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Energy Efficiency Improvement and Cost Saving Opportunities for the Glass Industry

An ENERGY STAR® Guide for Energy and Plant Managers

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Environmental Energy Technologies Division

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ABSTRACT

The U.S. glass industry is comprised of four primary industry segments—flat glass, container glass, specialty glass, and fiberglass—which together consume $1.6 billion in energy annually. On average, energy costs in the U.S. glass industry account for around 14% of total glass production costs. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings, especially in times of high energy price volatility. There is a variety of opportunities available at individual plants in the U.S. glass industry to reduce energy consumption in a cost-effective manner. This Energy Guide discusses energy efficiency practices and energy-efficient technologies that can be implemented at the component, process, system, and organizational levels. A discussion of the trends, structure, and energy consumption characteristics of the U.S. glass industry is provided along with a description of the major process steps in glass manufacturing. Expected savings in energy and energy-related costs are given for many energy efficiency measures, based on case study data from real-world applications in glass production facilities and related industries worldwide. Typical measure payback periods and references to further information in the technical literature are also provided, when available. The information in this Energy Guide is intended to help energy and plant managers in the U.S. glass industry reduce energy consumption in a cost-effective manner while maintaining the quality of products manufactured. Further research on the economics of the measures—as well on as their applicability to different production practices—is needed to assess potential implementation of selected technologies at individual plants.

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1. Introduction

As U.S. manufacturers face an increasingly competitive global business environment, they seek out opportunities to reduce production costs without negatively affecting product yield or quality. The volatility of energy prices in today's marketplace can also negatively affect predictable earnings, which is particularly concerning for publicly traded companies in the U.S. glass industry. For public and private companies alike, increasing energy prices are driving up costs while decreasing value added. For example, because of its reliance on natural gas as a process fuel, the glass industry was hit especially hard by the seasonal increases in natural gas prices in 2000 (James 2001).

The challenge of maintaining high product quality while simultaneously reducing production costs can often be met through investments in energy-efficient technologies and practices. Energy-efficient technologies frequently offer additional benefits, such as quality improvement, increased production, and increased process efficiency, which can lead to further productivity gains. Energy efficiency is also an important component of a company's environmental strategy, as energy efficiency improvements can often lead to reductions in pollutant emissions. A strong energy management program can also provide a solid foundation for corporate greenhouse gas management programs and can be an effective strategy to work towards the so-called "triple bottom line" that focuses on the social, economic, and environmental aspects of a business.[1] In short, energy efficiency investment is sound business strategy in today's manufacturing environment.

To assist industry in improving its competitiveness through increased energy efficiency and reduced environmental impact, the federal government offers several voluntary programs. ENERGY STAR® is a voluntary program operated by the U.S. Environmental Protection Agency (EPA) in coordination with the U.S. Department of Energy (DOE) that stresses the need for strong and strategic corporate energy management programs. ENERGY STAR also provides a host of energy management tools and strategies to support the successful implementation of corporate energy management programs. This Energy Guide reports on research conducted to support the U.S. EPA's ENERGY STAR Focus on Energy Efficiency in Glass Manufacturing, which works with the U.S. glass industry to identify information and resources for energy efficiency improvement. For further information on ENERGY STAR and its available tools for facilitating corporate energy management practices, visit www.energystar.gov.

In this Energy Guide, energy efficiency opportunities for glass plants are assessed. The U.S. glass industry includes establishments engaged in manufacturing flat glass, container glass, specialty glass, and fiberglass. These four primary industry segments produce over 20 million tons of glass per year, with a value of over $16 billion. Glass manufacturing in the United States is one of the most energy intensive industries; in 2003, energy costs were about $1.6 billion, representing around 14% of the industry's total production costs. Primary energy consumption of the glass industry is approximately 1% of total U.S. industrial energy use. In this Energy Guide, opportunities are presented that can help decrease these costs and increase energy efficiency.

This Energy Guide begins with a description of the trends, structure, and production characteristics of the glass industry in the United States. The main production processes in glass

[1] The concept of the "triple bottom line" was introduced by the World Business Council on Sustainable Development. The three aspects of the "triple bottom line" are interconnected as society depends on the economy and the economy depends on the global ecosystem, whose health represents the ultimate bottom line.

plants, the types of fuels used, and the major end uses of energy are then summarized. The remainder of this Energy Guide discusses opportunities for energy efficiency improvement in U.S. glass plants, focusing on energy-efficient measures and technologies that have successfully been demonstrated in individual plants in the United States or abroad.

Although new technologies are developed continuously (see e.g., Martin et al. 2000), this Energy Guide is focused on practices that are proven and currently commercially available. Some of the technologies that may hold promise for the future but are still in the research and development phase are included in Section 5.11.

This Energy Guide aims to serve as a resource for energy managers and decision-makers to help them develop efficient and effective corporate and plant energy management programs.

2. The U.S. Glass Industry

The U.S. glass industry manufactures a wide diversity of products, including food and beverage containers, fiberglass insulation, windows for automobiles and buildings, video displays, cookware, and light bulbs. The U.S. glass industry produces approximately 20 million tons of glass annually and accounts for 20% of total worldwide glass production (GMIC 2004). Glass production in the United States can be broken down into four primary segments—flat glass, container glass, specialty glass, and fiberglass—which are summarized in Table 1.[2] In 2003, these four industry segments had a combined value of shipments of over $16 billion and employed nearly 70,000 people directly (U.S. Census 2005a).

Table 1. Major U.S. glass industry segments and typical products

Segment	SIC	NAICS	Key Products
Flat glass	3211	327211	Sheet plate and float glass for residential and commercial construction, automotive applications, tabletops, and mirrors.
Container glass	3221	327213	Packaging of foods, beverages, household chemicals, pharmaceuticals, and cosmetics.
Specialty glass	3229	327212	Pressed and blown glass for tableware, cookware, lighting, televisions, liquid crystal displays, laboratory equipment, and optical communications.
Fiberglass[3]	3296	327993	Fiberglass (glass wool) insulation for buildings, roofing, and panels.
	3229	327212	Textile and plastic reinforcement fibers for the construction, transportation, and marine industries.

The U.S. glass industry is a largely consolidated industry, with production in each industry segment dominated by a handful of large manufacturers. Most glass production in the United States is concentrated near major population centers, due to the heavy concentration of customers in such areas and the high costs of shipping both raw materials and finished glass products. Table 2 provides the locations of major glass manufacturing plants in the United States (National Glass Budget 2004). States with the largest number of major glass plants include Ohio, Pennsylvania, California, Texas, New York, Kentucky, and North Carolina. A full listing of major glass plants by U.S. state and industry segment is provided in Appendix A of this Energy Guide.

[2] A fifth glass industry segment exits—glass products made from purchased glass (NAICS 327215, SIC 3231)—which does not manufacture glass from raw materials, but rather purchases glass manufactured by other glass industry segments to fabricate into final products. This Energy Guide focuses only on those glass industry segments that convert raw materials to glass melt (see Table 1).

[3] Fiberglass production is comprised of two distinct categories: fiberglass (glass wool) insulation, which is classified under the "mineral wool" sector (NAICS 327993), and textile/reinforcement fibers, which is classified under the "pressed and blown glass" (specialty glass) sector (NAICS 327212).

On a percent-of-shipments basis, glass production is one of the most energy-intensive industries in the United States (U.S. DOE 2004a). In 2003, energy purchases by the four primary industry segments totaled over $1.6 billion, or 10% of total value of shipments (U.S. Census 2005a). The estimated primary energy consumption of the U.S. glass industry in 2002 was 331 trillion Btu (TBtu) (see Chapter 4). Most of the energy consumed is in the form of natural gas, which is used to fuel glass furnaces and process heating equipment. Glass production is also very capital-intensive, due in part to the cost of rebuilding glass furnaces every 8-12 years.

Table 2. Distribution of major U.S. glass plants

State	Major Plants	State	Major Plants
Arkansas	1	North Carolina	7
Arizona	3	New Hampshire	2
California	12	New Jersey	4
Colorado	1	New York	9
Florida	1	Ohio	15
Georgia	6	Oklahoma	5
Iowa	1	Oregon	1
Illinois	6	Pennsylvania	12
Indiana	5	South Carolina	5
Kansas	5	Tennessee	5
Kentucky	8	Texas	10
Louisiana	2	Utah	1
Massachusetts	1	Virginia	7
Michigan	3	Washington	2
Minnesota	1	West Virginia	3
Mississippi	1	Wisconsin	3
Missouri	1		

Source: National Glass Budget (2004)

While most glass production in the United States serves U.S. consumers, export markets are also significant. In 2003, exports by the four primary industry segments totaled nearly $2.7 billion, or 17% of total value of shipments (U.S. Census 2005b). Exports are particularly important for the flat glass segment, which exports around 28% of its total value of shipments (GMIC 2004).

The **container glass** segment manufactures roughly 10 million tons of annual products, and is the U.S. glass industry's largest producer (U.S. DOE 2002a). Three manufacturers—Owens-Illinois, Saint-Gobain Containers, and Anchor Glass Containers— account together for more than 95% of U.S. container glass production (GMIC 2004). The majority of glass container products are made of clear (flint) (64%), amber (23%) or green glass (13%) comprising the remainder (GMIC 2002). The major markets are beer bottles (53%), food packaging (21%), non-alcoholic beverage bottles (10%), and wine bottles (6%) (Cattaneo 2001). Competition with alternative materials such as plastic, aluminum, and steel in these markets is intense.

In 2003, U.S. container glass manufacturers employed over 15,000 people directly and produced nearly $4.4 billion in shipments (U.S. Census 2005a). The total primary energy consumption of the U.S. container glass segment in 2002 totaled around 92 TBtu (EIA 2005), which is the largest amount for the four primary U.S. glass industry segments. The costs of purchased energy totaled $511 million, including $185 million for electricity.

The combination of rising energy, labor, and capital costs, as well as increased competition by alternative materials led to a larger number of plant closures since the late 1970's. As of 2002, approximately 55 glass container plants producing 36 billion glass containers annually remained in operation within the U.S., down from over 100 in 1979 (GMIC 2002).

The **flat glass** segment is the second largest producer in the U.S. glass industry, accounting for roughly 5 million tons of production per year (U.S. DOE 2002a). Flat glass production in the United States is dominated by six major manufacturers—PPG Industries, Guardian Industries, Cardinal FG, Automotive Components Holdings LLC, AFG Industries, and Pilkington—who operate 30 flat glass plants throughout the country (U.S. DOE 2002a; GMIC 2002). While flat glass is used in many different products, including mirrors, tabletops, and instrument gauges, the residential construction, commercial construction, and automotive industries account for about 80% of the flat glass market (GMIC 2002). As a result, U.S. flat glass production is highly dependent on the economic cycles of the automotive and construction industries. In the construction industry, increased attention to energy efficiency is likely to lead to increased demand for low-emissivity (low-E) flat glass in the future (James 2001).

In 2003, U.S. flat glass manufacturers employed over 10,000 people directly and produced over $2.8 billion in shipments (U.S. Census 2005a). The costs of purchased energy totaled $350 million, of which $101 million was for electricity. In 2002, the total primary energy consumed by the U.S. flat glass segment amounted to 73 TBtu (EIA 2005).

The **specialty glass** segment produces a wide diversity of products, including cookware, fiber optics, lighting products, textile fibers, television tubes, and liquid crystal display panels. In 1999, there were over 500 establishments in the United States producing over 100 different specialty glass products (U.S. DOE 2002a). On a value of shipments basis, the key end-use markets for specialty glass are textile fibers (33%), lighting, automotive, and electronics (30%), tableware and cookware (17%), and scientific glassware and lens blanks (16%).

The U.S. specialty glass segment produces roughly 2 million tons of glass per year (excluding textile fibers). Major specialty glass manufacturers in the United States include Corning, GE Lighting, GE Quartz, Libbey Glass, OSRAM Sylvania, PPG Industries, Techneglas, and World Kitchen (National Glass Budget 2001; U.S. DOE 2002a). While the U.S. specialty glass segment has experienced strong growth in recent years, intense competition from overseas (particularly in the electronics market) is putting increased pressure on U.S.-based producers.

The specialty glass segment employed over 25,000 people in 2003, more than any other segment in the U.S. glass industry (U.S Census 2005a). Total value of shipments in 2003 was $4.1 billion, while the costs of purchased energy totaled $398 million ($163 million of which was for electricity). In 2002, the U.S. specialty glass segment consumed an estimated 91 TBtu of primary energy, up from 32 TBtu of primary energy in 1991 (U.S. Census 2004; U.S. DOE 2002a, 2005b).

The **fiberglass** segment is comprised of two distinct production categories: fiberglass insulation and textile/reinforcement fibers, which account for 3 million tons of fiberglass products each year (GMIC 2002). Fiberglass insulation products include unbonded and bonded glass wool, batting, mats, pipe insulation, and ceiling tiles. Textile/reinforcement fibers are continuous fiber strands used to reinforce plastics and other materials used in the construction, transportation, and marine industries.

In the United States production of fiberglass insulation is dominated by Owens Corning, Johns Manville, Guardian Industries, and CertainTeed (National Glass Budget 2001; U.S. DOE 2002a). On a value of shipments basis, the major end-use markets for fiberglass insulation are building batting (39%), industrial and appliance insulation (27%), acoustical insulation (21%), boards (5%), and loose fiber (5%) (U.S. DOE 2002a).

The U.S. Census Bureau categorizes fiberglass insulation production as part of the mineral wool manufacturing sector (NAICS 327993, SIC 3296), which includes all mineral wool made from siliceous materials such as glass, rock, slag, or combinations of these. Thus, production and energy consumption data are not available for fiberglass insulation as a distinct production category. In 2003, the U.S. mineral wool manufacturing sector as a whole employed nearly 18,000 people directly and produced over $4.7 billion in shipments (U.S. Census 2005a). Energy purchases for the mineral wool manufacturing sector in 2003 amounted to $355 million, of which $158 million was for electricity. The total primary energy consumed by U.S. manufacturers of mineral wool in 2002 amounted to around 75 TBtu (EIA 2005).

The major manufacturers of textile/reinforcement fibers in the United States are PPG Industries, Saint-Gobain (Vetrotex), Owens Corning, and GAF Materials (National Glass Budget 2001; U.S. DOE 2002a). Since the U.S. Census Bureau categorizes textile/reinforcement fiber production under the specialty glass sector (NAICS 327212, SIC 3229), economic and energy data for textile/reinforcement fibers are included in the specialty glass category and not available separately.

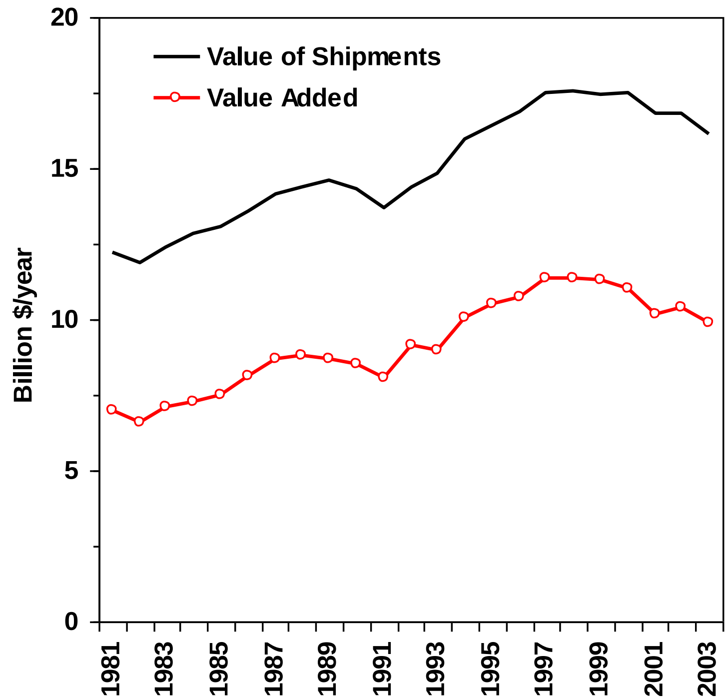
Within the U.S., fiberglass is the largest secondary market for post-consumer and industrial waste glass. Presently, fiberglass manufacturers in the U.S. recycle about 1 billion pounds of waste glass annually (GMIC 2002), and use 10-40% recycled glass in their final products.

Figure 1 plots the combined production value of the four primary segments in the U.S. glass industry, from 1981-2003.[4] From the early 1980s to the late 1990s, the glass industry as a whole experienced gradual, yet steady growth. In recent years, however, U.S. glass production has experienced a slight decline due to several different factors, including rising energy and labor costs, intense competition from developing nations, market penetration by alternative materials, and marginal growth in key end-use markets (U.S. DOE 2002a; GMIC 2004).

The economic contribution of each U.S. glass industry segment is shown in Figure 2, which plots the value of shipments of each segment from 1981-2003. Over the past two decades, the fastest growing industry segments have been specialty glass and mineral wool, while the flat glass segment has experienced slight growth (subject to the cyclical demands of the automotive and construction industries) and the container glass segment has struggled with competition from alternative materials (U.S. DOE 2004a). In all segments, U.S. producers are striving to reduce operating costs and to improve energy efficiency to maintain competitiveness.

