimental facilities that are essential for tackling complex problems.

Over the past four years, the U.S. DOE has worked with several organizations to leverage technical resources. For example, they have been an active contributor and member of the Liaison Board of the Center for Glass Research (CGR), an NSF Industry-University Center located at Alfred University. CGR has been a focal point for research, education, and technology exchange in the field of glass science and engineering and is participating on two DOE-funded projects. In 1997, the advanced ceramics community approached DOE to request their help in identifying needs within major process industries that could be met with high-temperature, corrosion-resistant ceramic materials. These discussions resulted in a September 1998 joint workshop between the glass and advanced ceramics industries on *Advanced Ceramics in Glass Production: Needs and Opportunities* (Eisenhauer et al. 1999). Workshop participants recommended several priorities for applying advanced ceramics in the glass manufacturing environment, including improved refractory compositions, coatings for molds, improved sheathing for thermocouples, and ceramic burners.

The glass industry, through the GMIC and DOE, is continuing discussions with several federal organizations with interests and activities related to the glass technology roadmap. In February 1999, for example, the GMIC hosted an "Agency Meeting" to explore opportunities for joint research. Organizations represented at that meeting included the National Science Foundation, the National Institute of Standards and Technology (Manufacturing Engineering Laboratory and Advanced Technology Program), the California Energy Commission, Great Lakes Industrial Technology Center, and the New York State Energy Research and Development Authority. The participants identified several promising research avenues that GMIC will pursue through subsequent meetings.

The glass partnership has also been active in hosting and participating in technical workshops to discuss common problems and best practices. In 1997, DOE hosted the *Oxy-Fuel Issues for Glassmaking in the 90's Workshop,* which addressed technical issues related to the implementation of oxy-fuel firing of glass furnaces. In February 1999, the GMIC hosted the *Oxy-Fuel Issues II Workshop: Approaching the New Millennium,* which provided additional insights on oxy-fuel conversion. DOE also sponsored a workshop on *Glass Modeling* to share information on the state-of-the-art for modeling of the glass bath and combustion space. DOE is also a regular participant and supporter of the annual *Glass Problems Conference,* hosted alternatively by Ohio State University and the University of Illinois, Urbana-Champlain. This conference is considered the principal technical conference addressing the needs of glass manufacturing and will continue to be a source of direction and feedback for the glass partnership.

A key advantage of the roadmap is that it helps to align and focus industry and government resources on areas of mutual interest. The roadmap also helps to ensure that glass research and technology investments are productive, relevant, and efficient. The DOE-industry partnership has developed an effective mechanism to solicit feedback and keep research focused on critical needs. For the past two years, DOE has held the *DOE Annual Glass Project Review,* in which technical managers from glass companies review the progress of ongoing glass research and advise the principal investigators on technical direction. These reviews have been highly successful and have attracted broad industry participation.

Next Steps

The DOE compact with the GMIC has created a focal point for future partnership activities that extends to all members of the glass manufacturing community. In 1999, the GMIC will play a leadership role in reviewing technical direction for the DOE glass research portfolio and overseeing the 1999 *DOE Annual Glass Project Review.* The GMIC will also build and strengthen its relationships with other key organizations within the glass community, including the Primary Glass Manufacturers Council (flat glass), the Glass Packaging Institute (container glass), the North American Insulation Manufacturers Association (fiber glass), the American Ceramic Society, and the Center for Glass Research to explore areas of mutual interest and benefit. The GMIC expects to publish the final *Glass Industry Technology Roadmap* and distribute it to glass manufacturers, customers, suppliers, and researchers.

One important effort being pursued by the GMIC is to help the glass industry develop its strategy for addressing climate change. President Clinton's Climate Change Proposal calls for "industry-by-industry consultations" to produce a voluntary agreement to reduce greenhouse gas emissions. Under the leadership of the GMIC, the industry is developing its strategy that will include actions to improve the efficiency of processes, increase recycling, and accelerate adoption of energy-efficient glass products. The industry goal is to develop an agreement that reduces greenhouse gas emissions, is supported by market economics, contains clear government incentives, and creates a level playing field for all glass producers.

The ultimate success of the Glass Industry Partnership may not be determined for several years. However, the partnership is helping the U.S. glass industry to define its future with a coordinated technology strategy that can position it for growth and profitability. The development and implementation of the glass technology roadmap is an excellent template for success that will require the support of many segments of the industry. The government role will continue to concentrate on facilitating the partnership by encouraging additional leveraging activities and making strategic research investments that support the roadmap and provide clear public benefits.

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