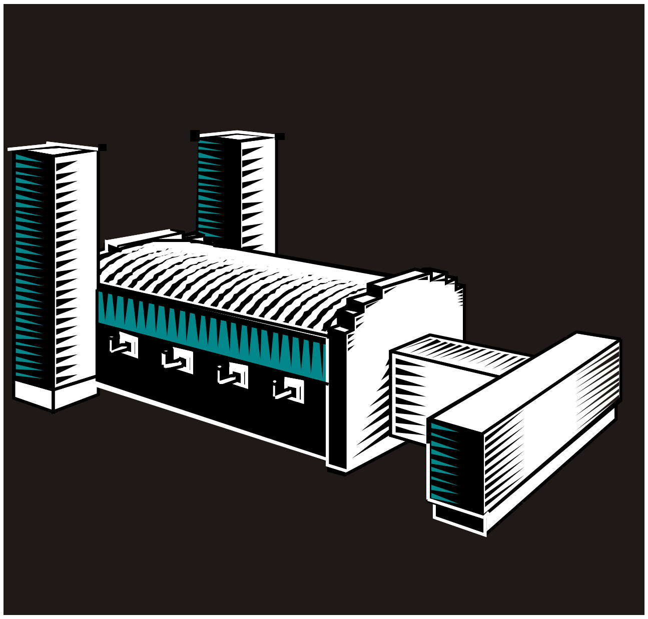
GLASS

INDUSTRY OF THE FUTURE



ENERGY AND ENVIRONMENTAL PROFILE OF THE U.S. GLASS INDUSTRY

APRIL 2002

OFFICE OF INDUSTRIAL TECHNOLOGIES

ENERGY EFFICIENCY AND RENEWABLE ENERGY • U.S. DEPARTMENT OF ENERGY

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Energy and
Environmental Profile of the
U.S. Glass Industry

April 2002

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FOREWORD

In 1996, the U.S. Department of Energy's Office of Industrial Technologies (DOE/OIT) began work on a series of reports in support of DOE/OIT's Industries of the Future strategy. Under this industry-led strategy, DOE/OIT works with U.S. industry to develop technology partnerships and support collaborative RD&D projects that enhance energy efficiency, competitiveness and environmental performance.

Though the profiles are intended primarily to better inform collaborative industry-DOE R&D planning, they provide a valuable resource that can be widely used by many others who are not directly involved in these efforts. Through these profiles, research managers, policymakers, industry analysts and others can gain a general perspective of energy use and environmental characteristics of the industry. The profiles do not attempt to recreate sources that already exist; rather, they provide a "snap-shot" of the industry and an excellent source of references on the topic.

The profiles synthesize into a single document information that is available in many different forms and sources. Aggregated data for the entire industry as well as data at the process level is presented according to the major unit operations of each industry. Data is obtained from the most currently available published sources, industry experts, and government reports. Prior to publication, profiles are reviewed by those working in the industry, trade associations, and experts in government and the national laboratories.

To date, energy and environmental profiles have been published for the aluminum, steel, metalcasting, petroleum refining, chemical, and glass industries. Development of profiles for the mining and forest products industries is currently underway.

1 Overview

1.1 The Glass Industry: Keystone of the U.S. Economy

Glass is an Integral Part of Daily Life

Glass has been produced for thousands of years, dating from as early as 7000 B.C. The earliest makers of glass, the Egyptians, considered it to be a precious material, like gemstones. Today glass is so commonly used that its presence often goes unnoticed. In its many forms, glass has become an integral part of the American lifestyle and a keystone of the U.S. economy.

The U.S. Department of Energy and the Glass Industry of the Future

The U.S. Department of Energy's (DOE's) Office of Industrial Technologies has formed a partnership with the U.S. glass industry to accelerate the development of technologies and processes that will improve the industry's energy efficiency and environmental performance. This report is intended to support the DOE/Glass Industry Partnership.

Glass is used in a myriad of products, primarily because it is inexpensive and has many desirable properties (see Table 1-1). Glass properties are unique to the chemical make-up of the glass, and can be varied and regulated by changing composition and/or production techniques. However, changing one glass property usually affects the other properties. When selecting a particular glass for a product, it is the combination of mechanical, chemical, thermal, optical and other properties that are important. At the core of the science of glassmaking is selecting the best combination of properties to suit the application.

The unique properties and cost-effectiveness of glass have helped establish and maintain its prominent use in buildings, transportation, containers, and scientific products. Glass has also found new uses in the communications and electronics industries and many experts believe that the potential for creating diverse materials and products from glass has hardly been realized.

Table 1-1. Properties of Glass

Property	Unique Characteristics of Glass
Chemical	Glass is highly resistant to chemical attack, and many chemicals and foods/beverages can be stored for decades without corrosion of the glass. Only a few chemicals aggressively attack glass (hydrofluoric acid, phosphoric acid, hot alkali solutions, superheated water).
Elasticity	Glass is perfectly elastic. After bending or stretching it returns exactly to its original shape when the force is removed. Glass will break, however, when the force applied exceeds the ultimate strength of the glass.
Strength	Glass is brittle, and will break rather than deform when subjected to severe impacts. However, in compression, glass is very strong (e.g., glass spheres are used in undersea applications where they are subjected to intense compressive forces). The tensile strength of glass can be increased by thermal tempering, chemical modification, or laminating.
Hardness	Glass is a hard material, with hardness values comparable to steel, and can withstand significant abrasion over its lifetime. Glasses with aluminum oxide are some of the hardest.
Optical	Glass is transparent or translucent to light, and some glasses are selectively transparent, transmitting light of one wavelength or color more efficiently than any other. Other glasses are designed to absorb infrared light and transmit visible light, or to transmit either ultraviolet or infrared while absorbing visible light. Glass can also bend light (as in a lens).
Electrical	Glass is a good insulator, and provides high resistance to the passage of electricity.
Thermal	Glasses with low thermal expansion have high thermal shock resistance.

Source: Corning 2000

Glass Manufacture is Divided Into Five Major Sectors

The glass industry is divided into the following four sectors based on end products:

- **Flat Glass:** windows, automobile windshields, picture glass
- **Container Glass:** bottles, jars, and packaging
- **Pressed/Blown Glass (specialty):** table and ovenware, flat panel display glass, light bulbs, television tubes, scientific and medical glassware
- **Glass Fiber:** insulation (fiberglass), textile fibers for material reinforcement, and optical fibers
- **Products From Purchased Glass:** items assembled from intermediate glass products (e.g., aquariums, table tops, mirrors, lab apparatus, ornaments, art glass)

In 1987 the glass industry was divided into various categories under the U.S. Standard Industrial Classification (SIC) system, based on the type of glass being produced [OMB 1987]. This system was replaced in 1997 by the North American Industry Classification System (NAICS) which covers all economic activities, producing and non-producing [OMB 1997]. NAICS recognizes new technologies and industries, and creates a uniform system for the three North American countries. These new classifications are now being used in surveys conducted by the Department of Commerce and other Federal agencies that collect data, and are reflected in this report.

The translation between both systems for the glass industry is shown in Table 1-2. The mineral wool sector includes all mineral wool (fiber insulation) made from siliceous materials, including glass, rock and slag or combinations of these. A separate classification is not available for glass fiber insulation. Under the NAICS, optical fibers and textile glass fibers are included under the pressed and blown glass classification, and some data will be reported in this way. However, optical and textile fibers processing will be included in discussions of fibrous glass throughout this report. Statistics for products made from purchased glass are included in tables to better define the scope of the glass industry, but processes for their manufacture are not covered.

Table 1-2. Glass Industry Re-Classification

Sector	SIC	NAICS
Flat	3211	327211
Container	3221	327213
Pressed/Blown	3229	327212
Mineral Wool	3296	327993
Products from Purchased Glass	3231	327215

Sources: OMB 1997, OMB 1987.

1.2 Industry Performance and Market Trends

The Glass Industry Has Experienced Many Changes Over the Last 50 Years

During the postwar era of the 1950's, the glass industry was swept up with the prosperity and optimism that permeated much of America. In the 1960's, glass manufacturers went through a decade of progress, with many technological advances changing the face of the industry (e.g., the float glass process) and expanding uses for glass.

During the 1970's, major events like the oil embargo, subsequent fuel shortages and the ensuing economic recession created a new challenge for glass manufacturers—increasing energy efficiency. The industry responded with a range of innovative products that increased energy efficiency in buildings and automobiles.

The 1980's started off with an economic recession and slow-down in construction and automotive sales, which reduced demand for glass. As a result, the glass industry entered an era of unprecedented consolidation and change that would last for two decades [Glass Facts 2000].

Over the last twenty years the glass industry has been challenged with plant overcapacity, increasing foreign trade and imports, capital intensiveness, rising costs for environmental compliance, and cyclical and moderate growth prospects. The industry response has been mergers, acquisitions, restructuring, and expansion into new markets.

During the late 1970s and 1980s, flat and container glass companies closed excess capacity to increase productivity, while specialty glass makers increased capacity to keep pace with demand for emerging breakthrough products. By the mid-1980's, the economy began to recover. New commercial construction began integrating more glass into architectural designs, and new products emerged.

During the 1990's, major consolidation occurred throughout the industry, and high-value niche industries such as fiber optics and glass for electronics began to gain market share. Along with consolidation has come an increase in foreign ownership. Today the industry has fewer major players in container, flat, and fiber glass, and prospects for growth are moderate but steady.

Today's Glass Industry is Efficient, Productive, and Competitive

Significant challenges have been faced in creating today's glass industry. Glass makers have been forced into a capital-intensive position due to market demands for large quantities of both relatively low cost products

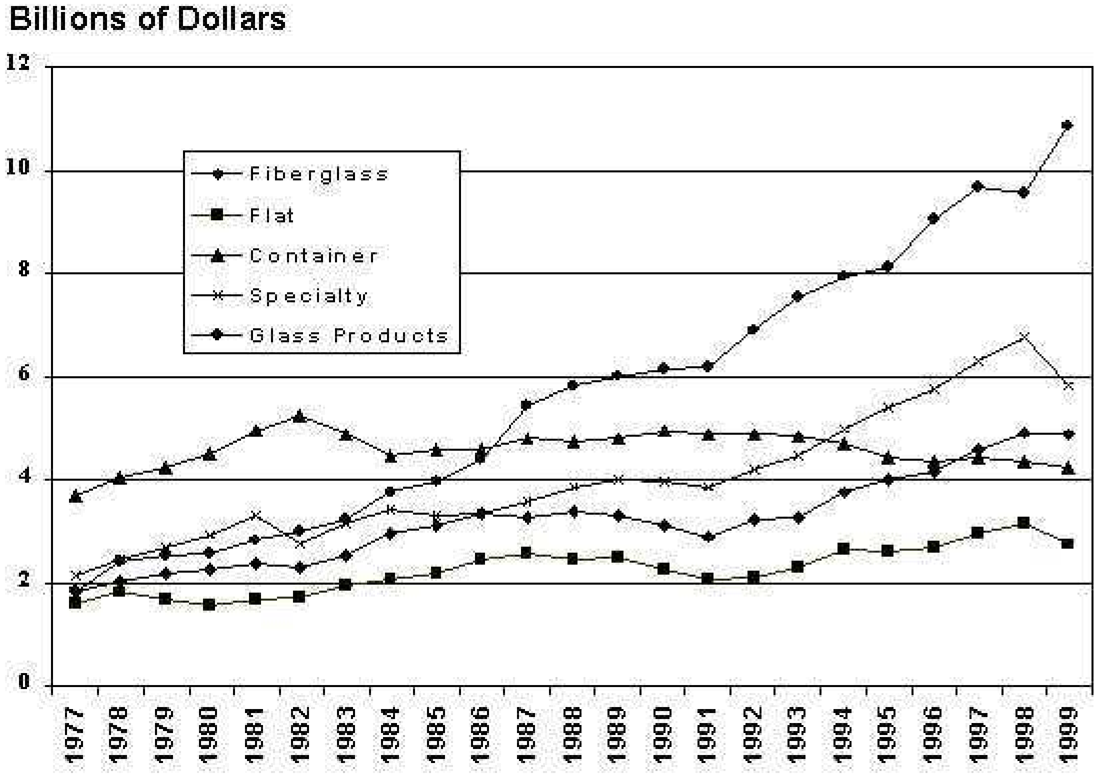

Figure 1-1. Historical Glass Industry Shipments [DOC ASM]

and expensive innovative specialty materials. For forty years glass has faced competition from plastic and aluminum. Profits have been further pressured by keen competition from developing nations and marginal growth in end-use markets.

Today the glass industry is more efficient and productive, and continues to seek new and improved products to maintain a competitive position. As a whole, the glass industry has experienced gradual, yet strong growth over the past two decades. In 1999 the glass industry shipped $28.4 billion in products and employed over 150,000 workers [DOE ASM 93-99]. Trends in shipments over the last 20 years are shown in Figure 1-1. Table 1-3 summarizes current shipments, investments and employment for all glass sectors in 1999.

To enhance its competitive position the glass industry has focused on innovation and profitable international expansion. Heat-resistant glass, photosensitive glass, and fiber optics have opened new markets for U.S. exports. Other innovative uses for glass, such as lightweight, break-resistant glass for containers and flat glass, fiberglass that recovers easily after being compacted, fiber composites, and fiber optics that carry more information than currently possible, are also expected to increase domestic and international demand.

Production and consumption for all four sectors are often concentrated near U.S. population centers due to the prohibitive shipping costs of both raw materials and products, and the heavy concentration of end-use customers. The bulk of glass plants are located in the Northeast, Midwest, and California (see Figure 1-2.)

Table 1-3. Summary of 1999 Industry Statistics

Sector	Shipments ($million)	Production (short tons)	Exports[d] ($million)	Imports[d] ($million)	Establish-ments[c]	Employees (1000)	Production Wages ($/hr)	Capital Expenses ($million)
Flat	2,746	5,000,521	788	576	36	11,053	21.76	322.7
Container	4,215	9,586,500	174	586	61	19,220	20.05	349.3
Pressed/ Blown [a]	5,787	2,484,182[e]	1,298	2,038	515	35,013	15.74	636.8
Mineral Wool [b]	4,844	3,040,000	360	251	298	22,823	17.12	285.8
Purchased Glass Products	10,847	na	1,157	1,047	1,657	62,405	12.79	na
INDUSTRY TOTAL	28,439	20,111,203	3,777	4,498	2,567	150,514	17.49	1,594.6

[a] Textile and optical fibers are included in pressed/blown glass under the NAICS codes.
[b] Includes wool made from siliceous materials such as glass, rock, slag, or combinations of these. Data for glass wool is not categorized separately.
[c] 1997 data, latest available.
[d] 2000 data.
[e] Estimated based on 92 Census Data dn 2% annual growth between 1992 and 1997.
na not available
Sources: DOC ASM 93-99, DOC MP 93-00, USITC 2001

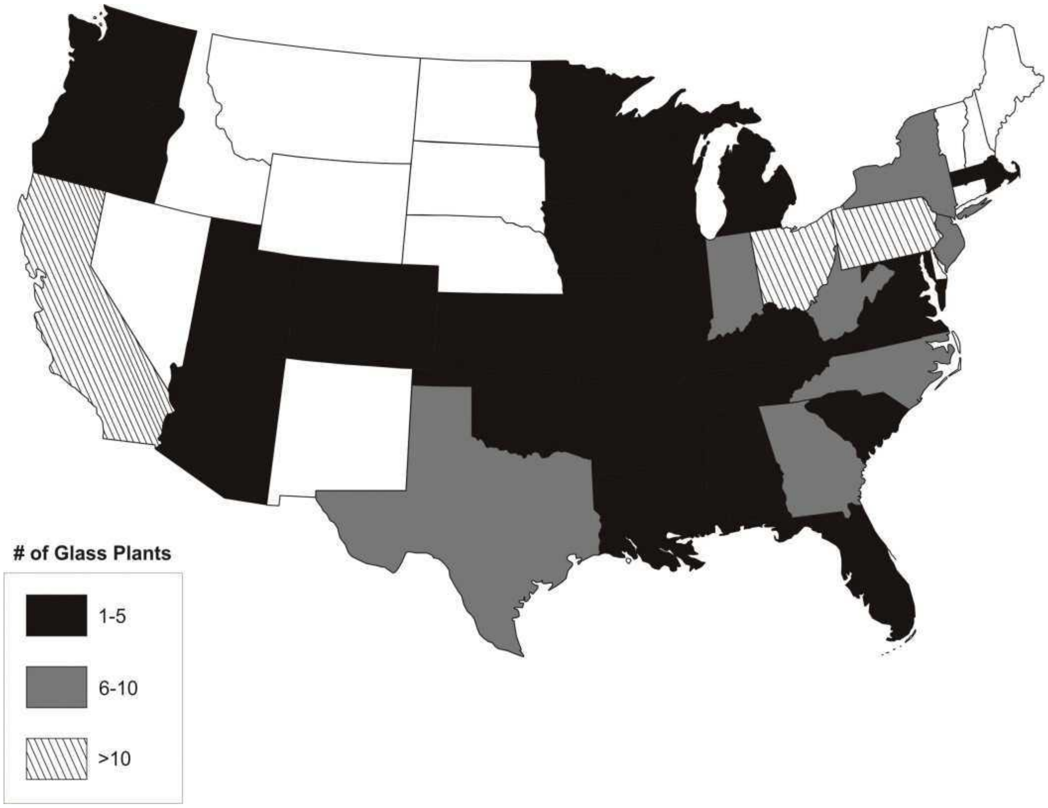

Figure 1-2. Distribution of Glass Plants in the United States
[DOC ASM 93-98, DOC 1997]

Growth, Demand, and Competitive Pressures Differ Between Sectors

Flat Glass

Flat glass, commonly called float glass after the process by which most of it is made, plays a dominate role in the Nation's buildings and vehicles. Since the development of the float glass process in 1959 and thin film coating technology during the last decade, flat glass has remained the transparent material of choice for automotive and construction applications.

In the United States, six major manufacturers account for about 21 percent of worldwide production of flat glass. Of these, four are wholly owned U.S. interests, and the other two are foreign-owned [Cer Ind 1998, Cer Ind 1997a]. Flat glass manufacturers export a significant amount of their products, and this sector has exhibited a favorable trade balance over the last decade. In 2000 nearly $800 billion in shipments of flat glass were exported, compared with $576 billion in imports [DOC ASM 93-99].

The flat glass sector employs over 11,000 workers, with the highest production wages of all the glass sectors (about $21.76/hour). Flat glass plants are typically large facilities—nearly 80 percent have more than 100 employees [DOC ASM 93-99, DOC MP 93-98].

Major Flat Glass Manufacturers

U.S. Owned
PPG Industries
Guardian Industries
Visteon (enterprise of Ford Motor Co)
Cardinal FG

Foreign Owned
AFG Industries (Japanese)
Pilkington (British)

The construction industry accounts for the largest share of the flat glass market (about 56 percent), followed by automotive applications (about 25 percent). Additional markets include glass used in mirror, furniture, non-automotive transportation equipment and appliances (see Figure 1-3).

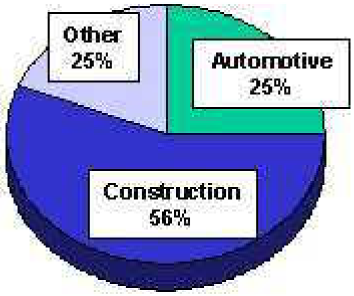

Figure 1-3. Flat Glass Markets
[Cer Ind 2000]

Tempered and insulated glass account for about 60 percent of all flat glass products. Growth in this market is dominated by products that are more energy efficient (laminated, insulating, low-emissivity, reflective) or damage-resistant (laminated safety glass) [Cer Ind 2000].

Demand for flat glass in the 1990s was driven by continued expansion in domestic motor vehicle and building construction industries, as well as by flat glass demand from the developing countries of Asia and Pacific Rim and Latin America. Worldwide the flat glass industry has experienced significant growth over the last decade, with the majority of new plants located in the Pacific Rim nations [Glass Ind 1996].

In the future it is predicted that the U.S. flat glass industry will grow at a rate of 2.5% per year to reach 6.3 billion square feet in 2003. Growth will be influenced by the trend toward larger homes with greater window area, double- or triple-paned insulating windows, and vehicles such as SUVs which incorporate a greater average amount of glass per vehicle [Cer Ind 2000].

Niche markets for value-added products continue to play a substantial role in the flat glass industry, with expected strong growth of 10 to 20 percent annually. Niche products include glass coatings that repel rain, improve night-time visibility, and provide solar control, electro- chromic glass, and glass with electromagnetic control properties.

International agreements are also paving the way for growth in the flat glass industry [Cer Ind 2000]. For example, the *Japan Flat Glass Agreement* with the U.S. contributed to a 270% growth in the value of U.S. shipments to Japan from 1994 to1996. Japan's Ministry of International Trade predicted a 30%–50% growth in imports between 1997 and the turn of the century. With 46% of the flat glass import market in Japan, the U.S. is well positioned to take advantage of this potential growth; however, the other Asian nations and the European Union, who have Japanese import market shares of 35% and 18% respectively, are formidable competitors [USITC 2001].

Container Glass

Glass containers are primarily used as a packaging material for beverages and food (see Figure 1-4). Over the last two decades the three largest markets (beer, food, and soft drinks) have faced increasingly strong competition from aluminum, polyethylene terepthalate (PET) and other plastic materials. As a result, the total share of the container market held by glass has been reduced to less than 14 percent [Ind Minerals 1998].

In the face of increasing competition, the glass container industry has gone through extensive consolidation over the last 10 to 15 years. In the first few years following the energy crisis of the 1970s, 15 U.S. container glass plants were shut down due to high oil costs and the cost of converting to natural gas. Only 54 of the 129 plants operating in 1979 are operating today, with closures due to increasing competition, the high cost of environmental compliance and rising labor costs [Ind Min1998, GIC 2001].

Three companies now dominate the container market, supplying about 90 percent of demand. Consolidation has allowed companies to cut costs and make much-needed investments in new product development. Two of the major players represent the merging of European and Canadian firms with U.S. firms. Ball-Foster evolved from a merger in 1995 with French company Saint-Gobain, and is now operating as Saint-Gobain Containers; Canadian-owned Consumer Packaging acquired Anchor in 1996, and is also affiliated with U.S. company Glenshaw Glass. Other than the three major players, privately-owned Gallo Glass is the largest producer of wine bottles in North America [Ind Minerals 1998].

Container shipments in 1999 were $4.2 billion. Unlike the flat glass sector, considerably more containers are imported than are exported (about $200 million in exports compared with $586 million in imports in 2000) [DOC ASM 93-99, USITC 2001].

Major Container Glass Manufacturers

U.S. Owned
Owens-Brockway Glass Containers
Gallo Glass Company

U.S./Foreign Owned
Saint-Gobain Containers (French)
Consumers Packaging Inc./Anchor
(U.S./Canadian)

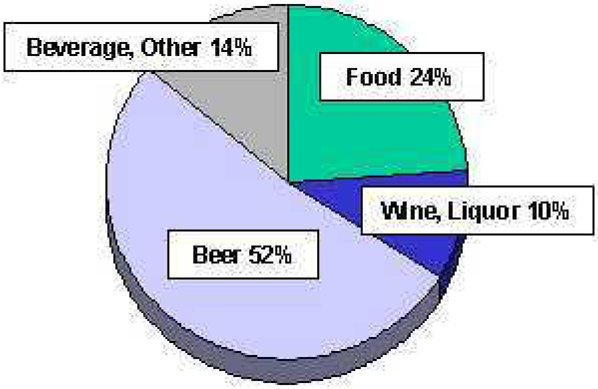

Figure 1-4. Glass Container Markets Based on Shipment Values [DOC MP 93-00]

The container sector employs about 20,000 workers annually, with an average production wage of $19.4 per hour. Container plants are relatively large facilities—all 61 establishments open in 1997 reported 100 employees or more, with more than half reporting 250 to 500 employees [DOC MP 93-98].

Demand in the container glass industry is predicted to expand at a rate of 2.2% annually through 2003. Sales will be supported by new product introductions and rising personal incomes. Although plastic containers will experience higher growth, their takeover in soft drink and milk markets has been mostly completed and advances into other beverage markets is slowing. However, as new markets develop in Asia and South America, demand could begin to shift towards plastic which is lighter-weight, shatter-resistant, and better suited to custom designs [Cer Ind 2000].

Glass containers are expected to gain ground in the cosmetic and toiletry markets where glass dominates for packaging perfume, nail cosmetics, and mid-to-upper market lotions and creams [Cer Ind 2000]. Glass will continue to lead the demand for beer containers, outnumbering aluminum cans (see Table 1-4). Growth is projected at 3% for glass containers, slightly less than the growth in cans [Cer Ind 1998].

Table 1-4. World Demand for Beer Containers (million gross)

Year	Total	Glass	% Market
1987	200	150	75.0
1992	238	170	71.4
1996	270	190	70.4
2001	310	220	71.0

Source: Cer Ind 1998.
Note: 1000 gross = 144,000 units

Pressed/Blown Glass (Specialty)

The specialty glass sector is characterized by very diverse products and processes, ranging from production of cookware to fiber optics, textile fibers, and television tubes (see Figure 1-5). Value-wise, textile fibers, lighting, automotive, and electronic glassware dominate shipments in this sector.

In 1999 there were over 500 establishments producing over 100 specialty glass products, with shipments of nearly $6 billion—the largest

Major Specialty Glass Manufacturers

U.S. Owned
Owens-Corning
PPG Industries
General Electric
Johns Mansville
Libbey

U.S./Foreign Owned
Saint-Gobain (French)
Thomson Multimedia (French)
Asahi (Japan)
Techneglas (Japan)
Royal Phillips (Netherlands)
Osram Sylvania (Siemans-Germany)

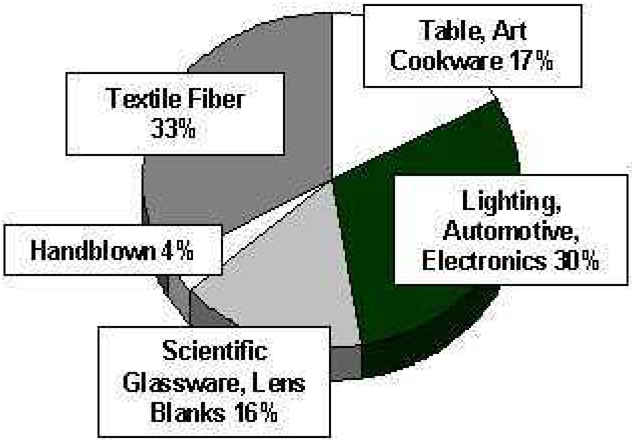

Figure 1-5. Specialty Glass Products, Distribution by Value of Shipments
[DOC MP 93-00]

in the glass manufacturing industry. Specialty glass also employs more people than any other sector—about 35,000 in 1999. A vast majority of these operations (about 400) are small plants having 20 or less employees [DOC MP 93-98].

The competitive position of this sector relies in large part on new technology to expand markets and create new products. Many **specialty products** do not face competition from alternative materials, particularly where the properties of glass make it the only logical material of choice (television tubes, liquid crystal displays). However, manufacturers of these products do face increasingly strong competitive challenges from foreign producers in Europe and Japan.

Complicating the competitive challenge are the lower costs for labor, environmental compliance, and tax liabilities in third world countries, which make it more difficult for U.S. producers to effectively compete. Mergers between foreign and U.S. companies in some ways may compensate for this imbalance.

On the other hand, traditional products such as **tableware and cookware** made by the specialty sector face considerable competition from alternative materials (ceramics, stainless steel). Competition from foreign producers of these products is also keen, which contributes to the sector's negative trade balance. In 2000 the sector reported imports of $1.3 billion compared with exports of $0.2 billion [USITC 2001].

The specialty glass sector has been positively impacted over the last decade by innovative products entering the market such as flat panel displays. Although tonnage produced is not high in comparison with other products like containers or flat glass, the value and profit margins are high. Continued advances in technology and new product innovations will be needed to continue growth in these markets.

Demand for **lighting products** is expected to grow at a steady pace. One of the most important trends in the industry is the use of more efficient, higher cost lighting to replace traditional bulbs and tubes. Initiatives supporting energy conservation and new regulations will continue to drive this change [Cer Ind 1997].

In the U.S. the **textile fiber** market is controlled by three major producers (PPG Industries, Saint Gobain, and Owens-Corning). Textile fibers are used primarily as reinforcements for plastics and other materials used in the automotive and construction markets, and are expected to experience growth of 3 percent annually. In construction markets, growth is fueled by the need for greater durability, lower maintenance and affordability. Automotive applications will be driven by the desire to reduce costs, weight, and maintenance requirements. To meet the challenge of foreign competition, some manufacturers are looking into the use of textile fibers for electronics which are experiencing considerable growth [Glass Ind 1999].

Fiber Optics

In the late 1800's Alexander Graham Bell first used sunlight to transmit voices without the use of copper wire. Although nightfall, clouds, and poor weather hampered these early efforts at using light to convey sound, the discovery of laser technology nearly 90 years later has made the concept a reality. Today very pure optical glass fibers thinner than fishing line can transmit thousands of times more information than traditional copper wire using laser light. One optical fiber, for example, can transmit all the information concerning 150 million shares of stock on the New York Stock Exchange in less than one second [Corning 2000].

The use of glass fibers for data communications has progressed considerably over the last two decades driven by tremendous advances in fiber performance. The fibers manufactured today are more efficient, less expensive, and can transmit more wavelengths at much greater distance that those of the 1970's. Fibers made of fused silica are most often selected for use in data communications; other types of glass fiber are used in illumination and sensing applications [FTI 2000].

Shipments of fiber optic cable and optical fibers have been steadily increasing (see Table 1-5). Currently about 25 companies are involved in the production of optical fiber, and 37 are producing insulated optical fiber cables. Until recently the industry was centered in the United States and led by Corning, Alcatel and Lucent. As restrictive patents that gave exclusive rights to these companies have started to expire, the industry has entered a new era of competition. Although Corning remains one of the largest producers, many other companies are now entering the market (Pirelli, Sumitomo, Alcoa-Fujikura, and Furukawa). The industry increasingly faces considerable challenges from foreign producers entering the market with government subsidies behind them [Glass Ind 1999, DOC MP 93-00, Vision 1996].

Major Manufacturers of Optical Fibers

U.S. Owned
Corning
Lucent

U.S./Foreign Owned
Alcatel (French)
Pirelli (Italian)
Sumitomo Electronics (Japanese)
Alcoa-Fujikura (U.S./Japanese)
Furukawa (Japanese)

Table 1-5. Fiber Optic Shipments ($ million)

Product	1997	1996	Change
Optical fiber for data and non-data transmission	1,210	1,031	17%
Insulated fiber optic cable	1,852	1,728	7%

Source: DOC MP 93-00.

Demand for optical fibers is expected to continue to grow as European, North American and Latin American countries expand their communications networks. Advances in technology will be a major factor in capturing market demand, as the performance of the fiber (amount of data it can carry) dictates its popularity. Based on the success of the LEAF fiber, in early 2000 Corning announced plans to invest $750 million in new optical fiber production capacity [Corning 2001, Glass Ind 1999]. More recently, while investment plans have slowed, the company remains committed to expansion.

The need for greater bandwidth and updated network systems is expected to continue to drive growth in this industry. Fiber performance is, however, limited by the inherent nature of the glass fiber, and not the technology used to transmit data. In future, advances in communications technology could ultimately outpace the ability of glass fiber to transmit data [Glass Ind 1999].

Glass Wool Insulation (Fiber Glass)

The major products from fibrous glass (excluding textile and optical fibers) include unbonded and bonded glass wool, mats, staple fiber, and cut strands, and molded products, pipe insulation, ceiling tile and specialty items (see Figure 1-6). Insulation is also made from other siliceous materials such as rock and slag, or can be a combination of these and glass fibers. For this reason, most of the available data on insulation includes all these materials and does not include glass wool as a separate category.

Four major companies dominate glass insulation production, accounting for about 93 percent of the U.S. insulation market. The industry has experienced slow growth, partly because of the public perception of the health risks associated with insulation products. Owens-Corning and Johns Manville are still being impacted by litigation on previous production of asbestos products [Glass Ind 1999, Glass Ind 1999a].

In 1999 the industry shipped $4.8 billion in products and employed about 23,000 people,

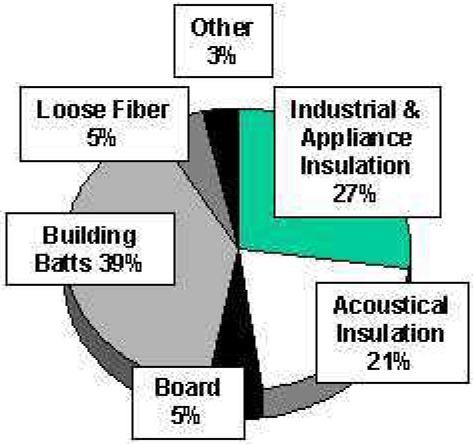

Figure 1-6. Product Distribution for Fiber Insulation [DOC MP 93-98]

with production wages of about $17.1 per hour.

The industry also posted a trade surplus, although most of the products manufactured are used in the United States. The size of establishments manufacturing insulation vary considerably, with about half reporting less than 20 employees. About 20 percent are large facilities with 100 or more employees [DOC MP 93-98].

Major Fiber Glass Manufacturers

Owens-Corning
PPG Industries
Johns Manville (a Berkshire Hathaway Co.)
Saint-Gobain (French)

The glass fiber industry, like the flat glass industry, depends heavily on the construction sector. Demand for fiberglass insulation is expected to expand in the future along with the demand for materials with greater durability, lower maintenance, and affordability as the driving force in the construction industry. Fiberglass insulation demand is expected to grow less than 2% per year to reach four billion pounds in 2003 [Cer Ind 1999].

