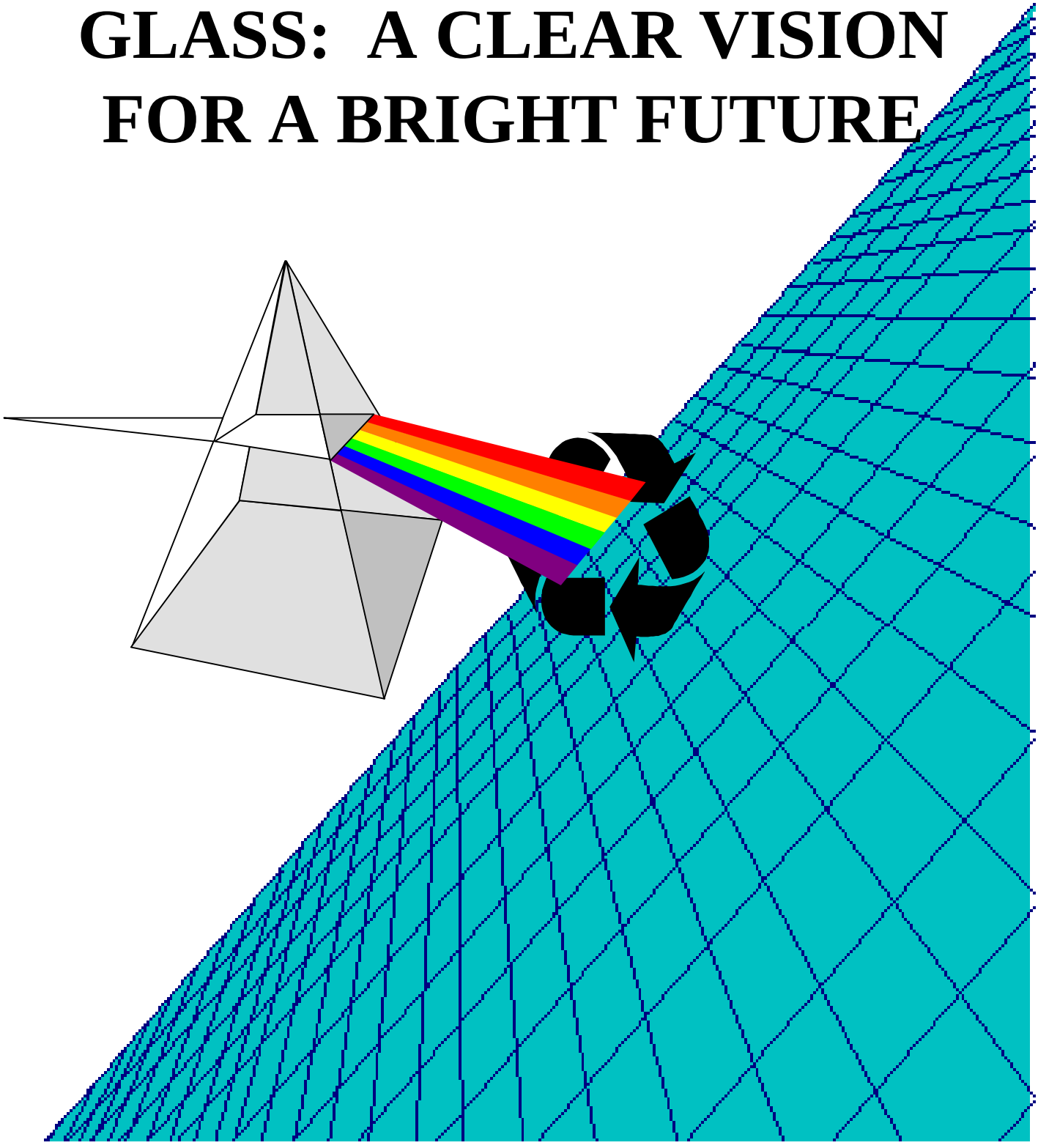
GLASS: A CLEAR VISION FOR A BRIGHT FUTURE



Background

This Technology Vision and Research Agenda was developed by representatives of the glass industry, with advice from research institutions and other organizations. Guidance was provided by the industry leadership through a committee of Chief Executive Officers.

Industry leaders and the corporations referenced herein approved this document and authorized the work needed to develop an implementation plan for the Research Agenda in collaboration with agencies of the federal government and the major institutions with expertise in the field.

Issued: January, 1996

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EXECUTIVE SYNOPSIS

The American glass industry is responsible for technological advancements that have been adapted for use worldwide and dramatically improve the quality of life for millions of people. Glass is an important component of the U.S. economy, employing more than 150,000 people in skilled jobs, and generating more than 21 million tons of consumer products each year with an estimated value of $22 billion. Glass demonstrates a clear advantage over other materials for the following reasons:

- one hundred percent recycling capability;
- diverse, unique applications;
- versatile manufacturing properties;
- environmentally friendly manufacturing processes and products;
- exceptional chemical durability;
- multi-faceted optical properties.

In theory, about 2.2 million BTUs of energy are required to melt a ton of glass. In reality, it takes twice as much energy because of inefficiencies and losses. To meet future challenges by the year 2020, the glass industry as a whole must enlarge the application of its technology and expand its usefulness to society through improvements in energy efficiency and other innovations. To remain vigorous and competitive, the glass industry has identified the following goals:

- Operate with production costs at least 20% below 1995 levels;
- Recycle 100% of all glass products in the manufacturing process, where consumption is greater than 5 lb/capita;
- Reduce process energy use from present facility levels by 50% toward theoretical energy use limits;
- Reduce of air/water emissions by a minimum of 20% through environmentally sound practices;
- Recover, recycle and minimize 100% of available post 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 improvements.

To achieve these goals, the glass industry has identified four key areas in which new research and technology will be required:

- Processing: advances in melting/refining processes, and fabricating/forming processes;
- Technology: development of new glassmaking techniques, processing controls and computer simulations to model new processes;
- Systems: improvements in emissions controls, recycling methods, and solid waste management;
- Products: development of innovative new uses for glass.

Finding new ways to use glass for specific purposes, maximizing process and energy efficiency, and enhancing the superior qualities of glass are critical because of challenges posed by alternate materials and international competitors. Coordinated planning and cooperation between industry, academia, and government research institutions is necessary to address the mounting competitive challenges.