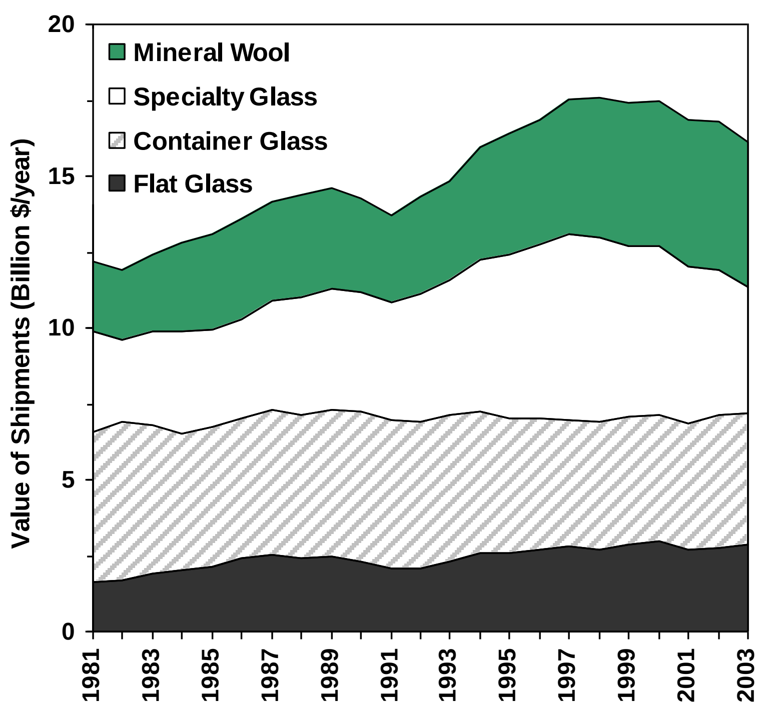
[4] Value of shipments is defined as the selling price of products. Value added is defined as the difference between the selling price of products and the cost of externally purchased materials and services.

Figure 1. Value of shipments and value added of the U.S. glass industry, 1981-2003



Sources: NBER (2000), U.S. Census (2003, 2005a)

Figure 2. Value of shipments of the four U.S. glass industry segments, 1981-2003

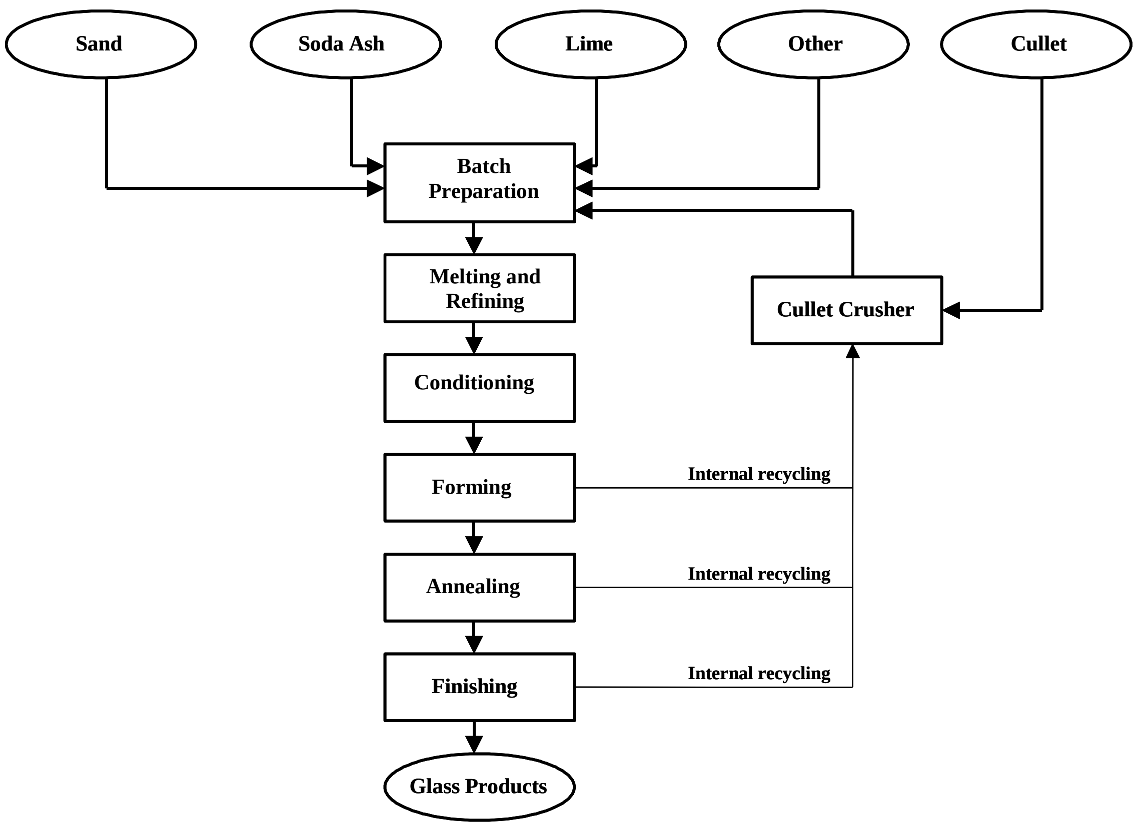


Sources: NBER (2000), U.S. Census (2003, 2005a)

3. Process Description

There is a large variety of glass products with varying characteristics and, hence, varying production and processing routes. While recognizing the variability, the process description will focus on the main steps that are found in virtually all glass plants. The process of manufacturing quality glass is comprised of six basic steps: (1) raw materials selection, (2) batch preparation (i.e. weighing and mixing raw materials), (3) melting and refining, (4) conditioning, (5) forming, and (6) post-processing (i.e. annealing, tempering, polishing or coating). The technologies employed in each step depend on the product manufactured. Figure 3 gives a simplified process overview of glassmaking.

Figure 3. Simplified process schematic of glass manufacture



Note: The process schematic may differ for the various glass products. Figure 3 is based on typical container glass production practices. Cullet is waste or broken glass for remelting. Cullet can be plant generated or recycled from the marketplace.

Raw materials selection & Batch preparation. The glass composition determines the physical and chemical properties of the glass, and varies therefore for each product/application. Of particular interest for most applications are the chemical durability, the transmission, the softening point and the thermal expansion of the glass. Depending on their function, glass-forming oxides can be grouped into network formers (for example SiO_2, B_2O_3, P_2O_5), intermediate oxides (for example Al_2O_3, TiO_2, ZrO_2), and network modifiers (for example Na_2O, CaO, MgO).

A typical soda-lime glass composition used for window or container glass consists of ~60% silica sand, ~18% calcium monoxide from limestone, and ~20% sodium monoxide from soda ash[5]; other common ingredients are feldspar, salt cake, colorants, and refining agents (for example arsenic, sodium chloride).

The use of 5 to 25 weight percent of clean cullet is not uncommon; in the case of colored container glass, sometimes more than 90 weight percent of cullet from post-consumer glass is used.

During batch preparation, the fine-ground raw materials are weighed according to the recipe, and subsequently mixed to achieve a homogenous composition. Cullet can be either mixed into the batch, or be charged into the glass melting tank simultaneously with the batch. Table 3 provides an overview of typical compositions.

Table 3. Approximate composition of different glass types

Oxide	Container Glass	Float glass	Fiberglass (E-Glass)	Laboratory Ware
SiO_2 [w%]	73	72	54	80
B_2O_3 [w%]			10	10
Al_2O_3 [w%]	1.5	0.3	14	3
CaO [w%]	10	9	17.5	1
MgO [w%]	0.1	4	4.5	1
Na_2O [w%]	14	14		5
K_2O [w%]	0.6			

Melting & Refining. With the exception of a few specialty glass manufacturing processes, continuously operated tank furnaces are commonly used for the melting of glass[6]. A typical glass-melting furnace ("tank") consists of a batch charging area ("doghouse") attached to a refractory basin covered by a refractory superstructure ("crown").

Common heating methods are combustion-heating (oxy-fuel, air-fuel burners) and direct electrical heating ("Joule heating"), as well as combinations of both ("electric boosting"). Many furnaces use electric boosting to increase production rates, or to increase the flexibility of the furnace operation (e.g. choice of energy source and production rates). Presently, most glass furnaces in the U.S. are heated with natural gas. To increase fuel efficiency and reduce emissions of nitrous oxides (NOx), oxygen is increasingly replacing combustion air. Electric boosting typically accounts for 10 to 30% of the total energy input (see for example Wooley 1992). Most electric furnaces have a uniform distribution of electrodes and have a cold top (Hibscher et al.

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[5] The U.S. glass industry consumes about 50% of the soda ash produced in the United States.

[6] Discontinuous glass melting is mostly done in pot furnaces and in day tanks. In pot furnaces, one or more crucibles made from refractory material are filled with batch and/or cullet, and placed in a gas-fired or electrical furnace. After melting of the batch material is completed, the temperature of the furnace is typically increased to lower the melt viscosity and activate refining agents to remove bubbles from the melt (refining), and subsequently lowered to condition the glass for forming. Day-tanks are small tanks which are recharged with batch and cullet, once the glass level falls below a certain mark; as in a pot furnace, the temperatures are adjusted for melting, refining and conditioning of the glass melt (often overnight).

2005). All-electric, cold-top furnaces are primarily used for wool-type fiberglass production (Ruth and Dell'Anno 1997) but are also used for specialty glass production. All of these heating technologies are discussed in more detail in Section 5.8.

To keep the glass level constant, the mixture of batch and cullet is continuously charged into the glass-melting furnace to compensate for the glass withdrawn.

The process of refining (also know as fining) takes place in the melting chamber. During this process, the batch of molten glass is freed of bubbles, homogenized, and heat conditioned before the glass is introduced into the forehearth.

Improved refractory materials for the construction of the crown and the basin allow for higher operating temperatures (and thereby better insulation) while being less prone to corrosion; this leads in some cases to an increase in campaign life from about 2 to more than 9 years.

To improve energy efficiency and achieve higher flame temperatures, air-fuel furnaces typically recover heat from exhaust gas streams with recuperative or regenerative systems to preheat the combustion air. In recuperative systems, heat is continuously transferred from the exhaust gases to the combustion air in a heat exchanger. In regenerative systems, the exhaust gases stream through large chambers packed with refractory bricks arranged in patterns forming open conduits. During the first part of the firing cycle, flue gases pass through the conduits and heat the brickwork before leaving through the stack. After a certain time (typically about 20 minutes), the exhaust port is closed and the firing direction is reversed: cold combustion air is passed through the heated brickwork in the opposite direction, and mixed with the fuel in a combustion chamber. Commonly, the cycle time is automatically adjusted by a control system to achieve the highest efficiency possible.

Excess heat in the off-gas stream of recuperative or regenerative systems can be used to generate steam in a waste-heat recovery boiler (for example for space heating), or to preheat cullet. Both measures can increase the overall efficiency of the glass furnace to 50-65% (Whittemore 1999). Modern glass furnace technology aims to increase the use of oxygen as a way to increase fuel efficiency and reduce emissions of nitrogen oxides (NO_x).

Average float glass furnaces, the largest in the industry, have a capacity of 450 tonnes/day, but can be as large as 2,000 tonnes per day, whereas container glass tanks generally have a capacity of 250 to 350 tonnes/day (GTI 2002). Common in both industry segments are regenerative furnaces. Larger float- and container-glass tanks tend to exhibit improved energy efficiency (GTI 2002). Fiberglass furnaces are generally smaller than container and flat glass furnaces. Typical capacities for insulation glass furnaces are 70 to 90 tonnes/day and 90 to 130 tonnes/day for textile glass furnaces. Pressed and blown glass furnaces are generally the smallest, operating at 4 to 22 tonnes/day (GTI 2002). About 90% of the furnaces in each of the sub-sectors are recuperative furnaces.

Natural gas is currently the fuel of choice for glass furnaces. In the U.S., some glass furnaces use electric boosters to help melt the glass, as glass is an electrical conductor at high temperatures. Generally, 10 to 30% of the energy input to the furnace is from the electric booster (Wooley 1992). For wool-type fiberglass production, melting is predominantly done with all electric, cold-top furnaces (Ruth and Dell'Anno 1997).

Due to the high temperatures in the tank, glass melting is a large source of NO_x emissions. State-of-the-art technology aims at further reductions in NO_x emissions, while simultaneously reducing energy costs.

The process of refining (also know as fining) takes place in the melting chamber. During this process, the batch of molten glass is freed of bubbles, homogenized, and heat conditioned before the glass is introduced into the forehearth.

The role of the forehearth is to condition the glass. Conditioning produces a stable, desired glass temperature, evenly distributed both vertically and laterally. Many defects are related to the temperature and result from the lack of thermal homogeneity of the glass, directly related to the conditioning of the forehearth.

Conditioning. After completion of the refining stage the fairly homogenous, bubble-free glass leaves the tank and enters the forehearth, sometimes through a specifically designed pathway (channel, "throat"). Main function of the forehearth is to condition the glass, i.e. to deliver glass with the desired temperature and temperature distribution to the forming process. Deviations from the desired thermal profile can cause undesirable differences in viscosity, and subsequently lead to visible defects in the finished product. Forehearths can be gas-fired or electrically heated.

Forming. The conditioned glass is delivered from the forehearth to the forming equipment at a constant rate ("pull rate"). Depending on the process, the viscous glass stream is either continuously shaped (floatglass, fiberglass), or severed into portions of constant weight and shape ("gobs") which are delivered to a forming machine (container glass).

Container glass is produced today by automated processes known as pressing, blowing, press-blowing, and blow-blowing. The viscous glass stream leaves the forehearth though an orifice ring at a constant rate, and is severed into portions of defined weight and shape ("gobs") by mechanical means. The gobs drop into a chute ("gob feeder"), and are delivered to the forming machine. In simple pressing machines, the gob drops into a preheated mold, and is subsequently pressed into shape by a preheated die. Forming machines for glass bottles pre-shape the gob by either pressing or blowing, and obtain the final shape by injecting air into the gob placed in a surrounding mold. Common is the delivery of multiple gobs at a time to multiple forming stations; typically, standard machines are capable of producing more than 200 containers per minute.

Flat glass is produced today either by the float glass process, continuous drawing (updraw, downdraw, overflow fusion), or continuous rolling. The float glass process was invented and commercialized by Pilkington Brothers PLC in the United Kingdom. Introduced on an industrial scale in 1959, the process and its variations are now the principal method of forming flat glass throughout the world.

After leaving the delivery system, the conditioned glass flows onto the surface of a molten tin-alloy ("float bath"). To avoid oxidation and reaction of the tin-alloy with the glass, the atmosphere in the float chamber is slightly reducing[7]. The temperature at the entrance of the float chamber is high enough to allow the glass to spread out on the liquid metal bath and form a flat ribbon, and remove irregularities in the surface figure; typical are temperatures of up to 1800°F (980°C). The ribbon is continuously withdrawn from the float chamber, and cools while floating

[7] Typical forming gas mixtures injected into the float chamber consist of nitrogen with up to 10 volume % of hydrogen.

on the tin-alloy bath to about 1100°F (590°C); the glass is then rigid enough to be lifted from the float bath without deformation and surface damage by conveyor rollers. The continuous ribbon passes through an annealing lehr to release stresses, and is finally cut to length.

The float process is capable of producing flat glass with a uniform thickness ranging from about 2.5mm (0.1") to more than 25mm (1"). Typical float glass plants produce more than 5000 tons per week, and operate without interruption for multiple years.

Patterned flat glass and wire glass are manufactured with a rolling process. A continuous stream of conditioned glass is poured between water-cooled rollers made out of cast iron or high-temperature stainless steel, and continuously withdrawn. If the glass ribbon is patterned on only one side, the slightly larger bottom roller is engraved with the negative of the pattern. The thickness of the glass ribbon can typically be varied in the range of 4 to 15mm by changing the diameter of the roller and adjusting the gap between the rollers. Glass temperatures of about 1900°F (1040°C) before, and 1600°F (850ºC) after completion of the shaping are typical for patterned glass. The formed continuous ribbon is supported by conveyor rollers, and passes through an annealing lehr before being cut to size.

Drawing processes are used today mainly for the manufacture of thin glass.

Glass fiber consists mainly of continuous glass fiber (e.g. textiles) and glass wool (used for insulation). Continuous glass fiber is a continuous strand, made up of a large number of individual filaments of glass. Molten glass is fed from the furnace through a forehearth to a series of bushings that contain over 1,600 accurately dimensioned holes or "forming tips," while modern production facilities may have over 4,000 holes in the bushing. Fine filaments of glass are drawn mechanically downwards at high speed, and are wound.

Glass wool is made in the crown or rotary process. From the forehearth of the glass tank, a thick stream of glass flows by gravity from the bushings into a rapidly rotating alloy steel dish "crown," which has several hundred fine holes around its periphery. The molten glass is ejected through the holes by centrifugal force to form filaments that are further extended into fine fibers by a high velocity blast of hot gas. After being sprayed with a suitable bonding agent, the fibers are drawn by suction onto a horizontally moving conveyor positioned below the rotating dish. The mat of tangled fibers is carried through an oven, which cures the bonding agent, and is then cut to size.

Optical fibers are considered a specialty product using extremely pure glass. Optical fibers consist of two distinct glasses, a core of highly refracting glass surrounded by a sheath of glass with lower refractive index between the two glasses. Optical signals are guided by total reflection at the core-sheath interface to the other end of the fiber. There are many manufacturing processes being used to produce cored fiber. For extremely accurate dimensions and complicated inner and outer profiles, extrusion is used to form the glass. Extrusion uses low process temperatures and a glass melt with unusually high viscosity compared to traditional forming methods like drawing or blowing.

Currently, fiber glass production is the main user of electric melting, as it allows producing a very homogenous and high quality product.

Finishing. Different finishing treatments can be used to influence product characteristics, e.g. annealing, toughening and coating.

In *annealing*, the strain in the glass can be reduced by slowly reheating the glass in an oven, called a lehr. First, the glass product is heated to a high temperature, varying between 800°F (400°C) and 1000°F (500°C), depending on the product. Next, the glass product is gradually reduced to a temperature at which no further strain can be induced. Then, it is cooled by fan air to room temperature. The time required for this process depends on the size of the product and its wall thickness, but the process is normally completed in less than an hour.