Demand for fiberglass will benefit from increasing energy standards for buildings, appliances, and other products. Homeowners especially are expected to take advantage of energy savings by installing fiberglass insulation in attics, basements, and house walls.

Reduced demand for building products can have a significant impact on the industry. In October 2000, Owens-Corning, the largest manufacturer of fiber glass insulation in the world, filed for reorganization under Chapter 11, primarily due to the combination of a multi-million dollar asbestos liability, falling demand for building materials, and increased costs for energy and raw materials. Twenty-two other fiber glass manufacturers involved with asbestos-related activities also undertook reorganization under Chapter 11. Despite the challenge of resolving asbestos claims, Owens-Corning remains strong today, the result of more recent upward trends in construction [Owens 2001].

Meanwhile, U.S. companies continue to expand into foreign markets by acquiring or establishing foreign plants. In early 1996 Owens-Corning, one of the major fiberglass manufacturers, opened an insulation plant in Shanghai, China a year after starting another insulation plant in Guangzhou. In March 2001, Johns Manville acquired Skloplast, a fiber glass manufacturing company located in Trnava, Slovakia, providing them with a significant presence in European fiber glass reinforcement markets [Manville 2001].

1.3 Energy Overview

Natural Gas is the Primary Source of Energy in Glassmaking

Glassmaking is relatively energy-intensive, primarily due to the large amount of energy required to melt and refine glass. According to the 1994 Manufacturing Energy Consumption Survey (MECS) conducted by the U.S. Department of Energy, the glass industry used about 250 trillion Btu to produce about 20 billion tons of glass in 1994 [MECS 1994]. The preliminary data recently released for the 1998 MECS survey indicated glass industry usage of 206 trillion Btu. However, there have been significant changes in the way the survey is

Changes to the Manufacturing Energy Consumption Survey

The 1994 MECS includes the four glass segments covered in this report: flat, container, specialty, and mineral wool. It did not include glass made from purchased glass rather than raw materials. For 1998, the MECS was changed and no longer breaks out energy use for these sectors. Mineral wool (glass insulation) is no longer separated, and is aggregated into mineral products. Glass that is produced from purchased glass (not manufactured from raw materials) is now included in a single glass category along with flat, container and specialty glass.

conducted which account for the large difference in energy use reported [MECS 1998]. Energy use for both years is shown for comparison in Table 1-6.

The Bureau of the Census also reports on energy consumption in the glass industry by sector in its Annual Survey of Manufactures (ASM) [DOC ASM 93-98]. Actual quantities of purchased electricity are reported, along with the cost of purchased fuels other than electricity.

In the glass industry, natural gas accounts for nearly all purchased fuels (about 99 percent). Estimates of energy consumption were made based on the ASM data using the national average values for the cost of natural gas for each year given. Electricity use is based on actual consumption. Table 1-7 provides the results by glass sector. Looking at both sets of data, the MECS data for 1994 is very similar to that provided by ASM.

Figure 1-7 illustrates the energy consumed among the four sectors in terms of electricity versus fuel use in 1998. The ratio of fuel use to electricity use is the highest for the flat glass industry, while the other sectors are relatively similar in consumption patterns.

Significant progress has been made in reducing energy intensity in some areas of the glass industry over the last ten years (see Figure 1-8). This increase in efficiency has been accomplished mostly through improved process control systems, the development and use of advanced refractory materials, and technologies such as oxy-fuel firing and electric boost which increase production capacity. Advanced technology has reduced the fuel consumed per ton of glass melted by 25 percent since the early 1980's. Energy use has declined in the fiber glass sector by 30 percent since 1978 [Vision 1996].

Although they vary between the glass sectors, energy costs on average account for about 15 percent of the total manufacturing costs for glass (see Figure 1-9) [Vision 1996]. The pressed and blown, or specialty glass sector exhibits the highest average energy consumption per ton of glass, which reflects the inefficiencies of the small-scale furnaces that are characteristic of this sector. The lowest per unit energy consumption is generally found in container and flat glass sectors, where larger furnace sizes and automation contribute to increased efficiency. Less stringent quality requirements are also a factor in lower energy use per unit in container manufacturing plants.

Trends in annual industry energy consumption in general reflect fluctuations in markets and demand (see Figure 1-10). Markets (and total annual energy use) for flat and fiber glass have remained relatively stable, with growth rates about the same as GDP. Container glass and pressed and blown glass have experienced significant dips and gains. Container glass has been challenged with strong competitive pressures from alternative materials, while the pressed and blown glass sector has fluctuated with the introduction of new products in electronics and other markets.

The glass industry relies on electricity and natural gas to supply the bulk of its energy needs. Glass melting consumes the most energy of all the production processes, and is accomplished using natural gas, a combination of natural gas and electricity (electric boost), or all electricity.

Table 1-6. U.S. Glass Industry Energy Use, MECS Estimates (Trillion Btu)

Sector	1994[b]					1998[c]				
	Purchased Electricity	Fuels	Net Energy Use	Losses[a]	Total Energy Use	Purchased Electricity	Fuels	Net Energy Use	Losses[a]	Total Energy Use
Flat	5	47	52	10.4	62.4	-	-	-	-	-
Container	15	68	83	31.2	114.2	-	-	-	-	-
Pressed/ Blown	11	52	63	22.9	85.9	-	-	-	-	-
Mineral Wool	12	39	51	24.9	75.9	-	-	-	-	-
INDUSTRY TOTAL	43	206	249	89.4	338.4	42	164	206	87	293

a Electricity losses incurred during the generation, transmission, and distribution of electricity based on a conversion factor of 10,500 Btu/kilowatt-hour.
b The 1994 survey does not include a separate category for products made from purchased glass.
c The 1998 survey no longer provides data at 6-digit NAICS levels for the glass industry; data shown is the total for NAICS 3272, which does not include mineral wool, but does include products made from purchased glass.
Sources: MECS 1994, 1998.

Table 1-7. U.S. Glass Industry Energy Use[a], 1993-1999, ASM Estimates (Trillion Btu)

Year	Purchased Electricity[b]	Fuels[c]	Net Energy Use	Losses[d]	Total Energy Use
1999	55.6	224.3	279.9	115.4	395.3
1998	54.7	222.7	277.4	113.6	391.0
1997	52.8	201.3	254.1	109.7	363.8
1996	51.9	200.6	252.5	107.9	360.4
1995	50.8	214.9	265.7	105.6	371.3
1994	50.3	211.2	261.5	104.4	365.9
1993	49.2	210.4	259.6	102.2	361.8

a Total for NAICS 3272 (flat, container, pressed/blown, products from purchased glass) plus NAICS 327993 (mineral wool).
b Does not consider electricity generated and sold offsite.
c Calculated based on annual cost of purchased fuels, using average national natural gas prices paid by the industrial sector for each year.
d Electricity losses incurred during the generation, transmission, and distribution of electricity based on a conversion factor of 10,500 Btu/kilowatt-hour.
Source: DOC ASM 93-99, DOE 2000.

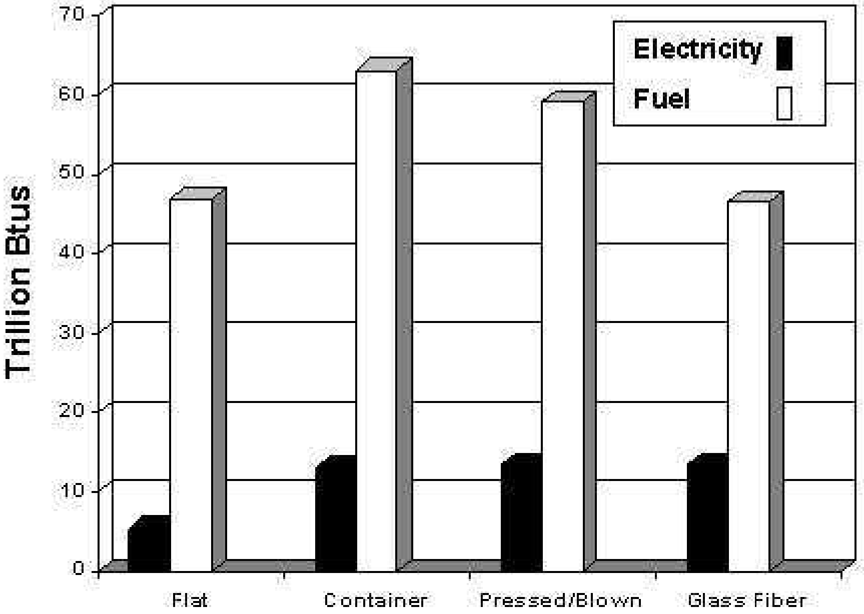

Figure 1-7. Electricity and Fuel Use in the Glass Industry, By Sector, 1998 [DOC ASM 93-99]

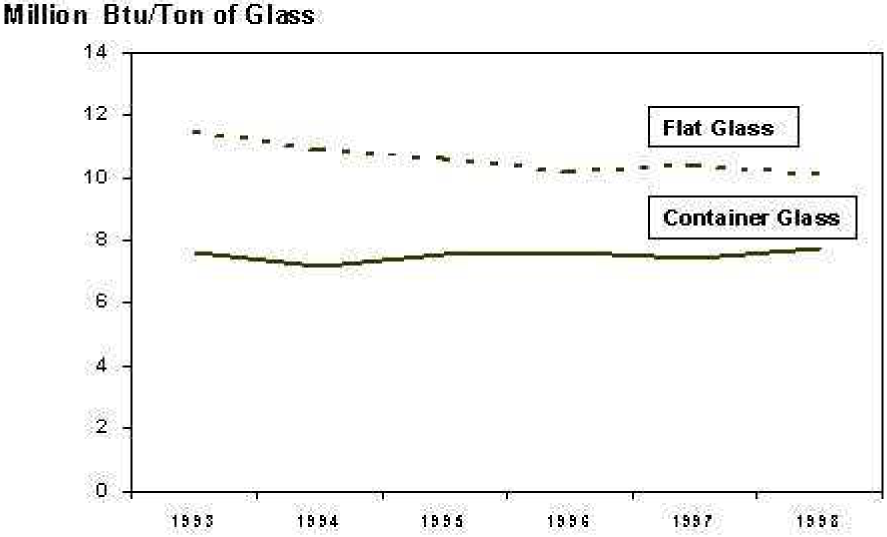

Figure 1-8. Energy Intensity Trends for Flat and Container Glass [DOC ASM 93-98, DOC MP 93-99]

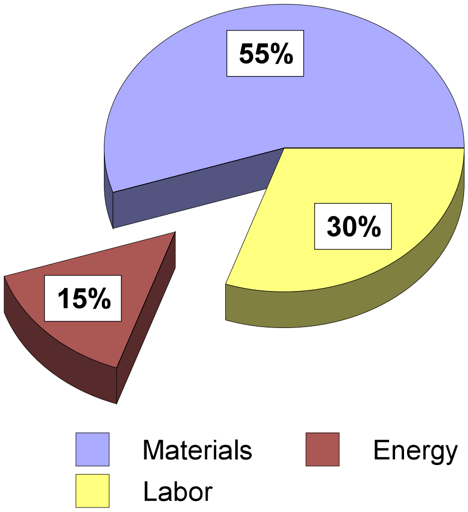

Figure 1-9. Glass Manufacturing Costs [Vision 1996]

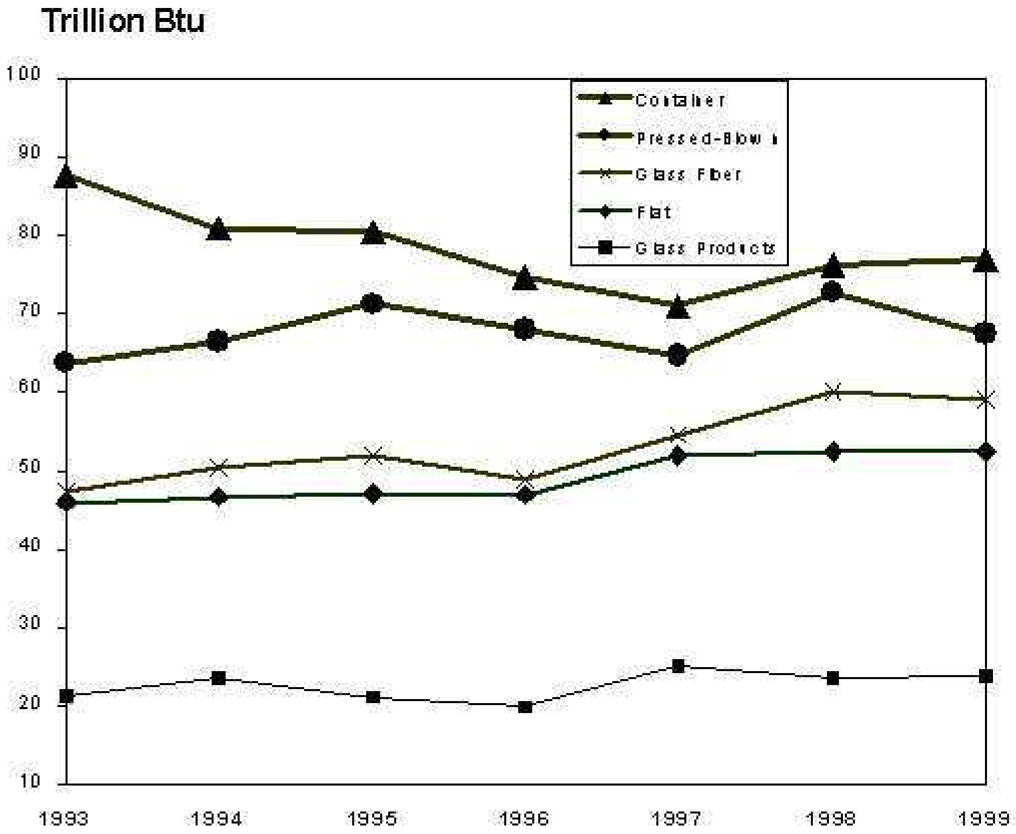

Figure 1-10. Annual Energy Use Trends for the Glass Industry
[DOC ASM 93-99]

Table 1-8. Unit Energy Consumption by Process Area, 1994

Process Area	Net Electricity	Residual Fuel Oil	Natural Gas	Other
Total Inputs	17.3%	1.6%	79.5%	0.8%
Indirect Uses -Boiler Fuel	0.0%	W	1.6%	–
Direct Uses - Total Process	14.9%	1.6%	74.7%	–
Process Heating	7.2%	1.6%	59.4%	–
Process Cooling and Refrigeration	0.4%	0.0%	0.0%	–
Machine Drive	7.6%	0.0%	0.8%	–
Direct Uses - Total Nonprocess	1.6%	0.0%	2.8%	–
Facility Heating, Ventilation, and Air Conditioning	0.4%	0.0%	2.8%	–
Facility Lighting	0.8%	–	–	–
Facility Support	0	0	0	–

Source: MECS 1994
W = data withheld to avoid disclosing individual company information.

Table 1-8 provides a more detailed description of the unit energy consumption by process area for the glass industry, based on the 1994 MECS survey [MECS 1994]. Industry-wide, natural gas accounts for nearly 80 percent of energy use for all purposes. Process heating, mostly in melting and refining, accounts for about 70 percent of energy use.

Natural gas is also used in the control of air emissions, particularly in glass fiber production. Some air emissions from these processes are hazardous or toxic and must be controlled through incineration, which is relatively energy-intensive.

About half of electricity use in glassmaking is for process heating, mostly in electric boosting of furnaces. A few sectors rely on all-electric melters, but these are not practical for larger production quantities. The remainder of electricity is used for machine drive on blowers, compressors, conveyers, and pumps, with a small share for facilities heating, ventilation, air conditioning, and lighting. Electricity is also used to control air emissions of particulates in some facilities (electrostatic precipitators).

Very little fuel oil is used in the glass industry (less than 2 percent of total energy). Natural gas is usually the fuel of choice as it is cleaner and in some cases, more cost-effective, depending on fuel prices. A few specialty glassmakers continue to use oil-fired direct melters or day tanks.

In theory, about 2.2 million Btu of energy are required to prepare a ton of molten glass, but the industry actually consumes much more than that because of inefficiencies and losses during processing. Much of the inefficiencies occur in the glass melting furnace. In the furnace, about 40 percent of the energy consumed goes to heating the batch and for the thermodynamic heat of reactions that occur. About 30 percent of energy is lost through the furnace structure, and another 30 percent exits with the stack gases [Vision 1996, EPA 1994].

Regenerative gas furnaces exhibit much higher efficiencies than pot furnaces, day tanks, or direct melters. All-electric melters are the most efficient, but the high cost of electricity limits their use in larger production applications.

Theoretical Energy Requirements for Glass

Stoichiometric Chemical Requirements	0.6 10^6 Btu/ton
Sensible Heat - Bringing Batch to 2800°F	1.6 10^6 Btu/ton
TOTAL	2.2 10^6 Btu/ton

Instead, larger producers often use electric boosting on furnaces to increase efficiency and yields. Cullet preheating and oxy-fuel firing can also reduce energy requirements and increase efficiency (see Chapter 4 for more detail on furnace technologies).

1.4 Environmental Overview

The Glass Industry is Working to Reduce Pollution and Improve Environmental Performance

Over the last decade the glass industry has made significant advances in protecting the environment as well as the health and safety of its workers. The industry participates in numerous voluntary pollution prevention efforts including the 33/50 program, Green Lights and Energy Star programs. EPA's 33/50 program aims to reduce toxic chemical releases and transfers of 17 chemicals by 50% from 1995 levels. According to EPA, nearly a third of the companies in SIC code 32 (includes stone, clay and glass) participate in this program. Many specialty glass manufacturers participate in EPA's Green Lights and Energy Star Programs as 'Allies' or providers of energy-efficient products.

In light of the problems arising from asbestos insulating products, the fiber glass industry has committed tens of millions of dollars to human health and safety research on fiber glass. Over 60 years of studies by the industry have shown that exposures are low during manufacture, installation, use and removal, and that manufacturing workers are not at risk [NAIMA 1998]. In 1999 the major trade association of the industry (North American Insulation Manufacturers Association—NAIMA) joined with OSHA and key insulation contractor organizations to announce the creation of the Health and Safety Partnership Program (HSPP) for fiber glass, rock wool and slag wool. The program promotes work practices and training endorsed by OSHA [NAIMA 2000].

The industry has also begun to participate in the rulemaking process with EPA. An example is the recently promulgated NESHAP (National Emission Standards for Hazardous Air Pollutants) ruling for the glass insulation industry, which is based on the participation of ten fiber glass plants in emissions tests.

In 1994, the most recent year for which data is available, the glass industry spent approximately $250 million on pollution abatement and control [DOC 1994]. These expenditures include the cost of capital equipment as well as annual operating costs for labor, material, energy, and supplies (see Figure 1-11). Capital equipment for control of air emissions accounts for the bulk of pollution abatement capital expenditures in most glass sectors. Operating costs account for about 74 percent of pollution abatement and control expenditures. In most sectors of the glass industry, notably container glass, glass wool, and specialty glass, fuel and electricity costs account for a significant portion of pollution controls costs (from 19 to 40 percent). Energy is primarily expended for control of particulates as well as volatile emissions of hazardous or toxic components, which must be destroyed in incinerators.

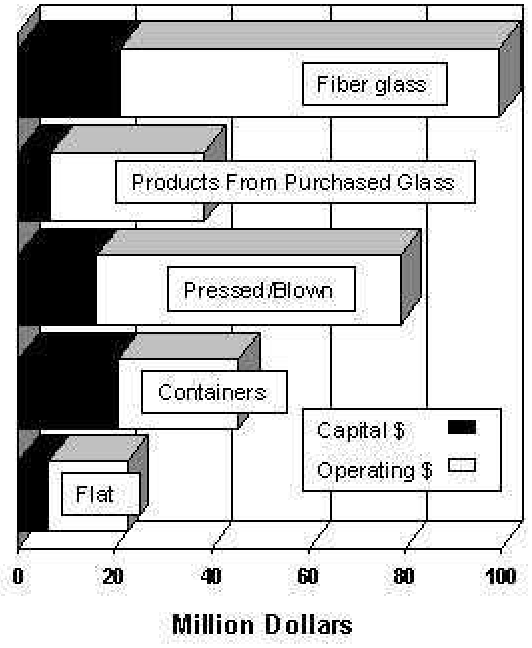

Figure 1-11. Cost Expenditures for Pollution Abatement and Control [DOC 1994]

Costs for pollution abatement and control on a per furnace basis are highest for glass wool manufacturers and lowest for flat glass producers. Differences in pollution abatement costs between sectors generally arise due to unique variations in downstream processing and fabrication (e.g., spinning of glass wool fiber versus float glass forming, higher generation of particulates).

According to its vision for the future, the glass industry has a goal of reducing its air and water emissions by at least 20% from current levels [Vision 1996]. Producers have also made changes to manufacturing processes to further reduce air and water discharges. Such investments are likely to continue in the future to improve environmental performance and ultimately reduce the cost of compliance.

The Glass Industry is Subject to a Number of Environmental Laws and Regulations

Glass manufacture is controlled by a growing number of state and Federal laws [EPA, 1997, Glass Ind 1998, EPA 1995]. Major legislation includes the following:

The Pollution Prevention Act of 1990 was implemented to reduce the amount of pollution generated by improving production, operation, and raw materials handling practices. Facilities are required to report information about the production, management and disposal of Toxic Release Inventory (TRI) chemicals, as well as efforts to reduce the type and quantity of these substances. Glass industry TRI statistics are collected together with the stone, clay, and concrete products industries and reported under SIC 32.

The Clean Air Act, first passed in 1970 and later amended in 1990, established national ambient air quality standards to limit levels of "criteria pollutants," including carbon monoxide, nitrogen dioxide, lead, particulate matter, ozone, and sulfur dioxide. New Source Performance Standards, uniform national emission standards for new stationary sources falling within particular industrial categories were also established by the Clean Air Act (CAA).

In addition to the generally applicable standards of the CAA, the glass industry must also comply with these industry specific environmental regulations [EPA 1995]:

- Standards of Performance for Glass Manufacturing Plants (40 CFR 60.290 Subpart CC) regulates emissions of particulate matter from glass melting furnaces.
- Standards of Performance for Wool Fiberglass Insulation Manufacturing Plants (40 CFR 60.680 Subpart PPP) regulates emissions of particulate matter by rotary spin wool fiberglass insulation manufacturers.
- National Emissions Standard for Inorganic Arsenic Emissions from Glass Manufacturing Plants (40 CFR 61.160 SubPart N) regulates emissions of arsenic. This subpart applies to glass melting furnaces that use commercial arsenic as a raw material.

- National Emissions Standards for Hazardous Air Pollutants (NESHAP) for Source Categories for Wool Fiberglass Manufacturing (40 CFR, Part 63) regulates emissions of three metals (arsenic, chromium and lead) and three organic hazardous air pollutants (formaldehyde, phenol, and methanol).

The Clean Water Act (CWA) regulates the amount of chemicals and toxins released by industries via direct and indirect wastewater/effluent discharges. Pollutants are classified as “priority” pollutants which include various toxic substances; “conventional” pollutants, such as biochemical oxygen demand, total suspended solids, fecal coliform, oil and grease, and pH; and “non-conventional” pollutants which are substances that do not fall under the “priority” or “conventional” classifications. Direct (point source) and indirect discharges are regulated by the National Pollutant Discharge Elimination System (NDPES) program.

The Toxic Substances Control Act (TSCA) of 1976 supplements the Clean Air Act and the Toxic Release Inventory, giving the EPA the ability to track chemicals produced or imported into the United States. Also included in EPA’s chemical tracking are chemicals under development. EPA has the authority to require testing of all chemicals (at any point during a chemical’s life cycle) that pose an environmental or human risk, and ban those that are deemed unreasonably risky.

The Resource Conservation and Recovery Act (RCRA) was passed in 1976 as an amendment to the Solid Waste Disposal Act to control hazardous waste from the “cradle-to-grave.” Management includes generation, transportation, treatment, storage, and disposal of hazardous waste. Although RCRA is a federal standard, the requirements are not industry specific, and enforcement is typically handled by the state.

The RCRA standards which are of most concern to the glass industry include:

Major Environmental Legislation Affecting the Glass Industry

- Clean Air Act and Amendments (CAA)
- Clean Water Act (CWA)
- Toxic Substances Control Act (TSCA)
- Resource Conservation and Recovery Act (RCRA)

- Land Disposal Restrictions (LDR) which require treatment of solvents, heavy metals and acids prior to land disposal (40 CFR 268).

- Used Oil Management Standards which impose requirements affecting the storage, transportation, burning, processing, and refining of used oil (40 CFR Part 279).

- Provisions requiring VOC generators to test, inspect, and monitor the waste stored in containers to ensure that they meet emission standards (40 CFR Part 264-265, SubPart CC).

- Restrictions, performance standards and emissions monitoring on companies that use boilers or furnaces to burn hazardous waste (e.g., incinerators) (40 CFR Part 266, SubPart H).

Air Emissions Are Generated in Melting and Finishing Processes

Melting raw materials and combustion products created by producing glass generate air emissions consisting of particulates, nitrogen oxides, and sulfur oxides. Emissions are also generated during the forming and finishing of glass products as a result of thermal decomposition of lubricants, binders and coatings. Table 1-9 summarizes the combustion air emissions from glass manufacturing, along with the emission factors used for estimating emissions.

Table 1-9. Criteria Pollutants From Combustion of Fuels in the Glass Industry, 1998 (Metric Tons)

Air Pollutant	Emission Factors (lb/MM Btu)		Glass Industry Emissions[a]
	Electricity	Natural Gas	
Sulfur Oxides	0.332	0	22,300
Nitrogen Oxides	0.28	0.212	39,500
Volatile Organic Compounds	0.006	0.006	989
Carbon Monoxide	0.048	0.058	8,890
Particulates	0.006	0	403

[a] Calculated based on 1998 energy consumption by fuel type, using conversion factors developed by the U.S. Environmental Protection Agency and U.S. Department of Energy. Includes losses incurred during the generation and transmission of electricity.

Sources: DOC ASM 993-99, EPA 1986, 1988, 1996; DOE 2000a.

Other emissions from forming and fabricating may include sodium fluoride, sodium fluorosilicate, silica, calcium fluoride, aluminum silicate, sodium sulfate, boron oxides, fluorides, boric acid, carbon dioxide and water vapor. These depend on the composition of the glass and the processes used for forming and post-forming. Dust particles may arise from various sources throughout the glass manufacturing process, but mostly from the preparation and sizing of the glass batch.

Glass manufacturers often use baghouse filters to capture the particulate emissions. The baghouse dust is then typically recycled back into the furnace.

Glass plants remove air pollutants through the use of aqueous media, filters, and precipitators. Air pollution control technologies used in the glass industry commonly transfer contaminates from one media (air) to another (water or hazardous waste) [EPA 1995].

Sulfur oxides and nitrogen oxides are the primary air pollutants produced during the production and manufacture of glass products. These emissions are stringently controlled by Federal regulations, and the glass industry has invested millions of dollars over the last two decades to institute control technology.

Oxy-fuel firing is the preferred technique for control of NO_x in most of the glass industry. Studies show that the oxy-firing technology many glassmakers have adopted to save energy and improve productivity also reduces NO_x emissions by about 70 percent and particulate emissions by 60 percent. One drawback in using pure oxygen rather than air is the potential for melter crown refractory corrosion [Geiger 1994, Gridley 2001, GIC 2001].

The second most used method for controlling NO_x is process control. Techniques incorporated into the glassmaking process are a third choice. For example, additional natural gas can be injected into the exhaust, which leads to a chemical reducing reaction which breaks down the nitrogen oxide into nitrogen gas [GCI 2001].

A Few Toxic Chemicals Result From Glass Manufacture

In 1995, SIC code 32 (stone, clay and glass combined) reported production-related waste of about 1.45 billion pounds of 100 different toxic chemicals covered by the Pollution Prevention Act, including solvents, acids, heavy metals, and other compounds (EPA 1995). The flat glass industry reported relatively low releases, with sulfuric acid accounting for more than two-thirds of the industry total. Releases from the fiberglass industry included significant amounts of acids, heavy metals, and solvents.

Solid and Liquid Wastes Result From Processing and Maintenance

Waste generated in the glass industry can be categorized into the following three groups:

- materials handling waste
- pollution control equipment waste
- plant maintenance waste.

Materials handling waste includes the waste generated during the receiving and transfer of raw materials at the facility for storage or processing, including raw materials that are rendered unusable when spilled during receiving and transfer.

Emissions control equipment at glass manufacturing plants generates waste residues from pollutants produced or captured during the melting, forming, and finishing steps. These may be hazardous or non-hazardous, depending on the process and type of glass.

Glass plant maintenance wastes include waste oil and solvents generated in the forming process, furnace slag, and refractory wastes.

Furnace dust, grinding and polishing sludge, and refractory rubble from the demolition of glass furnaces may contain metals and other unsafe materials [Geiger 1993]. During the forming process, oil is used in the forming machines and often contaminates the water that keeps the machines cool. Water-based glue for packaging is another example. Table 1-10 depicts specific pollutants for each of the key areas mentioned. Most of the industry's waste is managed on site via recycling, energy recovery, or treatment.

The remaining waste is treated and released to the environment through direct discharges to air, land, and water, underground injection or off-site disposal.

Increasingly, companies are recycling dust and other materials back into the furnaces. Particle-size distribution, chemical composition, and compaction behavior must be known for proper handling of these wastes. One company has developed an economic and environmentally sound system to turn the fine powder into pellets to be returned to the furnaces [Geiger 1994].

Glass Recycling is on the Rise

One of the most important properties of glass is that it can, in theory, be recycled an indefinite amount of times without any loss of quality. Mixing recycled glass (commonly referred to as cullet) with the glass batch has a number of benefits, including reduced costs for processing and raw materials, lower energy use, and a reduction in waste going to landfills. In 1998, one study estimated that glass recycling saved $60 million in energy costs and $100 million in disposal costs [EPA 1998]. However, to effectively recycle glass waste products, they must consist only of glass and be separated from contaminants such as ceramics and metals which can reduce the quality of new glass products.

Volumes of post-consumer glass cullet are rising, and manufacturers are steadily increasing the amount of cullet used. Recyclers are also moving increasingly toward mixed recycling systems. Commingling of waste makes it more difficult to cleanly separate glass from other recycled materials and minimize contamination. To increase recycling rates, glass producers need better color sorting and ceramic detection technology for post-consumer glass [Glass Ind 2000, GPI 1999, Ind Min 1998].

In spite of these issues, the use of recycled glass, commonly referred to as cullet, has been increasing steadily over the last two decades. Recycling of container glass has risen from around 25 percent in 1988 to over 35 percent in 1998. Glass packaging is recycled back into new packaging, and is also used as a feedstock for other glass products, including fiber glass insulation, roadbed aggregate, driving safety reflective beads, and decorative tile.

In the flat glass sector, manufacturers recycle anywhere from 15 to 30 percent of their own cullet, but seldom use outside sources because of the extremely high quality requirements for flat glass (see Figure 1-12). Fiber glass manufacturers are one of the largest recyclers

To encourage recycling, some states (notably California) mandate a minimum recycled glass content in glass food, drink or beverage containers and fiberglass products manufactured within the state.

Table 1-10. Summary of Inputs and Waste Products From Glass Manufacture		
Area of Manufacturing	**Material Inputs**	**Potential Waste/Emissions**
Materials Handling	silica sand; soda ash; limestone; cullet; oxides	unusable raw materials; particulates; cullet
Processing and Plant Maintenance	silica sand; soda ash; limestone; cullet; oxides; arsenic; stannic acid; oil; 1,1,1-trichloroethane (TCA); water-based glue; hydrofluoric acid (HF)	particulates; nitrogen oxides; sulfur oxides; TCA; furnace slag (magnesium oxide, sodium sulfate); waste oil; water-based glue (solid and liquid form);cullet; refractory wastes; HF; lime;
Pollution Control Equipment	water; sodium carbonate; aqueous media; ammonia; furnace gas	particulates; nitrogen oxides; sulfur oxides; arsenic; stannic acid; hydrochloric acid; ammonia; ammonium chloride; sulfates (selenium, chromium, cadmium, cobalt, lead, sodium)

Sources: EPA 1997, EPA 1995, EPA 1995, EPA 1986, EPA 1985.

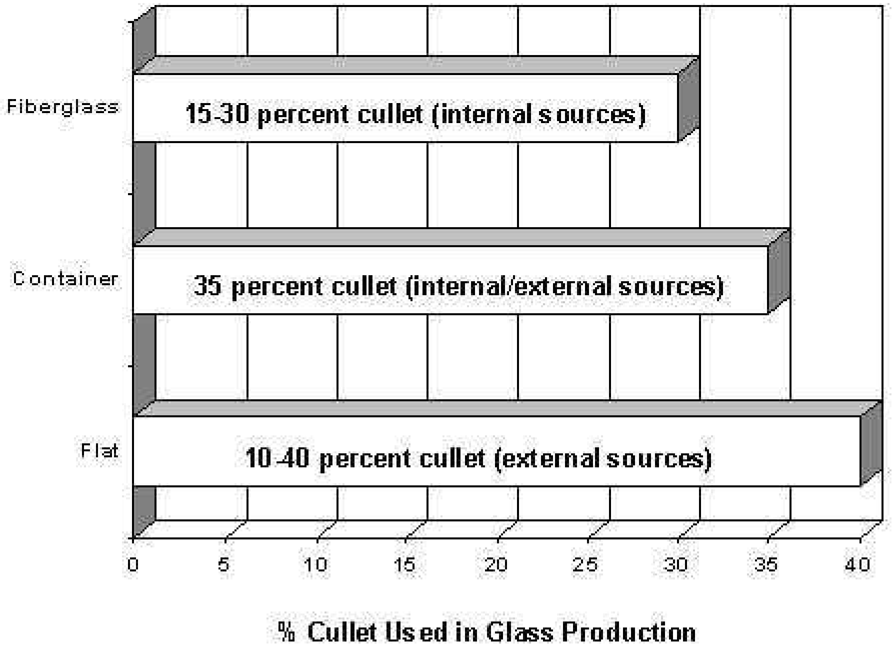

Figure 1-12. Current Recycling of Glass
[Glass Ind 1998, Vision 1996, GPI 1999]

of post-consumer and industrial waste glass. In 2001, a survey indicated that this sector recycled about 7.2 billion pounds of pre- and post-consumer waste glass over a six-year period [NAIMA 2001]. Currently fiber glass manufacturers use from 10 to 40 percent recycled glass, nearly all from outside sources (rather than fiber glass waste) [GPI 1999, Vision 1996].