This document presents perspectives on the glass industry's past, present, and future, with special attention to competitive challenges now facing the industry and technological responses that will reinforce its continuing contribution to the health of the American economy. The production of this document marks the first industry wide initiative to unite its various sectors in defining across the board research priorities.

The glass industry is committed to excellence and growth through public/private partnerships, and believes the benefits will far outweigh the initial investment, in providing jobs, services, and products of incalculable value to society in the future.

The research priorities identified in this document provide a clear vision for a bright future for the glass industry of tomorrow.

GLASS: A CLEAR VISION FOR A BRIGHT FUTURE

INTRODUCTION

Glass, its products are as abundant and durable as the sands of the earth from which they are made. The American Glass Industry has enjoyed preeminence in its production and application to durable and versatile consumer products for more than a century. In the year 2020, the American Glass Industry can continue to lead the international community in the sustainable development and production of glass products in an ecologically responsible manner. Employing improved glass technology will generate new and exciting products to enhance our quality of life.

This document presents perspectives on the glass industry's past, present and future, with special attention to competitive challenges now facing the industry and technological responses that will reinforce its continuing contribution to the health of the American economy.

Like the many prisms of a crystal goblet, the glass industry comprises diverse facets reflecting profitable niches within specialized markets. This report represents one of the first coordinated, industry-wide efforts to identify future research and technological needs and predict a course which will ensure continued prosperity for all.

With humble origins dating back to colonial Jamestown, America's first industry has grown into a world leader in innovation and commitment to quality. This heritage will enable glass manufacturers to find positive solutions to the economic challenges of coming decades through improved manufacturing processes, efficient use of energy, and responsible environmental safeguards.

The almost magical properties of glass have made it one of society's most beneficial creations. Glass, in its myriad forms and uses, is an integral part of the American lifestyle, and a staple of the nation's economic success. Glass is unmatched in durability, cost-effectiveness, diversity, and unique transparent properties.

The glass industry has always been evolving, with change coming so rapidly that many of the glass products we take for granted today were only developed in the last decade. Rapid change within the industry will continue in future years, as the industry finds fertile new fields to plow in telecommunications, medicine, electronics.

This report provides an overview of the glass industry as it is today, with profiles of the four major sectors: container glass, flat glass, fiberglass, and specialty glass. Efforts already made by the industry to adjust to changing economic and environmental conditions are discussed, and competitive challenges examined for each sector. A summary of the industry's colorful past, and a glimpse of its promising future, are presented.

Finally, this report defines industrial, academic, and government research partnerships that will ensure a bright future for America's first industry well into the 21st century.

A TRADITION OF EXCELLENCE

The American glass industry is responsible for technological advancements that have been adapted for use worldwide and dramatically improve the quality of life for millions of people. Glass is an important component of the U.S. economy, employing more than 150,000 people in skilled jobs, and generating more than 21 million tons of consumer products each year with an estimated value of $22 billion.

A world without glass is almost unimaginable today. Its uses range from everyday cookware to sophisticated fiber optics that are revolutionizing international communications. Glass insulates and lights our homes, brings us clear television pictures, opens windows on the world (or our own reflections), and provides safe, recyclable containers for everything from perfume to beer.

The foundation of these accomplishments lies in abundant natural resources; sand, minerals and compounds which, when heated at very high temperatures, meld to form the transparent and versatile material we know as glass. Glass also demonstrates a clear advantage over other materials for the following reasons:

- one hundred percent recycling capability;
- diverse, unique applications;
- versatile manufacturing properties;
- environmentally friendly manufacturing processes and products;
- exceptional chemical durability;
- multi-faceted optical properties.

In addition, glass offers other desirable attributes unequaled by substitute materials. Oxygen and other gases do not permeate glass, so beverages and food packaged in glass containers are better preserved and have a longer shelf life. Its transparency allows consumers to examine their purchases beforehand, and glass is extremely resistant to product tampering. It is still the least expensive form of packaging in the food industry.

Reflecting growing consumer interest in recyclable packaging, the glass industry has stepped up recycling efforts, and is a leader in cooperative curbside and community recycling programs throughout the nation. Between 1980 and 1993, 12 percent fewer glass bottles and jars made their way to the nation's landfills. 3 7 percent of all glass containers were recycled in 1994. Not only is glass packaging recycled back into new glass packaging, but it is also used as feedstock by other glass industry segments. Other glass products are recycled as well. Unlike many other materials, use of recycled glass actually lowers energy costs, by an average of $3 to $8 per ton compared to solely using virgin raw materials, depending upon the industry segment.

Despite its advantages, the glass industry is facing significant competitive challenges that have prompted dramatic restructuring of some segments and aggressive, preemptive market positioning by others. These economic forces will continue to reshape the glass industry and drive advances that will prove its resilience in coming decades.

COMPETITIVE PRESSURES

Since 1945, the pulse of change within the American glass industry has steadily quickened. These changes have been both fruitful and frustrating. Development of new glass products, such as fiberglass and fiber optics, have created new and profitable markets. At the same time, rising labor, energy and environmental compliance costs, compounded by devaluation of the dollar, excess capacity in some sectors and competition from alternate materials, have forced a realignment and streamlining of the industry as a whole.

The two most pressing competitive challenges facing the glass industry are outside competition from producers of alternate materials such as plastic, and internal competition from glass manufacturers in other countries, which frequently have lower labor and environmental compliance costs.

Meeting these challenges will require continued vigilance in the form of judicious investment, improved manufacturing processes, and research support to create additional uses for glass and reduce energy and waste disposal costs. Market forces are eliminating excess capacity in segments such as container glass, but increased demand in other sectors, such as specialty glass products, 'will require substantial financial commitments by American companies to remain competitive in the world marketplace.

Adding to these pressures are the expectations of the American public for clean, non-polluting industries. These expectations already have prompted substantial investments in emission control equipment and improved manufacturing processes, and will continue to do so in years to come. Likewise, recycling will become an even more integral component of the industry, and ways to make recycling efforts more effective and profitable should be pursued.

Because glass manufacturing requires significant capital outlays for equipment and distribution networks, demand for capital will continue to be a key factor in the future. Unlike some other industries, glass making is so specialized that manufacturing facilities for one type of glass cannot be easily adapted to other types of glass production. Thus, targeting investment toward growing segments of the industry, while preserving existing markets, is crucial.

With its rich history of innovation, international leadership and responsible corporate citizenship, the glass industry fully expects to meet these challenges and emerge even stronger and healthier in the future.