Re-heating the glass product uniformly to a temperature just above that at which deformation could take place and then rapidly cooling the surfaces by jets of air comprises *toughening*. Rapid cooling of both surfaces leads to the build-up of a compressive stress layer upon further cooling, since the hot core glass can still contract. Thermal strengthening can be applied to flat glass or simple shapes like curved car windscreens or tumblers. The glass thickness must be uniform, not too thin, and the shape of the article must be such that all surfaces can be uniformly cooled at the same time. Bottles cannot be toughened in this way. However, bottles can be toughened in a chemical process.

The *coating* of glass surfaces (e.g. mirrors, strengthening of bottles, and coloring) gives glass new physical, chemical, and optical properties. Lightweight glass containers are coated with organic compounds to give the surfaces a degree of lubricity, thus preventing abrasion in handling. This adds strength to the container and has enabled glass manufacturers to make a lighter and better product.

Finally, the glass product is packaged, stored in a warehouse or shipped to customers in different industries.

4. Energy Use in Glass Making

Energy costs are significant for the U.S. glass industry and, on average, account for around 14% of direct glass production costs (GMIC 2002). In 2003, the four primary glass industry segments—flat glass, container glass, specialty glass, and fiberglass—spent over $1.6 billion on purchased fuels and electricity (U.S. Census 2005a). Of this, $1 billion was spent on purchased fuels and $600 million was spent on purchased electricity. Natural gas accounts for nearly all purchased fuels and is the primary fuel used in melting and annealing processes. Electricity is typically used as booster energy in melting tanks and throughout the plant for lights, fans, pumps, compressed air systems, and forming equipment. In this chapter, an overview of energy use in the U.S. glass industry is provided with an assessment of energy consumption of each major process step.

Table 4 summarizes estimates of energy use by the U.S. glass industry, as reported in the Manufacturing Energy Consumption Survey (MECS) published by the U.S. Energy Information Administration (EIA 1994, 1997, 2001, 2005).[8] Due to significant differences in reporting formats between the different years of the MECS, it is not possible to develop a consistent time series for glass industry energy consumption using MECS data.[9]

Table 5 provides estimates of energy use by the U.S. glass industry in 2002, which were derived using data from the U.S. Census Bureau's Annual Survey of Manufactures (ASM).[10] The ASM data led to an estimate of 362 TBtu of primary energy consumed by the four primary segments of the U.S. glass industry in 2002. Comparing Tables 4 and 5, it can be seen that the MECS estimates of fuel use in each glass industry segment are generally lower than the ASM-derived estimates of fuel use. Both ASM and MECS report electricity consumption in kWh, and are comparable. The ASM fuel estimates were derived by dividing the fuel expenditures reported by the ASM by the 2002 average U.S. industrial natural gas price, which might result in significant uncertainties. The fuel consumption data in the MECS are based on a survey that directly reports on fuel use. However, in the MECS the results of a more limited sample are extrapolated to the sector as a whole. Adding the 2002 MECS estimates for the flat glass, container glass, and mineral wool segments to the 2002 ASM estimate for the specialty glass segment gives an

[8] Table 4 reports estimates for both final energy use and primary energy use. Final energy use is the sum of all purchased fuels and electricity (i.e., the energy consumed at the plant). Primary energy use includes final energy use as well as the energy losses associated with generating, transmitting, and distributing the electricity purchased by the plant. Electricity losses are calculated using an average U.S. conversion factor of 7,088 Btu of energy loss per kWh of electricity purchased (U.S DOE 1997, 2002a).

[9] The 1991 MECS and 1994 MECS report data for the flat glass, container glass, specialty glass, and mineral wool segments but do not report data for the purchased glass segment (NAICS 327215, SIC 3231). The 1998 MECS reports only data for the "glass and glass product manufacturing" sector (NAICS 3272) as a whole, which includes the flat glass, container glass, specialty glass, and purchased glass segments. The 1998 MECS does not provide data for the mineral wool segment. The 2002 MECS reports on NAICS 3272 as a whole, but also provides data for the flat glass, container glass, and mineral wool segments. The 2002 MECS does not provide data for the specialty glass segment.

[10] The estimates in Table 5 were derived based on 2002 ASM data using the national average industrial natural gas price for 2002 of $4.02 per 1000 ft^3 (U.S. DOE 2005a); purchased electricity use was based on actual consumption reported in the 2002 ASM. The estimates do not account for fuel purchased to generate electricity sold offsite. Electricity losses were calculated in the same manner as in Table 4.

estimated total primary energy consumption of 331 TBtu for the four primary industry segments. Due to the limitations described above, this estimate is considered to be uncertain.

Table 4. U.S. glass industry energy use data from MECS (TBtu)

	1991	1994	1998	2002
Glass Industry – Total				
Purchased electricity	39	43	42	42
Fuel oils	3	4	3	6
Natural gas	140	199	159	153
Total final energy	*186*	*249*	*206*	*201*
Electricity losses	81	89	87	87
Total primary energy	*267*	*338*	*293*	*288*
Flat Glass				
Purchased electricity	5	5	-	6
Fuel oils	withheld	2	-	3
Natural gas	42	45	-	52
Total final energy	*49*	*52*	-	*61*
Electricity losses	10	10	-	12
Total primary energy	*59*	*62*	-	*73*
Container Glass				
Purchased electricity	14	15	-	13
Fuel oils	2	2	-	withheld
Natural gas	69	66	-	52
Total final energy	*85*	*83*	-	*65*
Electricity losses	29	31	-	27
Total primary energy	*114*	*114*	-	*92*
Specialty Glass				
Purchased electricity	10	11	-	-
Fuel oils	1	withheld	-	-
Natural gas	withheld	51	-	-
Total final energy	*11*	*63*	-	-
Electricity losses	21	23	-	-
Total primary energy	*32*	*86*	-	-
Mineral Wool				
Purchased electricity	10	12	-	13
Fuel oils	withheld	withheld	-	-
Natural gas	29	37	-	35
Total final energy	*41*	*51*	-	*48*
Electricity losses	21	25	-	27
Total primary energy	*62*	*76*	-	*75*

Sources: EIA (1994, 1997, 2001, 2005)

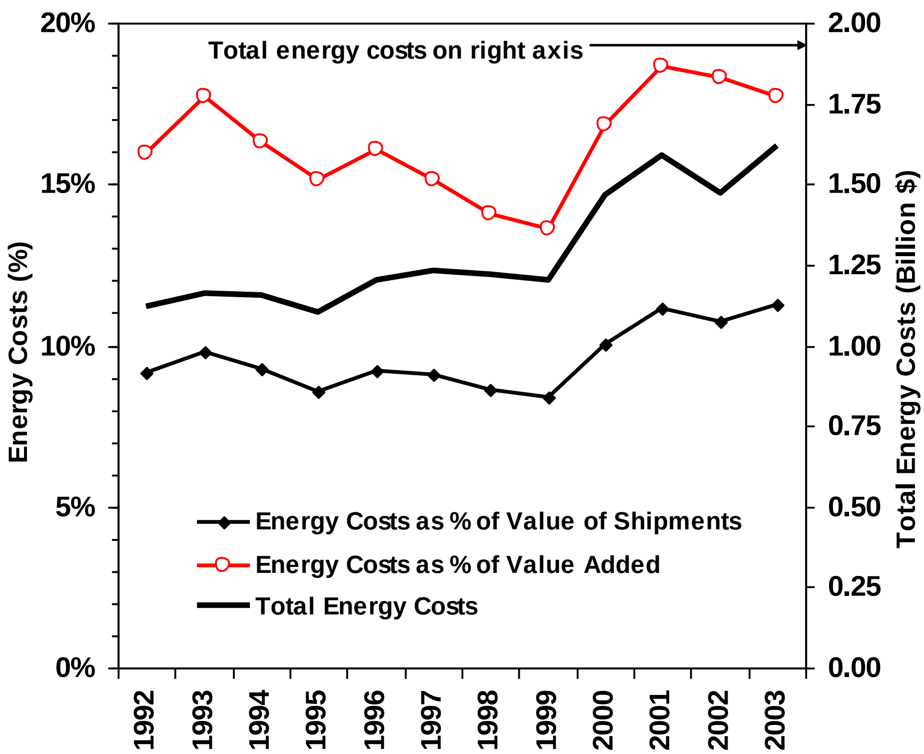
Table 5. 2002 U.S. glass industry energy use estimates based on ASM data (TBtu)

	Flat Glass	Container Glass	Specialty Glass	Mineral Wool	Total
Purchased electricity	7	13	12	12	44
Purchased fuels	59	66	53	45	223
Total final energy	*66*	*79*	*65*	*57*	*267*
Electricity losses	15	28	26	26	95
Total primary energy	*81*	*107*	*91*	*83*	*362*

Source: U.S. Census (2004), U.S. DOE (2005)

The U.S. glass industry's energy costs have increased steadily over the past decade, with the most rapid increases occurring since the late 1990s. Figure 4 plots the U.S. glass industry's energy costs, energy costs as a percentage of value added, and energy costs as a percentage of value of shipments from 1992-2003. The rapid increase in energy costs occurring since 1999 can be attributed to steep increases in the price of industrial natural gas over the same period. Between 1999 and 2003, the average price of industrial natural gas in the United States rose from \$3.12 per 1000 ft^3 to \$5.81 per 1000 ft^3 (U.S. DOE 2005a). Energy costs as a percentage of production (i.e., value added and value of shipments) decreased steadily throughout the 1990s, but have trended upward along with total energy costs since 1999, as natural gas and electricity prices increased.

Figure 4. Historical trends in energy costs for the U.S. glass industry

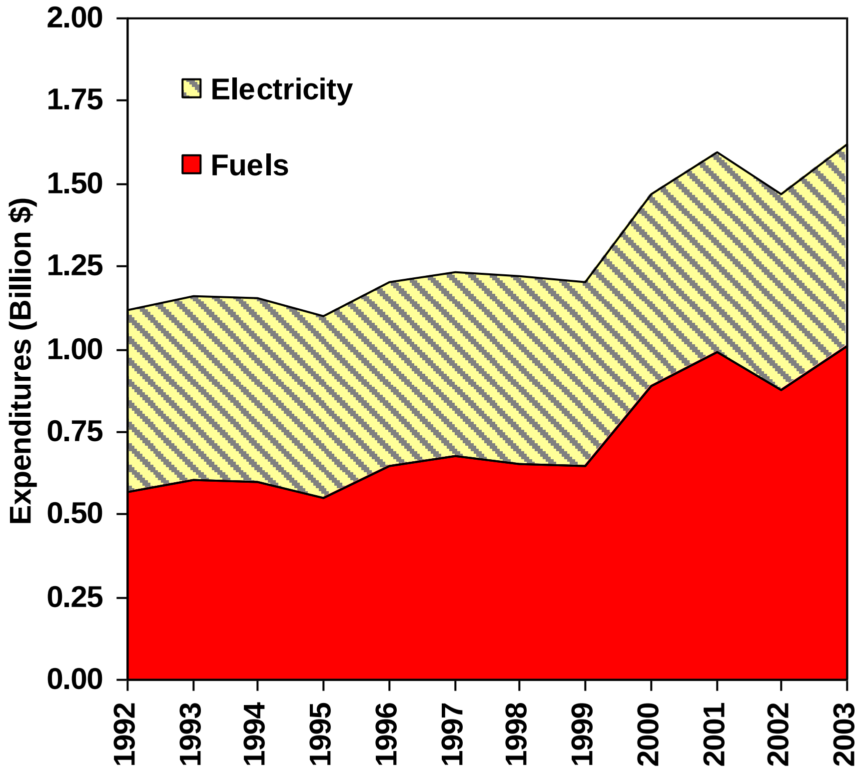


Sources: U.S. Census (1995, 1996, 1998, 2003, 2005a)

Figure 5 shows the energy expenditures of the U.S. glass industry from 1992-2003, broken down by expenditures on fuels and electricity. While industry expenditures on fuels and electricity were comparable throughout much of the 1990s, fuel expenditures have increased significantly in recent years (largely due to rapidly increasing natural gas costs). In 2003, fuel expenditures accounted for nearly two-thirds of the U.S. glass industry's energy costs.

Nearly all of the electricity consumed by the U.S. glass industry is purchased electricity. On average, less than 0.1% of the electricity consumed by U.S glass production facilities over the last decade was generated onsite (U.S. Census 1995, 1996, 1998, 2003, 2005a).

Figure 5. Historical energy expenditures by the U.S. glass industry



Sources: U.S. Census (1995, 1996, 1998, 2003, 2005a)

Of the total energy purchased by the U.S. glass industry, around 80% is used for process heating purposes, primarily to heat raw materials to transform them into glass (U.S. DOE 2004). Around 8% of purchased energy is consumed by machine drives and around 4% is consumed by facility heating, ventilation, and air conditioning (HVAC) equipment.

The specific energy of glass production (i.e., energy use per ton of product) depends heavily on the end product type (i.e. chemical composition), the percentage of cullet in the feed, the efficiency of the processes, and the type of furnace (EEBPP 2000). Table 6 summarizes the average specific energy use of the major process steps in glass making for each of the primary industry segments. Note that actual energy use may vary based on the chemical composition and the use of cullet. Melting and refining are the most energy-intensive processes within each industry segment, while batch preparation is usually the least energy-intensive process step. Further details on the specific energy consumption of each major process step are provided below.

Table 6. Specific energy consumption of major process steps by industry segment

Process Step	Average Specific Energy (MMBtu/ton)			
	Flat Glass	Container Glass	Specialty Glass	Fiberglass
Batch preparation	0.3	0.5	0.8	1.1
Melting and refining	6.5	5.8	7.3	5 – 6.5
Forming	1.5	0.4	5.3	1.5 – 4.5
Post-forming/finishing	2.2	0.7	3.0	1 - 2

Source: U.S. DOE (2002a); Rue et al. (2006)

Batch Preparation. Electricity is used to power the conveyors, crushers, mixers, hoppers, and baghouses. Average values of specific electricity use in batch preparation range from 80 kWh/ton (0.3 MMBtu/ton) for flat glass to 340 kWh/ton (1.1 MMBtu/ton) for fiberglass (U.S. DOE 2002a). The electricity consumed in batch preparation typically represents only around 4-5% of a plant's final energy demand.

Melting and Refining. The melting and refining of glass in continuous furnaces is the most energy-intensive process step in glass production. Theoretically, 2.2 MMBtu are required to melt one short ton of glass. In reality, however, most modern furnaces consume significantly more energy, depending on the percentage of cullet in the feed (EC-JRC 2000). In general, only about 33-40% of the energy consumed by a continuous furnace goes toward melting the glass (U.S. DOE 2002a, Pieper 1997). Up to 30% of the energy consumed by a furnace can be lost through its structure, while another 30% can be lost through flue gas exiting the stack.

The fuel consumed in melting and refining depends foremost on the chemical composition and the share of cullet used, but also on the type of furnace. In the production of flat glass, container glass, and specialty glass in the United States, the vast majority of furnaces are fired with natural gas and many of these will also use an electric boost. Electricity for boosting typically represents 10-20% of the final energy consumed by a furnace (U.S. EPA 1995; Wooley 1992). Electric boosting may contribute from 2 to 20% of the energy inputs in a furnace. However, in large scale container and flat glass furnaces boosting will be limited to 5-15%, depending on local electricity rates (GMIC 2004). If oxy-fuel is used, electricity is also consumed to produce oxygen. In the production of fiberglass insulation in the United States, electric melting furnaces predominate.

A recent study for the U.S. Department of Energy (Rue et al. 2006) surveyed glass plants in the U.S. to establish the current energy intensities in various segments of the glass industry. The study focused on the melting and shaping. The study concluded that for glass fiber the melting and refining energy use is typically 6.5±0.5MMBtu/ton for textile fibers and 4.5±0.5 MMBtu/ton for glass wool. For flat glass, the average melting and refining energy use was estimated at 6.5±0.5 MMBtu/ton, based on a found variation between 5 and 7.5 MMBtu/ton, while for container glass the average melting and refining intensity was estimated to be 5.75±0.25 MMBtu/ton (Rue et al. 2006).

Table 7 summarizes estimates for the specific energy consumption of furnaces in each glass industry segment by fuel and furnace type. Table 7 also provides the estimated production output of each furnace type by industry segment, to indicate the relative prevalence of each furnace technology in the United States.

Table 7. Estimated specific energy consumption of glass melting furnaces

Industry Segment/ Furnace Type	Current Estimated Share	Average Specific Energy (MMBtu/ton)[11]			
		Natural Gas	Electricity	Electricity Losses [12]	Primary Energy[13]
Flat Glass					
Regenerative	80%	8.5 (6.2-11.8)	0.3 (0.1-0.6)	0.6	9.4
Oxy-fuel	20%	4.7	0.7	1.5	6.9
Electric boost	n.a.	5.7 (5.1-6.3)	0.8 (0.6-1.1)	1.7	8.2
Container Glass					
Regenerative	70%	7.5 (4.8-10.2)	0.3 (0.1-0.5)	0.6	8.4
Electric boost	15%	4.7 (3.3-6.0)	0.8 (0.6-1.1)	1.7	7.2
Oxy-fuel	30%	4.0 (3.7-4.3)	0.7 (0.6-0.8)	1.5	6.2
Electric melter	n.a.	-	2.8 (2.5-3.0)	5.8	8.6
Specialty Glass					
Regenerative	26%	5.5 (3.8-7.1)	-	-	*5.5*
Direct melter	34%	12.0 (8.0-16.0)	-	-	*12.0*
Oxy-fuel	35%	3.6 (3.0-4.2)	-	-	*3.6*
Electric melter	5%	-	10.3 (8.9-11.6)	21.4	31.7
Fiberglass Insulation					
Electric melter	55%	-	7.5 (3.0-11.9)	15.6	23.1
Recuperative	10%	7.0 (6.0-8.0)	-	-	*7.0*
Oxy-fuel	35%	5.6 (3.4-7.8)	-	-	*5.6*
Textile/reinforcement Fibers					
Recuperative	25%	10.5 (6.0-15.0)	-	-	*10.5*
Oxy-Fuel	75%	5.6 (3.4-7.8)	-	-	*5.6*

Source: U.S. DOE (2002a); Rue et al. (2006)

As Table 7 shows, there is a wide variation in specific energy consumption between furnace types and even for the same furnace type. Important parameters affecting the furnace efficiency include the basic design, size, and age of the furnace, the type of glass being melted, the pull rate, and the type of fuel used (most furnaces are designed for a specific fuel; using other fuels can reduce efficiency).