In the specialty glass sector, cathode ray tube (CRT) manufacturers are looking for ways to recycle the glass elements of CRTs. Unusable CRTs now go to landfills because the glass is difficult to recover cost-effectively. However, with the escalation in the use and continual upgrading of computers, the amount of CRTs going to landfills is dramatically increasing. Potentially new ground glass waste re-use technologies could be used to recover at least part of the CRT in the future [Glass Ind 1998].

Reducing Greenhouse Gases May Be A Future Challenge

Global climate change refers to the myriad of environmental problems that are believed to be caused, in part, by the reaction of the world's climate (temperature, rainfall, cloud cover) to rapidly increasing human activities. The generation of greenhouse gases (carbon dioxide, methane, nitrous oxide) which trap heat in the atmosphere has been linked to global warming. These gases are transparent to solar radiation that enters the Earth's atmosphere, but strongly absorb the infrared thermal radiation emitted by the Earth.

At an international summit meeting in Kyoto, Japan, in late 1997, world leaders formulated the **Kyoto Protocol,** which calls for a significant reduction in greenhouse gases by the United States and European Nations by the year 2010 [CHEMWK 1999]. Many industries are concerned that the economic impacts of such a treaty are not well understood. One study indicates that mandatory emissions goals (holding emissions to 1990 levels) could result in a loss of gross domestic product of $227 billion (1992 dollars) in 2010 alone [WEFA 1997]. Although the Kyoto Protocol has not been ratified by the United States, the issue of greenhouse gas generation continues to be an important global issue and one of increasing concern to both the public and private sectors.

Combustion of Fuels in Glass Manufacturing Processes Produces Greenhouse Gases

In the glass industry, greenhouse gases (carbon dioxide) are emitted from the combustion of fossil fuels and the incorporation of soda ash in glass. The amount of carbon released when fossil fuels are burned is dependent on the carbon content, density, and gross heat of combustion for the particular fuel. The carbon coefficients and energy consumption data used to calculate **combustion-related emissions** of carbon dioxide from glass manufacture are shown in Table 1-11. A detailed explanation of how carbon coefficients were derived can be found in *Emissions of Greenhouse Gases in the United States, 1987-1992* [DOE 1994].

The use of soda ash (sodium carbonate) is another source of carbon dioxide in glass manufacture. As soda ash is processed into various products, additional carbon dioxide may be emitted if the carbon is oxidized. Emissions of carbon dioxide from this source in the glass industry are less than 0.005 MMTCE annually [DOE 1998]. Limestone (calcium carbonate), a glass batch material, is also a relatively small source of carbon dioxide.

Table 1-11 Carbon Emissions From Fuel Combustion in the Glass Industry, 1998 (Metric Tons)			
Fuel Type	**Carbon Coefficient (MMTCE/trillion Btu)**	**1998 Energy Use (trillion Btu)**	**Carbon (MMTCE)[a]**
Electricity	0.018	45.6	0.802
Natural Gas	0.0144	215.5	3.1
TOTAL GLASS INDUSTRY	-	261.1	3.9

[a] Does not include losses from the generation and transmission of electricity.
Sources: DOE 1995, DOC ASM 93-98.

2

Glass Manufacturing Processes

2.1 Overview of Glass Manufacturing Processes

Major Processes Include Batch Preparation, Melting and Refining, Forming and Post-Forming

Glass manufacture, regardless of the final product, requires four major processing steps: batch preparation, melting and refining, forming, and post forming. An overview of the general flow of glass manufacture is illustrated in Figure 2-1.

Batch preparation is the step where the raw materials for glass are blended to achieve the desired final glass product. While the main components in glass are high-quality sand (silica), limestone, and soda ash, there are many other components that can be added (see Chapter 3 for a full description of batch preparation).

Once mixed the batch is charged to a melting furnace. **Melting** of the batch may be accomplished in many different types and sizes of furnaces, depending upon the quantity and type of glass to be produced. The melting step is complete once the glass is free of any crystalline materials.

Refining (often referred to as fining) is the combined physical and chemical process occurring in the melting chamber during which the batch and molten glass are freed of bubbles, homogenized, and heat conditioned. Melting and refining are discussed in detail in Chapter 4.

After refining, the molten glass is sent to forming operations. **Forming** is the step in which the final product begins to take shape, and may involve casting, blow forming, sheet forming, fiberization, or other processes. Forming processes vary widely, depending on the type of glass being manufactured. Details on common forming processes are provided in Chapter 5.

Some products require **post-forming** procedures, and these vary widely depending upon the product. These may include processes which alter the properties of the glass, such as annealing, tempering, laminating and coating. Chapter 6 provides details on both post-forming and product handling operations.

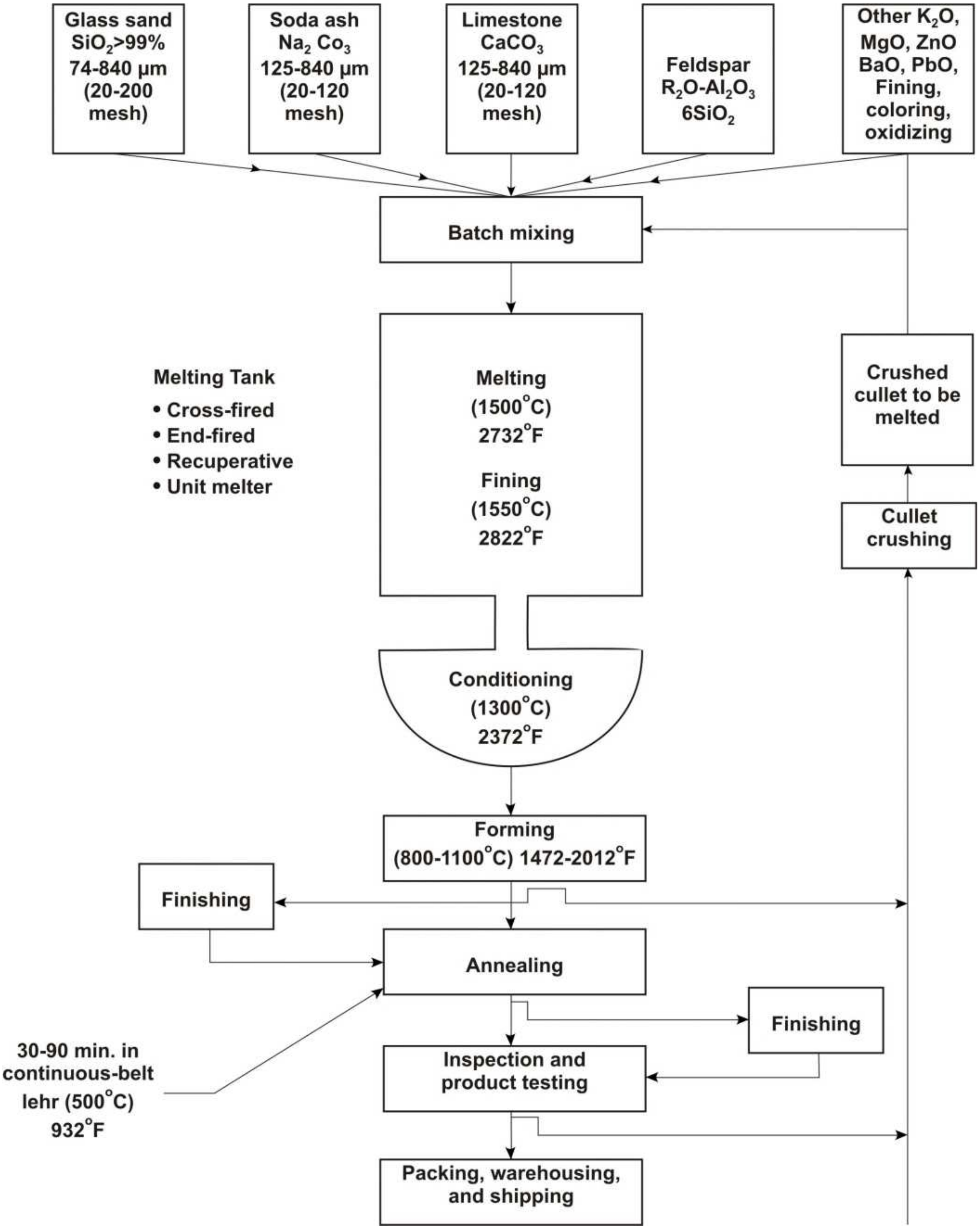

Figure 2-1. Overview of Glass Manufacture [EPA 1995, EPRI 1988]

Manufacturing Flows for Different Glass Sectors Have Many Similarities

While the overall flow diagrams for manufacturing of different glass products vary in complexity, there are many similarities. Process flows for major glass products are illustrated in Figures 2-2 to 2-5.

The process flow for all sectors is essentially the same through the melting and refining process. Regardless of the type of glass, all processes begin with batch preparation, which prepares the raw materials for charging to the furnace. where melting and refining take place. Although melting and refining are done in a wide range of furnace types, the process taking place is virtually the same.

Forming processes, however, vary widely as shown in Figures 2-2 to 2-5. Major forming operations include tin float baths for flat glass; blowing and pressing for glass containers; blowing, pressing, casting and drawing for specialty glass; and fiberization with spinners or air for fibrous glass.

The greatest amount of diversity is found within the pressed and blown glass sector, where a wide range of products are made, from art ware to glass for lighting and electronics. Post-forming processes are similar for many products (e.g., annealing)—nearly all glass products are annealed. Few, however, are tempered (e.g., glass sheets, oven ware).

2.2 Process Energy Overview

Table 2-1 provides estimates of process energy use across the glass sectors, and the contribution to overall glass industry use. The most energy intensive portion of the glass-making process, regardless of product type, is melting and refining. This portion of glass manufacturing accounts for 60 to 70 percent of total energy use in the glass industry.

Table 2-1. Estimated Energy Use in Glass Manufacturing Processes

Process	Specific Energy Use[a] (10^6 Btu/ton)	Average Specific Energy Use[b] (10^6 Btu/ton)	Annual Energy Use[d] (10^{12} Btu)
Batch Preparation	0.27 - 1.2	0.68	13.7
Melting and Refining			
Flat	6.5 - 8.8	8.6	42.9
Container	2.8 - 7.8	5.5	53.1
Pressed/Blown	3.6 - 12.0	7.3	18.1
Fiber[c]	5.6 - 10.5	8.4	25.6
Forming			
Flat	1.5	1.5	7.5
Container	0.4	4.0	38.4
Pressed/Blown	5.3	5.3	13.2
Fiber[c]	7.2	7.2	21.9
Post-Forming			
Flat	0.4 -4.2	2.2	11.1
Container	1.86	1.86	17.8
Pressed/Blown	3.0	3.0	7.5
Fiber[c]	3.3-4.4	3.9	12.0

[a] Electricity use based on a conversion factor of 3412 Btu/kWh.
[b] Weighted average based on furnace distribution.
[c] Includes insulation, textile fibers, and optical fibers.
[d] Based on glass production for 1997 as follows: flat - 5,000,521 short tons; container - 9,586,500 short tons; pressed/blown - 2,484,182 short tons; fiber - 3,040,000 short tons.

Sources: See respective chapters.

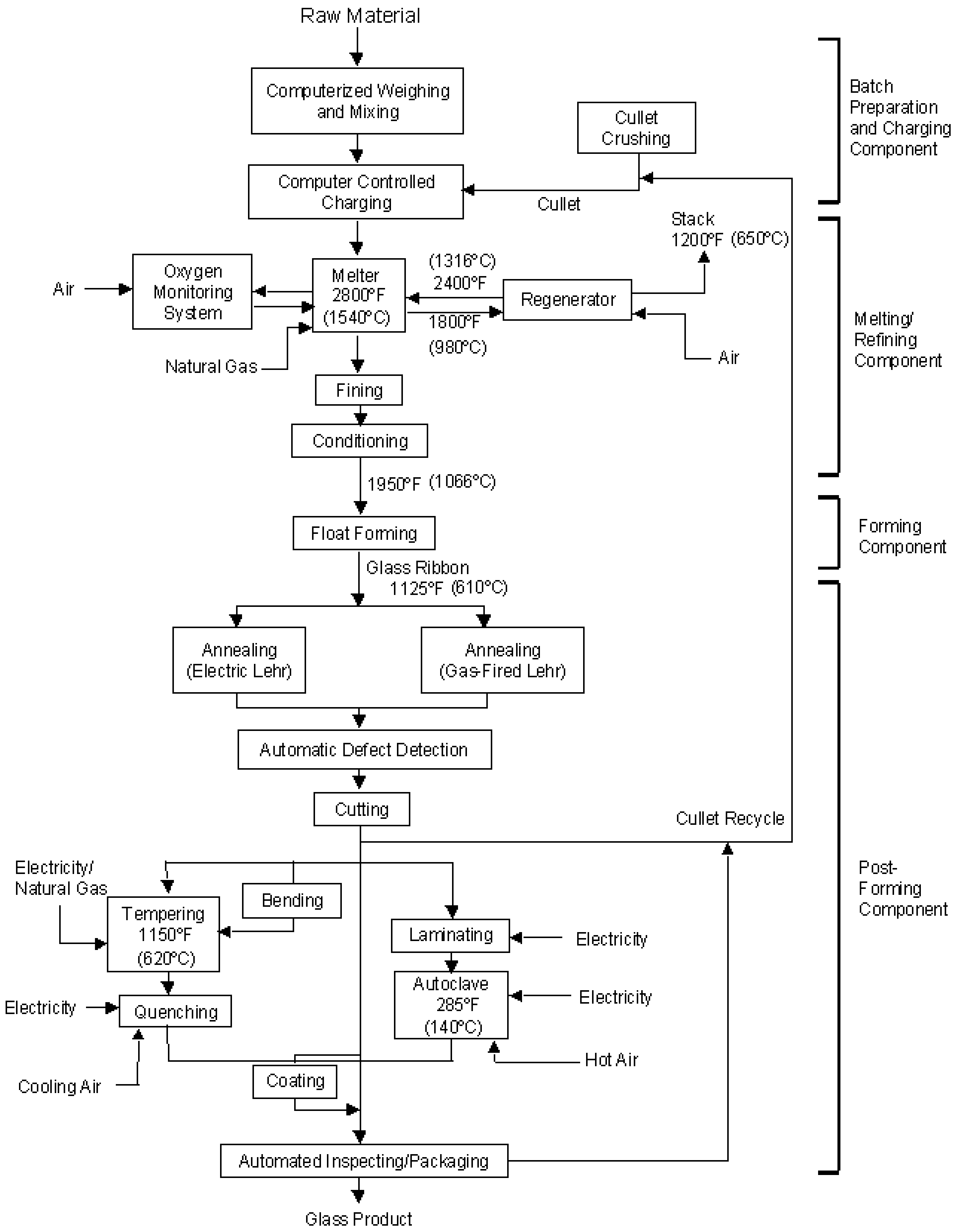

Figure 2-2. Flat Glass Production Line [Brown 1996, EPA 1995, EPRI 1988]

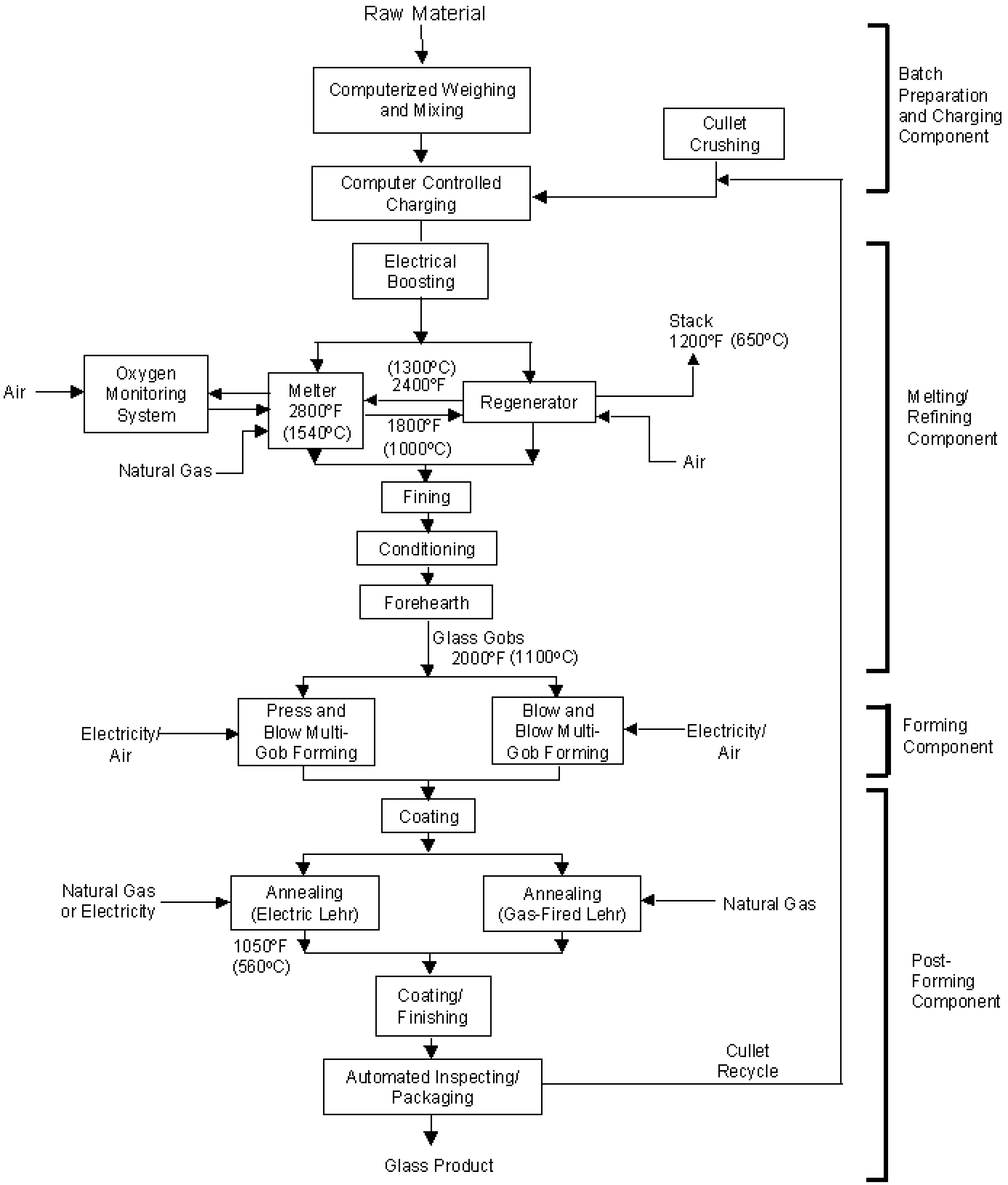

Figure 2-3. Container Glass Production Line [Brown 1996, EPA 1995, EPRI 1988]

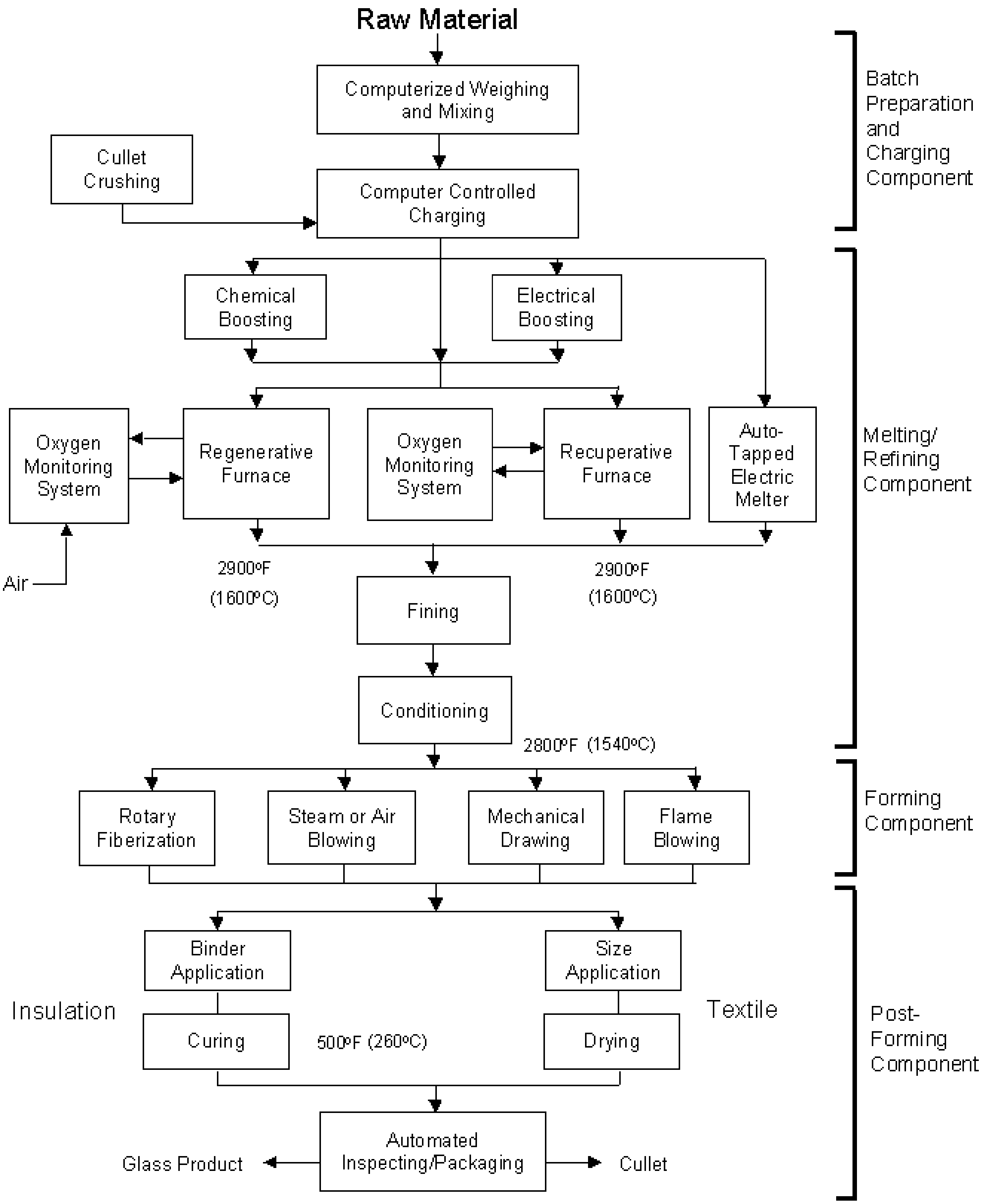

Figure 2-4. Fibrous Glass Production [Brown 1996, EPA 1995, EPRI 1988]

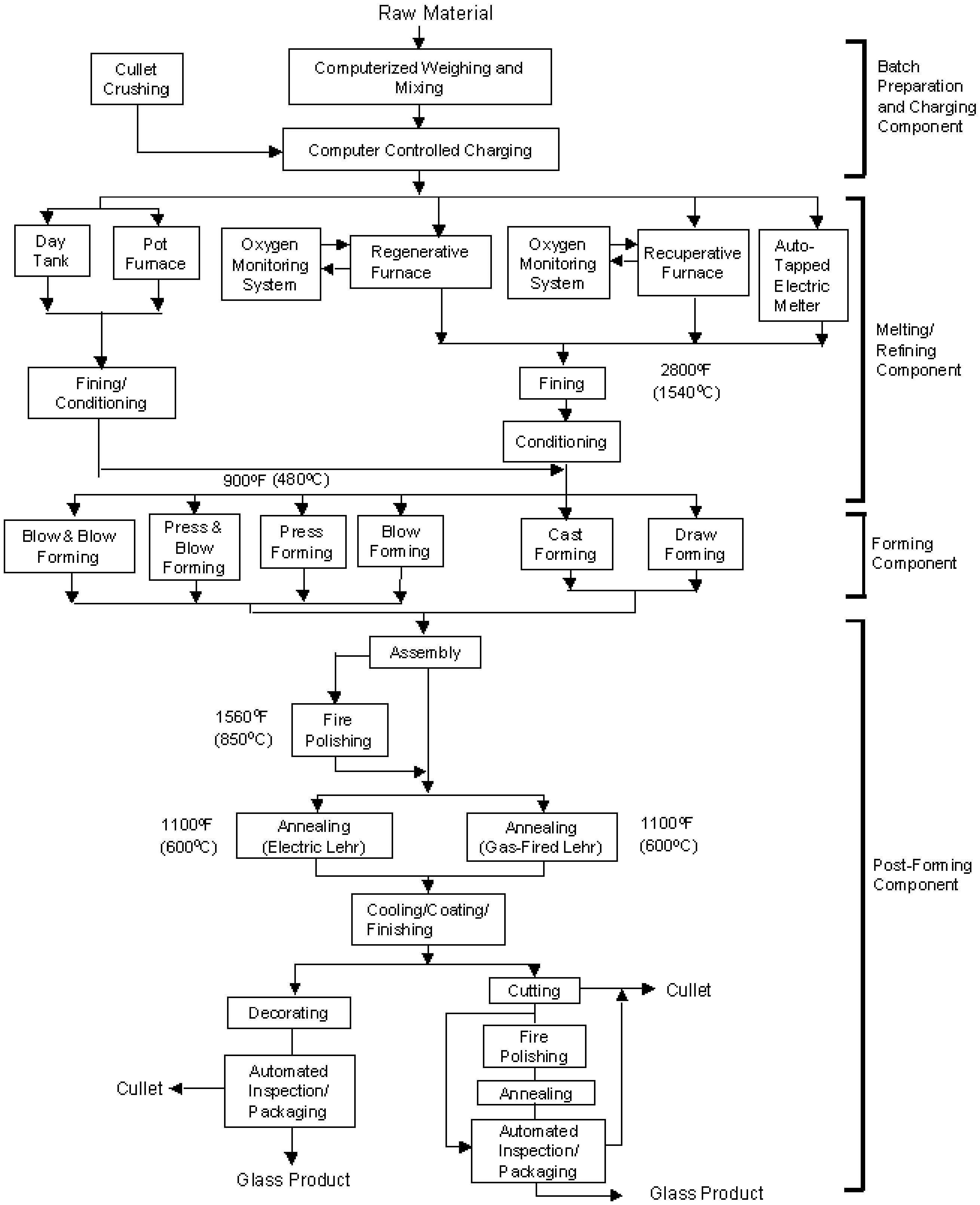

Figure 2-5. Pressed/Blown Glass Production Line [Brown 1996, EPA 1995, EPRI 1988]

2.3 Environmental Overview

Table 2-2 summarize the air emissions, effluents and solid wastes generated by glass manufacturing processes. Table 2-3 provides air emission factors for criteria pollutants (those regulated under the Clean Air Act) from melting furnaces, which are the largest source of these emissions.

Particulates constitute the largest air emissions from all glass manufacturing processes, excluding other air pollutants generated by the combustion of fossil fuels in the melting and refining furnace.

Table 2-2. Glass Manufacturing Process Emissions, Effluents, Byproducts and Wastes

Process	Air Emissions	Effluents	Byproducts / Solid Waste
Batch Preparation	Particulates in the form of dust (raw material particles) (controlled)	not applicable	Unusable raw materials, baghouse or filter dust residues (recycled)
Melting and Refining	Particulates, nitrogen and sulfur oxides, carbon monoxide, carbon dioxide, fluorides, formaldehyde, lead (mostly controlled)	not applicable	Furnace slag, filter and baghouse residues (recycled), refractory wastes
Flat Glass Forming and Post-Forming	Negligible	Waste water (may contain suspended solids, phosphorus)	Glass contaminated with refractory, cullet
Container Forming and Post-Forming	Particulates, organic condensible particulates, volatile organics	Waste oil and solvents, waste water (may contain dissolved solids, suspended solids, heavy metals)	Solid residues from pollution control equipment, cullet
Pressed/Blown Forming and Post-Forming	Particulates, volatile organics (controlled)	Waste water (may contain suspended solids, oil, lead or fluorides)	Cullet
Glass Wool Forming and Post-Forming	Particulates, organic condensible particulates, volatile organics (phenols and aldehydes) (all controlled)	Waste oil and solvents, waste water (may contain suspended solids, phenol, heavy metals)	Solid residues from pollution control equipment, cullet

Table 2-3. Emission Factors for Flat, Container, and Pressed/Blown Glass Melting (lb/ton glass materials processed)

Segment/Furnace	Particulates	SOx	NOx	CO	VOCs	Lead
Container						
Uncontrolled	1.4	3.4	1.8-21.6[a]	0.2	0.2	ND
Controlled						
Low-energy scrubber	0.7	1.7	6.2	0.2	0.2	ND
Venturi scrubber	0.1	0.2	6.2	0.2	0.2	ND
Baghouse	neg	3.4	6.2	0.2	0.2	ND
Electrostatic Precipitator	neg	3.4	6.2	0.2	0.2	ND
Flat Glass						
Uncontrolled	2.0	3.0	8.7-25.8[a]	<0.1	<0.1	ND
Controlled						
Low-energy scrubber	1.0	1.5	8.0	<0.1	<0.1	ND
Venturi scrubber	neg	0.2	8.0	<0.1	<0.1	ND
Baghouse	neg	3.0	8.0	<0.1	<0.1	ND
Electrostatic Precipitator	neg	3.0	8.0	<0.1	<0.1	ND
Pressed and Blown						
Uncontrolled	17.4	5.6	16.8-27.2[a]	0.2	0.3	ND
Controlled						
Low-energy scrubber	8.4	2.7	8.5	0.2	0.3	ND
Venturi scrubber	0.9	0.3	8.5	0.2	0.3	ND
Baghouse	0.2	5.6	8.5	0.2	0.3	ND
Electrostatic Precipitator	0.2	5.6	8.5	0.2	0.3	ND
Lead Glass Manufacturing						
Uncontrolled	15	0.2	10-25	<0.1	ND	3-15
Controlled						
Electrostatic Precipitator	0.2	0.2	10-25	<0.1	ND	0.1

ND = no data.

a Based on compilation of emissions in Alternative Control Techniques Document [EPA 1994].

Sources: EPA 1985/AP-42, Shell 2001 (lead glass).

3

Batch Preparation

3.1 Process Overview

A Variety of Raw Materials are Mixed During Batch Preparation

Although there are many differences in glass products, all glass manufacture begins with the weighing and mixing of dry ingredients to create a "batch" or charge for the melting furnace. Many different chemical compositions can be used to create glass, and each formula affects the mechanical, electrical, chemical, optical and thermal properties of the final glass product. There are many thousands of glass compositions available today, and new ones are continuously emerging. Table 3-1 illustrates the chemical composition of some of the more commonly-used glasses.

The glass batch contains formers, fluxes, stabilizers, and sometimes colorants (see Table 3-2). The basic ingredients in glass are called **formers**. The main former in all types of glass is silica (SiO_2) in the form of high-quality sand. More than 90 percent of the high-quality sand produced in the United States is used for glass manufacture.

A number of factors are considered when selecting sand for glass production. The cost to transport sand is 4 to 5 times the cost of the sand, and finer sands are more costly than coarse sand. Using the incorrect size sand can create melting and product quality problems. To minimize raw material costs, glass producers will often locate plants near the source of sand, and select a sand to balance cost and melting efficiency. For example, container glass producers will use a relatively coarse sand with a particle size ranging from 30-100 mesh to keep costs as low as possible but still achieve the desired melting efficiency. Fiberglass manufacturers must use a much finer sand, usually smaller than 200 mesh.[1]

Other major formers in glass are feldspar and borax or boric acid. Borax or boric acid, as well as ores such as colemanite, rasorite or ulexite, are used to provide a source of boron for the manufacture of high temperature glass, pyrex, or fiberglass. Feldspar provides a source of alumina. Fiber glass, for example, contains mostly sand, but also quantities of feldspar, sodium sulfate, anhydrous borax, boric acid, and other materials.

While silica alone can be used to make glass, it has a very high melting point (3133°F) and is

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[1] *Mesh size refers to the size of particles that pass through a screen, and is usually expressed as the number of squares per inch.*

Table 3-1. Typical Glass Compositions (weight percent)

Glass Type	SiO_2	Na_2O	K_2O	CaO	MgO	BaO	PbO	B_2O_3	Al_2O_3	Uses
Soda Lime Glass • general • containers	 73.6 72-73.5	 16 12-14	 0.6 0.6	 5.2 9-12	 3.6 1.2-2.0				 1.0 1.2-2.0	Windows, tubing, light bulbs, containers.
Ancient Roman Soda Lime Glass	67.0	18.0	1.0	8.0	1.0		0.01		2.5	Decorative glass objects, containers
Borosilicate • low expansion (Pyrex) • low electrical loss	 80.5 70.0	 3.8	 0.4 0.5				 - 1.2	 12.9 28.0	 2.2 1.1	Low expansion, good thermal shock and chemical resistance. Used in chemical industry, for pipelines, light bulbs, photo-chromic glasses, sealed-beam headlights, laboratory ware, bakeware, glass fiber.
Aluminoborosilicate • standard (apparatus) • low-alkali (E-glass)	 74.7 54.5	 6.4 0.5	 0.5 -	 0.9 22		 2.2 -		 9.6 8.5	 5.6 14.5	• laboratory apparatus • architectural glass, textile fibers
Aluminosilicate	57	1.0		5.5	12.0			4.0	20.5	Applications requiring strength at high temperatures, low expansion (e.g., space shuttle inner windows)
Lead Silicate • electrical • high lead	 63 35	 7.6 -	 6.0 7.2	 0.3	 0.2		 21.0 58.0	 0.2	 0.6	Decorative crystal glass, achromatic lenses, optical glass, radiation shielding, electrical uses, thermometer tubing.
Fused Silica	99.5+									Applications requiring very low expansion and high thermal shock resistance (astronomical telescopes, optical waveguides, mirror blanks, space vehicle windows). Difficult to melt and fabricate.
96% Silica (Vycor)	96.5							3.0	0.5	Very high temperature applications such as furnace sight glass, space vehicle windows.