A CLEAR VISION FOR THE FUTURE

To meet future challenges by the year 2020, the glass industry as a whole must enlarge the application of its technology and expand its usefulness to society through improvements in energy efficiency and waste/emissions reductions. The industry will operate with production costs at least twenty percent below 1995 levels. The manufacturing process will recycle one hundred percent of all glass products, after economically feasible beneficiation, where annual per capita consumption is greater than 5 lbs/yr. Process energy use will be reduced from present facility levels by fifty percent toward theoretical energy use limits through increased innovations in energy efficiency and reuse. Environmentally sound practices will reduce air and water emissions by a minimum of twenty percent from present levels. By employing new technologies on process waste minimization, recovery, and recycling of economically viable consumer byproducts, one hundred percent of all reasonably available post consumer glass waste will be used. Through innovations that optimize glass composition and strength, enhance automation and process control, and utilize computer simulation, manufacture of glass products will meet six sigma quality standards. Innovative products with enhanced attributes will broaden the market place for the glass manufacturer.

Overall, partnerships between the glass industry, its suppliers, and customers will be critical to meeting these goals. The quality of future raw materials, equipment, and energy will directly impact achieving industry objectives. Issues, such as standardization of materials and universal energy availability, along with technology innovations in equipment and process design will require involvement throughout the process. Since incoming and outgoing packaging influence waste generation, the industry will work with both customers and suppliers to minimize packaging waste. Equipment and materials firms must continue to develop innovations. The utilities must play an essential role by working to provide full time dependability and lowest possible rates. Energy utilization will be enhanced through the development of improved waste heat recovery, such as co-generation plants that meet smaller facility requirements. Innovations are also needed in refractories and in-process equipment, such as precious metals replacement, sensor development, and forming optimization.

Glass will remain the preferred material for many uses because of its widespread applicability, reasonable costs, and inherent advantages. But finding new ways to use glass for specific purposes, and to enhance its superior qualities, will become even more important because of challenges posed by alternate materials and international competitors.

The glass industry was among the first American industries to establish its own research laboratories, a commitment which has resulted in such ground-breaking achievements as heat-resistant glass, photo-sensitive glass and fiber optics. This farsighted approach to improving existing products and developing new ones will continue to serve the industry well in the future.

Society will reap many benefits from future glass innovations. New glass coatings will find their way into a variety of scientific and industrial applications. Smaller and ever more powerful optical scoping devices will render more invasive medical procedures obsolete. More efficient fiber amplifiers will accelerate the speed and quantity of information traversing communication channels. Flat-screen televisions as slim as a picture frame will replace the bulky sets now in use. Sustainable, abundant power through the promise of nuclear fusion will be produced with the aid of high-transmission optical lenses to conduct the intense laser energy necessary to sustain the reaction. Automobile windshields and building windows will darken and lighten automatically, or at the touch of a button, to adjust for sunlight and temperature.

But the increasingly competitive business environment facing American industries will limit the ability of private industry to finance as much long-term research as it has in the past. Thus, partnerships with federal agencies and research institutions, academia and other industrial firms will be increasingly important to facilitate these future advancements.

Within the industry itself, improved manufacturing techniques and new equipment will improve energy efficiency and reduce pollutant emissions. And new recycling processes will bring full circle the goals of reducing, reusing, and recycling glass products. Development of sophisticated computer simulation programs will allow the industry to test and refine these improvements in a cost-effective manner.

The raw materials used to make glass are some of the most environmentally benign available. Glass, one hundred percent recyclable, when disposed does not decompose, release leachates, or otherwise harm the environment. It simply returns to the inert state from which it came. These attributes, when compared to other raw materials and products, further support the continuing role of products made of glass.

The glass industry's commitment to quality and sensitivity to consumer needs will continue to be the basis for its profitability and investment appeal. Although the future for all American industries remains vulnerable to volatile changes, glass manufacturing will remain an integral player in national and international trade.

RESEARCH AND DEVELOPMENT PRIORITIES

To remain vigorous and competitive, the glass industry has identified four key areas in which new research and technology development will be required:

- Processing: advances in melting/refining processes, and fabricating/forming processes;
- Technology: development of new glassmaking techniques, processing controls and computer simulations to model new processes;

- Systems: improvements in emissions controls, recycling methods, and solid waste management;
- Products: development of innovative new uses for glass.

PARTNERS IN PROGRESS

The glass industry has been a leader in committing its own resources to development of advanced manufacturing techniques and new glass uses, and in working with established, high-tech research institutions. However, as economic conditions continue to erode the ability of individual companies to make that investment unilaterally, alliances within the industry, sharing of technology from other industries, and partnerships with public agencies, universities and laboratories will become increasingly vital.

The glass industry already participates in several cost-sharing R & D projects with the U.S. Department of Energy, and is committed to strengthening that alliance in the future. Those, and other successful partnerships, will ensure that America's first industry will have a vibrant future.

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THE AMERICAN GLASS INDUSTRY

The American glass industry is among the most productive and technologically advanced in the world. Its manufacturing techniques have been adopted throughout the world, and its innovative products have brought immeasurable benefits to society.

There are four major segments of the glass industry:

- Glass packaging, including bottles, jars and other containers;
- Fiberglass, including insulation for buildings and OEM applications, and textile fibers used as reinforcements for plastics and other materials;
- Flat glass, such as that used in windows, automobile windshields, mirrors and tabletops;
- Specialty glass, including table- and ovenware, flat panel display glass, light bulbs, television tubes, fiber optics and scientific and medical equipment.

Together, these segments employ more than 150,000 Americans and produce 21 million tons of products annually with an estimated value of $22 billion. Wages within the industry are higher than the industrial average; however, the number of workers has decreased because of increased automation and fiscal belt-tightening necessitated by the evolving marketplace. The largest employment reductions have occurred in the flat glass and container glass segments of the industry.

While primarily based upon the same core materials and arising from similar historical production methods, the different segments have developed diverse processes to create the different end products. Therefore, many of the statistics cited in this document reflect averages of the different industry segments. Some industry segments greatly exceed the figures provided.

Currently, 55 percent of the cost of producing glass comes from materials, 30 percent from labor, and 15 percent from energy. The industry believes significant reductions can be achieved, especially in the areas of energy and labor costs, from technology developments that lower energy expenditures and increase productivity and environmental performance.