Full electric glass melting furnaces are mainly used by smaller producers, as well as by producers of specialty glass and fiberglass products. The main disadvantages associated with electric furnaces are their potentially higher energy costs[14], higher primary energy use (due to significant

[11] For natural gas and electricity use, estimates of the specific energy consumption range are provided in parentheses.

[12] Electricity losses are calculated using an average U.S. conversion factor of 7,088 Btu of energy loss per kWh of electricity purchased (U.S DOE 1997, 2002a).

[13] Estimates noted in italics are based only on natural gas use as data on electricity use were not available.

electricity losses), and a lower turn down ratio (i.e. turn down of the pull rate is limited compared to gas-fired furnaces). Furthermore, the maximum capacity of electric melters is limited to a maximum of 300 tons/day, the cullet share is limited due to unwanted chemical reactions or increased energy losses, and campaign life is limited to about 4 years using modern refractories (Hibscher et al. 2005). However, a distinct advantage of electric furnaces is that they generate less direct emissions than natural gas-fired furnaces. However, sometimes the use of an electric furnace is a technical necessity, e.g. high melting-point glasses, volatilization, as there are glass types that can only be made with full-electric furnaces.

A recent survey of electric furnaces with capacities of over 10 tonnes/day estimated the average specific electricity consumption of electric furnaces at 1.18 kWh/kg (1070 kWh/short ton) (Fleishmann 1994, 1997). The survey was conducted in Germany and included a wide variety of electric furnace designs (cold top, semi-cold top, and shaft) and electrode arrangements (top, bottom, side, or a combination of these). The survey showed that electricity consumption varied widely with furnace capacity, daily throughput, and the percentage of cullet in the feed. Based on the survey results, a relationship between electricity use and throughput was derived (excluding cullet percentage):

$$\text{Electricity consumption (kWh/kg)} \approx 1.3 - 0.0066 * \text{Daily throughput (tonne/day)}$$

The survey also showed that some electric furnaces operated more efficiently than others, suggesting that there may be additional room for energy-efficiency improvement in the surveyed electric furnaces. Modern electric furnaces would consume about 780-800 kWh/short ton of soda-lime and sodium-borate glasses (Hibscher et al. 2005).

All furnaces are subject to stress and corrosion, and are therefore lined with refractories. The refractories may be coated to retard erosion. The refractories must be renewed periodically, as deterioration can lead to significant energy losses (at the end of campaign life energy use can be up to 20% more than at the beginning of campaign life due to lining loss) (EC-JRC 2000).

Forming. After glass is melted and refined in the furnace, molten glass is passed into the forehearth where it is conditioned to a temperature suitable for forming. The molten glass is then formed using any number of different processes, which depend on the desired shape of the final product (see Chapter 3). Natural gas and electricity are the main forms of energy used in forming. Most of the electricity is used to drive forming machines, fans, blowers, compressors, and conveyors (U.S. DOE 2002a). In forming processes where proper working temperatures need to be maintained, fuels (e.g. natural gas) and electricity are used to control the process heat.

The energy used in forming is highly product dependent; energy use in forming can account for anywhere from 12% (for flat glass) to 34% (for fiber forming) of the total primary energy consumed in glass production (Babcock et al. 1988). In flat glass production, electricity is used to maintain the molten state of the tin bath and to drive rollers. In the production of glass containers, final form is obtained using either compressed air (blow and blow method) or a combination of compressed air and electricity-driven mechanical pressing (press and blow method). The primary forming processes used in specialty glass production—press and blow, press-forming, lamp-forming, spinning, and drawing—are also electricity-driven. In the

[14] The cost differential is strongly dependent on the natural gas and electricity prices for the specific location of the plant. Electricity prices may vary widely, while natural gas prices have increased rapidly in recent years. Hence, for specific locations an electric furnace may still be an economic option.

production of glass wool, both electricity (for rotary spinners and conveyors) and fuels (for steam blowing or flame attenuation) can be consumed.

Estimates for the average specific energy use of forming processes in each glass industry segment are provided in Table 8.

Table 8. Estimated specific energy consumption of glass forming processes

Industry Segment	Average Specific Energy (MMBtu/ton)		
	Electricity	Electricity Losses[15]	Primary Energy[16]
Flat glass	1.5	3.1	4.6
Container glass	0.4 – 0.7	0.8 – 1.5	1.2 – 2.2
Specialty glass	5.3	11.0	15.3
Fiberglass	2 – 5.5	4 – 11.8	6 – 17.3

Source: U.S. DOE (2002a)

Post-Forming and Finishing. After being formed into its final shape, a glass product may be subjected to several different post-forming and finishing processes, including curing/drying, annealing, bending, tempering, laminating, coating, cutting, drilling, and polishing.

Annealing is performed on all glass products except fibers and thin-walled products, such as light bulbs. Annealing takes place in a lehr (an electric or natural gas-fired chamber or tunnel), where the rate of glass cooling is carefully controlled to remove internal stresses. Most annealing lehrs (over 90%) are fired with natural gas (U.S. DOE 2002a). Annealing process typically consume 2-5% of the total final energy in a glass plant (EC-JRC 2000).

After annealing, some flat glass (particularly automotive and architectural glass) is subjected to tempering to improve its strength. Tempering can occur in either an electric or natural gas-fired furnace. Automotive flat glass typically undergoes mechanical bending prior to tempering to attain desired curvature.

In the laminating process, two pieces of flat glass are sandwiched with a layer of resin in a rolling process. The assembly is then heated in an autoclave to liquefy the resin and to remove trapped air. Autoclaves are mostly powered with electricity (U.S. DOE 2002a).

Coatings are applied to glass containers after the annealing process to improve scratch resistance. Container coatings are typically applied using motor-driven hydraulic spray nozzles. Coatings are also applied to textile fibers after forming, using a rolling process.

Glass wool fibers are subjected to a curing and drying process after forming. The glass wool fibers are collected on a conveyor and sprayed with a binder solution. The resulting mat of glass wool is passed through a series of ovens, which cure the binder, and then through a dryer unit, which forces ambient air through the glass wool mat. Natural gas is the predominant form of energy in curing and drying, used for process heat and in the incineration of volatile organic fumes arising from the curing process.

[15] Electricity losses are calculated using an average U.S. conversion factor of 7,088 Btu of energy loss per kWh of electricity purchased (U.S DOE 1997, 2002a).

[16] Primary energy estimates include only electricity use as data on fuel use were not available.

Table 9 provides estimates for the specific energy use of post-forming and finishing process in each glass industry segment.

Table 9. Estimated specific energy consumption of post-forming and finishing processes

Industry Segment/Process	Average Specific Energy (MMBtu/ton)			
	Natural Gas/Fuel Oil	Electricity	Electricity Losses[17]	Primary Energy[18]
Flat Glass				
Annealing	0.4	0.01	0.02	0.43
Tempering (gas)	4.0	0.19	0.39	4.58
Tempering (electric)	-	1.85	3.84	5.69
Laminating	1.0	-	-	*1.0*
Autoclave	0.5	0.14	0.29	0.93
Container Glass				
Annealing & finishing	1.6	0.23	0.48	2.31
Specialty Glass				
Annealing & polishing	3.0	0.05	0.10	3.15
Fiberglass				
Glass Wool	4.4	-	-	*4.4*
Textile Fibers	3.3	-	-	*3.3*

Source: U.S. DOE (2002a)

[17] Electricity losses are calculated using an average U.S. conversion factor of 7,088 Btu of energy loss per kWh of electricity purchased (U.S DOE 1997, 2002a).

[18] Estimates noted in italics are based only on natural gas use as data on electricity use were not available.

5. Energy Efficiency Improvement Opportunities

Opportunities exist within U.S. glass plants to improve energy efficiency while maintaining or enhancing productivity. Improving energy efficiency at a glass plant should be approached from several directions. First, a glass plant uses energy for equipment such as motors, pumps, and compressors. These important components require regular maintenance, good operation, and replacement, when necessary. Thus, a critical element of plant energy management involves the efficient control of cross-cutting equipment that powers the production processes of a plant. A second and equally important area is the proper and efficient operation of the processes. Process optimization and ensuring that the most productive technologies are in place are key to realizing energy savings in a plant's operation. Finally, throughout a glass plant, there are many processes in operation at the same time. Coordinating their efficiency and operation is necessary to ensure energy savings are realized. If a corporation operates more than one plant, energy management can be more complex than just considering the needs of a single plant. Whether for a single plant or for an entire corporation, establishing a strong organizational energy management framework is important to ensure that energy efficiency measures are implemented effectively.

The sections below categorize energy efficiency measures by their utility systems (general, compressed air, motors, lighting, heat and steam distribution, and others) or by process (batch preparation, melting, electric furnaces (for small batches), forehearths and forming, and annealing and finishing). An introduction to energy management and programs is provided in Section 5.1. Case studies for glass plants in the United States and abroad with specific energy and cost savings data are included with measure descriptions, where available. For other measures, comparable data from similar facilities, such as other industries with high temperature melting processes, are provided. A recent study (Rue et al. 2006) estimated the potential for energy efficiency improvement of 20 to 25% in the glass industry, with the furnace being the most important area for improvements, followed by refining and conditioning, cullet and batch preheating, and increased cullet use.

This analysis excludes opportunity costs (such as down time for equipment replacement) and the cost associated with the replacement of non-depreciated equipment because these values vary among individual plants and may be as low as zero for some. When available data exist, simple payback period as a first measure of profitability is provided. Better methods exist for determining profitability, such as return on investment or life cycle costing. However, these methods often require much more data than are available in this Energy Guide. It is expected that the reader will use the payback period as a first criterion to determine whether or not to pursue further research on profitability of the measure.

For U.S. glass plants, actual payback and savings for the measures will vary, depending on plant configuration and size, manufactured products, operating characteristics, and location. The values presented in this review are offered as guidelines since only a detailed study of a specific location can produce reliable estimates for that plant. Wherever possible, a range of savings and paybacks found under varying conditions for each glass sector is provided. Table 10 lists energy efficiency measures that are general utility or cross-cutting measures, characterized by the system to which they apply. Table 11 similarly lists energy efficiency measures that are process-specific, characterized by the process to which they apply.

Table 10: Cross-cutting (utilities) energy efficiency measures for the glass industry

Energy Management (Section 5.1)	
Energy management programs	Energy monitoring and control systems
Compressed Air (Section 5.2)	
System improvements	Controls
Maintenance	Properly sized pipe diameters
Monitoring	Heat recovery
Leak reduction	Natural gas engine-driven compressors
Turning off unnecessary compressed air	Energy recovery for air drying
Modification of system	Compressor motors
Replacement of compressed air by other sources	Use air at lowest possible pressure
Improved load management	Maximizing pressure dew point at air intake
Pressure drop minimization	Properly sized regulators
Inlet air temperature reduction	
Motors (Section 5.3)	
Motor management plan	Strategic motor selection
Maintenance	Properly sized motors
Adjustable-speed drives	Power factor correction
Minimizing voltage unbalances	High efficiency belts (cog belts).
Switched reluctance drives	
Lighting (Section 5.4)	
Lighting controls	Replace metal halide HID with high-intensity fluorescents
Turn off lights in unoccupied areas	HID lights voltage reduction
Exit signs—LEDs or radium strips	Replace magnetic with electronic ballast
Replace incandescent with fluorescent or CFL	Reflectors
Replace T-12 with T-8 or metal halides	Day lighting
Replace mercury with metal halides or high pressure sodium lights	System improvements
Heat and Steam Distribution—Distribution & Boilers (Section 5.5)	
Improve boiler process control	Boilers-Replace obsolete burners w/ optimized boilers
Reduce flue gas quantities	Steam and Hot Water distribution
Reduce excess air	Distribution-improve insulation
Correct boiler sizing in design	Distribution-maintain insulation
Boilers—improve insulation	Improve steam traps
Boiler maintenance	Maintain steam traps
Boilers—recover heat from flue gas	Monitor steam traps automatically
Boilers—return condensate	Repair leaks
Boilers—recover steam from blowdown	Recover flash steam
Other Cross Cutting Measures (Section 5.6)	
HVAC—building shell	Energy-efficient transformers
Other HVAC Meaures	Combined heat and power (CHP)

Table 11: Process-related energy efficiency measures for the glass industry

Batch Preparation (Section 5.7)	
Grinding—new technology	High-efficiency motors
Mixing	Adjustable/variable speed drives
Fluxing agents	High efficiency belts
Reduce batch wetting	Conveyor belt systems
Selective batching	Cullet separation and grinding systems
Optimize conveyor belts	Cullet preparation
Re-sizing of motors	
Melting Task—Changes to Existing Furnaces (Section 5.8.1)	
Process control systems	Refractories/Insulation
Minimize excess air/reduce air leakage	Properly position burners
Premix burners	Sealed burners
Adjustable speed drives on combustion air fans	Low-NOx burner
Waste heat boiler	Recuperative burners
Bubbler	Vertically-fired furnaces
Melting Task—Furnace Designs (Section 5.8.2)	
End-fired furnaces	Increase size of the refrigerator
Regenerative furnaces	SORG® Flex Melter
Melting Task—Oxy-Fuel Furnaces (Section 5.8.3)	
Synthetic air	Heat recovery from oxy-fuel furnace
Oxygen enriched air staging	High luminosity burners (oxy-fuel)
Oxy-fuel furnace	Tall crown furnace (oxy-fuel)
Melting Task—Cullet Use and Preheating (Section 5.8.4)	
Use more cullet and or filter dust	Batch and cullet preheating
Melting Task—Electric Furnaces (Section 5.8.5)	
Top-heating	Replace by fuel-fired furnace
Optimize electrode placement	
Forehearths and Forming (Section 5.9)	
Process control	Oxy-Fuel fired forehearth
High efficiency forehearths	Improved insulation
Annealing and Finishing (Section 5.10)	
Controls	Insulation
Optimize plant lay-out	Product drying system upgrade
Reduce air leakage	Glass coating
Emerging Technologies (Section 5.11)	
Oscillating combustion	Advanced glass melter
Segmented melter	Air-bottom cycle
Plasma melter	Glass fiber recycling
High speed convection	Use of waste glass in cutting
Reengineer process to spend less time in tank	Other emerging technologies
Submerged combustion melting	

5.1 Energy Management Systems and Programs

Although technological changes in equipment conserve energy, changes in staff behavior and attitude can also have a great impact. Energy efficiency training programs can help a company's staff incorporate energy efficiency practices into their day-to-day work routines. Personnel at all levels should be aware of energy use and company objectives for energy efficiency improvement. Often such information is acquired by lower-level managers but neither passed up to higher-level management nor passed down to staff (Caffal 1995). Energy efficiency programs with regular feedback on staff behavior, such as reward systems, have had the best results. Though changes in staff behavior (such as switching off lights or closing windows and doors) often save only small amounts of energy at one time, taken continuously over longer periods they can have a much greater effect than more costly technological improvements.

Establishing formal management structures and systems for managing energy that focus on continuous improvement are important strategies for helping companies manage energy use and implement energy efficiency measures. The U.S. EPA's ENERGY STAR program has developed a framework for energy management based on the observed best practices of leading companies. Other management frameworks, such as ISO 14001, can be used to ensure better organizational management of energy. One ENERGY STAR partner noted that using energy management programs in combination with the ISO 14001 program has had a greater impact on conserving energy at its plants than any other strategy.

Improving energy efficiency in glass manufacturing should be approached from several directions. A strong, corporate-wide energy management program is essential. Ideally, such a program would include facility, operations, environmental, health, and safety, and management personnel. Energy efficiency improvements to cross-cutting technologies,[19] such as the use of energy-efficient motors and the optimization of compressed air systems, present well-documented opportunities for energy savings. Optimizing system design and operations, such as maximizing process waste heat recovery, can also lead to significant reductions in energy use. In addition, production processes can often be fine-tuned to produce similar savings.

Energy management programs. Changing how energy is managed by implementing an organization-wide energy management program is one of the most successful and cost-effective ways to bring about energy efficiency improvements.

Energy efficiency does not happen on its own. A strong energy management program is required to create a foundation for positive change and to provide guidance for managing energy throughout an organization. Energy management programs also help to ensure that energy efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an ongoing process of continuous improvement. Furthermore, without the backing of a sound energy management program, energy efficiency improvements might not reach their full potential due to lack of a systems perspective and/or proper maintenance and follow-up.