Source: Corning 2000, Flinn 1981, Gridley 2001.

difficult to work with in the liquid state because of its high viscosity. **Fluxes** are added to lower the temperature at which the batch melts. Soda ash (sodium carbonate, or Na_2CO_3) and potash (potassium carbonate, or K_2O), are commonly used alkali fluxes (present as oxides). About one-third of the soda ash produced in the United States is used by the glass industry.

The use of lithium compounds (lithium carbonate, lithium alumino silicate) as fluxing materials has been increasing steadily over the last 5 to 10 years. Lithium is the lightest, smallest and most reactive of the alkali metals, and possesses the smallest ionic radius and highest ionic potential. Lithium alumino silicate (spodumene) use in the glass industry has grown significantly over the last 15 years. Glass producers using spodumene report lower melting temperatures at equivalent melting energy and cullet input, improved forming properties, fewer defects, improved glass quality, and increased nominal furnace capacity [AMI 2002].

Stabilizers are used to make glass more chemically stable, and to keep the finished glass from dissolving, crumbling or falling apart. Common stabilizers include limestone, alumina, magnesia and barium carbonate. Limestone, which is typically available in the form of calcite, 95 percent calcium carbonate ($CaCO_3$), or dolomitic limestone (a mixture of dolomite and calcite), provides a source of calcium and magnesium for the silica-soda glass. As with sand, the cost to transport limestone is 3 to 5 times the original cost of the raw material.

There are a number of additives used to color and impart unique properties to glass. Common **colorants** include iron, chromium, cerium, cobalt and nickel. Amber glass is created by adding ferrous sulfide or iron pyrites. Cobalt and nickel oxides are used to decolorize the yellow-green tint that results when the melt is contaminated with iron. When mixed with iron and cobalt, selenium creates glass with a bronze color.

Cerium is often used to improve the ultraviolet (UV) absorption properties of optical glass, or to reduce x-ray browning effects. In some cases, small amounts of powdered anthracite coal, or even blast furnace slag, may be added to the batch to improve the melting characteristics of the glass, for reduction-oxidation control, or to replace feldspar. Sulfur and iron content, however, limit the use of these materials, depending on glass specifications.

Another raw material used in glass manufacture is "cullet." Cullet is recycled glass obtained from within the plant (rejects, trim, waste scrap) and from outside recycling firms. Cullet can constitute from 10-80 percent of the batch, depending upon the type of glass manufactured.

Many manufacturers prefer using in-house generated cullet. Cullet from external sources (recyclers) can be contaminated or of inconsistent quality, and is not generally used in applications where higher quality is required (e.g., flat glass). Metal and organic contaminants can lead to chemical instability during processing and result in degradation of glass quality. Ceramic contaminants do not chemically react with the molten glass, but will reside as inclusions in the final product. Organic compounds present in the batch may increase emissions of volatiles during processing, as well as costs for clean-up of flue gases.

Table 3-2. Common Glass Components	
Formers	Silica (SiO_2) Boron/Boric Acid (B_2O_3) Lead Oxide (PbO) Feldspar
Fluxes	Soda Ash (Na_2CO_3) Potash (K_2O) Lithium Carbonate Lithium Alumino Silicate
Stabilizers	Limestone ($CaCO_3$, CaO) Litharge Alumina (Al_2O_3) Magnesia (MgO) Barium Carbonate (BaO) Strontium Carbonate Zinc Oxide Zirconia
Colorants	Iron (sulfides or pyrites) Cobalt Oxide Nickel Oxide Selenium

Source: Corning 2000, EI 1988.

Glass manufacturers use cullet where possible because it is less costly than virgin materials, and reduces the energy required for melting. In cullet, the chemical reactions required for glass forming have already taken place. As a result, cullet requires only about half the melting energy required for virgin raw materials. In addition, as the cullet melts, it forms a molten bath that facilitates the transfer of heat to the other materials in the batch [Raw Materials Description: Corning 2000, Freitag 1997, EPA 1995, EPA 1994, CMP 1990, EPRI 1988].

Proper Mixing Determines the Uniformity and Quality of the Final Glass Product

Raw materials arrive at the plant by rail car and truck, and in drums and packages. They are unloaded using drag shovels, vacuum systems and/or vibrator/gravity systems, and conveyed to and from storage by belts, screws and bucket elevators.

Raw materials are crushed, ground, and sieved prior to receipt at the glass plant, and are stored in separate elevated bins. The dry ingredients are then sent through a gravity feed system and

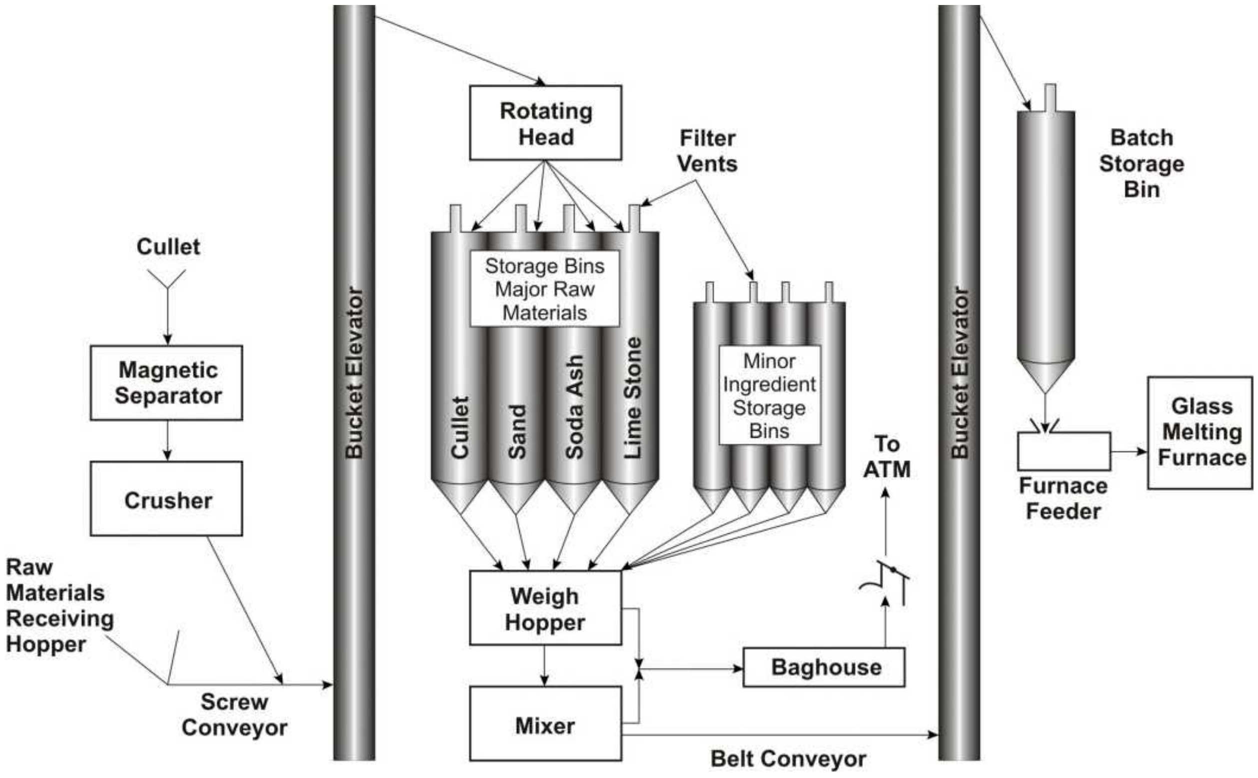

Figure 3-1. Batch Plant [EPA 1986]

Key Energy and Environmental Facts - Batch Preparation			
Energy	***Air Emissions***	***Effluents***	***Byproducts/Wastes***
Energy use per net ton of glass: 0.27 - 1.2 10^6 Btu/ton	*Particulates in the form of dust (raw material particles) (controlled)*	*not applicable*	*Unusable raw materials, baghouse or filter dust residues (recycled)*

on to a weigher and mixer. Crushed cullet is added, and the final mixture is conveyed to a batch hopper where it stays until being dropped into the feeder to the furnace. The equipment used for crushing and handling the raw materials is generally kept separate from the furnace in what is usually called the batch plant (see Figure 3-1).

Efficient blending of the dry ingredients is critically important to the quality of the glass product. If the batch is not properly blended, in-homogeneities may increase melting time and lead to product quality problems. For example, if not mixed properly, the molten glass may not have uniform viscosity, and when delivered to the forming machine will not flow evenly. The result could be a glass product of variable thickness, which is unacceptable. To ensure homogeneity of the melt extreme care is taken during batch preparation to ensure materials are of proper grain size, carefully weighed, and well-blended. In larger plants with continuous operation batch preparation is highly automated, with computer-controlled weighing equipment. Materials are generally weighed directly onto a conveyor belt which then feeds into a solids mixer. In smaller operations, batch components are weighed separately into a hopper which is rotated continuously for many hours to blend the ingredients. Non-automated mixing is the most inconsistent, method and is most often found in smaller plants making specialty products.

Different mixing techniques may be applied, depending on the type of glass. High silica, soda lime, boro-silicate or alumino-silicate glasses are usually batch-mixed in pan mixers for a short period of time (3-8 minutes). The dry batch is first mixed with a small amount of liquid to achieve wet blending. A small amount of water may be added to the batch (2-4 percent by weight) to prevent segregation of the batch during transport, to reduce dust, and ensure homogeneity. Minimizing dust increases furnace and regenerator life by minimizing dust in the furnace and limiting how much dust is carried over into the regenerators.

Occasionally agglomeration of the batch into pellets or briquettes is also used as a means of ensuring consistency and reducing dust. Batch agglomeration is typically used with glasses having high lead oxide content. In this case the batch particles are agglomerated using the smearing action of a Muller-type mixer[2].

The final step in preparation of the batch is charging (conveying) it to the furnace or melter. The batch is charged directly into the furnace, or sometimes into a refractory-lined extension of the furnace, commonly referred to as the "dog-house." As it enters the furnace the batch spreads out like a blanket across the surface of the existing molten glass or melt. The pattern by which the batch spreads depends on the operating conditions specific to the furnace [Process Description: Freitag 1997, EPA 1994, CMP 1990, EPRI 1988, EI 1988].

3.2 Summary of Inputs and Outputs

The following summarizes the essential inputs and outputs for preparation of the glass batch:

Inputs	**Outputs**
Sand/Silica and Other Formers	Homogeneous Batch
Limestone and Other Stabilizers	Particulates
Soda Ash/Potash	Unusable Raw Materials
Cullet	Filter Residues
Colorants	
Water	
Electricity	

3.3 Energy Requirements

Batch Preparation Relies on Electricity

Electricity is used in batch preparation for bucket elevators, pneumatic conveyors, batch mixers or blenders, and agglomeration of materials. The blender or batch mixer accounts for the greatest share of electricity use in both batch preparation and charging to the furnace. In general, electricity use in the materials handling step is only about 4 percent of a glass plant's total energy demand. Specific energy consumption for batch preparation depends on the type of glass being produced, and typically ranges from about 0.24 to 1.2 million Btu per ton of glass. Electricity consumption for batch preparation is summarized in Table 3-3, including industry-wide use for this step. Energy may be consumed in the crushing, grinding, and sieving of raw materials prior to being shipped to the glass plant, but is not considered here.

There are also significant energy costs associated with transportation of raw materials to the plant, which is one reason glass manufacturers locate plants close to the source [CMP 1990, EI 1988].

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[2] *A Muller-mixer, akin to a flat-bottomed pestle, such as that used to crush rock or grind pigments.*

Table 3-3. Electricity Use in Batch Preparation By Glass Segment

Energy Source	Average Specific Energy Use (kWh/ton)	Average Specific Energy Use [a] (10^6 Btu/ton)	1997 Annual Production (short tons)	Net Industry Use [b] (10^{12} Btu)	Electricity Losses [c] (10^{12} Btu)	Total Energy Use (10^{12} Btu)
Flat Glass	79	0.27	5,000,521	1.4	2.9	4.2
Container Glass	155	0.53	9,586,500	5.1	10.6	15.7
Pressed and Blown Glass	223	0.76	2,484,182[d]	1.9	3.9	5.8
Fibrous Glass	337	1.15	3,040,000[e]	3.5	7.3	10.8
INDUSTRY			20,111,203	11.9	24.7	36.5

a Based on a conversion factor of 3412 Btu/kWh of electricity.
b Excludes electricity losses.
c Losses associated with generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh of electricity.
d Estimated based on 92 Census Data and 2% annual growth between 1992 and 1997.
e Includes glass wool, textile fibers and optical fibers.
Sources: DOC 1997, Cer Ind 1999, Cer Ind 1997, 1992 DOC, EI 1988.

3.4 Emissions

Batch Preparation Generates Dust and Particulates

The primary pollutant generated during preparation of the batch is particulates in the form of fugitive dust (raw materials). Primary sources are material transfer points (e.g., where sand pours from a conveyor belt into a silo, transfer of batch to weighing and mixing, charging to furnace). The largest sources of particulate emissions are loading and conveying operations.

In most cases, about 99 to100 percent of fugitive dust emissions can be controlled by enclosing dust sources and using baghouses or cloth filters. Treating the batch by presintering, briquetting, pelletizing, or with liquid alkali can also be used to achieve nearly 100 percent control of dust.

Emission factors for particulates from batch preparation in fibrous glass manufacture are shown in Table 3-4. Particulate emissions from batch preparation in other types of glass manufacture are negligible [EPA 1985].

3.5 Byproducts and Wastes

Batch preparation generates waste during the receiving and transfer of raw materials, including raw materials that have been spilled and are unuseable. Baghouse filters used to capture fugitive dust also generate residues that can usually be recycled back into the glass-making process [EPA 1995].

Table 3-4. Air Emission Factors for Glass Fiber Batch Preparation

Batch Plant Source	Filterable Particulates (lb/ton of material processed)
Unloading and conveying	3.0
Storage bins	0.2
Mixing and weighing	0.6
Crushing and batch charging	Negligible

Source: EPA 1985.

4

Melting and Refining

4.1 Process Overview

Chemical Reactions Occur During Melting of Raw Materials

Glasses are formed by melting crystalline materials at high temperatures. As the molten glass cools, the atoms fuse into a disordered state rather than a perfect crystal formation. Glass materials remain in this plastic state after cooling, and subsequently do not have a sharp melting or freezing point.

Commercial melting of glass begins with the conversion of dry ingredients into a homogeneous molten liquid. First, the well-mixed batch is charged to the melting furnace and heated to temperatures ranging from 2600°F to 3100°F. As the batch is heated to these high temperatures a series of chemical reactions occur in specific order, including melting, dissolution, volatilization and oxidation-reduction (redox).

At about 1000°F, the higher melting ingredients in the batch (e.g., sand) dissolve, a process which is accelerated by the addition of metal fluxes such as soda ash and potash which melt at lower temperatures (see Chapter 3). At this time molten sodium meta-silicate deposits on the silica grains. As heating continues to 1300°F, further reactions begin to occur, and at about 1400°F a liquid eutectic mixture forms between the sodium silicate and silica. At this time alkaline earth carbonates present in the

Chemical Reactions Occurring During Glass Manufacture

Dissolution of Sand with Soda Ash as Flux
$Na_2CO_3 + SiO_2 \rightarrow Na_2SiO_3 + CO_2$ (1000°F)

Further Heating
$Na_2SiO_3 + SiO_2 \rightarrow Na_2Si_2O_5$ (1300°F)

Formation of Liquid Eutectic Mixture
$3Na_2SiO_3 \cdot SiO_2 + SO_2$ (1400°F+)

Carbonates in Limestone Decompose to Form Other Eutectic Glasses
$CaCO_3 + nSiO_2 \rightarrow CaO \cdot n\,SiO_2 + CO_2$ (1400°F+)

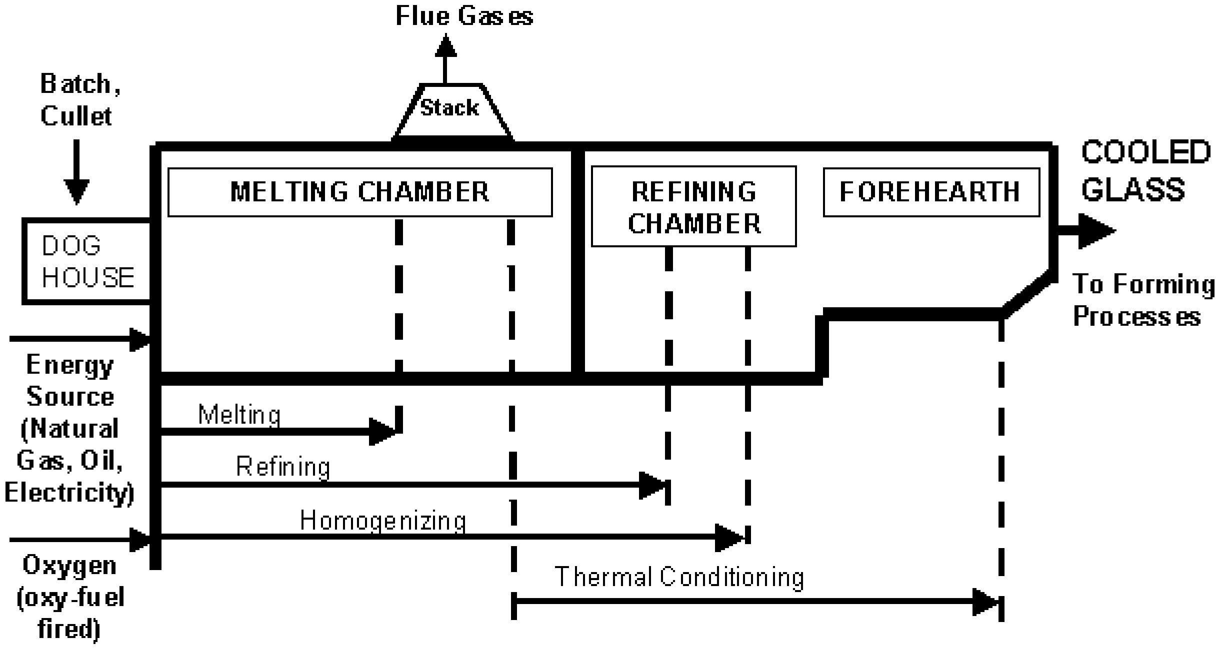

Figure 4-I. Melting and Refining Processes [EPA 1994, EPRI 1988, EI 1988]

Summary of Key Energy and Environmental Facts - Melting

Energy	***Air Emissions***	***Effluents***	***Byproducts/Wastes***
Energy use per net ton of glass: 3 - 16 10^6 Btu/ton	*Particulates, nitrogen and sulfur oxides, carbon monoxide, carbon dioxide, fluorides, formaldehyde, lead (mostly controlled)*	*Not applicable*	*Furnace slag, filter and baghouse residues (recycled), refractory wastes, used molybdenum electrodes*

limestone also begin to decompose and flux with the silica to produce molten eutectic[1] glasses [Corning 2000, EPA 1994, EPRI 1988].

Glass Goes Through Different Phases in the Melting Furnace

As the batch passes through the melting furnace, it essentially goes through four phases: melting, refining, homogenizing, and heat conditioning. A rough idea of how these occur is illustrated in Figure 4-1.

Melting begins when the batch enters the furnace, and is complete when the glass is free of crystalline materials. Optimally, melting should be complete before the batch has gone through the first half of the furnace.

Melting rate depends on the furnace temperature, composition of the batch, grain size of the batch ingredients, amount and grain

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[1] *A eutectic solution has the lowest possible melting point for its unique set of components.*

size of cullet, and homogeneity of the batch. For example, smaller grain batches will undergo melting quicker; batches with different grain sizes will melt slower. The addition of cullet reduces the amount of time required for melting, while poor homogeneity can seriously affect melting efficiency.

During **refining (**often referred to as fining), gas bubbles are eliminated from the batch and molten glass. Refining occurs throughout the melting chamber, beginning with the batch charge to the furnace and continuing until the complete dissolution of crystalline materials.

The refining section of the furnace is typically separated from the main melting section by a bridgewall, while glass flows through a wall opening called the "throat." The exception is flat glass furnaces, in which case the opening between the furnace and refining area is above the surface of the glass.

Imperfections (referred to as stones or cords) may be introduced into the glass during melting when the grains of dry raw material are too large to completely react by the time the flux has melted, or if the batch has not been adequately mixed. During refining these glass inclusions are eliminated or reduced.

As the temperature of the glass decreases, some of the gases are reabsorbed into the melt. As these dissolve, gaseous seeds or bubbles may form containing constituents such as oxygen, sulfur dioxide, water, nitrogen, or carbon dioxide, depending on the type of glass. Refining helps to remove these seeds. Carbon dioxide is present because carbonates are used in the glass batch, whereas gases like sulfur dioxide result from the use of refining agents. Compounds such as sodium sulfate, barium oxide, boric acid, sodium chloride and calcium fluoride are used as refining agents, although they also have a role in the melting process.

How much refining is done depends on the desired quality and properties of the glass. For example, manufacturers of flat and specialty glasses may have higher quality requirements and be willing to accept much fewer seeds than container glass. Thus, container glass will require less time and energy for refining.

Homogenizing occurs throughout the melting chamber, and is finished when the properties of the glass meet the desired specifications. Perfect homogeneity exists when the glass melt exhibits no variations in the desired properties. Variations might include local differences in refractive index, density or coefficient of expansion, all of which will affect the mechanical and optical properties of the glass. Glass with excessive stones, cords, or seeds is also non-homogeneous. Factors affecting homogeneity include temperature, time, batch composition, degree of mixing, and physiochemical relations in the glass refractory system. The degree of homogeneity attained is often a matter of economics, or of quality requirements, and varies considerably between glass sectors.

During **thermal conditioning**, glass is stabilized and brought to a uniform temperature. When thermal conditioning begins is a matter of interpretation, and depends on furnace type and operating conditions. In general, thermal conditioning is assumed to begin immediately after the glass melt reaches its highest average temperature in the furnace, since after this time it will begin cooling to the working temperature for forming. As shown in Figure 4-1, thermal conditioning is occurring in the melting and refining sections of the furnace, and in the forehearth. In container furnaces, the refining is used primarily for temperature conditioning [Gridley 2001].

Physical mixing in the feeder, bubblers, and stabilization of gases are all used to help achieve proper thermal conditioning. Stirring is usually accomplished with a water-cooled stainless steel or uncooled platinum paddle operating at the glass melt temperature. Bubblers are water-cooled, high-carbon steel nozzles located on the furnace floor.

After the melting and refining, the glass melt flows to the **forehearth**, where the glass is then transferred to the forming process. The forehearth cools the molten glass to a working temperature for forming (typically from 2000°F - 2100°F), removes temperature gradients, and provides the means to transfer the molten glass to forming operations. The forehearth consists of an insulated refractory channel and is equipped with burners and an air cooling system on both sides (see Figure 4-2). It can be heated with natural gas or electricity. A natural-gas heated forehearth reheats the cooler surface of the glass using radiant heat transfer, which also serves to equalize temperature gradients. Electrically-heated forehearths use submerged electrodes that heat the glass through conduction and convection.

The length of the forehearth is based on requirements specific to the individual product and the desired heat loss. Control of the glass melt through the forehearth is critical for forming, and the process is highly automated. Controls typically include automated setups, cooling air adjustments and precise zone temperature controls.

Continuous Furnaces Dominate in Larger Glass Plants

While the process of melting and refining is very similar throughout the industry, the type of furnaces used may vary considerably. In general, furnaces are classified as discontinuous or continuous.

Discontinuous Furnaces

Discontinuous furnaces are used in smaller glass melting operations, those on the order of less than five tons per day. Most of these furnaces are used by producers of small blown and pressed tableware, especially colored, crystal and other specialty glasses. They are operated for a short period of time and can usually go through the entire cycle of charging, melting, and removal of molten glass in a single day.

Discontinuous furnaces are either pot furnaces or day tanks. In a **pot furnace**, the glass is melted in a refractory pot inside the furnace, and the pot is externally heated. Pot furnaces may have single or multiple pots, and these may be open or closed. Open pots are open to the flames and gases generated by combustion of the fuel. Open pots have capacities ranging from 250-1000 pounds of glass, and must be operated with fuels that have minimum sulfur content. Few if any open pots are operated in the United States. Closed pots range in capacity from 250-2000 pounds of glass, and are used primarily for melting crystal, lead and colored glasses. Pot furnaces are generally operated to melt glass overnight and permit working of the glass during the day.

Day tanks are small units employing semi-manual operations, and the charging/melting/removal cycle is repeated daily. Day tanks are used for many types of specialty glass, and most commonly for opal, ruby, crystal, and soda-lime glasses. Melting times in these furnaces vary considerably. Soft opal or ruby can be melted in 8-10 hours, where soda-lime glass may take up to 24 hours. Automatic controls keep the melting temperature constant, and the glass melt must be sampled to determine when melting is complete.

Continuous Furnaces

Continuous furnaces are found in larger operations and are designed to be used continuously over a period of years. In the continuous furnace glass levels remain constant, with new batch materials constantly added as molten glass is removed.

Continuous furnaces can be fired by natural gas, electricity, or a combination of both. When both are used, the furnace is said to be fitted with “electric boost.” In natural gas furnaces, the gas is burned in the combustion space above the molten glass and the transfer of energy occurs through radiation and convection. When electricity is the energy source, electrical resistance is introduced using electrodes that are

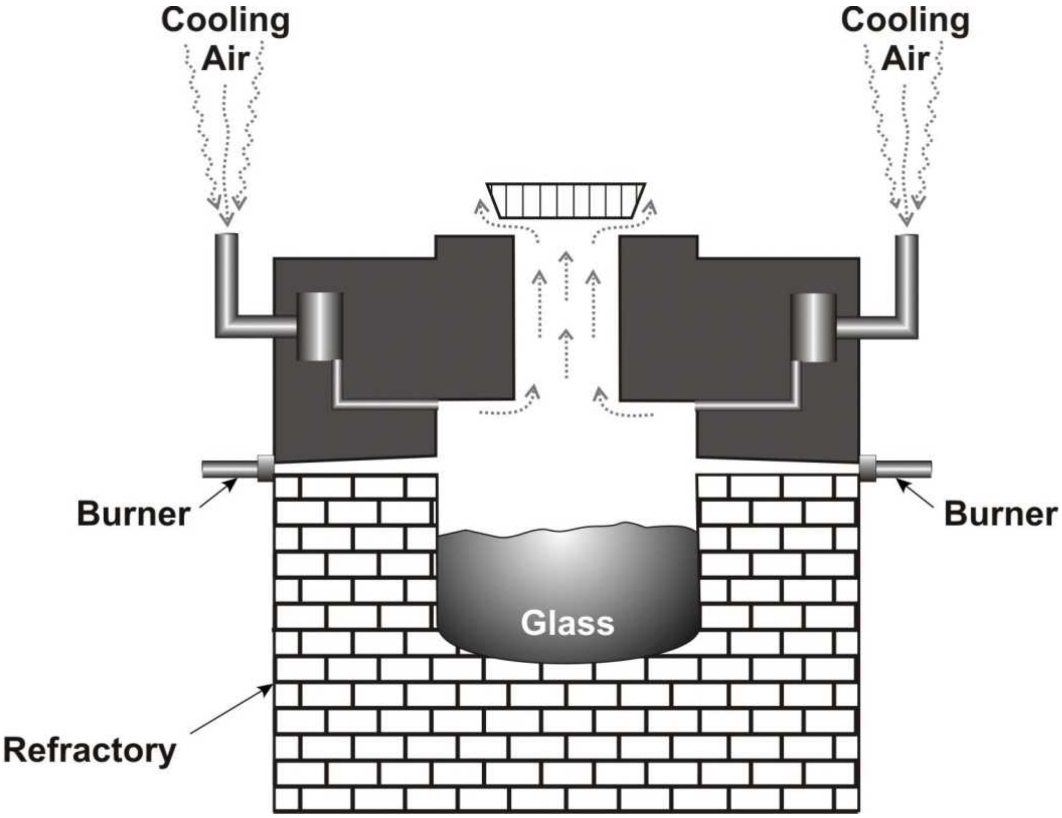


Figure 4-2. Forehearth [EI 1988]

placed directly in the molten glass. Continuous furnaces are classified into four categories: direct-fired, recuperative, regenerative, and electric.

Direct-fired furnaces, sometimes referred to as "unit melters," are fired with natural gas and are usually found in smaller operations producing 20-150 tons per day (see Figure 4-3). In the direct-fired furnace, natural gas is combusted continuously in banks of burners placed on either side of the furnace, which provides stable temperature conditions. The burners are controlled to generate convection currents, which create a longitudinal temperature gradient along the furnace and the glass melt. The hot combustion gases are drawn over the melt surface and then exhausted at the charging end of the furnace through the dog house.

Direct-fired furnaces are selected because of their lower capital cost, temperature stability, and when daily tonnage is too low to be practical for a regenerative furnace. They are also used in some cases for specialty glasses containing compounds (e.g., borosilicates) that could clog or degrade the refractory bricks in regenerators.

Recuperative furnaces are essentially direct-fired furnaces that have been fitted with a recuperator to recover heat from exhaust gases. They are used mostly in smaller operations, primarily in textile and insulation fiber production. They can be fired with either natural gas or oil, and some are equipped with electric boost.

Recuperative furnaces use a continuous heat exchanger to recover heat from the flue gases and preheat combustion air to1000°F to1500°F. The heat exchange can be of double-shell or tubular design, and is constructed from stainless steel or Inconel to enable operation in a high

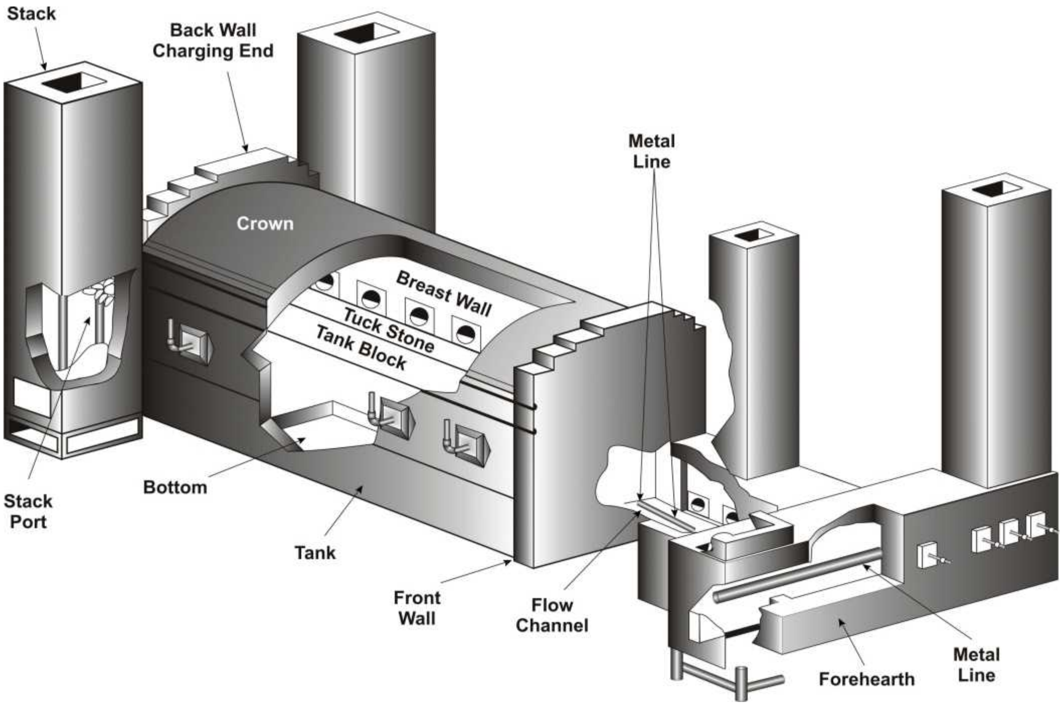


Figure 4-3. Direct-Fired Furnace [CMP 1990, EI 1998]

temperature corrosive environment. Recovering heat nearly doubles the thermal efficiency of the furnace to as much as 25-40 percent.

Regenerative furnaces are the most commonly used in the glass industry, accounting for about 42 percent of furnace population. Capacities in these furnaces are high (100-1000 tons per day), and they are relatively efficient (up to 65 percent thermal efficiency) when compared with direct-fired or recuperative furnaces. They can be fired with either natural gas or with gas and electric boost.

Much like the recuperative furnace, the latent heat in the furnace is collected in a regenerator and then used to preheat combustion air and achieve higher efficiency. Combustion air preheat temperatures can reach as high as 2300°F.

Checker bricks are placed within the melting/combustion chamber. During operation, incoming combustion air is heated as it passes through the first hot checker system, and is then joined with the fuel in the burner port. The flame burns above the surface of the glass inside the space under the top of the melter (combustion space). Combustion gases exit the melting area through opposite burner ports and exhausting regenerator chamber, heating the checker bricks. The flow is reversed after a short period of time (usually 15-20 minutes), which alternates the inlet and exhaust ports. Average furnace exhaust temperatures range from 1000°F to 1200°F. Direct-fired air recuperative furnaces may utilize high temperature metallic alloy heat exchangers that avoid the need to periodically reverse air flow.