In theory, about 2.2 million BTUs of energy are required to melt a ton of glass. In reality, it takes twice as much energy because of inefficiencies and losses. However, use

of cullet, or recycled glass, in processing significantly reduces energy consumption and the industry is constantly working to expand use of cullet in manufacturing.

In response to competitive challenges, the industry already has taken several proactive steps to reinforce its profitability and stature in the American economy. These measures include:

- Investing millions on pollution control equipment in the last 20 years to reduce water and air pollutants associated with manufacturing operations.

- Reducing energy use to lower fuel costs and increase efficiency. Industry-wide energy use has dropped from 190 trillion BTUs in 1991 to 170 trillion BTUs in 1994. While downsizing is responsible for some of that reduction, improvements in equipment and processing have played a major role. Higher production rates and advanced refractories used by the flat glass sector, for example, have shaved fuel consumption per ton of glass melted by 25 percent in the last 15 years. Energy use in the fiberglass segment has declined by almost 30 percent since 1978.

- Increasing recycling of glass products. Between 1988 and 1994, the amount of glass packaging recycled in the U.S. rose from 22 percent to 37 percent. In 1994, glass containers represented approximately 5.5 percent of all packaging in the municipal solid waste stream, compared with 41 percent for plastics and 43.6 percent for paper products.

- Eliminating obsolete manufacturing plants and unused capacity and moving manufacturing facilities closer to distribution networks.

- Converting plants to more environmentally friendly fuels and combustion processes, such as natural gas and oxy-fired furnaces.

The diversified nature of the glass industry means that the competitive challenges faced by one sector will not always be applicable to other sectors, and solutions must be tailormade as well. However, industry leaders agree that continued coordinated planning and cooperation between industry, government and research institutions is necessary to address the mounting competitive challenges.

A TRADITION OF EXCELLENCE: HISTORY OF THE AMERICAN GLASS INDUSTRY

The United States Glass Industry has been an important contributor to the health, safety, and economic well-being of the citizens of this country since the first glass furnace was built during Colonial times. From its humble beginnings the industry has endeavored to develop and implement innovative technologies. Initial innovations were primarily aimed at improving the

fabrication of glass products or the finishing operations. Early in this century advances in the manufacture of plate glass and containers enhanced the industry's competitive position. Advances in optics and other specialty glass areas aided in the development of weapons that helped ensure our freedom through two world wars and numerous armed conflicts.

Demand for glass products grew rapidly as our country's economy expanded. The resulting demand for large quantities of glass products at low cost, combined with the need for advanced technology to produce ever improving products resulted in a very capital intensive industry. Competition between glass and other materials has also reduced profit margins for many products important to the industry. This combination of high capital intensity and shrinking profits has limited investment in equipment to enhance productivity and in research and development activities.

The energy crisis of the 1970s had a profound influence on the industry. An increase in the cost of some energy sources combined with high capital costs necessary to convert to alternate fuels caused the closure of some plants. Past energy policies, environmental issues, and fuel pricing and availability have forced the industry to switch between using fuel oils, natural gas, and electricity in the melting process. Past regional and national shortages have also had a significant influence on manufacturing process configuration.

During the past several decades, restrictions in the standards for the emission of Nox, Sox, as well as particulate emissions strongly impacted the industry. Equipment was added and processes were modified to meet increasingly stringent requirements. Use of oxygen firing has proven to be a useful tool for emission reduction and may provide some energy savings. These changes have increased, operating costs and reduced the available capital funds for other process improvements.

The industry has also been affected by major restructuring, most recently in its container segment, where only three companies now account for over ninety percent of the production capacity. This is somewhat consistent with the merger trend that has affected other U.S. industries and partially reflects the need for the glass industry to decrease capacity and increase efficiency in order to remain competitive in view of the aggressive inroads of other materials. The flat and fiber segments have been similarly concentrated for many years and are more stable.

Glass industry profits have historically followed the fluctuations of the U.S. economy. The flat and fiber glass industries are tied closely to the trends in the overall U.S. economy. Commercial, educational, and residential construction as well as automotive purchases dominate changes in their product shipments. Container business is more closely related to changes in consumer packaging and product preferences. International trade significantly affects only the flat and specialty glass segments. Containers and insulation fiber glass face very few imports because of excessive transportation costs.

Recent advancements include the development of fiberglass for insulation and textile fibers for reinforcements in materials important to the transportation, marine and construction

industries, the improvement of glass picture tubes for televisions, the development of glass capable of safely storing radioactive materials, and continuing state-of-the-art research in fiber optics, which uses a thin strand of glass fiber to transmit information.

Despite these staggering achievements, accomplished largely in America, industry leaders believe the diversity of glass has not yet been fully tapped, and new frontiers remain to be explored.

INDUSTRY PROFILES

The 1970s and 1980s brought significant restructuring within the industry in response to changes in the global business climate. During this period, sectors such as container and flat glass pared excess capacity to maximize productivity, while others, such as specialty glass, expanded to keep pace with increased demand for new products just off the drawing board.

The often-painful tests of the past 20 years have produced a glass industry that is now more streamlined, more efficient, and more closely aligned to consumer needs. It is also an industry increasingly dependent on new, or improved products, and one that has led the way in pioneering research. Indeed, many glass products that now are considered commonplace, such as fiber optics, were only developed within the last two decades.

However, emerging nations, especially those in Southeast Asia, are presenting strong competition for many market segments, and exports of American glass generally are declining. In addition, all segments of the industry face significant capital investments to build new plants or upgrade older facilities.

This section profiles the various segments and examines the changes that have occurred in each over the last 25 years.

CONTAINER GLASS

The energy crisis of the 1970s had a profound influence on the container glass industry. An increase in the cost of oil, combined with high capital costs necessary to convert plants to alternate fuels such as natural gas, resulted in the closure of 15 plants between 1979 and 1983. Further economic pressures, in the form of increased competition, environmental compliance, and labor costs closed 33 more plants from 1983 to 1992. Currently, there are 66 plants operating in the U.S., producing 41 billion glass containers per year with sales of $5 billion. The typical container glass plant costs about $70 million to build.

Consolidation to maintain competitiveness has also dramatically changed the container glass industry. Three manufacturers now account for 95 percent of the domestic container glass market.

Although container glass sales are now stabilized, growth is limited by prohibitive costs associated with exporting containers. Thus, sales of glass containers are restricted to domestic markets and Canada, and plants are now located closer to the products for which the containers will be used.