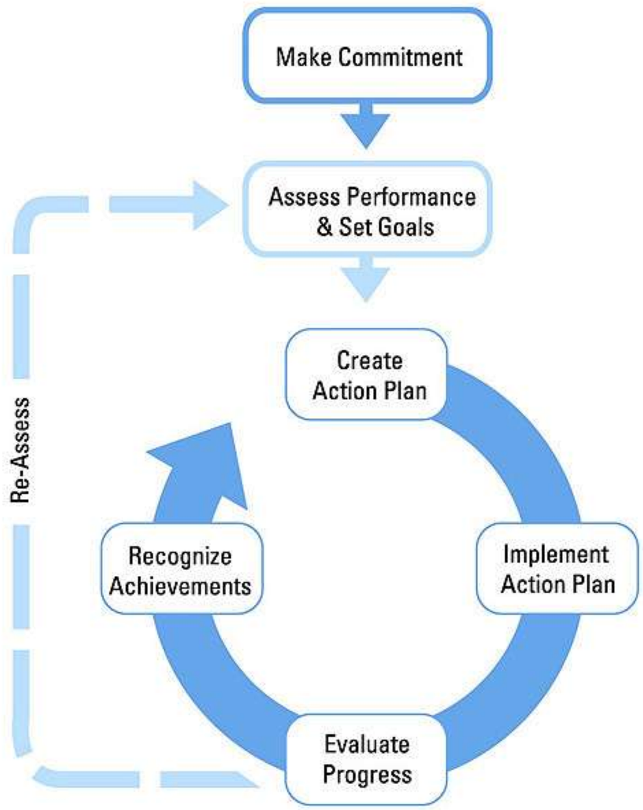
In companies without a clear program in place, opportunities for improvement may be known but may not be promoted or implemented because of organizational barriers. These barriers may include a lack of communication among plants, a poor understanding of how to create support for an energy efficiency project, limited finances, poor accountability for measures, or organizational

[19] Cross-cutting technologies are defined as equipment that is commonly used in many different sectors, such as boilers, pumps, motors, compressed air systems, and lighting.

inertia to changes from the status quo. Even when energy is a significant cost, many companies still lack a strong commitment to improve energy management.

The U.S. EPA, through ENERGY STAR, has worked with many of the leading industrial manufacturers to identify the basic aspects of an effective energy management program.[20] The major elements in a strategic energy management program are depicted in Figure 6.

Figure 6: Main elements of a strategic energy management program



A successful program in energy management begins with a strong organizational commitment to continuous improvement of energy efficiency. This involves assigning oversight and management duties to an energy director, establishing an energy policy, and creating a cross-functional energy team. Steps and procedures are then put in place to assess performance through regular reviews of energy data, technical assessments, and benchmarking. From this assessment, an organization is able to develop a baseline of energy use and set goals for improvement. Performance goals help to shape the development and implementation of an action plan.

An important aspect for ensuring the success of the action plan is involving personnel throughout the organization. Personnel at all levels should be aware of energy use and goals for efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all

[20] Read about strategic energy management at www.energystar.gov.

personnel, recognizing high achievement. Some examples of simple tasks employees can do are outlined in Appendix B.

Progress evaluation involves the regular review of both energy use data and the activities carried out as part of the action plan. Information gathered during the formal review process helps in setting new performance goals and action plans and in revealing best practices. Once best practices are established, the goal of the cross-functional energy team should be to replicate these practices throughout the organization. Establishing a strong communications program and seeking recognition for accomplishments are also critical steps. Strong communication and receiving recognition help to build support and momentum for future activities.

A quick assessment of an organization's efforts to manage energy can be made by comparing its current energy management program against the ENERGY STAR Energy Program Assessment Matrix provided in Appendix C.

An important step towards the development and successful implementation of a corporate energy management program is the formation of "energy teams". Successful programs in many companies have demonstrated the benefits of forming teams consisting of people from various plants and departments of the company to bring together the wide expertise needed for the successful development of energy efficiency programs and projects within a company or at a site. ENERGY STAR has developed a separate guide on forming energy management teams (US EPA 2006). Appendix D provides a checklist for the development of energy teams.

As discussed above, internal support for a business energy management program is crucial; however, support for business energy management programs can come from outside sources as well. Some utility companies work together with industrial clients to achieve energy savings. In these cases, utility personnel work directly with the company onsite. Furthermore, programs to support energy-efficiency improvements at industrial sites exist. Both the federal government and various states offer dedicated programs. Appendix E provides suggestions for programs that may offer support for energy management activities (e.g. tools, audits, financial support).

Facility audits can be a particularly effective form of outside support. In recent audits carried out by U.S. DOE Industrial Assessment Centers (IACs) at U.S. glass facilities, energy saving opportunities were identified that offered anywhere from $6,000-$300,000 in annual energy savings at payback periods ranging from only 1 to 11 months (U.S. DOE 2002b). In a U.S. DOE sponsored audit of the OSRAM Sylvania specialty glass plant in Exeter, New Hampshire, opportunities were identified for saving 1.7 million kWh of electricity and 3.3 MMBtu of natural gas per year, which would lead to savings of over $170,000 per year in energy costs (D'Antonio et al. 2003).

Specific energy savings and payback periods for overall adoption of a strategic energy management system vary from plant to plant and company to company. One company, United Glass, one of the leading glass container manufacturers in the UK, implemented many elements of the integrated energy management system discussed above, including setting up a monitoring and targeting program of energy consumption and costs, carrying out energy audits, improving motivation and awareness in all employees, setting up task force teams to deal with energy, and improving training (EEBPP 1996a). In addition to employing an energy manager, every member of the staff was trained for at least three days, while supervisors received more training. Savings in electricity, heavy fuel oils, and gas were $420,000 (1995) annually. The payback period for the energy manager's salary was 1 month, and for capital energy efficiency investment measures 1 to 2 years.

Energy monitoring and control systems. The use of energy monitoring and process control systems can play an important role in energy management and in reducing energy use. These may include sub-metering, monitoring, and control systems. They can reduce the time required to perform complex tasks, often improve product and data quality and consistency, optimize process operations, and improve production budgeting.

Monitoring and targeting systems can enable companies to achieve about 10% reduction in energy without any investment (EEBPP 1996b). Further improvements through improved data quality, improved time correspondence of data, and increased frequency or locations analyzed may improve the monitoring system and lead to further savings. For process control systems, energy and cost savings are typically around 5% or more for many industrial applications (but can vary greatly from plant to plant). These savings apply to plants without updated process control systems; many U.S. plants may already have modern process control systems in place to improve energy efficiency.

Waterford Crystal at Kilbarry, Dungarvan and Butlerstown (Ireland) began monitoring and targeting to reduce energy costs in 1993 (EEBPP 1996b). With continuous monitoring of production processes, HVAC, lighting, and upgrades to air conditioning and lighting in offices, they realized a 20% reduction in energy consumption with a payback of only 1 year.

Using a mathematical model to control its air drying process, Owens Corning Veil Netherlands was able to reduce drying air and optimize the consumption of natural gas (NOVEM 1997). They found savings of 500,000 m^3 per year worth \$67,000 (1997). With additional savings of \$52,000 (1997) from reduced product losses and a project cost of \$99,000 (1997), the payback was about 10 months.

5.2 Compressed Air

Compressed air may be used throughout the plant for tools, but is mostly used in the forming of containers as well as for the forming of other specialty glass products. Compressed air use will vary with product and from plant to plant. For container glass, electricity use for forming is estimated at 105 kWh/ton (U.S. DOE 2002a), of which a large part is for compressed air. At a specialty glass plant producing lamps (using an electric furnace), the share of electricity use for compressed air generation was estimated at 3% of total electricity use (D'Antonio et al. 2003), or 7% of all non-furnace electricity consumed. Compressed air is the most expensive form of energy used in an industrial plant because of its poor efficiency. Typically, efficiency from compressed air generation to end use is around 10% for compressed air systems (LBNL et al. 1998). Because of this inefficiency, if compressed air is used, it should be of minimum quantity for the shortest possible time. Compressed air should also be constantly monitored and reweighed against alternatives. In addition to the measures detailed in this section, many other motor-directed measures could also be applied to the compressors (see Section 5.3 on motors).

Many of the opportunities to reduce compressed air system energy use are not prohibitively expensive; payback periods for some options are extremely short. For example, at an Automotive Components Holdings glass plant in Nashville, Tennessee, a comprehensive energy audit and efficiency improvement campaign on its compressor systems led to leak reductions, lower operating pressures, and compressor efficiency upgrades that delivered annual savings of over \$700,000 at a payback of just 1 year (U.S. DOE 2003). Of the \$700,000 in annual savings,

$300,000 were due to energy savings and $400,000 were due to reduced maintenance and labor costs resulting from the efficiency improvements.

A similar comprehensive audit at OSRAM Sylvania's specialty glass plant in Exeter, New Hampshire (which included control strategies, leak detection, and demand reduction in its evaluation) identified opportunities for electricity savings of 164,000 kWh per year, which would lead to energy cost savings of nearly $14,000 per year (D'Antonio et al. 2003). The savings were equal to 25% of the electricity used in the compressed air system.

System improvements. Adding additional compressors should be considered only after a complete system evaluation. In many cases, compressed air system efficiency can be managed and reconfigured to operate more efficiently without purchasing additional compressors. System improvements utilize many of the energy efficiency measures for compressors discussed below. Compressed air system service providers offer integrated services both for system assessments and for ongoing system maintenance needs, alleviating the need to contact several separate firms. The Compressed Air Challenge® (http://www.compressedairchallenge.org) offers extensive training on the systems approach, technical publications, and free web-based guidance for selecting the right integrated service provider. Also provided are guidelines for walk-through evaluations, system assessments, and fully instrumented system audits (CAC 2002).

Beatson Clark (in the United Kingdom), a glass container manufacturer, refurbished its compressor system in 1992 by decommissioning five of the eight compressors and installing Programmable Logic Controllers (PLC) on the remaining three compressors (EEBPP 1995). The PLC cost $28,000 (1992), valve modification cost $22,000 (1992) and compressor overhaul (for all three) cost $19,000 (1992). They found energy savings of 522,732 kWh per year, a 12% savings over the old configuration, worth $32,800/year (1992). They also identified maintenance savings of $19,500/year (1992), resulting in an overall payback of 1.3 years. In addition to energy and maintenance saving benefits, the scrap rates from the forming stations have been reduced because of more stable air pressure.

Maintenance. Inadequate maintenance can lower compression efficiency and increase air leakage or pressure variability, as well as lead to increased operating temperatures, poor moisture control, and excessive contamination. Improved maintenance will reduce these problems and save energy. Compressors should be located in a dry, clean, cool (5°C to 35°C), and well-ventilated place with enough room for proper air flow and maintenance accessibility (Kaeser Compressors 1998). Proper maintenance includes the following (U.S. DOE and CAC 2003; Scales and McCulloch 2007):

- *Ongoing filter inspection and maintenance.* Blocked filters increase the pressure drop across the filter, which wastes system energy. By inspecting and periodically cleaning filters, filter pressure drops may be minimized. Fixing improperly operating filters will also prevent contaminants from entering into equipment, which can cause premature wear. Generally, when pressure drops exceed 2 psi to 3 psi, particulate and lubricant removal elements should be replaced. Regular filter cleaning and replacement has been projected to reduce compressed air system energy consumption by around 2% (Radgen and Blaustein 2001).

- *Keeping compressor motors properly lubricated and cleaned*. Poor motor cooling can increase motor temperature and winding resistance, shortening motor life and increasing energy consumption. Compressor lubricant should be changed every 2 to 18 months and periodically checked to make sure that it is at the proper level. In addition, proper compressor motor lubrication will reduce corrosion and degradation of the system. An analysis of several U.S. case studies in the container, fiber, and specialty glass industries shows an average payback period for using synthetic oil lubricants of less than 6 months (IAC 2005).[21]

- *Inspection of fans and water pumps* for peak performance.

- *Inspection of drain traps* to ensure that they are not stuck in either the open or closed position and are clean. Some users leave automatic condensate traps partially open at all times to allow for constant draining. This practice wastes substantial energy and should never be undertaken. Instead, simple pressure driven valves should be employed. Malfunctioning traps should be cleaned and repaired instead of left open. Some auto drains, such as float switch or electronic drains, do not waste air. Inspecting and maintaining drains typically has a payback of less than two years (U.S. DOE 2004c).

- *Maintaining the coolers* on the compressor to ensure that the dryer gets the lowest possible inlet temperature (U.S. DOE and CAC 2003).

- *Compressor belt inspection.* Where belt-driven compressors are used, belts should be checked regularly for wear and adjusted. A good rule of thumb is to adjust them after every 400 hours of operation.

- *Replacing air lubricant separators* according to specifications or sooner. Rotary screw compressors generally start with their air lubricant separators having a 2 psi to 3 psi pressure drop at full load. When the pressure drop increases to 10 psi, the separator should be changed (U.S. DOE and CAC 2003).

- *Checking water-cooling systems* regularly for water quality (pH and total dissolved solids), flow, and temperature. Water-cooling system filters and heat exchangers should be cleaned and replaced per the manufacturer's specifications.

- *Minimizing compressed air leak throughout the systems.*

- Applications requiring compressed air should be *checked for excessive pressure, duration, or volume*. Applications not requiring maximum system pressure should be regulated, either by production line sectioning or by pressure regulators on the equipment itself. Using more pressure than required wastes energy and can also result in shorter equipment life and higher maintenance costs. Case studies have demonstrated that the payback period for this measure can be shorter than half a year (IAC 2005).

Monitoring. In addition to proper maintenance, a continuous monitoring system can save significant energy and operating costs in compressed air systems. Effective monitoring systems typically include the following (CADDET 1997):

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[21] The Industrial Assessment Center (IAC) database contains case study data for a wide range of industrial energy efficiency measures. It gives a wide variety of information, including implementation costs and savings for each case study. Using this information, a simple payback for each case was calculated. An overall payback for a particular technology was calculated by averaging all the individual cases. In order to accurately represent applicable technology for the glass industry, only the SIC codes that pertained to the glass industry (i.e., SIC 3221, 3229, and 3296) were sampled.

- Pressure gauges on each receiver or main branch line and differential gauges across dryers, filters, etc.

- Temperature gauges across the compressor and its cooling system to detect fouling and blockages.

- Flow meters to measure the quantity of air used.

- Dew point temperature gauges to monitor the effectiveness of air dryers.

- Kilowatt-hour meters and hours run meters on the compressor drive.

- Checking of compressed air distribution systems after equipment has been reconfigured to be sure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.

- Checking for flow restrictions of any type in a system, such as an obstruction or roughness, which can unnecessarily raise system operating pressures. As a rule of thumb, every 2 psi pressure rise resulting from resistance to flow can increase compressor energy use by 1% (U.S. DOE and CAC 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles and lubricators (demand side), as well as air/lubricant separators, after-coolers, moisture separators, dryers and filters.

- Checking for compressed air use outside production hours.

Leak reduction. Air leaks can be a significant source of wasted energy. A typical industrial facility that has not been well maintained will likely have a leak rate ranging from 20% to 30% of total compressed air production capacity (U.S. DOE and CAC 2003). Overall, a 20% reduction of annual energy consumption in compressed air systems is projected for fixing leaks (Radgen and Blaustein 2001).

The magnitude of the energy loss associated with a leak varies with the size of the hole in the pipes or equipment. A compressor operating 2,500 hours per year at 87 psi with a leak diameter of 0.02 inches (½ mm) is estimated to lose 250 kWh per year; 0.04 inches (1 mm) to lose 1,100 kWh per year; 0.08 inches (2 mm) to lose 4,500 kWh per year; and 0.16 in. (4 mm) to lose 11,250 kWh per year (CADDET 1997). An analysis of several U.S. case studies in the fiber, flat, container, and specialty glass industries shows an average payback period for this measure of less than 4 months (IAC 2005).

In addition to increased energy consumption, leaks can make air-powered equipment less efficient, shorten equipment life, and lead to additional maintenance costs and increased unscheduled downtime. Leaks also cause an increase in compressor energy and maintenance costs.

The most common areas for leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects, and thread sealants. The best way to detect leaks is to use an ultrasonic acoustic detector, which can recognize the high frequency hissing sounds associated with air leaks. Leak detection and repair programs should be ongoing efforts.

A limited survey of the compressed air system at Anchor Glass Container Corporation's Warner Robins, Georgia, plant found that air leaks accounted for more than 20% of total air consumption. The survey recommended renewed efforts to reduce leaks (OIT 2002).

Turning off unnecessary compressed air. Equipment that is no longer using compressed air should have the air turned off completely. This can be done using a simple solenoid valve (Scales 2002). Compressed air distribution systems should be checked when equipment has been reconfigured to ensure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.

Modification of system in lieu of increased pressure. For individual applications that require a higher pressure, instead of raising the operating pressure of the whole system, special equipment modifications should be considered, such as employing a booster, increasing a cylinder bore, changing gear ratios, or changing operation to off peak hours.

Replacement of compressed air by alternative sources. Many operations can be accomplished more economically and efficiently using energy sources other than compressed air (U.S. DOE 2004c, 2004d). Various options exist to replace compressed air use, including:

- Cooling electrical cabinets: air conditioning fans should be used instead of using compressed air vortex tubes.

- Flowing high-pressure air past an orifice to create a vacuum: a vacuum pump system should be applied instead of compressed air venturi methods.

- Cooling, aspirating, agitating, mixing, or package inflating: use blowers instead of compressed air.

- Cleaning parts or removing debris: brushes, blowers, or vacuum pump systems should be used instead of compressed air.

- Moving parts: blowers, electric actuators, or hydraulics should be used instead of compressed air.

- Tools or actuators: electric motors should be considered because they are more efficient than using compressed air (Howe and Scales 1995). However, it has been reported that motors can have less precision, shorter lives, and lack safety compared to compressed air. In these cases, using compressed air may be a better choice.