Regenerative furnaces typically use alumina-zirconia-silica as the refractory of the sidewall, with zirconia content ranging from 33-41 percent. Chrome-containing refractories are used in the fiberglass industry because they resist erosion, but their use is decreasing due to environmental concerns about chrome. Refractories containing chrome are not used in the flat, container or pressed/blown glass industries because chrome impurities can discolor the glass. Silica is commonly used for the crown of the furnace, or sometimes mullite if oxy-fuel firing is employed. Due to chemical incompatibilities, a layer of alumina-zirconia-silica is often used as a buffer between the crown and sidewall (see Figure 4-4) [Freitag 1997].

Melting in the furnace is usually monitored with thermocouples above and below the melt, and though visual observation of burner nozzle performance. Thermocouples are sheathed with alumina, mullite, or platinum-coated alumina, and must be replaced every 2-3 months due to thermal shock or impact damage. Fiber optic probes are also being developed to enable monitoring of glass temperatures throughout the melt.

Regenerative furnaces can be end-port or side-port, depending on the placement of burner and exhaust ports. **End-port regenerative furnaces** use side-by-side ports located in the back wall of the furnace (see Figure 4-5). The flame enters through one port, and exhaust gases exit through the other. Thus, the flames travel in a u-shape over the melt from one side. Regenerator chambers are located next to each other against the back wall of the furnace.

In a **side-port regenerative furnace**, exhaust ports and burners are placed on opposing sides of the furnace along with two regenerators, one on each side (see Figure 4-6). Flames travel from one side of the furnace to the other. These furnaces are used mostly for very high through-put operations.

All-electric melters take advantage of the conductivity of molten glass. Molybdenum electrodes are embedded in the bottom or sides of the furnace, and pass electrical current through the refractory chamber, melting the raw materials. The furnace must first be heated with fossil fuel and the temperature of the batch raised prior to electrical melting. During the melting process the batch layer acts as an insulator on top of the melt which virtually eliminates energy losses from the molten glass due to radiation or convection. While the temperature of the melt is about 2600°F, the temperature at the top of the insulating 6-9 inch batch layer will be only about 200°F. This insulating effect, referred to as a “cold top,” increases thermal efficiency up to 60 to 90 percent. Some electric melters use natural gas for auxiliary heating—these are referred to as “hot-top” melters. Bubblers are commonly used to improve the homogeneity of the melt and to ensure that bubbles are eliminated.

Many advantages have been cited for electric melters, including reduced air pollution, higher efficiency, reduced emission of volatiles such as fluoride and lead oxide, improved glass uniformity, faster furnace rebuilds, and small space requirements. However, if the efficiency of electricity generation at the power plant is considered (30-35 percent efficient), the overall efficiency of electric melting is much lower (21 percent), and energy costs are high. For this reason, electric melters are not cost-competitive for many applications. The size limits of electric furnaces and the electrical conductivity of some batches at high temperatures also limit the use of all-electric melters.

Another issue is reduced refractory life in electric melters, which leads to more frequent furnace rebuilds. Typical rebuild time for an electric furnace is about 2 years, with 2 weeks of downtime [Gridley 2001].

Electric melters are commonly used for batches containing borosilicates or fluorides (e.g., fiber glass) to minimize volatilization of binders and resins. In a gas-fired furnace as much as 40 percent volatilization can occur, compared with less than 2 percent in electric melters. A typical electric melter configuration for producing fiber glass is illustrated in Figure 4-7.

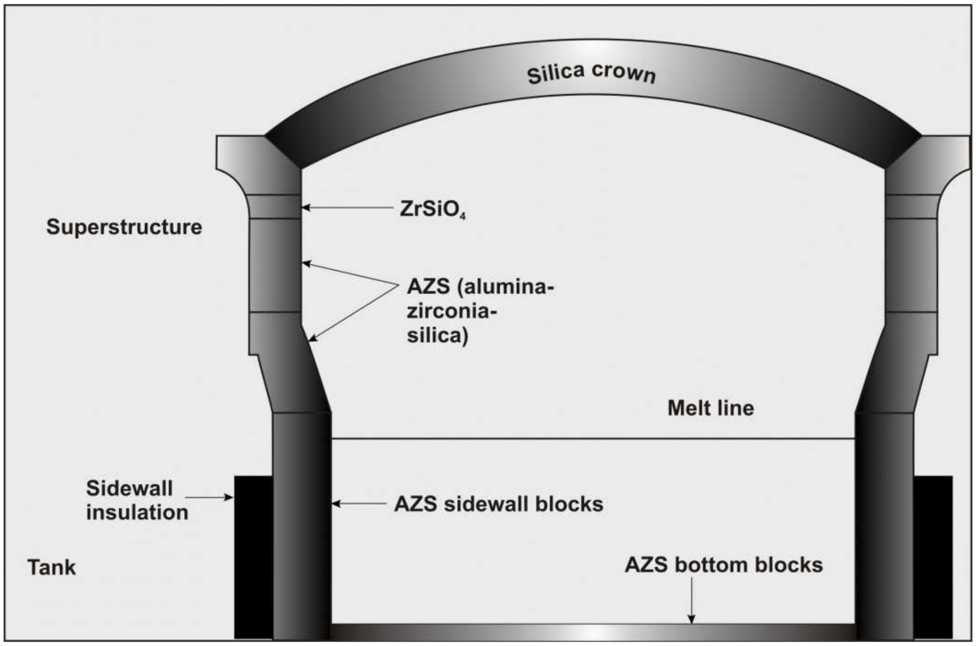


Figure 4-4. Typical Materials Used in Regenerative Furnaces [Freitag 1997]

Electric Boost, Oxy-Fuel Firing, and Batch Preheat Are Used to Increase Furnace Output, Efficiency, and Environmental Performance

The amount of glass that can be produced by a furnace is limited by the energy that can be provided to the molten glass inside the furnace structure. This limit occurs when the burners have reached their maximum heat output. Further increases in heat are limited by the temperature capabilities of the furnace structural materials, and the desire to keep emissions of nitrogen oxides low.

A number of techniques may be employed to meet needs for additional capacity without capital-intensive changes to the furnace. These include electrical boosting, oxy-fuel firing, and preheat of the batch and cullet. These methods may also lower operating costs and improve the environmental performance of the furnace.

Electric boost is used to add heat to the glass batch in a continuous gas-fired furnace by passing an electric current through the melt. This is typically accomplished by the placement of molybdenum electrodes in the sidewalls or bottom of the furnace. It is most often used to increase productivity (tonnage) available from an existing furnace, without increasing air emissions or making major changes to the furnace. Electric boost typically provides about 10 to15 percent of energy requirements in the furnace [EPA 1994].

For example, for an existing furnace operating at 25 percent efficiency and producing100 tons of glass per day, the addition of electric boosting could increase output to 160 tons per day and efficiency to 35 percent. Reduced combustion of fuel results in lower surface temperatures, fewer volatiles, and less costs for pollution abatement and control.

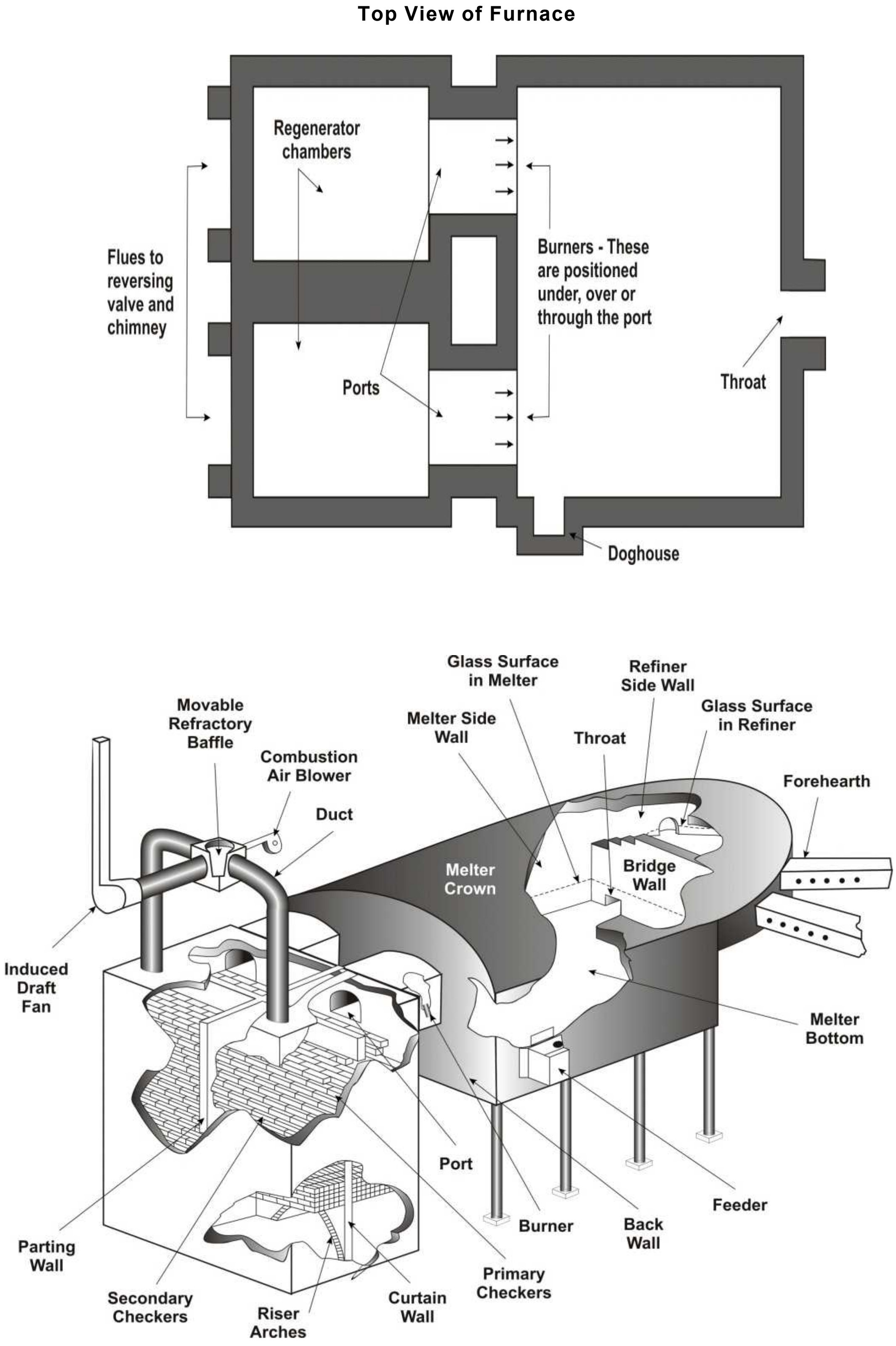


Figure 4-5. End-Port Furnace [EPA 1986, EPA 1995, EPA 1994, EI 1998]

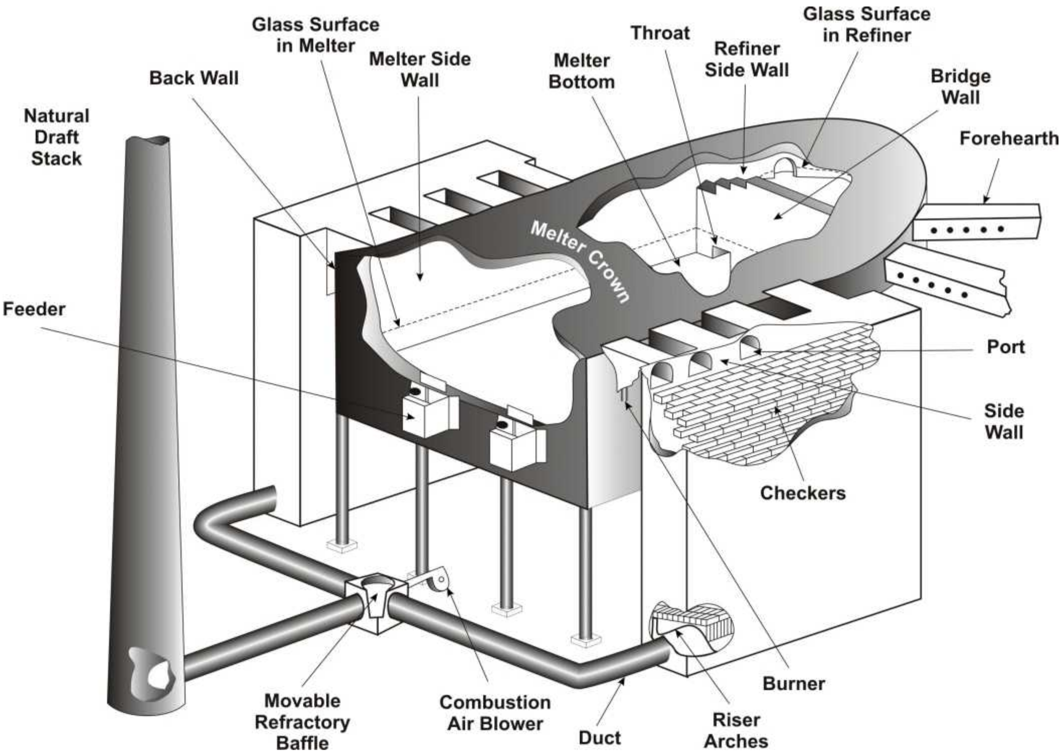


Figure 4-6. Side Port Regenerative Furnace
[EPA 1986, EPA 1995, EPA 1994, CMP 1990, EI 1988]

Electric boosting can also stabilize the convection currents in the furnace, enabling better mixing and improved homogeneity in the glass product [CMP 1990].

One issue with electric boosting is erosion of the molybdenum electrodes by the molten glass. For some glass products, erosion can result in unacceptable levels of molybdenum in the melt, and limits the useful life of the electrodes.

Oxy-fuel firing is used in many glass furnaces to increase combustion efficiency and reduce energy requirements. In melting furnaces, natural gas is combusted with air, which is comprised of about 21 percent oxygen and 78 percent nitrogen. The nitrogen absorbs large amounts of heat and leaves the furnace stack at high temperatures. The result is that a considerable amount of the heat from combustion is wasted, which lowers furnace efficiency. Even with heat recovery or controls that reduce excess air, modern glass furnace efficiency only reaches about 55-65 percent, primarily due to heat losses through the stack.

Using high purity oxygen or air that is enriched with oxygen (higher oxygen content) allows less nitrogen to be carried through the combustion process, which reduces stack gas volumes and subsequently heat losses. The result is higher thermal efficiency and fuel savings. It has been shown that fuel savings are possible even with relatively low levels of oxygen enrichment (see Figure 4-8). When 100 percent oxygen is used, or when burners with low flame temperatures are utilized, oxy-fuel-firing also leads to significant decreases in emissions of nitrogen oxides.

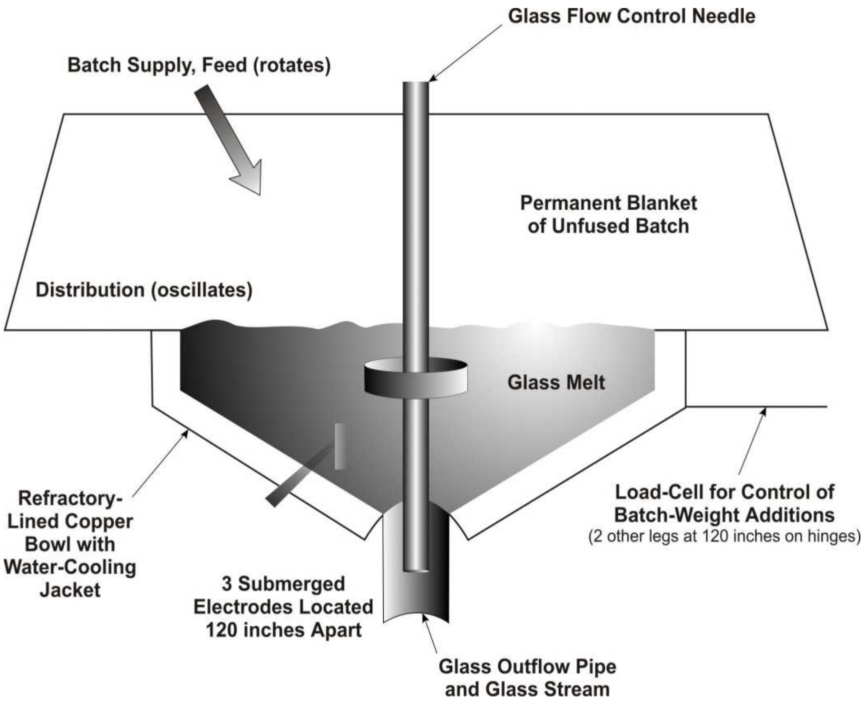


Figure 4-7. Electric Melter for Fiber Glass
[Freitag 1997]

Glass companies in all segments have instituted oxy-fuel-firing to some degree, and the trend toward using 100 percent oxygen is steadily rising [Glass Tech 1996]. Nearly 30 percent of glass furnaces now use oxygen enriched air. In many cases, oxy-fuel-firing is an attractive option for increasing throughput without major renovations to the furnace. A furnace that is equipped with oxygen-enriched air can produce the same amount of glass as with air combustion, but at lower fuel input.

When regenerative furnaces are converted to oxy-fuel firing, the regenerator's heat recovery checkers are no longer used and are eliminated. The exhaust volume is reduced by as much as 75 percent. In some configurations, the regenerator wall structures are modified to be part of a revised exhaust system. Other configurations will have the regenerators completely removed. If the exhaust gases require cooling for introduction into a particulate capture electrostatic precipitator or bag house, the regenerator space may be used to introduce water sprays or ambient air. A key factor is how factory space will be reallocated with the conversion.

To be economically feasible, oxygen enrichment requires a cost-effective and reliable source of oxygen. Current technologies for this purpose include adsorption (e.g., pressure swing, vapor swing), permeation membranes, cryogenic separation, liquid vaporization, and pipeline supply systems. A comparison of these options is illustrated in Table 4-1.

Liquified oxygen is transported by trains or trucks, and transportation costs limit the delivery radius to about 200 miles. Large volumes of gas can also be distributed to plants via pipelines from an air separation unit near the site. This option is only feasible for very large gas users. The type of system used for producing oxygen on-site depends on the volume of glass, local cost of electricity, and availability of oxygen production facilities off-site. Large-scale systems (greater than 200 tons/day of oxygen required) generally opt for cryogenic plants, while low-cost vapor swing adsorption units are more economic for plants with moderate oxygen requirements.

Preheat of the cullet and batch mixture can be accomplished using a separate burner or with the heat available from the furnace exhaust. The hot flue gas flows countercurrently to the falling batch, and a fan is used to pull the hot gases through the heat exchanger. Since the batch is hot when it enters the furnace, less energy is required to heat the batch to the melting point. Increased emissions can result from increase cullet and batch preheating.

Table 4-1. Comparison of Supply Options for Oxygen Enriched Air

Option	Capacity (tons/day)	Oxygen Purity (percent)	Power Required (kWh/ton O_2)	Cost ($/ton O_2)	Specifications
Delivered Liquid Oxygen	0 - 50	99.5+	700-800	na	Transportation costs limit delivery radius. Bulk storage tank and vaporizer required.
Pipeline	10-100	40+	400	na	Cost-effective for large volume users. Supply from nearby cryogenic air separation unit.
Vacuum Pressure Swing Adsorption	5-200	90-95	na	na	
Pressure Swing Adsorption (PSA)	10-100	80-95	250-600	30-50	Good economics for lower capacity operations.
Vacuum Swing Adsorption (VSA)	20-100	90-93	na	na	Modular units, low cost per ton, low energy use compared with PA.
Pressure Atmospheric (PA)	0.5 -50	na	na	na	Low cost oxygen for smaller plants. Requires no compressor in many applications (delivery pressure up to 50 psig), compact design, suited for smaller volume requirements.
Large Cryogenic Plant	50-1000	95-99.95	na	35-120	
Small Capacity On-Site Cryogenic Generators	80-200	90-98	350-400	na	Costs are 20% less than traditional large cryogenic plants. Produces useful byproducts (dry nitrogen, compressed dry air, liquid oxygen for backup). No oxygen compressor required (delivery pressure up to 230 psig).

Source: BOC 2000, DOE 1997, EI 1988.
na = not available

Furnace Type	Potential Energy Savings
Direct Melter with No Heat Recovery	40%
Recuperative	25%
Regenerative	15-20%

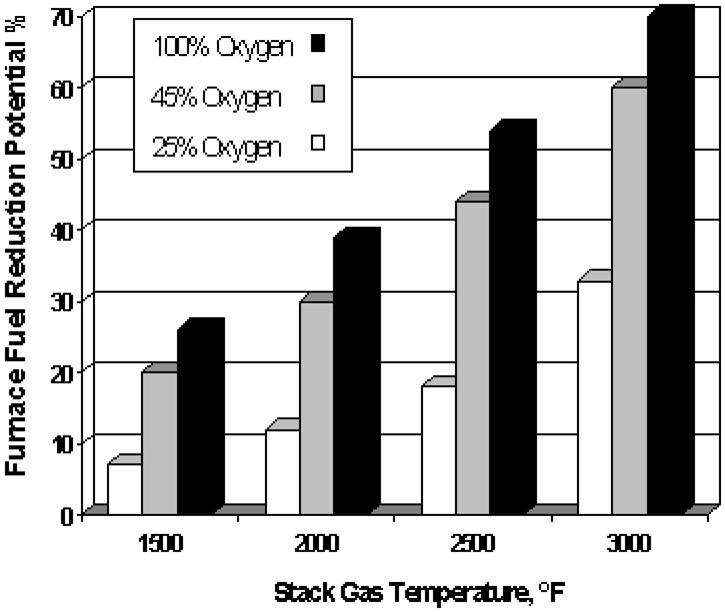


Figure 4-8. Oxy-Fuel Energy Savings As a Function of Furnace Type, Stack Gas Temperature, and Percent Oxygen [GCI 2001, EI 1988]

Oxygen-enriched air staging (OEAS) has recently been implemented on a number of glass furnaces as a successful strategy for reducing NOx. The process involves the creation of two distinct combustion zones in the melter, and an oxygen-deficient flame condition which produces lower NOx and higher carbon monoxide (CO). Air or oxygen is injected downstream of the flame to complete combustion [DOE 2000a]. NOx reductions of from 30 to 50 percent have been reported with the OEAS technology.

Melter Size and Characteristics Vary By Glass Product

The type, capacity, and performance characteristics of melting furnaces vary widely according to the type and quantity of glass produced (see Table 4-2).

Flat glass producers use side-port regenerative furnaces for all float glass operations. These are typically large furnaces with capacities ranging from 500 to 1000 tons per day. Large capacities are required to meet both volume demand and property requirements for higher quality flat glass. For example, flat glass manufacturers may reject glass on the basis of how many bubbles per ton of glass are present, compared with container manufacturers who consider the amount of bubbles per ounce of glass. To achieve the desired glass characteristics, flat glass requires higher average residence time in the furnace, which results in higher energy consumption for melting and refining relative to other glass products.

Due to the large size of flat glass melters, all-electric melters are not economical for this segment. However, about 10 percent of flat glass furnaces use electric boosting and about 5 percent use oxy-fuel-firing [GIC 2000, CMP 1990, EI 1988, EPRI 1988].

A large portion of the melters used in **container glass** manufacture are end-port furnaces (about 43 percent), with side-ports making up about 32 percent. All-electric melters are used in smaller container manufacturing plants (75 to 200 tons per day), and these comprise about 10 percent of furnace population. In addition, about 60 percent of the regenerative furnaces in use for container manufacture are equipped with electric boosting.

A moderate number of regenerative furnaces in container manufacture utilize oxygen enriched air (about 21 percent) [GIC 2000, CMP 1990].

Furnaces used in the **pressed and blown glass** segment are as diverse as their products, ranging from small day tanks and pot furnaces to large regenerative furnaces. Regenerative and recuperative furnaces are typically used to produce tableware, light bulbs, and television tubes on a relatively large scale. Specialty glasses (e.g., vitreous silica, leaded glass, opal glass, electronic glass) are manufactured with pot furnaces or day tanks. About 10 percent of furnaces used in the pressed and blown glass segment are all-electric. Electric boosting is not often used, however, because it does not provide much economic advantage at small scales. A relatively large percent, however, do use oxygen enriched air, particularly for lighting and television glass production. For example, 75 percent of furnaces used for television glass production are equipped with oxy-fuel-firing [GIC 2000, CMP 1990].

Fibrous glass is produced in either electric melters or recuperative furnaces. Glass insulation plants (glass wool) use electric melters because of the specific properties of their batch materials. Textile glass fiber is manufactured on a relatively large scale using direct melters with recuperators. A large percentage of textile fiber furnaces are equipped with oxy-fuel-firing (about 46 percent), as are glass fiber insulation furnaces (about 28 percent) [GIC 2000, CMP 1990].

Table 4-2. Furnace Characteristics by Glass Segment

Segment	Furnaces (number)	Capacity	Size	Melt Area
Flat Glass	Side-port regenerative (37) Oxy-fuel-fired (2) Electric (1) (~10% electric boost)	300-1000 tons/day (typical size 550+ tons/day)	30-35 ft wide, >100 ft long, 4-5 ft deep	6 ft^2/ton
Container Glass	End-port regenerative (52) Side-port regenerative (39) Oxy-fuel-fired (26) Electric (3) Unit melters (2) (~60-70% electric boost)	50-550 tons/day (typical size 250 tons/day)	20-30 ft wide, 20-40 ft long, 3-5 ft deep	2-5 ft^2/ton 5 ft^2/ton (bottles)
Pressed/ Blown Glass	Side-port regenerative (25) End-port regenerative (7) Oxy-fuel-fired (50) Unit melters (68) Electric (10)	1-300 tons/day (typical size 75 tons/day)	Variable	8 ft^2/ton (borosilicate glass)
Insulation Fiber Glass	Electric (35) Unit melters (9) Oxy-fuel-fired (12)	20-300 tons/day (typical size 100 tons/day)	Variable	
Textile Fiber Glass	Unit melters (30) Oxy-fuel-fired (31) Electric (7)	100-150 tons/day (typical size 100 tons/day)	8-20 ft wide 25-50 ft long 3-4 ft deep	9 - 10 ft^2/ton

Sources: GIC 2000, Gridley 2001, EI 1988, CMP 1990, EPRI 1988.

4.2 Summary of Inputs and Outputs for Melting

Inputs	Outputs
Crushed Cullet	Molten Glass
Glass Batch	Flue Gas
Refining Agents	Particulates/Dust
Natural Gas	Furnace Slag
Fuel Oil	Refractory Wastes
Electricity	
Air/Oxygen	

4.3 Energy Requirements

Melting and Refining Accounts for Most of the Energy Consumed in Glass Manufacture

Melting and refining of the glass batch is the most energy-intensive part of glass manufacture because of the high temperature chemistry involved in glass formation. Melting of raw materials consumes 60-70 percent of the total energy used to produce glass. In general, about 40 percent of the energy consumed in melting goes toward heating the batch and for the chemical conversion of the batch constituents.

As much as 30 percent of energy can be lost through the structure, and about 30 percent is lost through flue gas exiting the stack. The energy losses through structure and flue gases are proportional to the size of the melter. In general, smaller fossil-fuel fired melters will exhibit proportionately higher losses than larger furnaces [EPA 1994, EI 1988].

Theoretically, energy requirements for melting a ton of glass batch can be calculated from the heat capacity and heats of fusion of major components (silicon oxide, sodium carbonate, calcium carbonate, calcium fluoride, feldspar). In practice, energy requirements for glass furnaces vary considerably depending upon furnace type and operating conditions as well as glass composition.

Melting furnaces are fired with fossil fuels (mostly natural gas) or by electricity (electrical resistance heating). In some cases a combination of both is used. Most large continuous furnaces are fueled with natural gas. Many of these melters also use electrical boosting, where the melt is "boosted" by being resistively heated rather than by adding a resistive heater.

Electric boost and other techniques such as oxygen-enriched combustion air, cullet preheating, better combustion control, or increased insulation, can lower fuel requirements or increase glass production given the same fuel load. The Process Overview, Section 4.1 provides details on some of these technologies.

Small discontinuous furnaces can be fired with natural gas or electricity, and thermal efficiencies are very low (20 percent or less). Efficiencies in regenerative furnaces are typically much higher (60-65 percent). All-electric furnaces can be from 70-90 percent efficient (not considering the low efficiency of electricity generation off-site, which ranges from 25-30 percent). Electric melters are more efficient because there are no heat losses in the stack or regenerator. [EPA 1994, EPRI 1988]

The fuel chosen depends upon the type of glass produced, the capacity of the melter, and fuel costs. For example, large furnaces such as those used in flat glass production are fired with natural gas rather than electricity due to the higher cost of electricity. A comparison of fuel requirements for different furnaces is shown in Table 4-3. Actual fuel requirements can vary significantly between furnaces due to differences in furnace size, composition of the glass being melted, and the desired final product.

Average energy consumption for melting, given the current distribution of glass furnaces, is shown in Table 4-4, separated by glass segment. The larger specific energy requirements for pressed and blown glass are indicative of the relatively inefficient furnaces commonly in use in this segment (e.g., day tanks, pot furnaces, unit melters).

Table 4-3. Comparison of Energy Requirements for Glass Furnaces (Btu/ton)

Furnace Type	Range of Specific Energy (10^6 Btu/ton)	Average Specific Energy (10^6 Btu/ton)	% Electricity
Flat Glass			
• Regenerative Side-Port	6.5 - 11.0	8.8	2 - 5
• Electric Boost Side-Port	6.0 - 7.0	6.5	11-15
• Oxy-Fuel	ND	ND	ND
Container Glass			
• Large Regenerative	5.0 - 10.5	7.8	3 - 5
• Electric Boost	3.9 - 7.0	5.5	15
• Oxy-Fuel	4.4 - 5.0	4.7	15
• Small Electric Melter	2.5 - 3.0	2.8	100
• Direct Melter	5.0 - 12.0	8.5	ND
Pressed and Blown Glass			
• Regenerative	3.8 - 7.1	5.5	ND
• Direct Melters	8.0 - 16.0	12.0	ND
• Oxy-Fuel Fired	3.0 - 4.2	3.6	ND
• Electric Melters	8.9 - 11.7	10.3	100
Insulation Fiber Glass			
• Electric Melters	3.0 - 12.0	7.5	100
• Recuperative Melters	6.0 - 8.0	7.0	ND
• Oxy-Fuel Fired	3.4 - 7.8	5.6	ND
Textile Fiber			
• Recuperative Melters	6.0 - 15.0	10.5	ND
• Oxy-Fuel Fired	3.4 - 7.8	5.6	ND

ND = No data available.
Sources: GIC 1997, Brown 1996, CER IND 1994, AM CER SOC 1994, EPA 1994, Glass Ind 1993, CMP 1990, EI 1988, EPRI 1988.

Exhibit 4-4. Estimated Energy Use in Glass Melting

Energy Source	Natural Gas (10^6 Btu/ton)	Net Electricity[a] (10^6 Btu/ton)	Total Energy (10^6 Btu/ton)	1997 Production (tons)	Net Industry Use [b] (10^{12} Btu)	Electricity Losses [c] (10^{12} Btu)	Total Energy Use (10^{12} Btu)
Flat Glass							
• Regenerative Side-Port	8.5	0.3	8.8	4,500,469	39.6	2.8	42.4
• Electric Boost	5.7	0.8	6.5	500,052	3.3	0.8	4.1
TOTAL FLAT GLASS				**5,000,521**	**42.9**	**3.6**	**46.5**
Container Glass							
• Large Regenerative	7.5	0.3	7.8	1,437,975	11.2	0.9	12.1
• Electric Boost	4.7	0.8	5.5	5,751,900	31.6	9.6	41.2
• Oxy-Fuel	4.0	0.7	4.7	1,917,300	9.0	2.8	11.8
• Small Electric Melter	-	2.8	2.8	479,325	1.3	2.8	4.1
TOTAL CONTAINER GLASS				**9,586,500**	**53.1**	**16.1**	**69.2**
Pressed and Blown Glass							
• Regenerative	5.5	ND	5.5	645,887	3.6	-	3.6
• Direct Melters	12.0	ND	12.0	844,622	10.1	-	10.1
• Oxy-Fuel	3.6	ND	3.6	869,464	3.1	-	3.1
• Electric Melters	-	10.3	10.3	124,209	1.3	2.7	4.0
TOTAL PRESSED/BLOWN GLASS				**2,484,182[d]**	**18.1**	**2.7**	**20.8**
Insulation Fiber Glass							
• Electric Melters	-	7.5	7.5	1,436,400	10.8	22.4	33.2
• Recuperative Melters	7.0	-	7.0	402,192	2.8	-	2.8
• Oxy-Fuel	5.6	-	5.6	76,608	0.4	-	0.4
TOTAL INSULATION FIBER				**1,915,200**	**14.0**	**22.4**	**36.4**
Textile Fiber							
• Recuperative Melters	10.5	-	10.5	1,079,808	11.3	-	11.3
• Oxy-Fuel Fired	5.6	-	5.6	44,992	0.3	-	0.3
TOTAL TEXTILE FIBER				**1,124,800[e]**	**11.6**	**-**	**11.6**
TOTAL INDUSTRY				**20,111,203**	**139.7**	**44.8**	**184.5**

[a] Based on a conversion factor of 3412 Btu/kWh of electricity.

[b] Excludes electricity losses.

[c] Losses associated with generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh of electricity.

[d] Estimated based on 92 Census Data and 2% growth between 1992 and 1997.

[e] Assumes 37% of fiber production is textile fibers.

Sources: DOC 1997, GIC 1997, Brown 1996, Am Cer Soc 1994, EPA 1994, Cer Ind 1999, Cer Ind 1997, Cer Ind 1994, Glass Ind 1993, 1992 DOC, CMP 1990, EPRI 1988, EI 1988.