FLA T GLASS

Residential and commercial construction, and automotive uses, comprise 80 percent of the market for flat glass, making this segment (also known as float glass) vulnerable to economic cycles affecting those industries. The flat glass sector also includes mirrors, instrumentation gauges, and furniture such as table tops and cabinet doors.

There are currently six raw flat glass manufacturers in the U.S. operating 28 furnaces in 16 states with a production capacity of 14,000 tons of glass per day. The industry employs nearly 12,000 people. The industry has become international, with foreign ownership of some U.S. facilities and U.S. participation in overseas furnace construction. The estimated cost of a flat glass facility is $120 million.

Flat glass production fluctuates with economic cycles. More than 4.83 million square feet of flat glass were produced in the U.S. in 1987. That number fell to 4.28 million square feet in 1991 (when recession plagued the country) and rose to 4.96 million square feet in 1993, when sales reached $1.6 billion.

Exports have become an increasingly important component of the U.S. flat glass trade. In 1988, exports accounted for 13.6 percent of total flat glass revenues; in 1993, more than 21 percent of the revenues were generated by exports.

Flat glass manufacturers recycle 15 to 30 percent of their own cullet. Because of extremely high quality requirements, scrap glass from post-consumer sources such as building sites or household uses is incompatible with flat glass manufacturing.

FIBERGLASS

Fiberglass is composed of two distinct sub-industries: insulation, which is often referred to as glass wool, and textile fibers, which are continuous fiber strands used to reinforce plastics and other materials important to the transportation, marine and construction industries. Like flat glass, fiberglass production hinges on economic cycles in the construction, auto, and marine industries.

There are four major insulation fiberglass producers and six major textile fiberglass manufacturers, together employing about 16,000 workers. The industry is characterized by numerous, smaller manufacturing facilities located in close proximity to customer bases. Facility costs for a fiberglass manufacturing plant are about $ 100 million.

Fiberglass insulation is produced and used primarily in the U.S., and currently dominates the American insulation market. However, alternate materials such as foam and cellulose are beginning to make inroads. In Europe, mineral wool insulation dominates, and regulations -- combined with the excessive cost of shipping the fluffy material -- are an effective barrier to American fiberglass imports.

Recycling plays a prominent role in insulation fiberglass production. The fiberglass sector is the largest secondary market for post-consumer and industrial waste glass, reusing some 870 million pounds of post-consumer and waste glass in 1993. Fiberglass insulation companies now utilize 10 to 40 percent recycled glass in their manufacturing process. However, research is needed to facilitate recycling of fiberglass itself.

Because building codes vary throughout the world, uniform standards for insulation are needed to ensure that insulating materials manufactured elsewhere conform to the same high standards as those made by American fiberglass companies. In the U.S., the industry is working with the Department of Energy to develop insulation guidelines that boost energy efficiency in industrial buildings.

Textile, or composite, fiberglass faces little competition from alternate materials and exports remain steady. This sector expects to grow with more widespread use of fiberglass reinforced composites in automobiles and watercraft.

SPECIALTY GLASS

This segment has traditionally relied on high-tech research, which has helped create new and profitable materials such as fiber optics and photonics. These new products now routinely outperform traditional specialty glass segments such as lighting and cookware. The outlook for specialty glass is evolving so rapidly that the most profitable products today did not even exist a decade ago.

Specialty glass producers are generally unlike other glass industry sectors in that there are a few large, multinational corporations and many small, specialized manufacturers. This is because of the diversity of the markets and the intensive capital costs necessary to compete in these high technology markets. The ability of most manufacturers to invest in a broad R&D program and the diverse equipment required to produce different forms of specialty glass is a limitation. One example of specialty glass are the precision mirrors of the Hubble and Subaru space telescopes. The cost of building a glass facility to produce tableware is estimated at $70 million. A television glass plant with two glass furnaces and five production lines has an estimated capital cost of $300 million.

One segment of Specialty Glass is the historical hand glass producers. These hand glass producers, whose plants have predominantly been located in Pennsylvania, Ohio, and West Virginia, produce blown and pressed decorative glassware, stemware, and stained glass. This segment of the Specialty Glass sector includes approximately 19 companies with a collective

labor force exceeding 2,500. Such hand glass producers confront the same competitive pressures, environmental regulations, and technology needs as other specialty glass producers and require special consideration.

Employment figures are unavailable for the sector as a whole. However, 34,000 workers were employed in the pressed and blown glass segment alone in 1992. One television glass manufacturer alone employs over 3,000 employees.

The best-performing specialty glass products are also those with the highest capital investment costs. Finding capital to fuel research into advanced technologies remains a key concern.

COOPERATIVE RESEARCH BY THE AMERICAN GLASS INDUSTRY

Research, whether by the industries themselves or by government-financed institutions, was scaled back during the belt-tightening years of the 1980s. Industry leaders now recognize that cooperative partnerships are crucial to maximize available financial resources and create new uses for glass. Research dollars, in particular, are targeted toward innovations which will reduce the fuel needs of this energy-intensive industry and lower pollutant emissions.

Currently, the glass industry, the U.S. Department of Energy, and academia are conducting several joint research projects which will provide substantial reductions in pollution emissions and energy consumption. They include developing technology that will permit oxygen, instead of air, to fire large glass-melting furnaces; increasing the use of waste glass, or cullet, in glass manufacturing; devising new coatings and new structural components to enhance the performance of manufacturing equipment; and developing advanced temperature sensors for furnaces that will increase energy efficiency.

These partnerships mark the acceleration, rather than the start, of joint research initiatives. In fact, the glass industry has long utilized academic and government resources in developing advanced technologies

In addition, the glass and power industries jointly conduct annual seminars to discuss energy needs and identify needed improvements.

Some glass companies have participated in joint research programs with other industries to devise manufacturing improvements that benefit both. This is true of the specialty glass sector, which has successfully staved off challengers for some product lines by entering into joint robotics and materials research with would-be competitors.

Within the industry, the annual Glass Problems Conference brings together the many diverse sectors to discuss and find solutions to common production problems.

In academia, several universities and colleges throughout the nation have departments and programs that impact glass. One of the key academic partnerships is the Industry-University Center for Glass Research, New York State College of Ceramics at Alfred University.

These and other accomplishments testify to the glass industry's desire to actively pursue future partnerships for progress. The coordinated planning now underway with the production of this document marks the first industry-wide initiative to unite its various sectors in defining across-the-board research priorities.