Four cases studies in the U.S. glass industry (one in the flat glass segment, one in the specialty glass segment, and two in the fiber glass segment) estimate an average payback period for replacing compressed air with other applications of 5 months (IAC 2005).[22]

Improved load management. Because of the large amount of energy consumed by compressors, whether in full operation or not, partial load operation should be avoided. For example, unloaded rotary screw compressors still consume 15% to 35% of full-load power while delivering no useful

[22] Numerous case studies across all U.S. industries estimate the average payback period for this measure to be only slightly higher at less than 9 months (IAC 2005).

work (U.S. DOE and CAC 2003). Centrifugal compressors are cost effective when operated at high loads (Castellow et al. 1997).

Air receivers can be employed near high demand areas to provide a supply buffer to meet short-term demand spikes that can exceed normal compressor capacity. In this way, the number of required online compressors may be reduced. Multi-stage compressors theoretically operate more efficiently than single-stage compressors. Multi-stage compressors save energy by cooling the air between stages, reducing the volume and work required to compress the air. Replacing single-stage compressors with two-stage compressors typically provides a payback period of two years or less (Ingersoll-Rand 2001). Using multiple smaller compressors instead of one large compressor can save energy as well. Large compressors consume more electricity when they are unloaded than do multiple smaller compressors with similar overall capacity. An analysis of U.S. case studies shows an average payback period for optimally sizing compressors of about 1.2 years (IAC 2005).

An assessment of the compressed air system at Anchor Glass Container Corp's plant in Warner Robins, Georgia, recommended the use of a high-pressure air receiver, so that a trim compressor could be shut down for 10-20 minutes each time between loads (OIT 2002).

Pressure drop minimization. An excessive pressure drop will result in poor system performance and excessive energy consumption. Flow restrictions of any type in a system, such as an obstruction or roughness, results in higher operating pressures than is truly needed. Resistance to flow increases the drive energy on positive displacement compressors by 1% of connected power for each 2 psi of differential (U.S. DOE and CAC 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles, and lubricators (demand side), as well as air/lubricant separators on lubricated rotary compressors and after-coolers, moisture separators, dryers, and filters (supply side).

Minimizing pressure drop requires a systems approach in design and maintenance. Air treatment components should be selected with the lowest possible pressure drop at specified maximum operating conditions and best performance. Manufacturers' recommendations for maintenance should be followed, particularly in air filtering and drying equipment, which can have damaging moisture effects like pipe corrosion. Finally, the distance the air travels through the distribution system should be minimized. Audits of industrial facilities found that the payback period is typically shorter than 3 months for this measure (IAC 2005).

Inlet air temperature reduction. If airflow is kept constant, reducing the inlet air temperature reduces the energy used by the compressor. In many plants, it is possible to reduce the inlet air temperature to the compressor by taking suction from outside the building. As a rule of thumb, each temperature reduction of 5°F (3°C) will save 1% compressor energy (CADDET 1997a; Parekh 2000). A payback period of two to five years has been reported for importing fresh air (CADDET 1997a). In addition to energy savings, compressor capacity is increased when cold air from outside is used. Industrial case studies have found an average payback period for importing outside air of less than 1.7 years (IAC 2005), but costs can vary significantly depending on facility layout.

Controls. The primary objectives of compressor control strategies are to shut off unneeded compressors and to delay bringing on additional compressors until needed. Energy savings for sophisticated compressor controls have been reported at around 12% annually (Radgen and Blaustein 2001). An excellent review of compressor controls can be found in Compressed Air

Challenge® *Best Practices for Compressed Air Systems* (Second Edition) (Scales and McCulloch 2007). Common control strategies for compressed air systems include:

- *Start/stop (on/off) controls*, in which the compressor motor is turned on or off in response to the discharge pressure of the machine. Start/stop controls can be used for applications with very low duty cycles and are applicable to reciprocating or rotary screw compressors. The typical payback for start/stop controls is one to two years (CADDET 1997).

- *Load/unload controls*, or constant speed controls, which allow the motor to run continuously but unloads the compressor when the discharge pressure is adequate. In most cases, unloaded rotary screw compressors still consume 15% to 35% of full-load power while delivering no useful work (U.S. DOE and CAC 2003). Hence, load/unload controls can be inefficient.

- *Modulating or throttling controls*, which allow the output of a compressor to be varied to meet flow requirements by closing down the inlet valve and restricting inlet air to the compressor. Throttling controls are applied to centrifugal and rotary screw compressors.

- *Single master sequencing system controls*, which take individual compressor capacities on-line and off-line in response to monitored system pressure demand and shut down any compressors running unnecessarily. System controls for multiple compressors typically offer a higher efficiency than individual compressor controls.

- *Multi-master controls*, which are the latest technology in compressed air system control. Multi-master controls are capable of handling four or more compressors and provide both individual compressor control and system regulation by means of a network of individual controllers (Martin et al. 2000). The controllers share information, allowing the system to respond more quickly and accurately to demand changes. One controller acts as the lead, regulating the whole operation. This strategy allows each compressor to function at a level that produces the most efficient overall operation. The result is a highly controlled system pressure that can be reduced close to the minimum level required (U.S. DOE and CAC 2003). According to Nadel et al. (2002), such advanced compressor controls are expected to deliver energy savings of about 3.5% where applied.

A variable speed air compressor was installed at the Lewis and Towers, Ltd. glass container manufacturing plant in Edenbridge, United Kingdom, for one of four compressors being replaced (EEBPP 1999). In addition, independent monitoring was undertaken to confirm operating characteristics and energy savings of the compressors. The additional cost of a variable speed drive (VSD) compressor was $10,000 (1999). They found the VSD compressor is saving about 31,200 kWh per year in electricity, totaling about $2,820 (1999). Through the monitoring, they also found one of the other four compressors not operating correctly. Predicted savings when all four compressors are working properly are 83,100 kWh or $5,700 (1999). This would result in a payback for the VSD compressor of 1.7 years. As it were, with the faulty compressor, payback would be 3.4 years.

Properly sized pipe diameters. Increasing pipe diameters to the greatest size that is feasible and economical for a compressed air system can help to minimize pressure losses and leaks, which reduces system operating pressures and leads to energy savings. Increasing pipe diameters typically reduces compressed air system energy consumption by 3% (Radgen and Blaustein

2001). Further savings can be realized by ensuring other system components (e.g., filters, fittings, and hoses) are properly sized.

Heat recovery. As much as 90% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a heat recovery unit can recover 50% to 90% of this available thermal energy and apply it to space heating, process heating, water heating, make-up air heating, boiler make-up water preheating, and heat pump applications (Parekh 2000). It has been estimated that approximately 50,000 Btu/hour of recoverable heat is available for each 100 cfm of compressor capacity (U.S. DOE and CAC 2003). Payback periods are typically less than one year (Galitsky et al. 2005a).

Heat recovery for space heating is not as common with water-cooled compressors because an extra stage of heat exchange is required and the temperature of the available heat is somewhat low. However, with large water-cooled compressors, recovery efficiencies of 50% to 60% are typical (U.S. DOE and CAC 2003). Implementing this measure can recover up to 20% of the energy used in compressed air systems annually for space heating (Radgen and Blaustein 2001). Two case studies in the specialty and fiber glass industries estimate the payback period for this measure is less than 6 months (IAC 2005).

Natural gas engine-driven air compressors. Gas engine-driven air compressors can replace electric compressors with some advantages and disadvantages. Gas engine-driven compressors are more expensive and can have higher maintenance costs, but may have lower overall operating costs depending on the relative costs of electricity and gas. Variable-speed capability is standard for gas-fired compressors, offering a high efficiency over a wide range of loads. Heat can be recovered from the engine jacket and exhaust system. However, gas engine-driven compressors have some drawbacks: they need more maintenance, have a shorter useful life, and sustain a greater likelihood of downtime. According to Galitsky et al. (2005a), gas engine-driven compressors currently account for less than 1% of the total air compressor market.

Ultra Creative Corporation, a U.S. manufacturer of specialty plastic bags, installed gas engine-driven compressors in its plant in Brooklyn, New York. The initial costs were $85,000 each for two 220 hp units and $65,000 for one 95 hp unit. The company reported savings of $9,000 in monthly utilities (averaging $108,000 annually) (Audin 1996).

Nestlé Canada found that its gas engine-driven air compressor system was a cost effective option when it was operated properly. The company's projected payback period was estimated as low as 2.6 years with a 75% efficient heat recovery system, and as high as 4.2 years without heat recovery (Audin 1996).

Energy recovery for air drying. In many industries including glass, compressed air must be dried before use. The traditional method of drying compressed air typically includes an after-cooler and a refrigerated dryer. Alternatively, some operators are beginning to switch to a reheat system that has a low capital investment, lower energy use, and maintenance free operation (R P Adams Co. 1998). The heat exchanger's cooling source is the same compressed air that has already been cooled by the reheat system after-cooler. A cyclone separator removes up to 99% of the condensed liquid present in the air stream prior to returning it to the regenerative heat exchanger. Two main advantages exist. The system reduces the amount of coolant needed in the after-cooler because the regenerative heat exchanger performs part of the cooling load. The compressed air is reheated using its own waste heat, hence energy use is reduced.

Compressor motors. Motors are important in compressor systems as well, and are discussed in detail in section 5.3. Below are a few examples of their use with compressors:

- *Adjustable speed drives (ASDs).* Implementing adjustable speed drives in rotary compressor systems can save 15% of the annual energy consumption (Radgen and Blaustein 2001). A Glasuld glass wool insulation manufacturing plant in Vamdrup, Denmark, installed an ASD on its main compressor, which led to annual electricity savings of 200 MWh (a 29% reduction). The payback period of the project was 3 years (CADDET 1998).

- *High efficiency motors.* Installing high efficiency motors in compressor systems reduces annual energy consumption by 2%, and has a payback period of less than 3 years (Radgen and Blaustein 2001). For compressor systems, the largest savings in motor performance are typically found in small machines operating less than 10 kW.

Use air at lowest possible pressure. Although system pressure may be higher, air used for a particular application should be at the lowest pressure needed. In one example in the auto industry, Toyota uses their entire piping system as air receivers/regulators to manage air to applications (see "load management," above). Quality should also be at the lowest required; it is more economical to treat small amounts of compressed air for a particular application than to treat the entire air supply (Kaeser Compressors 1998). An analysis of several U.S. case studies in the fiber, flat, and specialty glass industries shows an average payback period for using lower pressure of less than 3 months (IAC 2005).

Maximizing the allowable pressure dew point at air intake. Choose the dryer that has the maximum allowable pressure dew point, and best efficiency. A rule of thumb is that desiccant dryers consume 7 to 14% of the total energy of the compressor, whereas refrigerated dryers consume 1 to 2% as much energy as the compressor (Ingersoll Rand 2001). Consider using a dryer with a floating dew point.

Properly sized regulators. Regulators can provide the largest energy savings in compressed air systems (Toyota 2002). By properly sizing regulators, compressed air will be saved that is otherwise wasted as excess air. Also, specify pressure regulators that close when failing.

5.3 Motors[23]

Motors are used throughout glass manufacturing plants in compressed air systems, cooling water pumps, furnace air blowers, ventilation fans, as well as for transport (conveyors). According to the U.S. DOE, the typical industrial plant in the United States can reduce its electricity use by around 5% to 15% by improving the efficiency of its motor-driven systems (U.S. DOE 2006).

When considering energy efficiency improvements to a facility's motor systems, it is important to take a "systems approach." A systems approach strives to optimize the energy efficiency of entire

[23] The U.S. DOE's Industrial Technologies Program provides a variety of resources for improving the efficiency of industrial motor systems, which can be consulted for more detailed information on many of the measures presented in this section. For a collection of tips, tools, and industrial case studies on motor efficiency, visit the Industrial Technologies Program's *BestPractices* Motors, Pumps, and Fans website at: http://www1.eere.energy.gov/industry/bestpractices/systems.html. Furthermore, the Motor Decisions Matter[SM] Campaign also provides a number of excellent resources for improving motor system efficiency (http://www.motorsmatter.org/).

motor systems (i.e., motors, drives, driven equipment such as pumps, fans, and compressors, and controls), not just the energy efficiency of motors as individual components. A systems approach analyzes both the energy supply and energy demand sides of motor systems as well as how these sides interact to optimize total system performance, which includes not only energy use but also system uptime and productivity.

A systems approach typically involves the following steps. First, all applications of motors in a facility should be located and identified. Second, the conditions and specifications of each motor should be documented to provide a current systems inventory. Third, the needs and the actual use of the motor systems should be assessed to determine whether or not motors are properly sized and also how well each motor meets the needs of its driven equipment. Fourth, information on potential repairs and upgrades to the motor systems should be collected, including the economic costs and benefits of implementing repairs and upgrades to enable the energy efficiency improvement decision-making process. Finally, if upgrades are pursued, the performance of the upgraded motor systems should be monitored to determine the actual costs savings (SCE 2003).

The motor system energy efficiency measures below reflect important aspects of this systems approach, including matching motor speeds and loads, proper motor sizing, and upgrading system components.

Motor management plan. A motor management plan is an essential part of a plant's energy management strategy. Having a motor management plan in place can help companies realize long-term motor system energy savings and will ensure that motor failures are handled in a quick and cost effective manner. The Motor Decisions Matter^{SM} Campaign suggests the following key elements for a sound motor management plan (MDM 2007):

1. Creation of a motor survey and tracking program.
2. Development of guidelines for proactive repair/replace decisions.
3. Preparation for motor failure by creating a spares inventory.
4. Development of a purchasing specification.
5. Development of a repair specification.
6. Development and implementation of a predictive and preventive maintenance program.

The Motor Decisions Matter^{SM} Campaign's *Motor Planning Kit* contains further details on each of these elements (MDM 2007).

Strategic motor selection. Several factors are important when selecting a motor, including motor speed, horsepower, enclosure type, temperature rating, efficiency level, and quality of power supply. When selecting and purchasing a motor, it is also critical to consider the life-cycle costs of that motor rather than just its initial purchase and installation costs. Up to 95% of a motor's costs can be attributed to the energy it consumes over its lifetime, while only around 5% of a motor's costs are typically attributed to its purchase, installation, and maintenance (MDM 2007). Life cycle costing (LCC) is an accounting framework that allows one to calculate the total costs of ownership for different investment options, which leads to a more sound evaluation of competing options in motor purchasing and repair or replacement decisions. A specific LCC guide has been developed for pump systems (Fenning et al. 2001), which also provides an introduction to LCC for motor systems.

The selection of energy-efficient motors can be an important strategy for reducing motor system life-cycle costs. Energy-efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also run cooler (which may help reduce facility heating loads) and have higher service factors, longer bearing life, longer insulation life, and less vibration.

To be considered energy efficient in the United States, a motor must meet performance criteria published by the National Electrical Manufacturers Association (NEMA). The Consortium for Energy Efficiency (CEE) has described the evolution of standards for energy-efficient motors in the United States, which is helpful for understanding "efficient" motor nomenclature (CEE 2007):

- NEMA Energy Efficient (NEMA EE) was developed in the mid-1980s to define the term "energy efficient" in the marketplace for motors. NEMA Standards Publication No. MG-1 (Revision 3), Table 12-11 defines efficiency levels for a range of different motors (NEMA 2002).

- The Energy Policy Act of 1992 (EPACT) required that many commonly used motors comply with NEMA "energy efficient" ratings if offered for sale in the United States.

- In 1996, the CEE Premium Efficiency Criteria specification was designed to promote motors with higher efficiency levels than EPACT required, for the same classes of motors covered by EPACT. The CEE efficiency levels specified were generally two NEMA efficiency bands (Table 12-10, NEMA MG-1 Revision 3) above those required by EPACT.

- In 2001, the NEMA Premium® Efficiency Electric Motor specification was developed to address confusion with respect to what constituted the most efficient motors available in the market. This specification was developed by NEMA, CEE, and other stakeholders, and was adapted from the CEE 1996 criteria. It currently serves as the benchmark for premium energy efficient motors. NEMA Premium® also denotes a brand name for motors which meet this specification. Specifically, this specification covers motors with the following attributes:

    - Speed: 2, 4, and 6 pole
    - Size: 1-500 horsepower (hp)
    - Design: NEMA A and B
    - Enclosure type: open and closed
    - Voltage: low and medium voltage
    - Class: general, definite, and special purpose

The choice of installing a premium efficiency motor strongly depends on motor operating conditions and the life cycle costs associated with the investment. In general, premium efficiency motors are most economically attractive when replacing motors with annual operation exceeding 2,000 hours/year. However, software tools such as MotorMaster+ (see Appendix E) can help identify attractive applications of premium efficiency motors based on the specific conditions at a given plant.

Sometimes, even replacing an operating motor with a premium efficiency model may have a low payback period. According to data from the Copper Development Association, the upgrade to high-efficiency motors, as compared to motors that achieve the minimum efficiency as specified by EPACT, can have paybacks of less than 15 months for 50 hp motors (CDA 2001). Payback times will vary based on size, load factor, running time, local energy costs, and available rebates and/or incentives (see Appendix E). Given the quick payback time, it usually makes sense to by the most efficient motor available (U.S. DOE and CAC 2003).

NEMA and other organizations have created the Motor Decisions Matter℠ campaign to help industrial and commercial customers evaluate their motor repair and replacement options, promote cost-effective applications of NEMA Premium® motors and "best practice" repair, and support the development of motor management plans before motors fail.

An audit of two Anchor Glass Container plants in Georgia and Florida found opportunities to replace large motors with energy-efficient motors with a payback period of 2.5 years or less (OIT 2002).

In some cases, it may be cost-effective to rewind an existing energy efficient motor, instead of purchasing a new motor. As a rule of thumb, when rewinding costs exceed 60% of the costs of a new motor, purchasing the new motor may be a better choice (MDM 2007). When rewinding a motor, it is important to choose a motor service center that follows best practice motor rewinding standards in order to minimize potential efficiency losses. An ANSI-approved recommended best practice standard has been offered by the Electric Apparatus Service Association (EASA) for the repair and rewinding of motors (EASA 2006). When best rewinding practices are implemented, efficiency losses are typically less than 0.5% to 1% (EASA 2003). However, poor quality rewinds may result in larger efficiency losses. It is therefore important to inquire whether the motor service center follows EASA best practice standards (EASA 2006).