4.4 Emissions

Glass Melting Produces Volatiles, Particulates, and Combustion Products

The melting and refining process accounts for about 90 percent of the air emissions produced from a glass manufacturing plant. Melting and refining of the batch results in the release of volatile compounds (e.g., alkali or borates) from the molten glass, particulates of raw materials that are trapped in the flue gas, and pollutants from the combustion of fossil fuels (sulfur oxides, nitrogen oxides, carbon monoxide, and particulate matter).

Emission rates vary depending upon the type of furnace employed due to variable operating temperatures, the composition of raw materials, fuels used, and flow rate of the flue gas. The least efficient furnaces generally have the greatest emission rates. Electric furnaces have the lowest emission rates because combustion products are eliminated, and the melt surface is maintained at a lower temperature.

Particulates are released when materials in the melt volatilize and combine with gases to form condensates. Particulates emitted from soda-lime glass are primarily sodium sulfate. In regenerative furnaces these collect in the furnace checkers and gas passages or are emitted to the atmosphere. The checkers and passages must be routinely cleaned to prevent the formation of slag that can clog passages and deteriorate the condition and efficiency of the furnace. Particulates are also generated by the combustion of fuels, although when using natural gas these are comparatively low.

Fibrous glass melting results in large emissions of particulates due to the nature of the batch, particularly when non-electric melters are used. The manufacture of textile fiber glass, which is done mostly in relatively inefficient direct melters or recuperative furnaces, typically has higher pollutant and particulate emission rates. Volatile compounds (borates) are emitted during the manufacture of both insulation fiber glass and textile fiber glass as the result of constituents present in the glass batch.

Nitrogen oxides (NOx) are an issue of special concern for glass makers, as they are the subject of increasingly stringent regulation. Glass melting furnaces generate NOx by:

- homogeneous gas phase reaction of N_2 and O_2 in the combustion air, which produces mostly NO,
- evolution of NO_2 from nitrate compounds present in the batch,
- oxidation of nitrogen in the fuel.

The homogeneous formation of NO is dependent on the temperature of the combustion air and the concentration of nitrogen and oxygen in the gas (see Table 4-5). NOx is formed by a series of reactions, the most dominant of which occurs as the combustion air contacts the flame in the furnace at temperatures ranging from 2700°F to 3100°F. This reaction is temperature sensitive, and requires very high activation energy. Because of its high activation energy, once NOx is formed by this reaction, it does not easily decompose back to nitrogen and oxygen. As Table 4-5 illustrates, flue gases emerging from the furnace at around 1000°F should theoretically contain about 1 ppm total NOx. However, as the combustion air is heated to temperatures above 2000°F, much higher amounts of NOx are formed. As the gases cool, the reverse of the reaction is kinetically limited, and much of the NOx remains in the flue gas [EPA 1994].

Sulfur oxides (SOx) result during the decomposition of sulfates in the glass batch, and from sulfur in the fuel during combustion. Other emissions from combustion of fuels include carbon monoxide (CO), volatile organic compounds (VOCs), and carbon dioxide (CO_2). Carbon dioxide is also produced as a byproduct of the reaction of silica with sodium carbonate and other carbonates which are added to the batch.

Emission factors for container, flat, pressed and blown, and lead glass manufacturing are shown in Table 4-6. Emission factors for textile and insulation fiber manufacturing are given in Table 4-7. These emission factors are an average of all furnace types within each

Table 4-5. Predicted Equilibrium Concentrations of NOx in Air and Flue Gas (ppm)

	Air		Flue Gas	
Temperature (°F)	NO	NO_2	NO	NO_2
80 (ambient conditions)	$3.4\ 10^{-10}$	$2.1\ 10^{-10}$	$1.1\ 10^{-10}$	$3.3\ 10^{-3}$
980 (~glass furnace exhaust)	2.3	0.7	0.8	0.1
2,910 (~peak furnace temperature during melting)	6,100	12	2,000	1.8

Source: EPA 1994.

segment. In some segments (e.g., flat glass) a single furnace type dominates (regenerative side-port).

Furnace emissions can vary considerably, depending on the type, age and condition of the furnace. A study done in 1994, which looked at alternative control technologies for nitrogen oxides, illustrates this wide variability in emissions from 22 facilities (see Table 4-8).

Emissions From Glass Furnaces are Subject to Regulation Under the Clean Air Act

Glass furnaces are subject to the general rules of the Clean Air Act and its Amendments, principally for nitrogen oxides (NOx), sulfur oxides (SOx), and particulates. The most stringent standards are found in California, which has a high concentration of glass furnaces. California standards are 4.0 lbs NOx/ton of glass [Cer Ind 1991]. However, there are no uniform State limits—NOx limits are lower in some areas. New Source Performance Standards for particulates for all furnace types are shown in Table 4-9.

To meet regulations, glass manufacturers employ a variety of pollution abatement technologies to control emissions from the melting furnace. The most effective of these for particulates is the high-energy venturi scrubber, which reduces approximately 95 percent of emissions. This method is about 60 to 70 percent effective for sulfur oxides. Low-energy wet centrifugal scrubbers are also in use, but only have about a 50 percent efficiency rate for controlling particulates and sulfur oxides.

In some cases batching techniques (e.g., pelletizing, briquetting) can be used to control emissions. Anthracitic coal is also sometimes added to the batch to reduce emissions of sodium sulfate as particulate matter. Increasing the batch percentage of cullet, which has already been processed, can also reduce emissions.

Baghouses can collect 95 to 98 percent of particulates, but the fabric corrodes at high temperatures and careful temperature controls must be instituted. Electrostatic precipitators are most effective for particulate control, with up to 90 percent efficiency [GIC 2001]. In fiber glass manufacturing, fabric filtration is the primary method of emissions control. These filters are effective for control of particulates,sulfur oxides, and to a lesser extent, carbon monoxide, nitrogen oxides, and fluorides.

Fabric Filtration Efficiency in Fibrous Glass Manufacture

Regenerative and Recuperative Wool Furnaces

Particulates	95%+
SOx	99%
Carbon Monoxide	30%
Fluorides	91-99%

Source: EPA 1997

Table 4-6. Emission Factors for Flat, Container, and Pressed/Blown Glass Melting (lb/ton glass materials processed)

Segment/Furnace	Particulates	SOx	NOx	CO	VOCs	Lead
Container						
Uncontrolled	1.4	3.4	1.8-21.6[a]	0.2	0.2	ND
Controlled						
Low-energy scrubber	0.7	1.7	6.2	0.2	0.2	ND
Venturi scrubber	0.1	0.2	6.2	0.2	0.2	ND
Baghouse	neg	3.4	6.2	0.2	0.2	ND
Electrostatic Precipitator	neg	3.4	6.2	0.2	0.2	ND
Flat Glass						
Uncontrolled	2.0	3.0	8.7-25.8[a]	<0.1	<0.1	ND
Controlled						
Low-energy scrubber	1.0	1.5	8.0	<0.1	<0.1	ND
Venturi scrubber	neg	0.2	8.0	<0.1	<0.1	ND
Baghouse	neg	3.0	8.0	<0.1	<0.1	ND
Electrostatic Precipitator	neg	3.0	8.0	<0.1	<0.1	ND
Pressed and Blown						
Uncontrolled	17.4	5.6	16.8-27.2[a]	0.2	0.3	ND
Controlled						
Low-energy scrubber	8.4	2.7	8.5	0.2	0.3	ND
Venturi scrubber	0.9	0.3	8.5	0.2	0.3	ND
Baghouse	0.2	5.6	8.5	0.2	0.3	ND
Electrostatic Precipitator	0.2	5.6	8.5	0.2	0.3	ND
Lead Glass Manufacturing						
All Processes	ND	ND	ND	ND	ND	5.0

ND = no data.

[a] Based on compilation of emissions in Alternative Control Techniques Document [EPA 1994].

Source: EPA 1985/AP-42

Techniques for reducing NOx emissions include process modifications (cullet preheat, electric boost), combustion modifications (oxy- fuel firing, low NOx burners, oxygen-enriched air staging), and gas reburn. These methods are described in detail in the Process Overview, Section 4.1. Their relative potential for reducing NOx emissions is shown in Table 4-10. Comparative costs for installation and use of various NOx control technologies are shown in Tables 4-11 and 4-12.

Table 4-7. Emission Factors for Fibrous Glass Melting (lb/ton glass materials)

Furnace Type	Filterable Particulates	SOx	NOx	CO	Fluorides
Insulation Fiber Glass					
Electric	0.02-0.7*	0.04	0.27	0.05	0.002
Gas - Regenerative	0.02 - 1.08*	10	5	0.25	0.12
Gas - Recuperative	0.02 - 1.08*	10	1.7	0.25	0.11
Gas - Direct Melter	9	0.6	0.3	0.25	0.12
Textile Fiber Glass					
Gas - Regenerative	2	3	20	0.5	2
Gas - Recuperative	16	30	20	1	2
Gas - Direct Melter	6	ND	20	0.9	2

ND = no data.
*1997 data. EPA Docket II-I-20. Background for Proposed Ruling for 40 CFR Part 63. Furnaces equipped with baghouses: 0.02 - 1.08 lb/ton; equipped with electrostatic precipitators: 0.02 - 0.5 lb/ton.
Source: EPA 1985/AP-42.

Table 4-8. Comparison of Uncontrolled NOx Emissions from Glass Furnaces

Segment	Furnace Type	Design Capacity (ton/day)	Uncontrolled NOx Emissions (lb/ton)	Average NOx Emissions[a] (lb/ton)
Container	Side-Port	250 - 400	5.2 - 12.0	8.6
Container	End-Port	75 - 165	7.0 - 21.0	12.2
Flat	Side-Port	~550	9.8 - 25.8	15.5
Pressed/Blown	Not Reported	66-226	16.8 - 27.2	22.0

[a] Average data for reporting facilities.
Source: EPA 1994.

Table 4-9. New Source Performance Standards for Particulates Emitted From Glass Manufacturing Furnaces[a]

Segment	Gas-Fired Furnace (lb/ton glass)	Liquid-Fired Furnace (lb/ton glass)
Container Glass	0.2	0.26
Flat Glass	0.45	0.45
Pressed and Blown Glass		
• Borosilicate recipes	1.0	1.3
• Soda-lime and lead recipes	0.2	0.26
• Other than above (opal, fluoride, others)	0.5	0.65
Wool Fiberglass	0.5	0.65

[a] Excludes all-electric melters, hand glass melters, and furnaces producing less than 5 tons/day.
Source: 40 CFR 60 CC.

Table 4-10. NOx Reductions for Different Control Options	
Technology	**NO Reduction (%)**
Combustion Modifications	
Low NOx Burners	40
Oxy-Fuel Firing	80-85
Oxygen Enriched Air Staging (OEAS)	30-75
Process Modifications	
Cullet Preheat	5-25
Electric Boost	10-30
Post-Combustion Modifications	
SCR	
SNCR	75
	40

Source: EPA 1994, DOE 2000a.

Table 4-11. Cost Comparison for Combustion/Post-Combustion NOx Control Options (1000$, unless noted otherwise)

	OEAS	Low NOx Burners			Oxy-Fuel Firing		
Plant Size (tons/day)	$/ton NOx	Capital Cost	Annual Cost	$/ton NOx	Capital Cost	Annual Cost	$/ton NOx
50 (pressed/blown)		265	123	1,680	1,930	706	4,400
250 (container)	400[a]	695	320	1,920	5,070	1,860	5,300
750 (flat)		1,340	621	790	9,810	3,590	2,150

Source: EPA 1994, January 1994$.
Note: Costs are very furnace-specific.
[a] Average cost, no size or sector specific data available

Table 4-12. Cost Comparison for NOx Control Options Requiring Process Modifications (1000$, unless noted otherwise)

	Cullet Preheat			Electric Boost	
Plant Size (tons/day)	Capital Cost	Annual Cost	$/ton NOx	Annual Cost	$/ton/ NOx
50 (pressed/blown)	188	42	890	178	9,900
250 (container)	492	110	1,040	339	8,060
750 (flat)	NF	NF	NF	525	2,600

Source: EPA 1994, January 1994$.
NF = not feasible

Some Air Emissions From Melting Furnaces Are Hazardous

In the pressed and blown glass sector, furnaces producing glass with arsenic, fluorides, or lead must be carefully controlled to avoid emissions of these constituents. For this reason smaller melters are often used to produce these glasses. In 1986, the EPA made a determination that if glass manufacturers were not using arsenic as a raw material, but as an additive, then they were not subject to regulations or record-keeping requirements. For those glass manufacturers producing arsenic-containing glass (arsenic is added as a raw material), emissions of arsenic from the melting furnace are limited to less than 2.75 tons per year under the Clean Air Act. New or modified furnaces must keep emissions below 0.44 tons per year [40 CFR 61.160].

National Emissions Standards for Hazardous Air Pollutants (NESHAP) were proposed in 1997 for facilities manufacturing fiber glass from sand, feldspar, sodium sulfate, anhydrous borax, or boric acid. The rulings cover three metals (arsenic, chromium, and lead) and three organic hazardous air pollutants—HAPs—(formaldehyde, phenol and methanol).

Regulation of these compounds is required as exposure can result in reversible or irreversible effects on human health, including those that are carcinogenic, respiratory, nervous system, developmental, reproductive, and dermal.

Annual emissions of HAPs and particulate matter (PM) from fiber glass melting furnaces are shown in Table 4-13. Only a very small portion of these are metal HAPs—most are organic. These emission estimates are based on tests conducted by the Environmental Protection Agency (EPA) in cooperation with the member companies of the North American Insulation Manufacturers Association (NAIMA).

For the melting portion of the fiberglass manufacturing process, particulates (including HAPs) are subject to the same limits as those shown in Table 4-9 and defined under New Source Performance Standards. The most effective methods of control for both particulate and metals HAPs are the electrostatic precipitator and the pulse-jet baghouse. As of 1997, a large percentage of fiber manufacturing furnaces were already fitted with these types of control technology [40 CFR 63, EPA 1997].

Table 4-13. Current Emissions of Hazardous Air Pollutants(HAPs) and Particulates (PM) from Insulation Fiber Glass Manufacture

Furnace	HAPs (lb/yr)	PM (ton/yr)
All Furnaces	600	830
Electric (hot-top)	20	700
Electric (cold-top)	60	60

Source: EPA 1997

4.5 Byproducts and Wastes

Waste residues are generated from pollution control equipment installed on glass furnaces to control particulates and other emissions. Pollutants may be controlled using aqueous media, filters, and electrostatic precipitators. When aqueous media is used, a solid residue may result. An example of this is the quench reactor, which reacts sulfur dioxide with water and sodium carbonate. The water evaporates upon contact with the hot flue gases, leaving behind a solid residue which may contain a number of constituents, depending upon the type of glass.

Constituents in the residue may include selenium, chromium, cadmium, cobalt, lead, sodium sulfate and other compounds, some of which are hazardous compounds. In fiber manufacturing, trapped emissions may include calcium carbonate, sodium fluoride, sodium fluorosilicate, silica, calcium fluoride, aluminum silicate, sodium sulfate, and boron oxides. Particulates are also trapped in baghouses or filters, and in most cases the dust residue from these can be recycled back to the process.

Another byproduct of the melting process is furnace slag. The slag is formed from small quantities of raw batch materials entrained by the fires and carried into the checkers of the regenerators where it forms a partially glassy material. It is composed mostly of the oxides of silica, sodium and calcium in the upper checkers and some sodium sulfate in the lower checker pack. Some of this material is eventually deposited in the bottom of the regenerators and is periodically removed as "checker rakings" or "flue slag." Maintenance of the furnace also produces refractory wastes [EPA 1995].

5

Glass Forming

5.1 Process Overview

The Transformation Into Finished Glass Products Begins With Forming

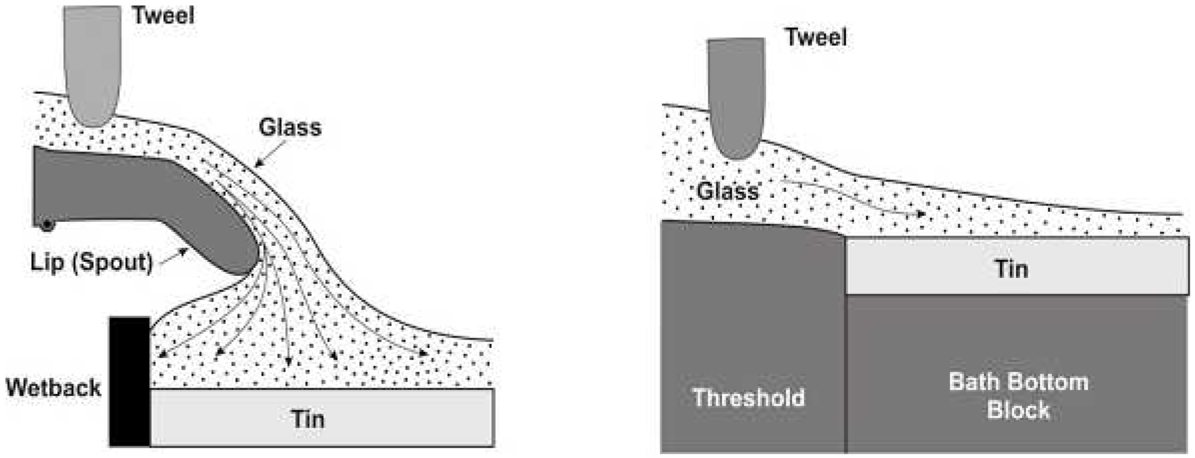
Forming is the stage where the molten glass begins its transformation into a final shape. As it moves from the melting tank to the forming machine, the molten glass looks like a thick, red-orange syrup. Forming processes must mold the molten glass quickly, because it becomes rigid as it cools.

There are a wide range of forming processes, even within some glass segments. Molten glass can be molded, drawn, rolled, cast, blown, pressed, or spun into fibers. Regardless of the process, forming begins with the flow of molten glass from the forehearth, where it has been cooled to a temperature suitable for working the glass. From that stage on, forming processes depend on the shape of the finished product.

Flat Glass is Formed Using the Float Glass Process

Nearly all flat glass in the United States is produced by the float glass process. This process, developed in the 1950s by Pilkington Brothers of England and licensed in the United States in1962, revolutionized flat glass manufacture and has since replaced the energy- and waste-intensive plate glass process. Float glass processing uses much less energy than its predecessors (plate or sheet glass forming) due to the use of larger, more efficient furnaces and the elimination of the need for surface finishing (polishing and grinding), which can consume as much as 3 million Btu per ton of glass. The process produces a fire-polished glass that is close to the quality of ground and polished plate glass. Since the float process is used to produce virtually all flat glass, the terms float glass and flat glass are now used interchangeably.

In the float glass process, molten glass (at about 1950°F) flows horizontally from the forehearth under a tweel and over a lip (or spout) into a



PB process delivery system

PPG process delivery system

Figure 5-1. Delivery Systems for Molten Glass to the Flat Glass Tin Bath [EI 1988]

pool of molten tin about 160-190 feet long and 12-30 feet wide. As the hot glass passes over the molten tin it conforms to the perfect flatness of the tin surface and develops a uniform thickness without distortion. Another process developed by PPG Industries in 1974 passes the molten glass over a wide threshold made of a non-reactive material rather than a lip. The PPG process has the advantage of reducing the size required for the molten tin bath and produces a velocity field that is more suited to forming the final glass ribbon. Figure 5-1 illustrates both methods of delivering the molten glass to the tin bath.

Rollers made of high temperature strength alloys are used for some flat glass, but the glass produced has a rougher surface. The rollers are sometimes embossed to produce a pattern in the glass.

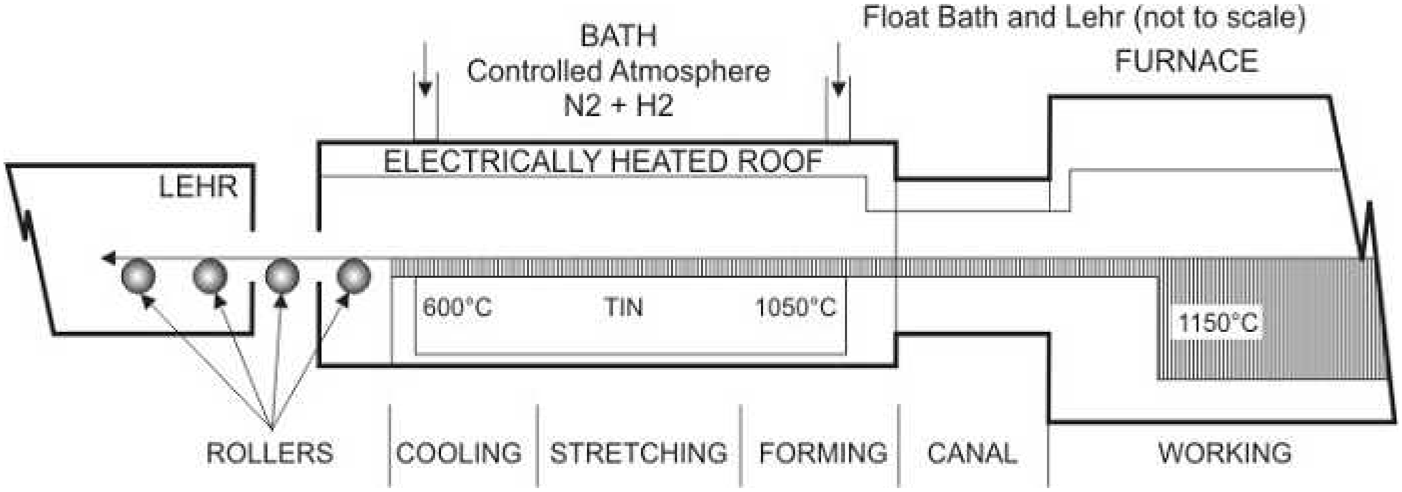
At the end of the chamber a continuous glass is drawn from the spreading glass. Glass that is contaminated with refractory is pushed to the outside of the ribbon where it can be removed and scrapped. Through the float chamber, different temperature zones allow for heating, fire-polishing, stretching, and forming of the glass ribbon (see Figure 5-2).

The tin bath is kept under a blanket of inert nitrogen gas to prevent oxidation, and is kept in a molten state by electrical heating. The thicker the glass is, the less heating is required. The glass emerges from the tin bath at about 1125°F and is then transferred to finishing processes (see Post-Forming, Chapter 6). The thickness of the glass leaving the bath ranges from about 0.078 to 0.78 inches [Corning 2000, EPA 1995, EPA 1994, EI 1988, EPRI 1988].

Glass Containers Are Formed Using Molds

Molten glass is formed into containers by transferring it into molds. The most common method of doing this is by forcing the molten glass through small holes and then transferring it into container molds, a method called gob feeding. During gob feeding, the weight and shape of the molten glass gobs through an orifice are controlled using a revolving tube and reciprocating plunger. The glass is then cut using mechanical shears to form the gobs, which range in temperature from1800°F to 2250°F.

The temperature of the molten glass is very important to the formation of gobs. If the glass



Summary of Key Energy and Environmental Facts - Float Glass Forming			
Energy	***Air Emissions***	***Effluents***	***Byproducts/Wastes***
Energy use per ton of glass: *1.5 10^6 Btu/ton*	*Negligible*	*Waste water (may contain suspended solids, phosphorus)*	*Glass contaminated with refractory*

is too cool, the melt is too viscous to transfer properly. Cooling systems may be employed to eliminate temperature variations in the gobs. The forehearth temperature is also carefully controlled for this reason (see Chapter 5, Melting and Refining).

Today nearly all container manufacturers use the IS (individual section) machine to automatically form containers from gobs. Each "individual section" of the machine contains its own set of molds and is independent of the other sections. Any section of the machine may be shut down and be repaired or maintained without disruption of the other sections.

The IS machine is capable of handling a variety of types and sizes of molds, and can produce containers at rates of well over 100 per minute. An IS machine can hold up to ten identical sections mounted on a single base with a distributor on top that feeds gobs of molten glass to the molds. IS machines can be mounted with single, double, triple, or quadruple gobs (e.g., double gobs produce two bottles per cycle, etc.). Double gobbing can be used for containers weighing up to about 20 ounces; triple gobbing can be used for containers weighing up to 10 ounces.

Double, triple and quadruple gobbing machines have substantially increased the speed of bottle making, and larger machines are much more productive. For example, a "ten quad" machine developed by Owens Illinois with four banks of ten sections can produce more than 500 bottles per minute. Two modes of operation are commonly used in IS machines: blow and blow, and press and blow. IS machines can form glass by either method, and can be easily converted from one to the other, allowing for greater flexibility and productivity.

In the blow and blow method, the gob is first transferred to a blank mold and settled using compressed air (referred to as the settle blow). A counter blow is then used to create what is called a parison. The parison is then transferred to a second blow mold where the final shape is created using air (final blow). This operation is illustrated in Figure 5-3. Control of container dimension is moderately good with this method, and a high quality surface finish is more easily obtained than with pressed methods.

The press and blow method uses a plunger to form the initial parison in a blank mold (see Figure 5-4). The parison is inverted and transferred to a blow mold, where it undergoes final shaping with vacuum or air pressure in the mold. In either case, the blank mold is a thick-walled but smaller version of the final container. Pressing provide greater control of dimensions than blowing, and permits molding of thicker cross-sections. All molds must be maintained at a constant temperature to ensure that the product quality is consistent [Corning 2000, EPRI 1988, EI 1988].

Forming Operations for Pressed and Blown Glass Differ Widely

Pressed and blown glass products are very diverse, as are the operations used for forming. Products include hand-made and machine made table, kitchen and art ware, lighting, electronic glassware, television tubes, and scientific and industrial glass.

Table, Kitchen and Art Ware

The largest portion of products from the blown and press glass segment includes table, kitchen, and art ware. Most all of these (about 85 percent) are machine-made using the automated press and blow described in the previous section under container manufacture.

Some table and kitchen ware are manufactured using **press-forming** machines. Press-forming utilizes a mold, plunger and ring to form the finish area (see Figure 5-5). Press-forming molds are mostly made of cast iron, and in some cases, stainless steels or other materials. Simple glassware (bowls, plates) is often made using press-forming.

Machine pressing is done using a round, single table machine in a one-step process where the same plunger can be used on several molds. Tables may be driven by air or motor, and pressing mechanisms may work via air cylinders or mechanical toggles. Production speeds for pressed ware are variable, ranging from 10-60 pieces per minutes. Production speeds are dependent on the time required for cooling the glass and allowing it to set up in the press. Formed pieces are removed either manually or automatically. Methods include removal by air jets or vacuum lift, by automated tongs, by turning the mold over, or hand removal.

When hot molds are used in press-forming the mold temperatures must be carefully controlled to prevent overheating and sticking of the product to the mold. This is accomplished using fans or compressed air. Plungers are cooled using water that is circulated internally. The mold may also be sprayed with lubricants or even water to reduce the potential for sticking.

The spinning process is sometimes used to produce circular articles such as plates and shallow bowls (see Figure 5-6). A hot glass gob is dropped into the mold, and is then rotated to form the article by centrifugal force [EC 2000]. Paste molds are often used to produce both medium- and high-grade tumblers. The parison in this case is created by using a plunger and a cast iron mold. As the cast iron mold pulls away, a two-section water-cooled paste mold folds into place around the parison. The paste mold is then rotated during final air blowing to attain a smooth, high-luster finish [Corning 2000, EPRI 1988, EI 1988].

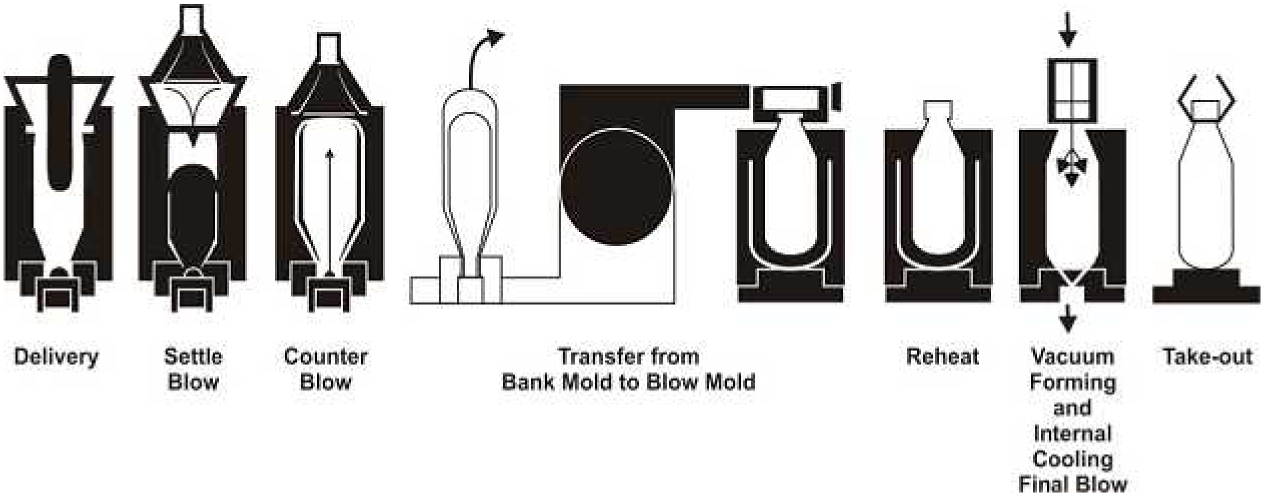


Figure 5-3. Container Glass Forming Blow & Blow
[Corning 2000, EPRI 1988]

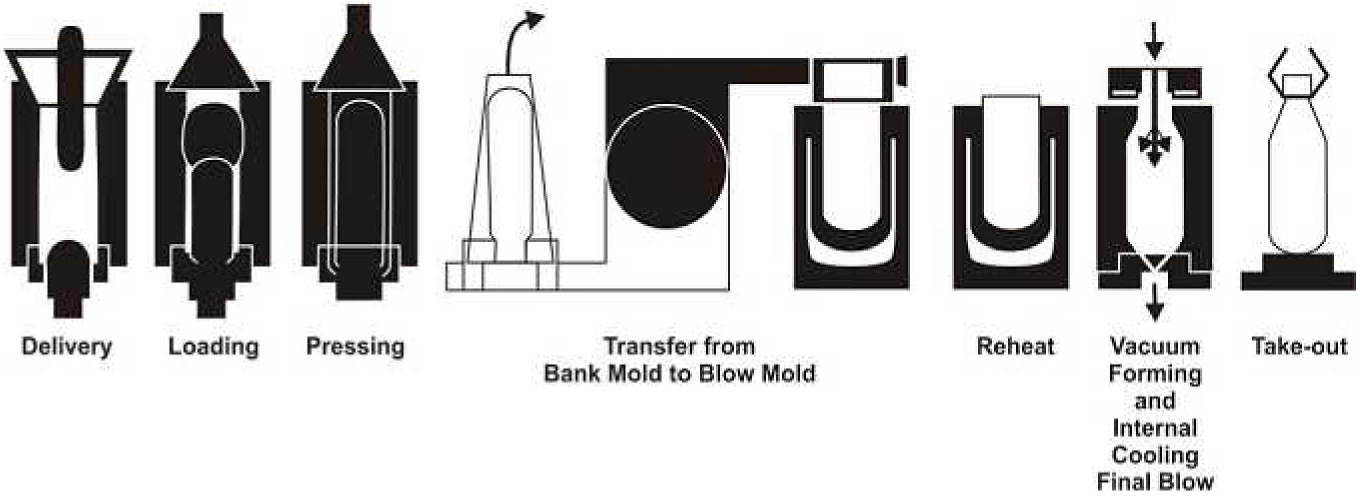


Figure 5-4. Container Glass Forming Press & Blow
[Corning 2000, EPRI 1998]

Summary of Key Energy and Environmental Facts - Container Glass Forming			
Energy	***Air Emissions***	***Effluents***	***Byproducts/Wastes***
Energy use per ton of glass: 0.4 10^6 Btu/ton	*Particulates, organic condensible particulates, volatile organics, resin and binder droplets, formaldehyde (all controlled)*	*Waste oil and solvents, waste water (may contain dissolved solids, suspended solids, heavy metals)*	*Solid residues from pollution control equipment*

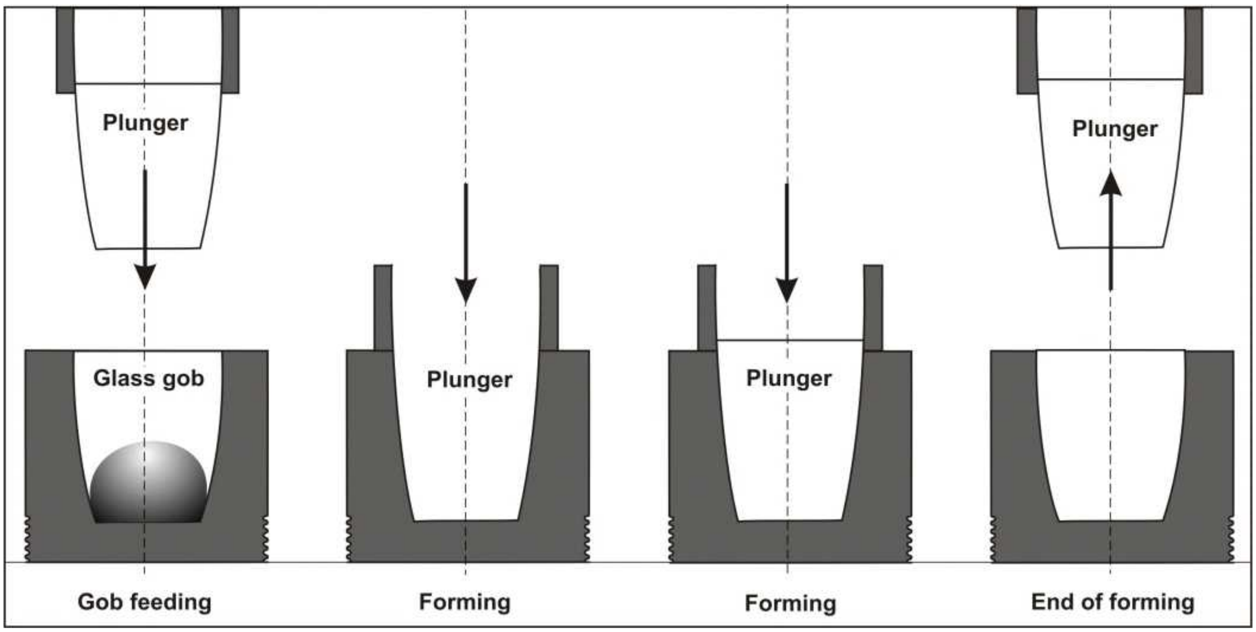


Figure 5-5. Press Forming [EC 2000]