THROUGH THE LOOKING GLASS: THE FUTURE OF THE INDUSTRY

To meet future challenges by the year 2020, the glass industry as a whole must enlarge the application of its technology and expand its usefulness to society through improvements in energy efficiency and waste/emissions reductions. The industry will operate with production costs at least twenty percent below 1995 levels. The manufacturing process will recycle one hundred percent of all glass products, after economically feasible beneficiation, where annual per capita consumption is greater than 5 lbs/yr. Process energy use will be reduced from present facility levels by fifty percent toward theoretical energy use limits through increased innovations in energy efficiency and reuse. Environmentally sound practices will reduce air and water emissions by a minimum of twenty percent from present levels. By employing new technologies on process waste minimization, recovery, and recycling of economically viable consumer byproducts, one hundred percent of all reasonably available post consumer glass waste will be used. Through innovations that optimize glass composition and strength, enhance automation and process control, and utilize computer simulation, manufacture of glass products will meet six sigma quality standards. Innovative products with enhanced attributes will broaden the market place for the glass manufacturer.

Overall, partnerships between the glass industry, its suppliers and customers will be critical to meeting these goals. The quality of future raw materials, equipment, and energy will directly impact achieving industry objectives. Issues, such as standardization of materials and universal energy availability, along with technology innovations in equipment and process design will require involvement throughout the process. Since incoming and outgoing packaging influence waste generation, the industry will work both customers and suppliers to minimize packaging waste. Equipment and materials firms must continue to develop innovations. The utilities must play an essential role by working to provide full time dependability and lowest possible rates. Energy utilization will be enhanced through the development of improved waste heat recovery, such as co-generation plants that meet smaller facility requirements. Innovations are also needed in refractories and in-process equipment, such as precious metals replacement, sensor development, and forming optimization.

Strides still must be made to preserve the glass industry's position in the face of increased international competition for markets. In addition, competition from alternate materials will continue to challenge most sectors.

The realignments of recent years will reap rewards for the industry in the future, resulting in more streamlined, efficient operations closely attuned to consumer needs. Flexibility will be a common theme for the glass industry of the future, with smaller, but more numerous, facilities springing up to replace the giant manufacturing complexes of past decades. New technology will be used to make these the most energy efficient and environmentally friendly facilities in the world.

Investment will be directed at increasing automation and more efficient technologies for producing glass. Glass producers will diversify their holdings and operations more to retain strong market positions and expand to new markets.

The glass industry's labor force will be even more skilled and more involved in solving production problems. Flexibility and increased responsibility will enable the industry to retain its proud tradition of superior workmanship.

The glass industry will implement improvements that will boost its competitiveness, particularly in the realms of process control, environmental engineering, and energy reduction. The industry of the future will continue to move toward cleaner sources of fuel that can be produced domestically, and toward reductions in environmental pollutants.

Recycling will increase in coming years, and will provide cost savings in energy use, raw materials, and waste disposal. Recycling research will devise new ways of reusing all types of glass, both within the industry and by other industries. These efforts will pay off in lower consumer costs for glass products and increased public realization of the economic and environmental value of choosing glass over other materials.

Development of innovative uses of glass is a linchpin of the industry's future.

Cooperative efforts with government, academia, and other industries will spawn state-of-the-art breakthroughs that will increasingly expand the importance of glass to modern-day society.

COMPETITIVE PRESSURES FACING THE GLASS INDUSTRY

In general, the American glass industry faces two overriding challenges: competition from alternate materials, and competition from alternate producers, particularly those in emerging nations. Because of the diverse nature of the industry, specific pressures are examined below for each sector.

CONTAINER GLASS

Competition in this largest of the glass industry sectors comes primarily from alternate materials, particularly plastic and aluminum.

Plastic and aluminum have made substantial inroads into the container market, especially for foods and soft drinks, which once were stalwarts of the glass container industry. Beverage and food now account for the lion's share of U.S. glass container production. The last new glass container plant in the U.S. was constructed in 198 1, though existing plants have been rebuilt or upgraded since then.

In the future, the gains made by plastic in the past two decades may be offset somewhat by growing concerns about waste disposal and toxic emissions associated with plastic manufacturing. Glass manufacturing, on the whole, has fewer environmental hazards.

Distribution remains a limiting factor for container glass because the weight containers prohibits transportation over long distances.

FLA T GLASS

Few alternate materials exist for flat glass, securing its prominence in future markets. However, this sector is subject to economic cycles, particularly in the construction and automotive industries, and consequently is subject to both surpluses and shortages that make growth patterns difficult to predict.

Uncertainty over fuel prices is a concern for this sector. While natural gas currently is plentiful and relatively inexpensive, future supplies may be less so. Added regulations affecting the construction and automotive industries also present challenges by imposing new energy-efficiency and safety requirements on glass used in buildings and vehicles.

Environmental costs are a major factor impacting manufacturing facility economics, effectiveness and life. Considerable administrative and personnel costs are incurred due to compliance regulations. A typical float glass plant has capital expenditures averaging $2 million dollars for new environmental control systems averaging 20% annual operating costs. The cost of environmental compliance is about 2.5% of total manufacturing costs, substantial relative to low profit margins associated with this mature industry.

International exports of flat glass remain strong and currently outpace imports, but the industry is now feeling pressure from manufacturers in other countries.

FIBERGLASS

Like flat glass, fiberglass production depends on the health of other industries, primarily construction, automotive, and boat building.

Insulation fiberglass faces few international competitors because of the excessive costs of transporting the bulky fiber insulation. Conversely, this sector presently has limited export potential. Because the binders used to hold the insulating fibers together can fail when the insulation is compressed beyond its limits, development of new binders that allow more intense compression during packaging could save shipping costs and make exports more feasible.

Textile fiberglass is still an emerging market, with strong international potential. Fiberglass reinforced polymer composites are an alternative replacement material for many traditional wood and metal applications. Currently, this sector faces little competition from alternate materials, though new developments in polymer fibers could change that.

SPECIALTY GLASS

Specialty glass encompasses dozens of different products that face varying degrees of competition. This sector heavily depends upon new technology to keep ahead of the increasing competition and to find new markets for glass products.