Maintenance. The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can be categorized as either preventative or predictive. Preventative measures, the purpose of which is to prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, load consideration, and motor ventilation, alignment, and lubrication. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs (Barnish et al. 1997). The savings associated with an ongoing motor maintenance program are significant, and could range from 2% to 30% of total motor system energy use (Efficiency Partnership 2004).

Properly sized motors. Motors that are sized inappropriately result in unnecessary energy losses. Where peak loads on driven equipment can be reduced, motor size can also be reduced. Replacing oversized motors with properly sized motors saves, on average for U.S. industry, 1.2% of total motor system electricity consumption (Xenergy 1998). Higher savings can often be realized for smaller motors and individual motor systems.

To determine the proper motor size, the following data are needed: load on the motor, operating efficiency of the motor at that load point, the full-load speed of the motor to be replaced, and the full-load speed of the replacement motor. The U.S. DOE's BestPractices program provides a fact sheet that can assist in decisions regarding replacement of oversized and under loaded motors (U.S. DOE 1996). Additionally, software packages such as MotorMaster+ (see Appendix E) can aid in proper motor selection.

Adjustable speed drives (ASDs).[24] Adjustable-speed drives better match speed to load requirements for motor operations, and therefore ensure that motor energy use is optimized to a

[24] Several terms are used in practice to describe a motor system that permits a mechanical load to be driven at variable speeds, including adjustable speed drives (ASDs), variable speed drives (VSDs), adjustable

given application. Adjustable-speed drive systems are offered by many suppliers and are available worldwide. Worrell et al. (1997) provide an overview of savings achieved with ASDs in a wide array of applications; typical energy savings are shown to vary between 7% and 60%.

A 1994 survey by the U.S. EIA reports that over 60% of the establishments surveyed in the glass industry report the use of ASDs to some degree (EIA 1997). This suggests that there may still be potential for expansion of the use of ASDs in the glass industry.

Anchor Glass, supported by the U.S. DOE, undertook an audit of energy efficiency opportunities at their container glass plants in Warner Robins, Georgia, and Jacksonville, Florida. Large electricity savings were found by implementing ASDs for cooling water pumps to optimize the cooling tower water flow and pressure (payback of 1.8 years). They also identified the potential application of ASDs for furnace air and stack draft blowers (payback of 1.7 years) and for cooling blowers in the forming and glass handling (payback of 1.8 years) (OIT 2002). Potential savings were identified for ASDs on cooling water pumps at 524,600 kWh per year, and 808,400 kWh per year for furnace air blowers. An analysis of other U.S. case studies shows an average payback of less than two years (IAC 2005).

Automotive Components Holdings's Nashville, Tennessee automotive glass plant changed its old pumps to new, smaller pumps fitted with VSDs (OIT 2003). Not only did the project save energy, but water use was reduced, expensive water treatment chemicals needs reduced, plant safety improved by eliminating an electrical hazard on the pump barge and labor costs were reduced because the new pumps also contained remote monitoring capabilities not found on the old pumps. Total costs were $350,000 and total annual savings were $280,000, yielding a payback period of 15 months. Energy savings were 3.2 million kWh or $98,000 per year.

An audit of a Corning specialty glass plant in Greenville, Ohio, found various potential applications of VSDs. Installing a VSD on a mold cooling fan motor was estimated to save 700 MWh/year (equivalent to $20,000/year) at a payback period of about 1 year. Installing a VSD on a cooling loop motor would result in savings of 200 MWh/year with a payback period of 1.2 years, while installing a VSD on a machine cooling loop motor would result in savings of 100 MWh/year with a payback period of 2.8 years (US DOE 2004b).

At Knauf Insulation Ltd., a manufacturer of glass wool insulation based in Wales (United Kingdom), ASDs were installed on the main suction fan motors in its wool forming process. The ASDs led to annual energy savings of nearly 55% compared to the old constant-speed fan drives that the ASDs replaced (CADDET 2003). The annual energy savings of this measure were estimated at 3.8 million kWh, which led to a reduction in electricity-related CO_2 emissions of 1.6 kt CO_2 per year. The payback period of this project was less than 2 years.

Power factor correction. Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor. A low power factor may result in increased power consumption, and hence increased electricity costs. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with premium-efficient motors (see above), and installing capacitors in the AC circuit to reduce the magnitude of reactive power in the system.

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frequency drives (AFDs), and variable frequency drives (VFDs). The term ASD is used throughout this Energy Guide for consistency.

Minimizing voltage unbalances. A voltage unbalance degrades the performance and shortens the life of three-phase motors. A voltage unbalance causes a current unbalance, which will result in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating, which can reduce the life of a motor's winding insulation. Voltage unbalances may be caused by faulty operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1%. Even a 1% unbalance will reduce motor efficiency at part load operation, while a 2.5% unbalance will reduce motor efficiency at full load operation.

For a 100 hp motor operating 8,000 hours per year, a correction of the voltage unbalance from 2.5% to 1% will result in electricity savings of 9,500 kWh or almost $500 at an electricity rate of $0.05/kWh (U.S. DOE 2005b).

By regularly monitoring the voltages at the motor terminal and through regular thermographic inspections of motors, voltage unbalances may be identified. It is also recommended to verify that single-phase loads are uniformly distributed and to install ground fault indicators as required. Another indicator that a voltage unbalance may be a problem is 120 Hz vibration, which should prompt an immediate check of voltage balance (U.S. DOE 2005b). The typical payback period for voltage controller installation on lightly loaded motors in the United States is 2.6 years (IAC 2005).

High efficiency belts (cog belts). Belts make up a variable, but significant portion of the total motor drive in most plants. Standard vee belts tend to stretch, slip, bend, and compress, which leads to a loss of efficiency (CIPEC 2001b). Replacing standard vee belts with cog belts can save energy and money, even as a retrofit. Cog belts run cooler, last longer, require less maintenance and have an efficiency that is about 2% higher than standard vee belts (U.S. DOE 2001b; CIPEC 2001b). Upgrading to high-torque cog belts can result in up to 6% savings over standard vee belts (CIPEC 2001b). Motor load reductions of 2 to 10% have been shown from replacing vee belts with cog belts (Price and Ross 1989). CIPEC (2001b) estimates the payback for replacing standard belts with more efficient ones to be 6 months to 3 years. Other case studies taken from each of the glass segments (fiber, flat, container, and specialty) estimate the average payback period over all glass sectors for installing more efficient belts at less than 10 months (IAC 2005).

Installation of efficient notched belts on belt-driven applications at Corning's Greenville, Ohio, plant was estimated to save 200 MWh/year with a virtually immediate payback (U.S. DOE 2004b).

Switched reluctance drives. Switched reluctance drives are an old technology that is being improved, incorporating adjustable speed drives and high efficiency motors. The switched reluctance motor offers variable speed capacity and precision control, in addition to higher torque and efficiency (Martin et al. 2000). Because this is an emerging technology, no documented case studies could be found on glass plants that have implemented it.

5.4 Lighting

Lighting is used either to provide overall ambient light throughout the refining, storage, and office spaces or to provide low bay and task lighting to specific areas. Given the high energy intensity of the glass manufacturing processes, energy use for lighting is comparatively small. Based on 2002 MECS data, electricity use for lighting in the glass industry is estimated at 5% of total electricity use, though the share of electricity used for lighting may vary from facility to facility.

High-intensity discharge (HID) sources are typical for plant floor lighting, and include metal halide, high-pressure sodium, and mercury vapor lamps. Fluorescent, compact fluorescent (CFL) and incandescent lights are typical for task lighting and offices. Lighting controls are recommended for all areas of the plant. Green Lights, a voluntary program now incorporated into the U.S. EPA's ENERGY STAR Program, suggests cost-effective ways to save on lighting energy costs. These suggestions are online at (http://www.epa.gov).

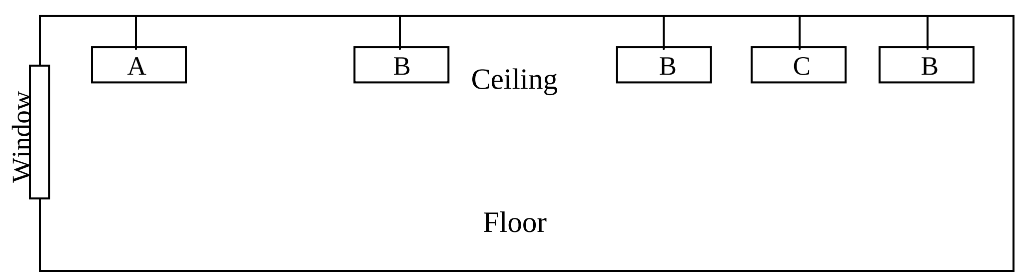
Lighting also generates a significant amount of heat. Thus, the downstream savings associated with energy-efficient lighting include cost savings in HVAC operation and energy use. The magnitude of downstream savings depends on climate and weather conditions (Sezgen and Koomey 2000).

Lighting controls. Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors that turn off lights when a space becomes unoccupied. Occupancy sensors can save up to 10-20% of facility lighting energy use. Numerous case studies throughout the United States suggest that the average payback period for occupancy sensors is approximately 1 year (IAC 2005).

Manual controls can be used in conjunction with automatic controls to save additional energy in smaller areas. One of the easiest measures is to install switches to allow occupants to control lights. It is also important to make employees aware of the importance of turning off lights in unoccupied spaces (EDR 2000). Other lighting controls include daylight controls for indoor and outdoor lights, which adjust the intensity of electrical lighting based on the availability of daylight.

An example of energy-efficient lighting control is illustrated by Figure 7, which depicts five rows of overhead lights in a workspace. During the brightest part of the day, ample daylight is provided by the window and thus only row C would need to be turned on. At times when daylight levels drop, all B rows would be turned on and row C would be turned off. Only at night or on very dark days would it be necessary to have both rows A and B turned on (Cayless and Marsden 1983). These methods can also be used as a control strategy on a retrofit by adapting the luminaries already present. For example, turning on the lighting in the rows away from the windows during the brightest parts of the day, and turning on supplemental rows (as needed) later in the day.

Figure 8. Lighting placement and controls



An audit of the OSRAM Sylvania plant in Exeter, New Hampshire, identified electricity savings of 96 MWh due to the installation of lighting control systems (D'Antonio et al. 2003). This is equivalent to savings of 50% of the electricity demand for lighting and 0.4% of total electricity demand. OSRAM Sylvania's plant uses electric furnaces to produce specialty glass for lighting systems.

Turning off lights in unoccupied areas. An easy and effective measure is to encourage personnel to turn off lights in unoccupied building spaces. An energy management program that aims to improve the awareness of personnel with regard to energy use can help staff get in the habit of switching off lights and other equipment when not in use.

Exit Signs - Light emitting diodes (LEDs) or radium lights. One way to reduce energy costs is simply switching from incandescent lamps to LEDs or radium strips in exit sign lighting. An incandescent exit sign uses about 40 W, while LED-signs may use about 4-8 W, reducing electricity use by 80-90%. A 1998 Lighting Research Center survey found that about 80 % of exit signs being sold use LEDs (LRC 2001). The lifetime of an LED exit sign is about 10 years, compared to one year for incandescent signs, reducing maintenance costs considerably. In addition to exit signs, LEDs are increasingly being used for path marking and emergency wayfinding systems. Their long life and cool operation allows them to be embedded in plastic materials, which makes them perfect for these applications (LRC 2001).

A new LED-exit sign costs about $20-30/piece. Kits are sold to retrofit the lamps in existing exit signs for similar prices. The payback period can be as low as 6 months. EPA's ENERGY STAR Program provides a list of suppliers of LED exit signs.

An alternative is the Tritium exit sign that is self-luminous, and does not need any power supply. The lifetime of these signs is estimated at about 10 years, while the costs are $200 apiece or more. The high capital costs make this type of sign attractive for new construction or if no power supply is available. Radium strips use no energy at all and can be used similarly.

Replace incandescent lights with fluorescent lights or compact fluorescent. The fluorescent lamp lasts roughly ten times longer than an incandescent light and is 3 times more effective (U.S. EPA 2001a; Honda 2001). Compact fluorescent lights are most efficient. Many models are available to fit a variety of fixtures and lamps.

Replacing T-12 tubes with T-8 tubes. In many industrial facilities- T-12 lighting tubes[25] can be found. T-12 tubes consume significant amounts of electricity, and have extremely poor efficacy, lamp life, lumen depreciation, and color rendering index. Hence, the maintenance and energy costs of T-12 tubes are high. Replacing T-12 lamps with T-8 lamps approximately doubles the efficacy of the former. Also, T-8 tubes generally last 60% longer than T-12 tubes, which lead to savings in maintenance costs. Typical energy savings from the replacement of a T-12 lamp by a T-8 lamp are around 30%. Based on experiences with several U.S. industrial facilities, the investment costs for replacing a T-12 lamp by a T-8 lamp with electronic ballast are estimated at $0.25-$0.30/kWh-saved.

Since there are a number of different T-8 lights and ballasts, it is important to work with the suppliers and manufacturers on the system as a whole

The Gillette Company manufacturing facility in Santa Monica, California replaced 4,300 T-12 lamps with 496 metal halide lamps in addition to replacing 10 manual switches with 10 daylight

[25] T-12 lighting tubes are 12/8 inches in diameter (the "T-" designation refers to a tube's diameter in terms of 1/8 inch increments)

switches (U.S. EPA 2001a). They reduced electricity by 58% and saved $128,608 annually. The total project cost was $176,534, producing a payback of less than 1.5 years.

Similarly, an audit of Corning Inc.'s specialty glass plant in Greenville, Ohio, identified electricity savings associated with this measure of 200 MWh/year with capital costs of $5,000 and a payback period of 0.6 years (US DOE 2004b).

Replace mercury lights by metal halide or high pressure sodium lights. Where color rendition is critical, metal halide lamps can save 50% compared to mercury or fluorescent lamps (Price and Ross 1989). Where color rendition is not critical, high-pressure sodium lamps offer energy savings of 50 to 60% compared to mercury lamps. In addition to energy reductions, the metal halide lights provide better lighting, provide better distribution of light across work surfaces, and reduce operating costs (GM 2001). High pressure sodium lights are most efficient.

High-intensity fluorescent lights. Traditional HID lighting can be replaced with high-intensity fluorescent lighting. These new systems incorporate high-efficiency fluorescent lamps, electronic ballasts and high-efficacy fixtures that maximize output to the workspace. Advantages of the new system are many; they have lower energy consumption, lower lumen depreciation over the lifetime of the lamp, better dimming options, faster start-up and restrike capability, better color rendition, higher pupil lumens ratings, and less glare (Martin et al. 2000). High-intensity fluorescent systems yield 50% electricity savings over standard metal halide HID. Dimming controls that are impractical in the metal halide HIDs can also save significant energy in the new system. Retrofitted systems cost about $185 per fixture, including installation costs (Martin et al. 2000). In addition to energy savings and better lighting qualities, high-intensity fluorescents can help improve productivity and have reduced maintenance costs.

High-intensity discharge (HID) voltage reduction. Reducing lighting system voltage can also save energy. A Toyota plant installed reduced-voltage HID lights and realized a 30% reduction in lighting energy consumption (Toyota 2002). There are commercial products on the market that attach to a central panel switch (controllable by computer) and constrict the flow of electricity to lighting fixtures, thereby reducing voltage and saving energy, with an imperceptible loss of light. Voltage controllers work with both HID and fluorescent lighting systems and are available from multiple vendors.

Electronics ballasts. A ballast is a mechanism that regulates the amount of electricity required to start a lighting fixture and maintain a steady output of light. Electronic ballasts save 12-25% power over their magnetic predecessors (U.S. EPA 2001a). Electronic ballasts have dimming capabilities as well (Eley et al. 1993). If automatic daylight sensing, occupancy sensing and manual dimming are included with the ballasts, savings can be greater than 65% (Turiel et al. 1995).

Reflectors. A reflector is a highly polished "mirror-like" component that directs light downward, reducing light loss within a fixture. Reflectors can minimize required wattage by using less light more effectively.

Daylighting. Daylighting is the efficient use of natural light in order to minimize the need for artificial light in buildings. Increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70% (CADDET 2001). Unlike conventional skylights, an efficient daylighting system may provide evenly dispersed light without creating heat gains. The reduced heat gains will reduce the need for cooling compared to skylights. Daylighting differs from other energy efficiency measures because its features are integral to the architecture of a building, and so it is applied primarily to new buildings and incorporated at the design stage. However, existing buildings can be cost-effectively refitted with daylighting systems. Various daylighting systems are available on the market; some of which can be supplied as kits to retrofit an existing building.

Daylighting can be combined with lighting controls to maximize its benefits. Because of its variability, daylighting is usually combined with artificial lighting to provide the necessary illumination on cloudy days or after dark (see also Figure 8). Daylighting technologies include properly placed and shaded windows, atria, angular or traditional (flat) rooflights, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts utilize angles of the sun and redirect light with walls or reflectors.

Not all parts of a facility may be suitable for the application of daylighting. Daylighting is most appropriate for those areas that are used in daytime hours by people. In office spaces, daylighting may save between 30 and 70% (CADDET 2001). The savings will vary widely depending the facility and buildings. Some problems associated with daylighting in industrial buildings have been identified due to the structure of the building. On flat roofed industrial plant buildings, some daylights have been found to leak and fog from exposure to UV after a number of years.