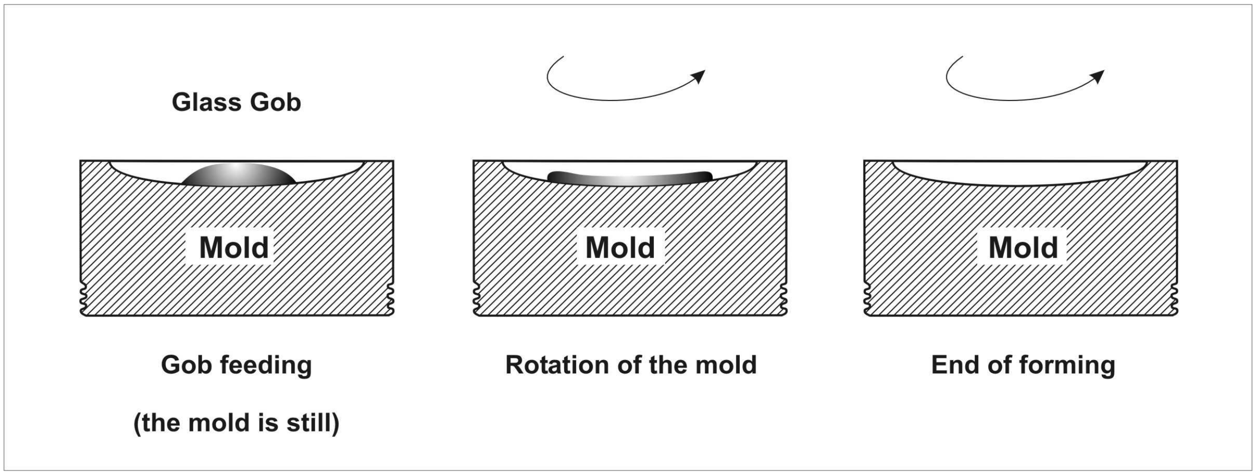


Figure 5-6. Spin Forming [EC 2000]

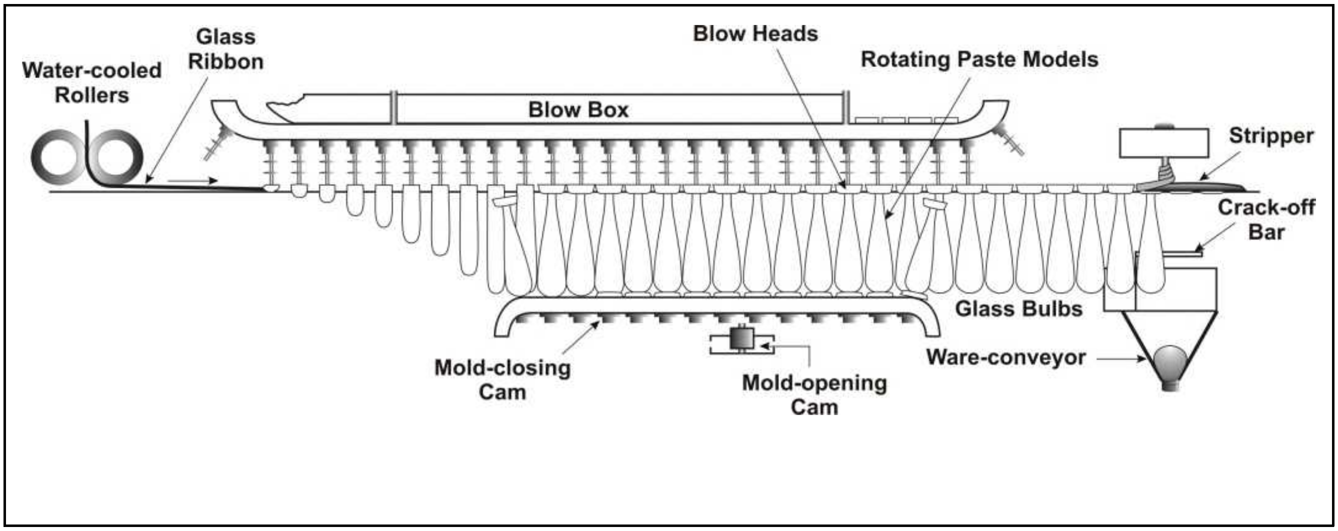


Figure 5-7. Lamp Envelope Forming [Corning 2000 The Glass Ribbon]

Summary of Key Energy and Environmental Facts - Incandescent Lamp Forming			
Energy	***Air Emissions***	***Effluents***	***Byproducts/Wastes***
ND	*Particulates (controlled)*	*Waste water (may contain suspended solids or oil)*	*Cullet*

Lighting and Electronic Products

Lighting and electronic products such as lamp envelopes, television tube enclosure assemblies, resistors, capacitors, and glass tubing are manufactured using blowing, pressing, press and blow, casting and drawing techniques.

The ribbon machine, first conceived by William Woods in 1922, is used to form **incandescent lamp glass** envelopes. Prior to that time the "E" and "F" machines were the industry standard, able to produce from 10 to 42 bulbs respectively per minute. The "E" machine semi-automated the motions of human glassblowers, requiring an operator to open and close the mold and remove the blowpipe. The fully automated "F" machine ultimately eliminated the need for human assistants. William Woods' idea was to blow bulbs automatically by sagging a ribbon of glass through holes in a continuously moving steel belt, and then shaping the bulbs with a puff of air from below. By 1926 his revolutionary idea was put into commercial production, and the first ribbon machine produced 250 bulbs per minute. Modern ribbon machines can now produce over 2,000 bulbs per minute. These machines are also used to produce other types of bulbs (e.g., Christmas lights).

In the ribbon process (see Figure 5-7) a continuous stream of molten glass from the forehearth is passed between two water-cooled rollers. This serves to flatten the stream into a ribbon with heavier sections located at regular intervals. The ribbon is transported onto a moving chain of steel plates which has an orifice located at the same intervals as the heavier sections of ribbon. The heavier portions of the glass ribbon sag through the orifices and form small bubbles. As this happens, a second chain

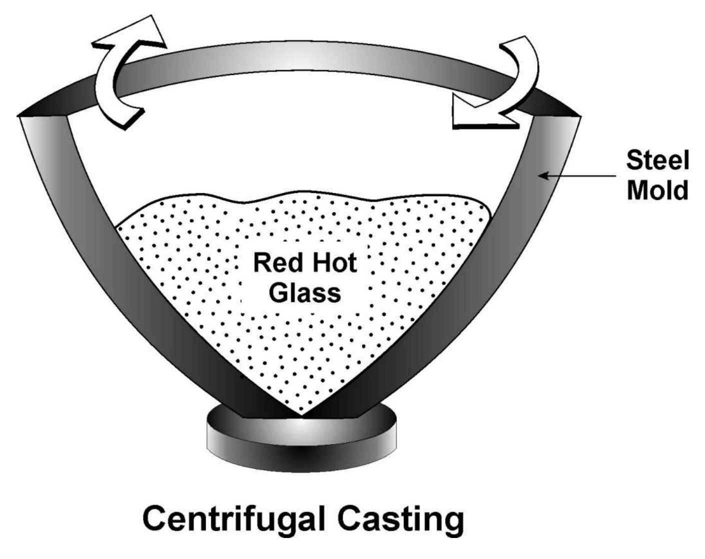


Figure 5-8. Centrifugal Casting of TV Tube Conical Sections [Corning 2000]

Summary of Key Energy and Environmental Facts - Television Tube Forming			
Energy	***Air Emissions***	***Effluents***	***Byproducts/Wastes***
ND	*Volatile organic compounds (VOC's)*	*Waste water (may contain suspended solids, oil, lead, fluoride)*	*Cullet*

with blowing tips at the same intervals puffs air into the bubbles to expand them. After the bubbles are expanded they are enclosed in a mold for the final blowing step. After final blowing, the molds are opened and the lamp envelopes are cracked away from the ribbon.

A two-part process is used for the forming of the conical sections of **television tubes**. A centrifugal casting process is first used where molten glass is cut into gobs and dropped into a cast mold while it rotates (see Figure 5-8). The mold is then spun so that the glass spreads uniformly on the inside surface of the mold. **Television face plates** (viewing screens), **glass building blocks**, and similar products are formed by casting gobs of molten glass directly into finish molds. The molded piece is then pressed to obtain the final product [Corning 2000, EPRI 1988, EI 1988, Babcock 1977].

Astronomical mirror blanks are cast directly into a mold, and the final shape is formed by gravity. The glass is then subjected to annealing and other treatments to create a glass-crystalline material with a coefficient of expansion near zero [Corning 2000].

Tubing and Rods

Glass tubing or rods can be formed using the Danner, Vello, or Updraw drawing processes (see Figure 5-9). During the **Danner process**, a regulated amount of glass is dropped onto the surface of a rotating, horizontal mandrel. Glass tubing is pulled away from the mandrel while air is continuously blown through the center. Air keeps the tubing from collapsing until it becomes rigid. The speed and quantity of air blownthrough the center controls the dimensions of the glass tubing.

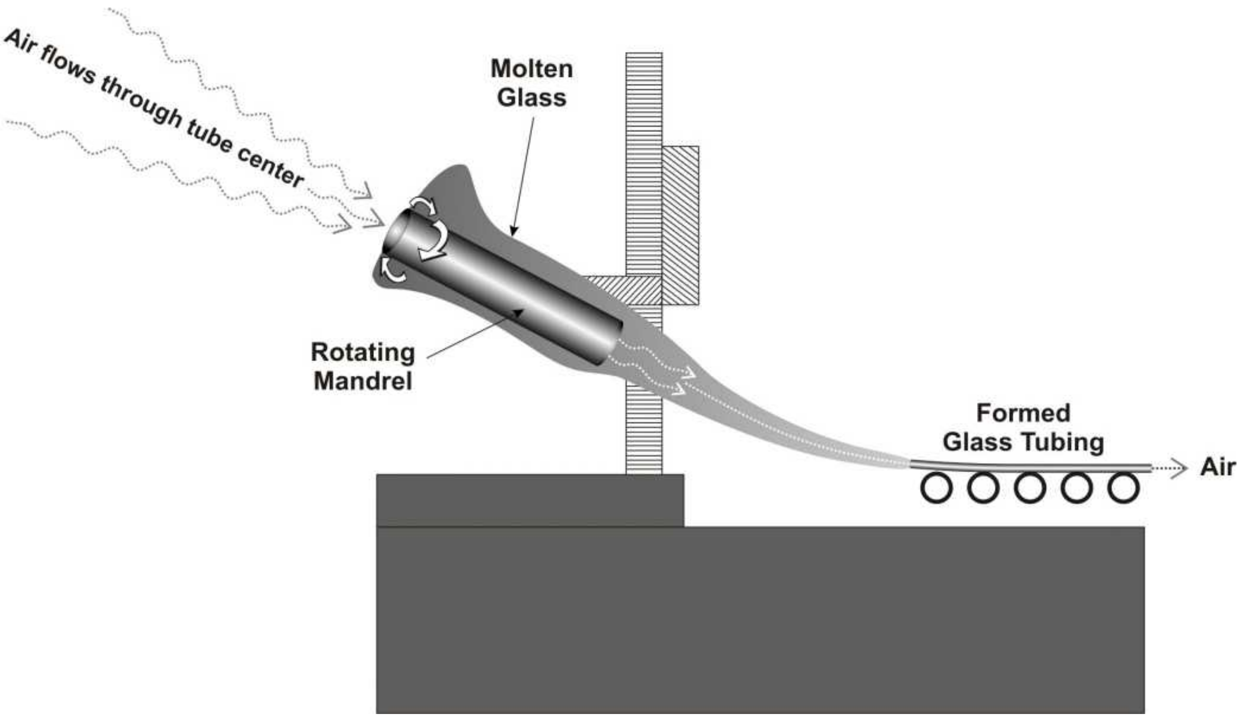


Figure 5-9. Drawing Processes for Tubing [Corning 2000 Machine Forming]

During the **Vello process**, molten glass is passed downward through an annular space between a vertical mandrel and refractory ring. The mandrel is set in a forehearth at the bottom of a melting tank. Drawing is accomplished in a manner similar to that of the Danner process.

The **Updraw process** is used to make large diameter tubing and pipe. In this process, air is blown up through a cone to control the dimensions of the glass tube. In any of the processes described, rods can be formed instead of tubing by turning off or reducing the air pressure, which allows the glass to collapse and form rods [Corning 2000, EPRI 1988, EI 1988].

Hand-Made Glass

Hand-made glass is a small, very diverse part of the industry, and includes items such as unique tableware (lead and crystal goblets), scientific glassware, and other decorative glass. Hand-made glass is still based on the art of glass blowing (discovered by the Romans sometime around 50 B.C.), where molten glass is inflated like a bubble on the end of a hollow blowing pipe.

Modern hand-forming of glass begins with a step called "gathering" which involves taking molten glass from a melting tank using a pipe called a blow iron. As the pipe touches the hot surface it is rotated and the hot glass adheres to the pipe. Inserting the pipe once into the tank provides enough "gather" for making a vase or tumbler. Large objects might require repeated "gatherings" with the pipe removed and the glass slightly cooled each time.

After gathering is completed, the blow iron is rotated slowly to keep the glass centered. Air is then blown by mouth through the pipe to form an initial bubble, which is further shaped by "marvering," or rolling the glass on a flat surface.

The cooling effects of the metal or stone table allow the glass to become more rigid and easily controlled as the bubble is blown and enlarged. This initial parison is lengthened by swinging the blow pipe or pulling the glass with a tool. Later the parison may be flattened with a paddle, shaped in a mold, or shaped in some other way. Intermittent heating may be needed to finish the forming operation [Corning 2000, EPRI 1988, EI 1988].

Glass Fibers are Made Into Glass Wool Insulation, Textiles, or Fiber Optic Cables

Fiber glass is usually produced as wool-type fibers (glass wool) or as textile fibers (long, continuous strands or filaments). In the last fifteen years glass has also been increasingly used to make fiber optic cables for transmission of information. Different processes are used for the production wool fibers, textile fibers, and optical fibers.

Glass fibers of any type can be formed directly using molten glass from the furnace forehearth, or indirectly by first forming glass marbles or small rods which can later be remelted. Direct forming requires less fuel, but is less adaptable than the marble process. With an operation that uses marbles, glass composition can be more readily changed to produce different types of fiber glass. A disadvantage with marbles is that it is more difficult to detect defects (stones and seeds), and marbles may be broken in shipment or incorrectly sized, leading to less than 100 percent use.

The two most common ways of forming wool fibers are rotary spin fiberizing and flame attenuation. Rotary spin processes account for the larger share of production. Either process can be adapted to use molten glass directly from the forehearth or indirectly with marbles.

In the **rotary spin process**, a stream of molten glass from the forehearth is converted to fibers using a high-temperature alloy spinner rotating at 2000 to 3000 rpm (see Figure 5-10). The molten glass is forced through thousands of fine holes in the spinning drum by centrifugal action. The mechanical rotation of the drum forces the glass stream to break up and exude from the band of holes which are located around the perimeter of the spinner. A downward blast of hot air or gas is used to sweep the fibers down the outside of the drum onto a conveyor belt. Up to 12 spinners can be fed from a single forehearth.

The **flame attenuation process** uses flames or hot air to attentuate fiber. Molten glass flows by gravity from a furnace through numerous small orifices to create threads that are attenuated (stretched nearly to the breaking point) using high velocity, hot air, and/or a flame (see Figure 5-11). This process results in more agglomeration of the glass, producing as much as 30 weight percent of unusable small beads or globules.

Glass wool can also be made using **steam or air blowing**. In this process, streams of molten glass flow through platinum alloy bushings, and are subjected to jets of steam or air which attenuate the glass into fibers. The length and coarseness of fibers can be adjusted by regulating the jet pressure or glass temperature (see Figure 5-12).

Regardless of the method of forming, wool fibers are sprayed with a chemical binder as they are being formed. Binder compositions vary, but are typically composed of a solution of phenol-formaldehyde resin, water, urea, lignin, silane, and ammonia. In some cases colorants may be added to the binder solution. After wool fibers are created they are again sprayed with a binding solution before being collected on a conveyor belt to form a mat.

Wool fibers are produced in a wide range of thicknesses, from 0.3 to 10 microns[1] in diameter, with most fibers produced being about 3 to 10 microns in diameter. Fibers are generally a little more than an inch in length.

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[1] *One micron is 1/1,000,000 of a meter, or 1/25,400 of an inch.*

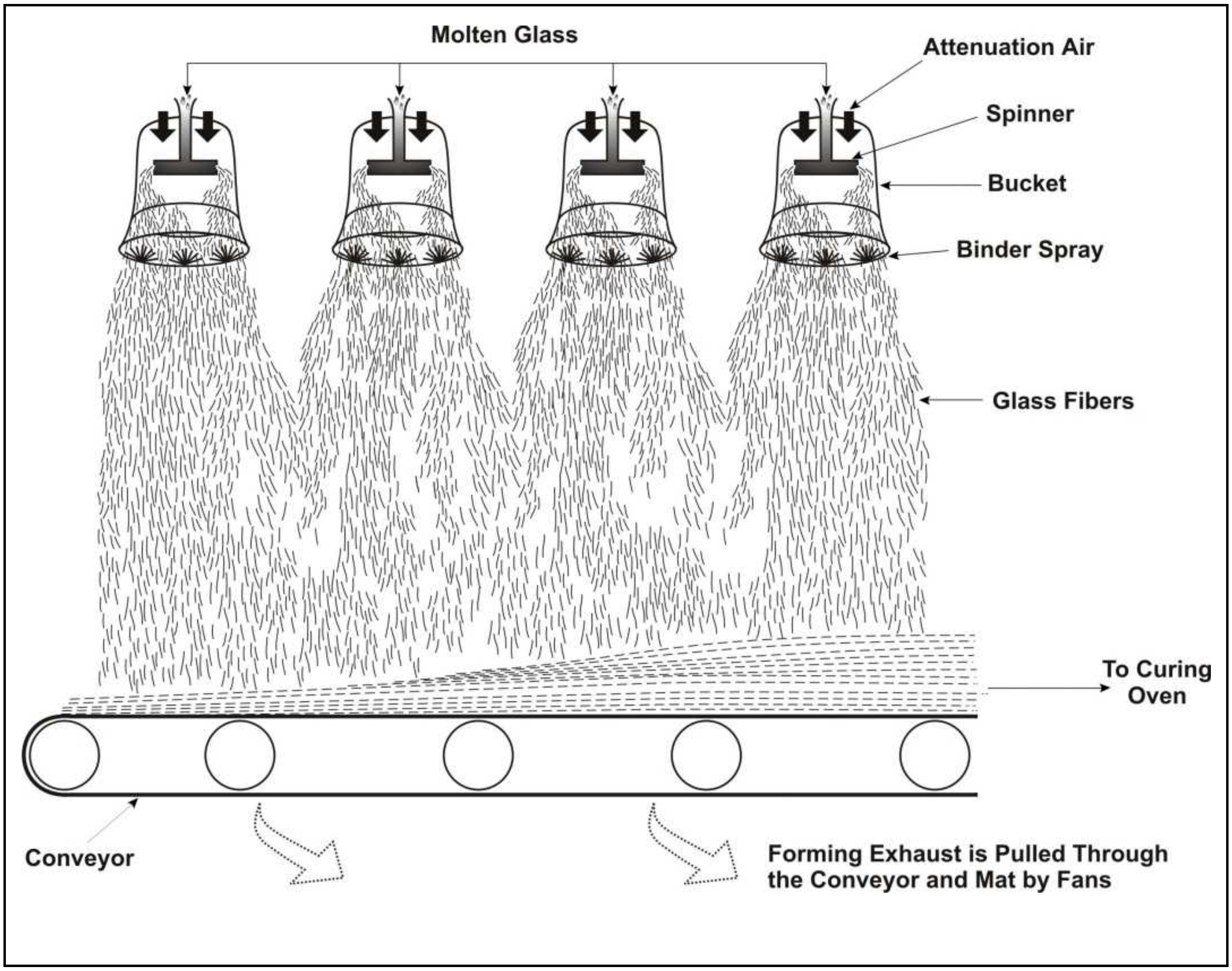

Figure 5-10. Rotary Spin Glass Fiber Manufacture [EPA 1985]

Summary of Key Energy and Environmental Facts - Container Glass Forming			
Energy	*Air Emissions*	*Effluents*	*Byproducts/Wastes*
Energy use per ton of glass: 0.4 10^6 Btu/ton	*Particulates, organic condensible particulates, volatile organics, resin and binder droplets, formaldehyde (all controlled)*	*Waste oil and solvents, waste water (may contain dissolved solids, suspended solids, heavy metals)*	*Solid residues from pollution control equipment*

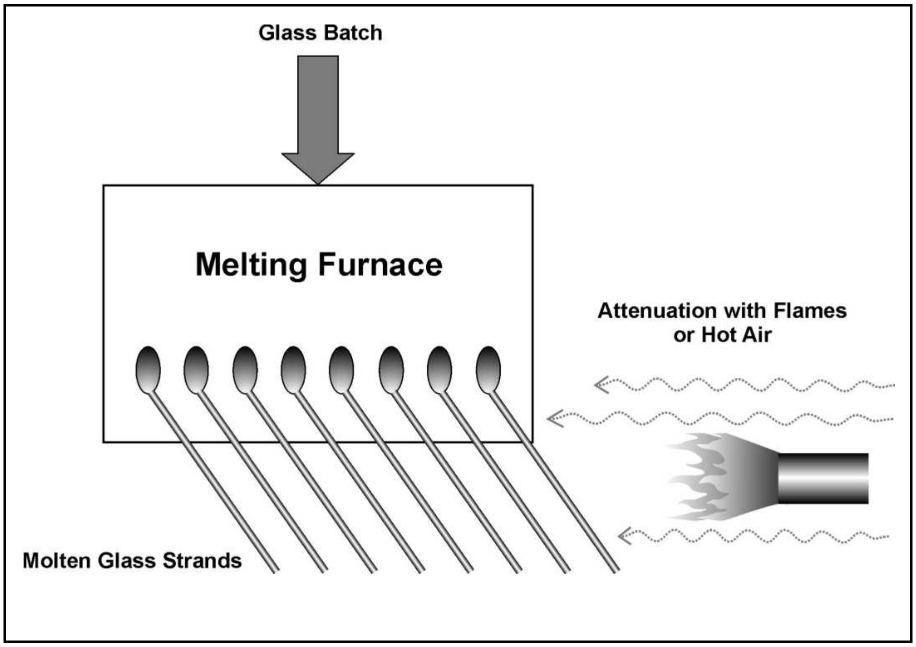

Figure 5-11. Flame Attenuation Glass Fiber Manufacture [EPA 1985]

Textile fibers (continuous filaments) are formed by forcing low alkali-content molten glass (E-glass) through a multitude of small orificies in heated platinum alloy bushings containing a number of very small holes. The continuous fibers coming through the holes are drawn over a roller which applies a coating of water-soluble sizing and/or coupling agents. The coated fibers are then wound onto a spindle before being conveyed to finishing operations [Fiber Forming Descriptions: NAIMA 1998, EPA 1994, EI 1988, EPRI 1988, EPA 1985].

Optical fibers used in the production of fiber optic cable are manufactured and formed according to very strict specifications for purity. Optical fibers must be free of bubbles, ripples or other defects that could interfere with the passage or bending of light. All six basic types of glass can be manufactured into optical fibers, and there are also unique compositions designed especially for fiber optic applications. The glass used for optical fibers is commonly ultra-pure, ultra-transparent silicon dioxide or fused quartz. Impurities are added to the glass to achieve a specified index of refraction. Elements such as Germanium or phosphorus, for example, increase the index, while boron or fluorine decrease the index.

In 1970, the first optical fibers with losses under 20 dB/km (decibels/kilometer) were produced at Corning Glass Works, making fiber optics a practical option for the transmission of information through light sources. Today losses in the best fibers are less than 0.2 dB/km [Corning 2000, Sterling 1987].

Optical glass fibers consist of two concentric layers called the core and cladding. Light is transmitted through the inner core. The outer cladding creates a difference in refractive index that permits total internal reflection of light through the core material. This difference must be controlled during manufacture to ensure that it does not exceed 1%. For example, a typical core index might be 1.47, while the cladding index is 1.46.

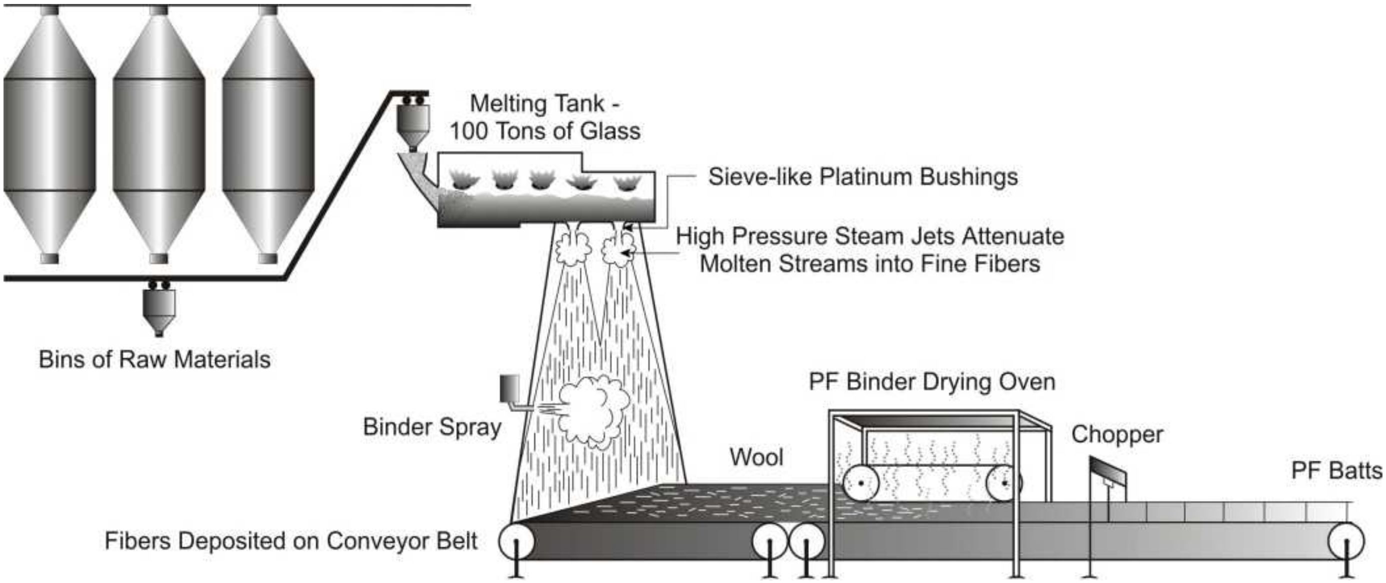

Figure 5-12. Steam or Air Injection Process for Glass Wool Manufacture [EI 1988]

Most optical fibers also have a polymer coating around the cladding to protect both cladding and core materials from shocks that could affect optical properties (see Figure 5-13). The polymer serves as a buffer or shock absorber and has no optical properties. Fibers are produced in very small diameters, which means that the forming process must be exceedingly exact to maintain proper tolerances (see Table 5-1). To understand how small these diameters are, by comparison a human hair is about 100µm [Sterling 1987].

5.2 Summary of Inputs and Outputs for Glass Forming

Inputs	Outputs
Molten Glass	Formed Glass
Glass Marbles	Cullet
Electricity	Contaminated Glass
Tin (float glass)	Spent Cooling Water
Lubricants	Particulates
Air	Organic Condensable
Cooling Water	Particulates
Nitrogen	Volatile Organics (VOCs)

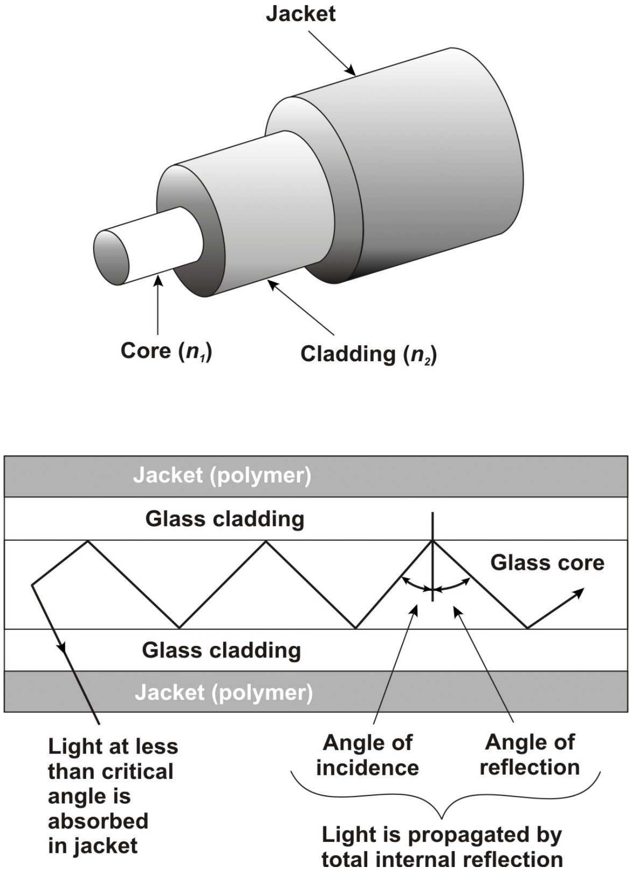

Figure 5-13. Optical Fibers [Sterling 1987]

5.3 Energy Requirements

Forming operations are very diverse among the glass segments, and can use anywhere from 12 percent (e.g., flat glass) to 34 percent (fiber forming) of total energy (considering electricity losses) [EI 1988]. The energy consumed in forming operations across the industry is shown in Table 5-2.

In most cases forming processes do not require much heat. Most of the energy used is electricity for machinery operation, fans, blowers, compressors, conveyors, and other equipment. In flat glass production, electricity is used for heating tin [CMP 1990].

In container glass production, energy consumption depends on the weight of the container being produced and the efficiency of the forming operation. Lighter containers generally require less energy to produce per container.

Production efficiency (referred to as the pack-to-melt ratio), which is actually the ratio of saleable product to gross production volume, also has an impact on energy use. The greater the pack-to-melt ratio, the lower the energy required to produce that product.

Table 5-1. Diameters of Commonly Used Optical Fibers (µm)

Core	Cladding
8	125
50	125
62.5	125
100	140

Source: Sterling 1987

Table 5-2. Energy Use in Glass Forming

Energy Source	Net Electricity [a] (kWh/ton)	Net Electricity (10^6 Btu/ton)	Annual Production (tons)	Net Industry Use [b] (10^{12} Btu)	Electricity Losses [c] (10^{12} Btu)	Total Energy (10^{12} Btu)
Flat Glass	440	1.5	5,000,521	7.5	15.6	23.1
Container Glass	105	0.4	9,586,500	4.0	7.0	7.4
Pressed and Blown Glass	1553	5.3	2,484,182[d]	13.2	27.4	40.6
Fibrous Glass	2110	7.2	3,040,000[e]	21.9	45.5	67.4
Total Industry	-	-	20,111,203	46.6	95.5	138.5

[a] Based on a conversion factor of 3412 Btu/kWh of electricity.
[b] Excludes electricity losses.
[c] Losses associated with generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh of electricity.
[d] Estimated based on 92 Census Data and 2% growth between 1992 and 1997.
[e] Includes glass wool, textile fibers and optical fibers.

Sources: GIC 2001 (container), DOC 1997, Cer Ind 1999, Cer Ind 1997, Brown 1996, 1992 DOC, EI 1988.

Production efficiency for container forming ranges from 86 to 96 percent. The bulk of energy used in container forming is electricity, and is used mostly for generating compressed air. Forming accounts for an average 27 percent of energy consumption in the pressed and blown glass segment [EI 1988].

In fiber glass forming, additional fuel is required for the process where marbles or small rods must be reheated. Otherwise, fuel requirements vary widely for different fibrous glass forming operations. Overall, flame attenuation requires the least energy, while mechanical drawing requires the most [EI 1988].

5.4 Emissions

Forming Can Generate Emissions of Particulates, Volatile Organics, and Some Hazardous Air Pollutants

The primary emissions from the forming of **container** and **pressed and blown glass** result from the gob coming into contact with mold lubricants, which may result in flash vaporization of hydrocarbon greases. In many cases these lubricants have been replaced by silicone emulsions and water soluble oils (oil-graphite, water-graphite), which eliminate emissions of volatile organics (VOCs) (emissions are particulates). Emissions from forming of flat glass are virtually non-existent. Table 5-3 provides emission factors for glass forming processes by segment [Gridley 2001, EPA 1995, EPA 1986].

The primary emissions from forming of **wool fibers** are solid particles of glass and binder resin, droplets of binder, and components of the binder that have volatilized. Glass particles may be entrained in the exhaust gas stream from forming, curing, or cooling, but 99 percent come from forming. Droplets of organic binder may also result from condensation of gaseous pollutants as the gas stream is cooled. Uncontrolled emissions from fibrous glass manufacturing are shown in Table 5-4.