Although there are few alternate materials for such products as television tubes and LCD displays, the electronic glass segment faces strong challenges from competitive producers, particularly in Europe and Japan. The world technological race between the U.S., Europe, and Japan is very obvious in this sector as key alliances between manufacturers and materials suppliers can determine the viability of key industrial segments. Lower environmental compliance, labor costs, and enlightened tax policies in the third world are additional complications competing against resources in the U.S. Joint ventures between American and foreign-owned companies may partially compensate for this phenomenon, and alliances are required to enter some overseas markets, such as telecommunications.

The traditional consumer specialty glass products such as kitchen and tableware and fine crystal are challenged by many alternative materials (such as ceramics, stainless steel and enamel), and are impacted greatly by imports. The few remaining American manufacturers of these products are holding their own in the worldwide market, but the absence of long-term capital investment and research dollars remain a concern.

Recycling is also an issue for this segment. By their very nature, certain specialty products do not justify recycling due to insufficient volume and glass being an inherently environmentally friendly material. However, waste reduction goals and mandates may make recycling justifiable when volume makes it practical. For example, the television glass industry

is undertaking efforts to recycle glass from used television sets and computer monitors.

High-tech products such as fiber optics, on the other hand, are an overwhelming success. Although a low tonnage item in terms of production, they have very high market value and profit margins, along with attention-grabbing appeal as a state-of-the-art American product. Currently, U.S. fiber optics are doing very well internationally, but foreign manufacturers, with government support, create intense international competition to threaten the American glass industry's leadership in this field. Additionally, the character of the telecommunications industry is changing rapidly as alliances among the telephone, cable and systems companies rushing to enter this lucrative market change as the government mandated ground rules change.

Innovative technology for all of the specialty glass segment must continue to improve. New products in new markets are necessary to maintain U.S. domination.

TECHNOLOGY CHALLENGES

To build a strong foundation for the future of American glass, the industry must direct technology improvements to the following areas:

- Production efficiency, including improved manufacturing processes and new techniques that maximize glass strength and quality;
- Energy efficiency and conservation;
- Recycling;
- Environmental protections, including control of nitrogen oxides, sulfur oxides and particulates; solid waste reductions; and wastewater reuse;
- Innovative uses.

Production Efficiency

The glass industry will step up efforts to improve melting and refining processes that will save energy and produce more product at lower costs. This may involve new fuels, oxygen injection or new uses for existing fuels to lower energy costs, and development of techniques for rapid melting of glass and removal of impurities to ensure a higher quality product. Domestic transportation costs also will fall as manufacturers move closer to customer bases and discover new, lighter-weight glass products. Development of computer models that simulate actual manufacturing conditions will provide a cost-effective method for testing new ideas and processes without high capital investment.

Production efficiency also will be helped by increased automation, improved waste management practices, reuse of wastewater and solid waste associated with glass making, and increased use of recycled glass in the manufacturing process. Specifically, attention should be directed to development of :

- contact and non-contact glass temperature sensors; refractory temperature sensors and refractory thickness sensors; sensors that detect and assess the physical properties of glass, such as viscosity, during manufacturing; and sensors and controls that integrate and consolidate glass fabrication;

- glass coatings that maximize strength;

- alternate glass compositions that minimize or eliminate use of potentially hazardous materials;

- handling equipment that eliminates glass surface damage;

- improved gas and electric furnaces;

- computer models that simulate melting and refining processes, furnace performance, bottle forming (container glass sector) and tin bath characterizations to improve flatness (flat glass sector);

- achievement of six sigma quality during processing.

Energy Efficiency and Conservation

The glass industry must find economical ways to reduce fuel use and lower energy costs. Improvements are targeted at:

- optimizing electric boost to reduce total energy consumption;

- improving furnace design and operation to maximize combustion efficiency;

- recovering and reusing waste heat from oxy-fired furnaces;

- producing oxygen more efficiently for oxy-fuel firing.

Recycling

Increased emphasis on wise use of natural resources and solid waste reductions will spur additional gains in recycling by the glass industry. Specific improvements will include:

- development of technology for recycling of post-consumer fiberglass insulation;

- separation of recycled glass by color;

- advancements in preparation of cullet, or waste glass;

- removal of non-glass contaminants that can damage equipment from the recycling waste stream.

Environmental Protection

Investments in technology to keep even with new and more stringent pollution control regulations will drive advances in this area. The payoffs include leaner operations with lower waste disposal costs. Efforts will include:

- development of combustion processes that reduce air emissions;
- expanded use of 100 percent oxygen combustion;
- development of alternate materials or furnace designs that reduce or eliminate particulates;
- new manufacturing processes that generate less solid waste;
- reuse of wastewater and solid waste, or use of solid waste as a raw material for other industries;
- development of refractories that do not generate hazardous materials.
- elimination of halide emissions associated with some types of specialty glass production.

Innovative Uses

Creating new uses for glass, and enhancing existing materials, is essential to the gla industry's future. Needed improvements include:

- design of "smart windows" that react to natural lighting conditions and temperatures (specialty glass sector);
- development of lighter-weight, impact-resistant containers and flat glass (container and flat glass sectors);
- development of fiberglass that compacts and rebounds easily (fiberglass sector);
- development of new optical fiber designs and components capable of transmitting greater amounts of information (specialty glass sector).

RESEARCH PRIORITIES

The glass industry has identified several areas where short- and long-term research is needed to improve its competitiveness. Priorities are:

- development of computer models that simulate manufacturing processes;
- development of commercially viable rapid glass melters that speed up the melting process, reducing the size of the batch and the time required to produce glass;
- creation of temperature and viscosity sensors that give precise, real-time information for quality control during processing;
- development of glass coatings that maximize strength and minimize weight;
- development of processes and equipment to further lightweight and strengthen glass packaging;
- design of a simple forming mechanism that allows flexibility, quick process changing, precise control and feedback;
- integration of energy-efficient fuels into more aspects of the manufacturing process, and recovery of waste heat generated by those processes;
- increased recycling ratios and expansion of recycling to all industry sectors;
- identification and refining of technologies used in other industries that also are applicable to the glass industry;
- development of direct combustion techniques to speed up heat transfer during processing;
- techniques to combine various composites of glass, and incorporate other materials with desirable attributes (such as ceramics) into glass products.

CONCLUSION

The American glass industry has prevailed and prospered despite turbulent upheavals in the domestic and international economy that have forced a dramatic restructuring of the industry as a whole. The industry remains the overall leader in glass manufacturing and product innovation, but faces strong competitive challenges from alternate materials and producers.

Overcoming these challenges will require increased collaboration with government, academia, and other industries to leverage scarce research dollars. Collaboration in such areas

as waste reduction, energy efficiency, and quality control dovetail with the overall public interest in clean air and water, less waste and a healthy economy.

The glass industry welcomes a team approach to solving problems that provides easier access to technology, simplifies participation in joint undertakings, and emphasizes communication and coordination. The industry is committed to these public/private partnerships, and believes the potential benefits will far outweigh the initial investment, in providing services and products of incalculable value to society in the future.

The research priorities identified in this document provide a clear vision for a bright future for the glass industry of tomorrow.

ACKNOWLEDGMENTS

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APPENDIX A

CHRONOLOGICAL HISTORICAL SUMMARY OF THE AMERICAN GLASS INDUSTRY

Glass manufacturing was the first industry developed in the fledgling American colonies, beginning with a small glass factory at Jamestown in 1608. But, despite the country's seemingly endless supply of wood, sand and other natural resources needed for forming glass, the industry faced formidable obstacles. Few glass artisans were willing to leave the comforts of European life for the hardships of the new world, the struggling colonists had little use for objects considered too fragile and frivolous for pioneer life, and even those who did believed that British glass was of better quality and thus more desirable. It was not until 1739 that the industry achieved any success, with the opening of Caspar Wistar's glass works in New Jersey. It would be nearly another century before glass making finally became a permanent fixture in America and, by 1810, the U.S. Census showed 22 glass works in the nation, with window glass accounting for about four-fifths of total production.

By the end of the 19th century, American ingenuity -- in the form of mechanization and chemical innovation -- produced glass of such quality and value that Americans wholeheartedly embraced the domestic products. This period was characterized by inventions such as the pressing machine, which made mass production of glass possible and revolutionized the industry. The 19th century also saw the rise of Western Pennsylvania and Southwestern New York State, with ample supplies of coal and sand, as the center of U.S. glass making.

The 20th century heralded a continuation of the frenetic pace of change for the industry. In 1903, Michael J. Owens invented the bottle-making machine, another development which galvanized the industry. In the same year, J. H. Lubbers invented a machine for blowing glass automatically, and two years after that Irving W. Colburn patented a process for the production of continuous sheets of glass drawn directly from tanks which had been fired at intense heat for long periods.

In 1908, the Coming Glass Works established a research laboratory -- one of the first to be financed by any American industry. That investment paid off in 1915 with the introduction of heat-resistant Pyrex cookware -- an innovation that began when a Coming researcher had his wife bake a cake in the lower half of a glass battery jar.

The 1950s saw the development of the float-glass manufacturing process still in use today, and the 1960s ushered in an era of innovation that saw the creation of laser glass, laminated glass and photo-sensitive glass. Chemical treatments were added in the 1970s to improve the performance and durability of containers and other glass products. In 1970, Coming made the breakthrough in chemical vapor deposition to produce the world's first low loss optical fiber for telecommunications.

APPENDIX B

COMPLETED OR ONGOING PROJECTS WITH
DEPARTMENT OF ENERGY

Completed or ongoing projects with DOE include:

- Construction of a pilot plant utilizing rapid glass melting techniques;
- Testing of new sensors that detect temperatures without contacting the glass during the manufacturing process;
- Development of a prototype shallow glass refiner using electric heating elements;
- Research into the feasibility of combining oxygen and pre-heated air to better control the stages of combustion in side-port furnaces;
- Development of technology to utilize waste heat in oxy-fired furnaces to preheat cullet or batch;
- Formation of glass from non-traditional organo-metallic materials, such as silicones, that require less energy to process;
- Development and evaluation of application technology for molybdenum disilicide coatings on refractories used in glass melters for better resistance to heat and corrosion;
- Development of computer models that examine the complex chemistry of combustion and how that process is affected by furnace configurations, burners and other elements;
- Evaluation of alternate materials, such as new refractories and molding equipment, for better processing efficiencies;
- Completion of a broad-based industry survey of energy consumption to determine best operating practices and most efficient equipment

Glass
A Clear Vision for a Bright Future

April 29, 1996

This Compact is a voluntary collaborative effort between the glass industry (container, flat, fiberglass, and specialty glass) and the U.S. Department of Energy. The purpose of the compact is to provide the framework for identifying appropriate areas for joint research, development, and technology demonstrations. The results will be a research partnership between the Department of Energy and the glass industry.

The partnership will work to demonstrate, evaluate, and accelerate new technologies and scientific insights that address several specific needs in the following areas:

- *Processing advances in melting/refining processes, and fabricating/forming processes.*
- *Technology development of new glassmaking techniques, processing controls and computer simulations to model new processes.*
- *Systems improvements in emission controls, recycling methods, and solid waste management.*
- *Products development of innovative new uses for glass.*

The projects identified by the research partnership will be carried out in a joint Federal-industry program designed to develop technologies for the industry's end-users. The program will be guided by various collaborations among: industry, glass associations, Federal agencies, universities, national laboratories, and other major research institutions.

Although process/product development is essential to the long-term success of the glass industry, it is also a primary element for competition among companies through product differentiation. Therefore, pre-competitive projects that benefit the industry across the board will be addressed in this program. Specific product development will be left to individual companies.

The compact is also intended to re-emphasize and reinforce the activities already underway through collaboration between the government, industry, and academic institutions. The glass industry is supporting pre-competitive research and development projects in production efficiency, energy efficiency and conservation, recycling, environmental protections, and innovative uses, with both short-term and long-term potential. These efforts are emphasized in order to build upon the successes of the past. Examples include: simplified, flexible forming; high strength coatings; direct, optimized heat transfer combustion; and waste minimization. For the future vision of the glass industry to become a practical reality, a program of long-term R&D will be required.

This compact expresses the intentions of the parties to pursue collaborative research efforts. It does not, however, create legal rights or obligations for any party and any party may withdraw without penalty and without being subject to remedies at law or equity.

This compact shall become effective upon execution by representatives of the United States Department of Energy, Anchor Glass Container, Carr Lowrey, Vetrotex- Certainteed, Corning Incorporated, Fenton Art Glass, Ford Motor Company Glass Division, Glass Packaging Institute, North American Insulation Manufacturers Association, Society of Glass Sciences, and Technegias . It shall remain in effect for two years, but may be extended by mutual agreement of the parties. Signed this 29th of April, 1996 by:

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