Particulate matter is the major pollutant that has been identified and measured at insulation manufacturing facilities, primarily from rotary spin operations. Building insulation (R-11 and R-19), ductboard, and heavy-density insulation account for about 90 percent of the output from rotary spin processes. Ductboard manufacture exhibits the highest emission rate of particulates. Particulate standards for rotary spin manufacturing are 11.0 pounds per ton of glass pulled [40 CFR 60 PPP, EPA 1997, EPA 1985].

A variety of methods are used to control emissions in glass wool manufacture, and emissions from forming, curing and cooling may be controlled separately or in combination. Control technologies include wet electrostatic precipitators, wet scrubbers, thermal incinerators, high velocity air filters, and process modifications. Process modifications are usually proprietary and information on specifics is not available, although they are used to control both particulates and volatile organics (phenols, formaldehyde). The most effective add-on control technology is the wet electrostatic precipitator.

Controlled emissions of formaldehyde from rotary spin and flame attenuation fiber manufacture are shown in Tables 5-5 and 5-6. Emissions of formaldehyde from all fibrous glass manufacture are regulated under National Emissions Standards for Hazardous Air Pollutants. Current limits, which were set in 1999, are shown in Table 5-7.

Emissions from **textile fiber** manufacturing include particles of glass fiber, resin, and hydrocarbons (phenols and aldehydes). Textile fiber manufacture usually creates less emissions than the manufacture of glass wool, primarily due to less turbulence in the forming step, and the user of rollers for adding coatings [EPA 1997, EPA 1995, EPA 1985].

5.5 Effluents

Oil used in forming machines may contaminate the water used to keep the machines cool, creating a waste oil stream that must be disposed of [EPA 1995]. The amount of contaminants in waste water from glass operations is subject to limitations under the Clean Water Act. Effluent guidelines specifically geared toward glass manufacturing are shown in Table 5-8 [40 CFR 426]. In addition to waste solvents and lubricants, these regulations limit the amount of suspended solid, heavy metals, and biological entities that may be present in effluents.

Table 5-3. Emission Factors for Forming of Flat, Container, and Pressed/Blown Glass (lb/ton glass materials processed)

Segment	VOCs
Container Glass	8.7
Flat Glass	Neg
Pressed and Blown Glass	9.0

Neg = negligible

Source: EPA 1986/AP-42
Note: Emissions of particulates, SOx, NOx, and CO from forming operations are negligible. All emissions from lead glass production are shown in Table 4-6 in Chapter 4, Melting and Refining. Emission factor for container glass is for glass decorating process.

Table 5-4. Uncontrolled Emission Factors for Fibrous Glass Forming (lb/ton glass materials)

Source	Filterable PM [a]	Organic Condensible PM [b]	VOCs	Phenolics	Phenol	Formal-dehyde
Insulation Glass Wool						
Flame Attenuation	2	ND	0.3	ND	ND	ND
Rotary Spin Glass Wool Manufacturing [c]						
R-19	36.21	8.52	ND	6.92	1.92	1.50
R-11	39.21	6.37	ND	12.41	1.84	2.46
Ductboard	55.42	17.08	ND	21.31	7.68	3.61
Heavy Density	9.81	2.33	ND	1.74	1.04	0.85
Textile Fiber Glass						
Forming	1	ND	neg	ND	ND	ND

[a] Filterable particulate matter (PM) is collected on or before the filter of an EPA Method 5 or equivalent sampling train.
[b] Condensible PM is that PM collected in the impinger portion of a PM sampling train.
[c] Units are lbs/ton of finished product.
ND = no data.
NA = not applicable.
Uncontrolled indicates prior to filtering or other control technology.
Source: EPA 1997, EPA 1985/AP-42.

Table 5-5 Controlled Formaldehyde Emissions from Forming Operations in Rotary Spin Fiber Glass Manufacturing

Operation	Control Technology	lb/ton
Forming	Process Modifications[a]	0.3 - 1.2

a process modifications include resin and binder chemistry, fiberization technology, binder application, and forming conditions.

b temperatures ranging from 1300-1500°F; residence times from 0.5-2.5 seconds.

Source: EPA 1997.

Table 5-6. Average Formaldehyde Emissions from Flame Attenuation (FA) Fiber Glass Manufacturing

Forming Operation	Control Technology	lb/ton
Heavy Density Products	**Process Modifications[a]**	4.6 - 7.8
Pipe Insulation	**Process Modifications[a]**	3.4 - 6.8

a Includes forming and curing. Curing is not controlled.

Source: EPA 1997

Table 5-7. National Emission Standards for Formaldehyde Emissions From Fiber Glass Manufacturing

Process	lb formaldehyde/ ton glass
Rotary Spin	
Existing Lines	1.20[a]
New Lines	0.80
Flame Attenuation	
Pipe Insulation	6.8[b]
Heavy Density	7.8[c]

a Based on combined emissions from forming, curing and cooling. Process modifications are the MACT technology for forming; incinerators are the MACT technology for curing.

b For new and existing manufacturing lines. Process modifications are used as the MACT control technology for forming and curing.

c New lines only.

Sources: 40 CFR 63 NNN, EPA 1997.

5.6 Byproducts and Wastes

In some cases dibutyltin trichloride, an organometallic material, is applied on containers immediately after forming to provide some surface lubricity for ease of handling and scratch resistance. A small amount of solid residue may be generated during this process [Gridley 2001].

Table 5-8. Effluent Limitations for Forming Operations- Average Daily Values for 30 Consecutive Days (lbs/1000 lbs of glass product)

Segment	Phenol	TSS	pH	Oil	Lead	Phos-phorus	Fluoride	COD	BOD$_5$
Plate Glass (BPT)	-	2.76	6-9	-	-	-	-	-	-
Float Glass									
• Existing Sources	-	0.0040	6-9	0.0028	-	0.001	-	-	-
• New Sources	-	0.0014	6-9	0.0028	-	0.001	-	-	-
Container Glass									
• Existing Sources	-	0.07	6-9	0.03	-	-	-	-	-
• New Sources	-	0.0008	6-9	0.0008	-	-	-	-	-
Glass Tubing									
• Existing Sources	-	0.23	6-9	-	-	-	-	-	-
• New Sources	-	0.0002	6-9	-	-	-	-	-	-
TV Picture Tubes Envelope									
• Existing Sources	-	0.15	6-9	0.13	0.0045	-	0.07	-	-
• New Sources	-	0.13	6-9	0.13	0.00045	-	0.06	-	-
Incandescent Lamps									
• Existing Sources	-	0.23	6-9	0.115	-	-	-	-	-
• New Sources	-	0.045	6-9	0.045	-	-	-	-	-
Pressed/Blown Glass[a]	-	10.0	6-9	-	0.1	-	13.0	-	-
Insulation Fiberglass (BPT)	0.0003	0.015	6-9	-	-	-	-	0.165	0.012

Source: 40 CFR 426

Notes: BPT = best practicable control technology currently available.

TSS = Total Suspended Solids

COD = Chemical oxygen demand, a relative measure of environmental damage from wastewater based on oxygen demand. It is equal to the number of milligrams of oxygen which a liter of sample will absorb from a hot, acidic solution of potassium dichromate.

BOD5 = Biochemical oxygen demand. The 5 subscript indicates an incubation period of 5 days.

a Pressed/Blown Glass includes plants producing leaded glass and non-leaded glass, employing hydrofluoric acid finishing, and discharging greater than 50 gallons/day wastewater. Standards are for new sources, in mg/liter.

b Chemical oxygen demand (COD) is a relative measure of environmental damage from wastewater based on oxygen demand. It is equal to the number of milligrams of oxygen which a liter of sample will absorb from a hot, acidic solution of potassium dichromate.

c Biological oxygen demand (BOD) in water, based on an incubation period of 5 days.

6

Post-Forming and Finishing Operations

6.1 Process Overview

Post-Forming Operations Include Finishing, Curing and Annealing

After being formed into its final shape, the glass product may be subjected to curing/drying, tempering, annealing, laminating, coating, polishing, decorating, cutting or drilling.

- **Curing or drying** in ovens may be necessary to heat-set resins or other compounds that have been added to the glass.
- **Annealing** is the process of slowly cooling the glass so that it will not be highly strained by the time it reaches room temperature. If a hot glass object cools too quickly, it may break easily at room temperature. For small, thin-walled shapes this effect is not significant, but for larger, thicker shapes the strain can be very detrimental. Strain is dependent on how quickly glass passes through a critical temperature range, usually around 840°F. Cooling the glass slowly through that range to maintain consistent temperatures through the product reduces the amount of strain. Annealing is done for all types of glass except fibers and very thin-walled products such as light bulbs.
- **Tempering** is used to impart strength to glass sheets and oven ware. It is accomplished by first heating annealed glass to just below its softening temperature, and then rapidly quenching it with ambient air. The rapid cooling allows the glass surface to shrink in relation to internal regions which continue to flow and remain stress-free. Continued cooling in this manner creates a uniform temperature profile throughout the glass, and distributes stresses. The result is increased resistance to bending failure.
- **Laminating** is the process of placing an organic plastic film between two or more layers of glass. If the glass is broken, the pieces are held in place by the plastic.
- **Coatings** are applied to impart specific properties, such as heat reflection or scratch resistance.
- Other finishing processes, such as **polishing** or **decorating** may be done to enhance appearance, or to achieve optical properties.

- **Mechanical cutting** involves scoring the glass with a glass-cutting wheel, then pressing against the score to break the glass.
- **Thermal cutting** uses a sharp flame to heat a narrow section of the glass product. A jet of water then causes the glass to break at the heated section. Sometimes a ring of sharp flame is used to heat the glass to the softening point, where it can then be pulled apart. A good example of thermal cutting is the smooth open edge of a glass tumbler.
- **Drilling holes** in the glass product is sometimes necessary. Drilling is accomplished using a tube of mild steel or other soft metal. The tube is rotated while a slurry of water and abrasive grains is fed under the tube. Tungsten-carbide or diamond core drill bits are also sometimes used to obtain faster drilling rates and better dimensional control. These are more expensive but have a longer drilling life.

Post-forming processes are different for flat, containers, pressed and blown, and fibrous glass [General Forming Processes: Corning 2000, EI 1988, Babcock 1977].

Flat Glass Is Usually Annealed, Tempered, and Laminated

After it is formed into sheets at high temperatures, flat glass is **annealed** to ensure that it is virtually strain-free and can be easily cut. This process is conducted in electric or natural-gas fired chambers called lehrs (see Figure 6-1). Annealing of flat glass is accomplished through stages in the lehr:

- First, the formed glass sheet is heated to just above the annealing temperature (about 1000°F - 1050°F for soda-lime glass) and maintained at that temperature until internal stresses are relieved.
- Second, the glass sheet is cooled slowly to room temperature to ensure that temperature gradients do not develop between the inside and outside surfaces of the glass.
- Third, a uniform temperature is maintained across the lehr to ensure that annealing is consistent throughout the glass melt.

Modern lehrs have evolved to provide energy-efficient, uniform annealing of the glass. Current lehrs are modular or zonal, with strategically placed heat sources. Many use hot air re-circulation within zones and recuperate waste heat.

In some cases, lehrs are operated without additional energy input as the temperature of the glass entering the lehr is higher than the required annealing temperature. However, in most cases the lehrs are fired with natural gas or electricity. Lehrs powered by electricity are cleaner and have a lower initial capital cost, but require a large power source and are more costly to operate, particularly during peak demand for electricity. Electric lehrs are currently used for annealing storefront glass and safety glass, and for some car windshields. Natural-gas fired lehrs provide more exact firing but have a higher initial capital cost, and are the most popular. Most lehrs (over 90 percent) are fired with natural gas.

After annealing, some types of flat glass are subjected to **tempering,** particularly automotive and some architectural glass. Inside the tempering furnace several heat-transfer processes occur, the most important of which is radiation heat transfer between the glass and the hot surfaces, such as heating elements, rollers, walls, and floors. Another important process taking place is heat conduction between the glass and the conveyance or support system. Natural convection to the glass from the furnace atmosphere and radiation heat transfer within the glass also occur.

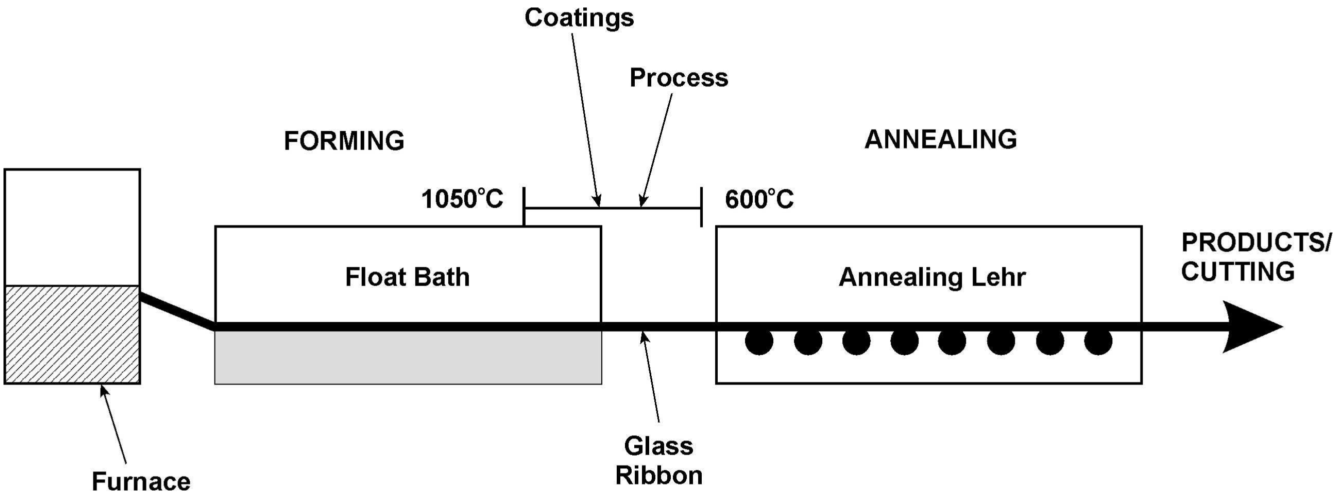

Figure 6-1. Flat Glass Post Forming/Annealing in the Lehr [EPRI 1988]

During tempering the glass sheet is supported by a separate conveyance system (tong-held, rollerhearth, or gas/air float) or an in-line system (see Figure 6-2). In-line systems include loading, heating and bending, quenching, cooling, and unloading sections. Systems can be continuous, batch, or batch-loaded. Flat glass that must be bent can only be tempered in a batch system.

Glass that is going to be used for automotive door, side, and rear windows and windshields may require **bending** prior to tempering. In this process the glass is heated in a bending furnace, bent to the required shape, and quickly quenched to cool.

Maintaining the correct temperature during tempering is critical and precisely controlled through heat input and conveyance speed. Only a narrow range of temperatures will produce a product that has been correctly tempered (referred to as the temperature window). Temperature non-uniformities and deformities in the glass may occur as the result of conveyance, heating and quenching mechanisms. For example, tongs may shield the edges of the glass, and glass on roller hearths may sag between rollers. Even with very uniform heat sources, there can still be non-uniformities in heating due to the "hot edge" effect. This effect results because only the edges and surfaces of the glass sheet receive radiant energy from the energy source, resulting in higher temperatures at the edge than in the middle. To help alleviate problems in maintaining temperature uniformities, heating elements are carefully placed, and lehrs are equipped with forced air circulation.

Laminating is performed on flat glass used for both automotive and architectural applications. Prior to the laminating process, annealed glass sheets are cut to size and washed. If the glass is bent (such as windshields) it is laminated without tempering. During laminating two pieces of bent glass are sandwiched with a plasticized poly vinyl butyral (PVB) resin. Air trapped between layers is removed as the glass passes through a pair of rubber rollers. After air is removed, the glass laminate is put in an autoclave operating at about 150 psi and 300°F. The interlayer becomes a viscous liquid at this temperature and pressure, and any remaining air dissolves into the laminate layer. After cooling the laminated product is ready for edge grinding or cleaning if needed.

Coatings are sometimes applied to flat glass to achieve specific properties. One example is

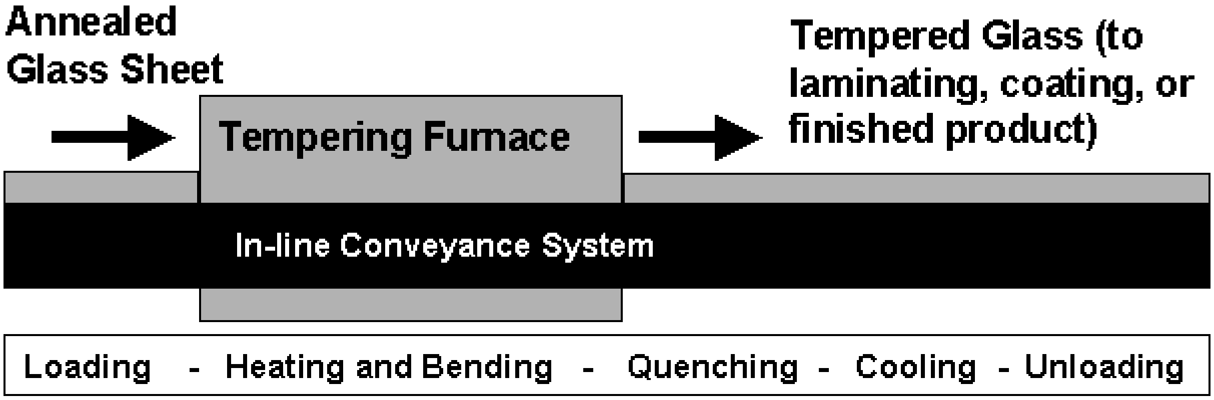

Figure 6-2. Tempering Process for Flat Glass [CMP 1990]

Summary of Key Energy and Environmental Facts - Tempering of Flat Glass			
Energy	***Air Emissions***	***Effluents***	***Byproducts/Wastes***
Energy use per net ton of glass: $4.2\ 10^6$ Btu/ton	*n/a*	*Wastewater*	*n/a*

low-emissivity (low-E) glass used for architectural applications. Low-E glass has been coated with a metallic coating that reflects radiant heat to reduce heat losses in winter [Flat Glass Post-Forming: Corning 2000, CMP 1991, EI 1988].

Container Glass is Annealed and Coated

All glass containers are **annealed** after forming in a process similar to that used for flat glass. As with flat glass annealing, there are difficulties in maintaining uniform temperatures. For containers, problems with non-uniform temperatures occur due to large variations in glass thickness and weight, the complexity of shapes, and temperature gradients caused during forming.

All types of glass containers require that the outside surfaces be under low levels of compressive stresses to increase strength and reduce potential for breakage. To remove temperature gradients and existing stresses in the container, it is first “soaked” at constant temperature within its annealing temperature window. After soaking the containers are slowly cooled at a uniform rate through the temperature range where thermal gradients can cause viscous flow. Once past this range, the rate of cooling is increased within reasonable limits to prevent damage.

Container thicknesses and shapes vary considerably, as do the specific operating parameters of annealing processes. These are usually determined empirically from a working knowledge of heat transfer conditions and good engineering practices used successfully for individual types of containers. Stress levels and stress patterns in the finished products are checked periodically to aid in monitoring the process.

Most glass containers are **coated** to minimize damage from abrasion and lubricate the surface.

Scratch-resistant coatings consist of a thin, nearly colorless coating of tin or titanium oxide which bonds to the glass surface. The tin or titanium oxide layer is then coated with a lubricant such as polyethylene. The coatings are not affected by external processes (e.g., pasteurization) and impart scratch resistance and lubricity to both wet and dry container surfaces.

The first coating is applied to the container just before annealing using a vapor of dibutyltin trichloride, an organometallic material. After annealing the lubricant is applied using an aqueous spray or under a vapor hood while the containers are still hot (about 200°F). The two-step process is very inefficient, with a great deal of material consumed in over-spraying of the containers. Tin coatings are also very expensive. New coatings are now emerging that are much more efficient, environmentally sound and less expensive.

Dome-style nozzles are the most commonly used type of airless flat spray nozzle. They are ideal for applying thin, easy-to-atomize materials. Atomization quality and pattern uniformity can be affected by variations in the geometry of the inner dome cavity and surface finish. Cross-cut nozzles are available in a wide variety of designs. These have several advantages over dome-style nozzles, including longer life, wider fan patterns, lower flow rates, improved atomization at lower pressures, and greater resistance to plugging [Nordson 2000, CMP 1991, EI 1988].

Most Pressed and Blown Glass Is Annealed

Most pressed and blown glass is annealed in a fashion similar to container glass, although specific operating conditions vary widely. Tempering of pressed and blown glass is usually done only on soda-lime oven ware, and for some specialty glasses (e.g., optical lenses).

Annealing of optical glass, thermometers, and other specialty glass products is done by very precise processes. After annealing, further heat treating may be done to achieve the desired performance characteristics. In the case of optical glass, for example, final annealing is done to ensure the uniformity of the refractive index [EI 1988, Babcock 1977].

Fibrous Glass Goes Through Curing and Drying Processes

At the end of the forming process, **glass wool fibers** are sprayed with an aqueous phenolic binder solution, then collected on a conveyor belt in the form of a mat. The mat is carried through a large oven or series of ovens where the thermosetting binder is cured. Curing temperatures range from 350°F to 900°F (average about 600°F) for wool insulation, depending upon the thickness of the mat. Phenolic gases are produced during curing and are incinerated. After curing the mat passes through a cooling section where ambient air flows down through the mat (see Figure 6-3). Uneven edges are trimmed from the mat while it sits on the conveyor. In some cases a backing may be applied to the mat using an adhesive. Once the mat is trimmed and finished, it is cut into batts and packaged.

Textile fibers, once formed, are drawn over a roller which applies a coating of water-soluble sizing and/or coating agent. The coated fibers are then wound onto spindles, which are conveyed to a drying oven. In the drying oven moisture is removed from the sizing and coating agents. After drying, the spindles are conveyed to a curing oven to cure the coatings. In the final finishing step the fibers may be twisted, chopped, or woven into the desired product, and then packaged.

Packaging and Product Handling Are Unique to the Glass Product

After post-forming processes are completed, the product is visually, optically or mechanically inspected for variations in dimension and

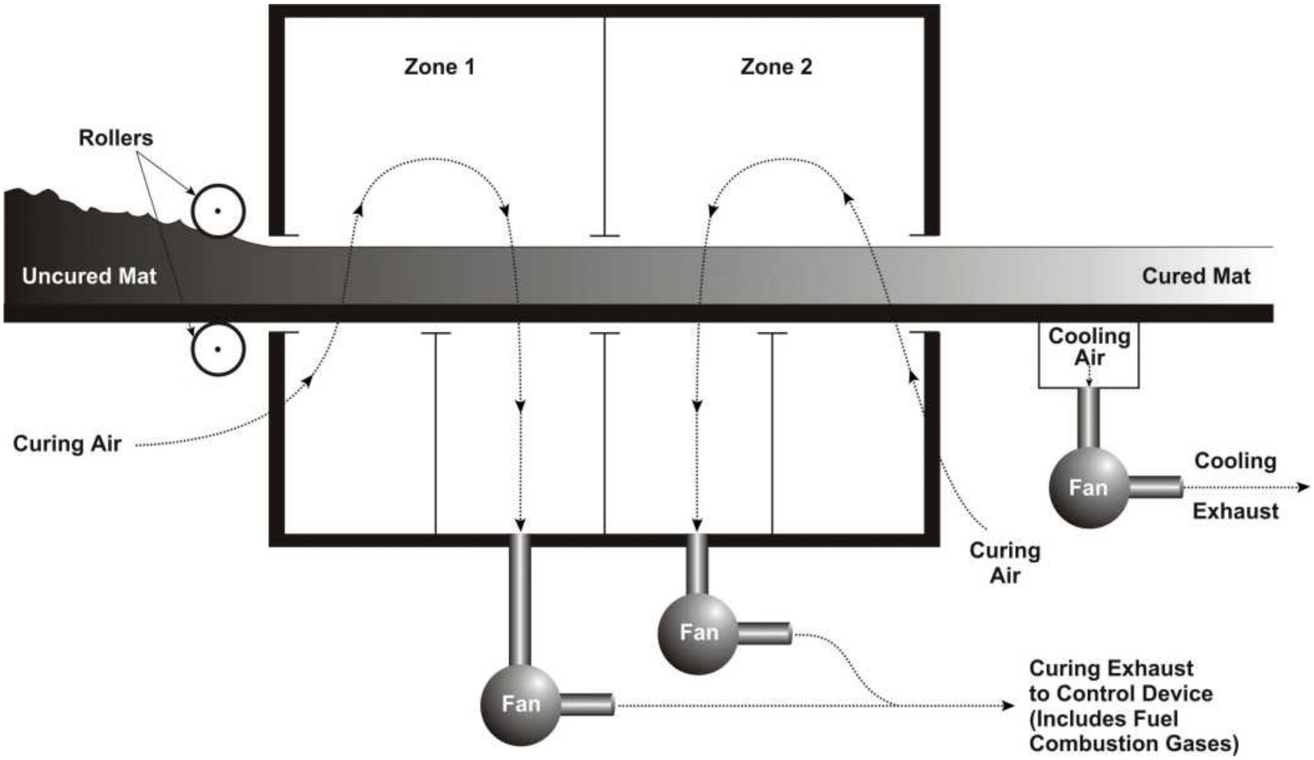

Figure 6-3. Fiber Glass Curing Oven [EPA 1985]

Summary of Key Energy and Environmental Facts - Curing and Drying Fibrous Glass			
Energy	***Air Emissions***	***Effluents***	***Byproducts/Wastes***
Energy use per net ton of glass: 3.3 - 4.4 10^6 Btu/ton	*Volatile organics (phenols and aldehydes)*	*n/a*	*n/a*

appearance (cracks, cords, other defects). Cylindrical containers may be strength-tested by pushing them through opposing rubber belts or rollers or by applying internal air pressure. Beverage containers for carbonated beverages are subjected to destructive burst tests.

After inspection, approved products are conveyed to a packaging area and packaged for shipment. Products that are damaged or defective (but not contaminated) are transferred back to the batch plant to be used as cullet. Glass that has been contaminated with refractory materials is scrapped [EI 1988].

6.2 Summary of Inputs and Outputs for Post Forming

Inputs	**Outputs**
Formed Glass	Finished Products
Natural Gas	Cullet
Electricity	Particulates
Air	Volatile Organics
Coatings and Resins	Waste Water

6.3 Energy Requirements

The amount of energy consumed in post-forming operations generally ranges from 13-17 percent [EI 1988]. Post-forming of container glass requires the least energy consumption, while post-forming of flat glass is at the higher end of energy consumption. Table 6-1 provides estimated energy use in post-forming operations among the different segments.

Annealing of flat glass typically consumes between 500 and 1000 Btu/ft^2 of flat glass, with an average specific energy consumption of 0.42 million Btu per ton of glass. Autoclaving of flat glass during the laminating process requires about 0.68 million Btu per ton of glass, and is mostly powered with electricity.

About 10 percent of plant energy consumption goes to curing and drying of textile fibers, and about 12 percent in glass wool production. Fiber glass wool curing consumes about 470 to 588 Btu/lb of glass; incineration of phenolic fumes consumes about 588 Btu/lb [EI 1988].

6.4 Emissions

Post-Forming Produces Hazardous Air Pollutants and Particulates

Air emissions from finishing of **flat glass** products is virtually non-existent. Some gases are emitted during finishing of **container** and **pressed and blown glass,** particularly during surface treatment and decorating processes. Emission factors for these are shown in Table 6-2. These gaseous emissions are controlled using incineration, absorption or condensation processes.

In **glass wool** manufacture, air emissions result from combustion of fuels volatilization of liquid binder in the curing ovens. Some of the vaporized binder will condense as the gas stream cools in the emission control device, or in ductwork. In **textile fiber** manufacturing, combustion products from dryers and ovens may be emitted, along with some hydrocarbons (phenols and aldehydes). Emission factors for glass wool and textile fiber manufacturing are shown in Table 6-3. Particulate emissions from fiber manufacture are covered under NESHAP regulations (see Table 5-7), and limits are provided for combined curing and forming operations.

Rotary spin manufacturing of glass wool also produces emissions of formaldehyde as the fibers go through curing ovens. These are typically controlled with an end-of-the-line incinerator to acceptable limits (see Table 6-4).

6.5 Effluents

Machine lubricants and solvents used during finishing may create a source of contaminated effluents. Sources are automotive glass finishing where the glass is cut and passed through processes that grind and polish the edges, bent, and then tempered to produce side and back windows. Other automotive processes that produce effluents include cutting, bending, and washing to produce auto windshields, and the process where plastic sheet is laminated between two layers of glass. The production of incandescent lamp envelopes may also create effluents during the process where they are etched with hydrofluoric acid to produce frosted envelopes.

The amount of contaminants in waste water from glass operations is subject to limitations under the Clean Water Act. Effluent guidelines specifically geared toward glass manufacturing are shown in Table 6-5 [40 CFR 426].

Exhibit 6-1. Energy Use in Post-Forming of Glass

Energy Source	Natural Gas/Fuel Oil (10^6 Btu/ton)	Net Electricity[a] (10^6 Btu/ton)	Total Energy (10^6 Btu/ton)	1997 Annual Production (tons)	Net Industry Use [b] (10^{12} Btu)	Electricity Losses [c] (10^{12} Btu)	Total Energy (10^{12} Btu)
Flat Glass							
-Annealing	0.41	0.01	0.42	5,000,521	2.1	0.15	2.25
-Tempering (gas)	4.01	0.19	4.20	1,250,130	5.3	0.49	5.8
-Tempering (elec)	-	1.85	1.85	1,250,130	2.3	4.8	7.1
-Laminating	0.96	-	0.96	830,087	0.8	-	0.8
- Autoclave	0.54	0.14	0.68	830,087	0.6	0.24	0.84
TOTAL FLAT					11.1	5.68	16.8
Container Glass[f]	1.63	0.23	1.86	9,586,500	17.8	4.6	22.4
Pressed and Blown Glass[g]	2.95	0.05	3.0	2,484,182[d]	7.5	0.26	7.8
Fibrous Glass[h]							
-Glass Wool	4.38	-	4.38	1,915,200[e]	8.3	-	8.3
-Textile Fibers	3.28	-	3.28	1,124,800	3.7	-	3.7
Total Industry				20,111,203	48.4	10.54	59.0

[a] Based on a conversion factor of 3412 Btu/kWh of electricity.

[b] Excludes electricity losses.

[c] Losses associated with generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh of electricity.

[d] Estimated based on 92 Census Data and 2% growth between 1992 and 1997.

[e] Assumes 37% is textile fibers.

[f] Includes annealing and finishing.

[g] Includes fire polishing and annealing.

Sources: DOC 1997, Cer Ind 1999, Cer Ind 1997, Brown 1996, 1992 DOC, EI 1988.

Table 6-2. Emission Factors for Glass Finishing (lb/ton glass materials)

Source	VOCs	Other Gases[a]
Container		
Decorating/Surface Treatment	8.7	0.2
Pressed and Blown		
Decorating/Surface Treatment	9.0	0.2

[a] Tin chloride, hydrated tin chloride, and hydrogen chloride

Source: EPA 1985.

Table 6-3. Emission Factors for Fibrous Glass Finishing (lb/ton glass materials)					
Source	Filterable PM[a]	SOx	NOx	CO	VOCs
Insulation Glass Wool					
Oven Curing - Flame Attenuation	6	ND	2.0	3.5	7
Textile Fiber Glass					
Oven Curing and Cooling	1.2	NA	2.6	1.5	neg

Source: EPA 1985.

Table 6-4 Controlled Formaldehyde Emissions from Curing Operations in Rotary Spin Fiber Glass Manufacturing		
Operation	Control Technology	lb/ton
Curing	Incinerator[b] Inlet Outlet	 0.994 0.00292 - 0.00078

a process modifications include resin and binder chemistry, fiberization technology, binder application, and forming conditions.

b temperatures ranging from 1300-1500°F; residence times from 0.5-2.5 seconds.

Source: EPA 1997.

Table 6-5. Effluent Limitations for Post-Forming Operations- Average Daily Values for 30 Consecutive Days (lbs/1000 lbs of glass product)						
Segment	Ammonia	TSS	pH	Oil	Phosphorus	Fluoride
Automotive Glass Tempering[a]						
Existing Sources (BPT)	-	0.25	6-9	0.13	-	-
New Sources	-	0.05	6-9	0.10	-	-
Automotive Glass Laminating						
Existing Sources (BPT)	-	0.90	6-9	0.36	0.22	-
New Sources	-	0.18	6-9	0.36	0.06	-
Incandescent Lamp Frosting[a]						
Existing Sources (BPT)	no limit	0.23	6-9	-	-	0.115
New Sources	0.12	0.04	6-9	-	-	0.052

a Refers to process where glass is cut and passed through processes that grind and polish the edges, bend the glass, and then temper to produce side and back windows for automobiles. Also includes cutting, bending, and washing to produce auto windshields.

b Process where plastic sheet is laminated between two layers of glass

c Incandescent lamp envelopes are etched with hydrofluoric acid to produce frosted envelopes.

BPT = Best Practicable Technology

Source: 40 CFR 426

6.6 Byproducts and Wastes

Cullet, or unusable glass product, is the major byproduct generated during finishing operations. Cullet is generated as products are cut into shape (fiber mats), if the product is defective (shape, performance, quality), or broken. Cullet is almost always returned to the batch plant for recycling (except in fiberglass manufacturing).

Effluent from acid polishing of some glasses usually contains hydrofluoric acid and high levels of lead and fluorides. This waste must be slaked with lime, dewatered, and disposed of. Some manufacturers are developing recycling systems that clean the waste and then recover the constituents for reuse in the process [Glass Ind 1998].

Packaging glue can sometimes be a source of waste. Solidified glue is typically sent to the municipal landfill.

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