Various companies offer daylighting technologies. More information on daylighting can be found at the website of the Daylighting Collaborative led by the Energy Center Wisconsin (http://www.daylighting.org/). Daylighting systems will have a payback period of around 4 years, although shorter paybacks have been achieved.

System improvements. By combining several of the lighting measures above, light system improvements can be the most effective and comprehensive way to reduce lighting energy. High frequency ballasts and specular reflectors can be combined with 50% fewer efficient high-frequency fluorescent tubes and produce 90% as much light while saving 50 to 60% of the energy formerly used (Price and Ross 1989). An office building in Michigan reworked their lighting system using high-efficiency fluorescent ballasts and reduced lighting load by 50% and total building electrical load by nearly 10% (Price and Ross 1989). Similar results were obtained in a manufacturing facility when replacing fluorescent fixtures with metal halide lamps. Often, these system improvements improve lighting as well as decrease energy consumption.

Electric City is one of the suppliers of EnergySaver, a unit that attaches to a central panel switches (controllable by computer) and constricts the flow of electricity to fixtures, thereby reducing voltage and saving energy, with an imperceptible loss of light. Bristol Park Industries has patented another lighting voltage controller called the Wattman© Lighting Voltage Controller that works with HID and fluorescent lighting systems with similar energy saving results (Bristol Park Industries 2002).

5.5 Heat and Steam Distribution

The capacity of boilers in the glass and mineral wool industry is very small. Fuel use for boilers in 2002 in the glass and mineral wool industry is estimated at 2 TBtu of natural gas.[26] Fuel use other than natural gas is limited in the glass industry, so it is assumed that 2 TBtu is a reasonable estimate of fuel use for steam generation in boilers. Steam may be used for batch wetting. A few glass plants have steam boilers available to produce steam for back-up power generation. Most of

[26] Data on other fuels are withheld or not available (so as not to disclose proprietary data).

the boilers in the stone, clay and glass industries are medium-sized boilers. It is assumed that this holds also for the glass industry. Even given the relatively low energy demand for boilers, energy efficiency measures can still be implemented in the steam system to further reduce steam use.

Boilers are the heart of the steam generation system. The main efficiency measures are listed below. These measures center on improved process control, reduced heat loss, and improved heat recovery. In addition to the measures below, it is important to note that new boilers should usually be constructed in a custom configuration. Pre-designed boilers are often out-of-date designs that cannot be tuned to the needs of a particular steam system (Ganapathy 1994). However, one expert claims many package boilers are “state of the art and provide excellent operation” (Harrell 2005).

Boilers - improve process control. Flue gas monitors maintain optimum flame temperature and monitor carbon monoxide (CO), oxygen, and smoke. The oxygen content of the exhaust gas is a combination of excess air (which is deliberately introduced to improve safety or reduce emissions) and air infiltration (air leaking into the boiler). By combining an oxygen monitor with an intake airflow monitor, it is possible to detect even small leaks. A small 1% air infiltration will result in 20% higher oxygen readings. A higher CO or smoke content in the exhaust gas is a sign that there is insufficient air to complete the fuel burning. Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature, thus achieving the best energy efficiency and lower air pollutant emissions. It is assumed that this measure can be applied to large boilers only because small boilers will not make up the initial capital cost as easily.

Boilers - reduce flue gas quantities. Often excessive flue gas results from leaks in the boiler and the flue. This reduces the heat transferred to the steam, and increases pumping requirements. These leaks are often easily repaired. Savings amount to 2-5% (U.S. DOE 2001a). This measure differs from flue gas monitoring in that it consists of a periodic repair based on visual inspection. The savings from this measure and from flue gas monitoring are not cumulative, as they both address the same losses.

Boilers - reduce excess air. The more air is used to burn the fuel, the more heat is wasted in heating this air rather than in producing steam. Air slightly in excess of the ideal stochiometric fuel/air ratio is required for safety, and to reduce NO_x emissions, but approximately 15% is adequate (U.S. DOE 2001a; Ganapathy 1994), although the actual value is dependent on type of fuel used in the boiler. Coal and wood, for example, may require higher excess air values. Poorly maintained boilers may have up to 140% excess air, but this is rare. Reducing this boiler back down to 15% even without continuous automatic monitoring would save 8% of total fuel use. A rule of thumb often used is that boiler efficiency can be increased by 1% for each 15% reduction in excess air or 40°F (22°C) reduction in stack gas temperature (U.S. DOE 2001a). CIPEC (2001a) estimates reducing oxygen (O_2) in the flue gas by 1% increases boiler efficiency by 2.5%, although this varies depending on the initial flue gas oxygen content (Harrell 2005). Several case studies have indicated an average payback for reducing excess air of about 5 months (IAC 2005).

Boilers - correct sizing in design. Correctly designing the system at the proper steam pressure can save energy by reducing stack temperature, reducing piping radiation losses and reducing leaks in traps and other sources. In a study done in Canada on 30 boiler plants, savings from this measure have ranged from 3% to 8% of the total gas consumption (Griffin 2000). Savings were greatest when the pressure is reduced below 70 psig.

Boilers - improve insulation. It is possible to use new materials that insulate better, and have a lower heat capacity (and thus warm up faster). Savings of 6-26% shell loss (which equals about 1% of the fuel input (Harrell 2005)) can be achieved if this improved insulation is combined with improved heater circuit controls. Improved control is required to maintain the output temperature range of the old firebrick system. Because of the ceramic fiber's lower heat capacity, the output temperature is more vulnerable to temperature fluctuations in the heating elements (Caffal 1995). An additional benefit is that heating is more rapid when starting the boiler. One fiber glass manufacturer in the U.S. installed insulation and found a payback period of less than four months (IAC 2005).

Boilers - maintenance. A simple maintenance program to ensure that all components of the boiler are operating at peak performance may result in substantial savings. In the absence of a good maintenance system, the burners and condensate return systems can wear or get out of adjustment. These factors may end up costing a steam system up to 20-30% of initial efficiency over 2-3 years (U.S. DOE 2001a). It is estimated that 10% energy savings on average are possible (U.S. DOE 2001a). Improved maintenance may also reduce the emission of criteria air pollutants.

Fouling of the fireside of the boiler tubes or scaling on the waterside of the boiler should also be controlled. Fouling is more of a problem with coal fed boilers than natural gas or oil fed ones Boilers that burn solid fuels like coal should be checked more often as they have a higher fouling tendency than liquid fuel boilers do. Tests show a soot layer of 0.03 inches (0.8 mm) reduces heat transfer by 9.5%, while a 0.18 inch (4.5 mm) layer reduces heat transfer by 69% (CIPEC 2001a). For scaling, 0.04 inches (1 mm) of buildup can increase fuel consumption by 2% (CIPEC 2001a). Often, scaling also results in tube failures.

Boilers - recover heat from flue gas. According to CIPEC (2001a), heat recovery from the flue gas is the best opportunity for heat recovery in a boilerhouse. Heat from flue gases can be used to preheat boiler feed water in an economizer. While this measure is common in large boilers, there is often still room for heat recovery, especially in smaller boilers.

The limiting factor for flue gas heat recovery is that one must ensure that the economizer wall temperature does not drop below the dew point of acids in the flue gas (such as sulfuric acid in sulfur containing fossil fuels). Traditionally this has been done by keeping the flue gases exiting the economizer at a temperature significantly above the acid dew point. In fact, the economizer wall temperature is much more dependent on the feed water temperature than the flue gas temperature because of the high heat transfer coefficient of water. As a result, it makes more sense to preheat the feed water to close to the acid dew point before it enters the economizer. This allows the economizer to be designed so that the flue gas exiting the economizer is just barely above the acid dew point. In general, 1% of fuel use is saved for every 45°F (25°C) reduction in exhaust gas temperature (Ganapathy 1994); however, the value varies with fuel type and excess air concentration. Since exhaust gas temperatures are already quite low in most boilers but can still take advantage of using the higher temperature feed water mentioned above, a 1% savings is estimated.

Boilers - return condensate. Reusing the hot condensate in the boiler saves energy, reduces the need for treated boiler feed water, and reclaims water at up to 100°C (212°F). Usually fresh water must be treated to remove solids that may accumulate in the boiler, and returning condensate may substantially reduce the amount of purchased chemicals required to accomplish this treatment. The fact that this measure can save substantial energy costs and purchased chemicals costs makes building a return piping system attractive. This measure has, however, already been implemented in most of the sites where it is easy to accomplish. It is assumed that up to 10% energy savings and payback of about 1.1 years are possible (U.S. DOE 2001a; Harrell 2005). An additional benefit associated with condensate recovery is the reduction of blowdown flow rate because feedwater quality has been increased (Harrell 2005).

If no steam main is handy, it is often possible to use the condensate flash to heat water by direct contact, using a simple "shower bath" arrangement.

Boilers - recover steam from blowdown. When the water is blown from a high-pressure boiler tank (steam drum), the pressure reduction often produces substantial amounts of steam. This steam is low grade, but can be used for space heating and feed water preheating. It is assumed that this measure saves 1-2% of boiler fuel use in small boilers[27]. Einstein et al. (2001) estimate an overall payback of 2.7 years. In addition to energy savings, blowdown recovery may reduce the potential for corrosion damage in piping in the steam system. Operating expense may increase slightly with this system.

An audit of Corning Inc.'s Greenville, Ohio, plant identified small fuel savings by using blowdown steam to produce low-pressure steam (U.S. DOE 2004b). The simple payback period was estimated at 1.8 years.

Boilers - replace obsolete burners by new optimized boilers. Replacing inefficient boilers with new boilers increases energy efficiency and reduces emissions.

Steam and hot water distribution systems are often quite extensive, and can be major contributors to energy losses at any industrial plant. The purpose of steam distribution is simple: to get steam from the boiler to the process where it will be used. The methods for reducing energy losses are correspondingly simple: retaining more heat and recovering it after it has been used.

Distribution - improve insulation. Using more insulating material or using the best insulation material for the application can save energy in steam systems. Crucial factors in choosing insulating material include low thermal conductivity, dimensional stability under temperature change, resistance to water absorption, and resistance to combustion. Other characteristics of insulating material may also be important depending on the application. These characteristics include tolerance of large temperature variation and system vibration, and compressive strength where insulation is load bearing (Baen and Barth 1994). According to data from the U.S. DOE's Steam Challenge program, improving insulation of the existing stock of heat distribution systems would save an average of 3-13% with an average payback of 1.1 years (U.S. DOE 2001a; Einstein et al. 2001). Several case studies in the specialty and fiber glass industries in the U.S. indicated that insulation of the steam pipes and system would result in a payback period of less than 6 months (IAC 2005). CIPEC (2001a) estimates that insulating a 10 foot (3 m) long 4 inch (10 cm) steam pipe can be paid back in less than 6 months.

Distribution - maintain insulation. It is often found that after heat distribution systems have undergone some form of repair, the insulation is not replaced. In addition, some types of insulation may become brittle or rot under normal wear. As a result, introducing a regular

[27] Based on the following assumptions: up to 10% of boiler water is blown down (U.S. DOE 2001a) and 13-40% of the energy can be recovered from this (Johnston 1995, Harrell 2005). Harrell (2005) claims most systems can recover more than 40% of the blowdown energy with flash steam recovery (this amount depends on the operating pressure of the system), while a second stage blowdown thermal energy recovery can be installed to recover more than 40% more thermal energy.

inspection and maintenance system for insulation saves energy (Zeitz 1997). Exact energy savings and payback periods are unknown and vary based on the existing practices.

Distribution - improve steam traps. Using modern thermostatic element steam traps may reduce energy use while improving reliability. The main efficiency advantages offered by these traps are that they open when the temperature is very close to that of the saturated steam (within 4°F or 2°C), purge non-condensable gases after each opening, and are open on startup to allow a fast steam system warm-up. These traps also have the advantage of being highly reliable and useable for a wide variety of steam pressures (Alesson 1995). One measure implemented at a pressed glassware plant in the United States found a payback period of less than 5 months after installing new steam traps (IAC 2005). Energy savings were about 2,372 MMBtu natural gas annually.

Distribution - maintain steam traps. A simple program of checking steam traps to ensure they are operating properly can save significant amounts of energy for very little money. Energy savings for a regular system of steam trap checks and follow-up maintenance is estimated to be up to 10% (U.S. DOE 2001a; Jones 1997; Bloss 1997; Harrell 2005). Einstein et al. (2001) estimate a payback of less than one year for this measure. Although this measure offers a quick payback, it is often not implemented because maintenance and energy costs are separately budgeted. In addition to energy and cost savings, proper functioning of steam traps will reduce the risk of corrosion in the steam distribution system, saving even more in the long term.

Distribution - monitor steam traps automatically. Attaching automated monitors to steam traps in conjunction with a maintenance program can save even more energy without significant added cost. This system is an improvement over steam trap maintenance alone, because it gives quicker notice of steam trap failure, and can detect when a steam trap is not performing at peak efficiency. Using automatic monitoring is conservatively estimated to give an additional 5% energy savings over steam trap maintenance alone with a payback of 1 year[28] (Johnston 1995; Jones 1997). Systems that are able to implement steam trap maintenance are also likely to be able to implement automatic monitoring. There may, however, be some small additional operation and maintenance costs to maintain the monitors.

Distribution - repair leaks. As with steam traps, the distribution pipes themselves often have leaks that go unnoticed without a program of regular inspection and maintenance. In addition to saving 3% of energy costs, having such a program may reduce the likelihood of having to repair major leaks, thus saving even more in the long term (U.S. DOE 2001a).

Distribution - recover flash steam. When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. As with flash steam produced by boiler blowdown, this steam can be used for space heating or feed water preheating (Johnston 1995). The potential for this measure is extremely site dependent, as it is unlikely that a producer will want to build an entirely new system of pipes to transport this low grade steam to some places where it can be used. If, on the other hand, the areas where low-grade heat is useful were very close to the steam traps anyway, this measure would be easy to implement.

[28] Calculated based on a UK payback of 0.75 years. The U.S. payback is longer because energy prices in the United States were lower, while capital costs are similar.

5.6 Other Cross-Cutting Measures

HVAC - Building shell. The building shell can serve as insulation from the weather (either hot or cold). For example, use of a reflective coating on the roof of buildings in sunny, hot climates can save on air conditioning costs inside. Two medical offices in Northern California used reflective roofs on their buildings; one found summertime daily air conditioning savings of 13% and reduced air conditioning demand of 8%, the other found summertime daily air conditioning savings of 18% and reduced air conditioning demand of 12%, (Konopacki et al. 1998). For colder climates, heat lost due to cool roofs (in the winter, for example) also needs to be taken into account, and often negates savings. In addition to location and weather, other primary factors influence energy savings, such as roof insulation, air conditioning efficiency, and building age. Reflective roof materials are available in different forms and colors.

Roof gardens on a flat roof improve the insulation of the building against both hot and cold by providing both heat and air conditioning. In winter, green roofs can freeze, so they carry a slight heating penalty but they still yield a net energy savings (Holtcamp 2001). When temperatures plummet below freezing, the roof surface remains at 32°F (0°C), an advantage in very cold climates. In addition, a roof garden can increase the lifetime of the roof, provide and reduce runoff, and reduce air pollution and dust. Today, Germany installs over 10 million ft^2 of green roofs a year, helped in part by economic incentives (Holtcamp 2001). The Gap Headquarters in San Bruno, California, installed green roofs in 1997 (Greenroofs.com 2001). In addition to saving energy and lasting longer than traditional roofs, their roof garden also absorbs rain, slowing run-off to local storm-drains.

Low-emittance windows could lower the heat transmitted through the panes and therefore increase the insulating ability. There are two types of low-emittance glass, high solar transmitting (for regions with higher winter utility bills) and low solar transmitting (for regions with higher summer utility bills) (U.S. DOE 1997).

Many other simple options for decreasing energy use exist for certain conditions. Shade trees reduce cooling for hot climates. Shade trees should be deciduous trees (providing shade in the summer and none in the winter) and planted on the southwest side of the building. Trees planted on the North side of the building in cold climates can reduce heating in winter by shielding the building from the wind. Vines can provide both shade and wind shielding.

Other HVAC measures. Other measures for HVAC in commercial buildings may be applicable to some glass plant facilities, particularly office buildings that are similarly designed. For example, resetting thermostat set points by a few degrees can have significant savings. Better insulation of the ducts and repair of duct leaks has been found to save significant energy for homes and offices. Studies demonstrate that 30% to 40% of thermal energy was lost via those leaks and conduction through walls for houses in California (Jump and Modera 1994). One commercial building in Apple Valley, California, adopted a technique called the mobile aerosol-sealant injection system (MASIS) to reduce duct leakage. This measure resulted in the reduction of duct leakage from 582 cfm to 74 cfm and improved the HVAC-efficiency by 34%.

Energy-efficient transformers. Transformers are electrical devices that convert one voltage to another voltage. Most commercial and industrial buildings require several transformers to decrease the voltage of electricity received from utilities to the levels used by lights, computers, equipment, and other indoor applications (U.S. EPA 2001b). An important application of transformers in the glass industry is to power electric furnaces or the electric booster in fuel-fired furnaces. An analysis of the electricity use at OSRAM Sylvania’s glass plant in Exeter, New

Hampshire, found that the transformer losses were equal to 12% of total electricity use (D'Antonio et al. 2003).

Commercial and industrial transformers have a life between 25 and 35 years—typically as long as the process they support. Depending on the size of the transformer, an ENERGY STAR labeled transformer can save \$100 to \$300 each year at an electricity rate of \$0.075 cents/kWh, and has an average payback period between 2 and 5 years (U.S. EPA 2001b). According to Haggerty et al. (1998), improved efficiency liquid-filled transformers can be designed with the lowest overall losses and lowest cost. In addition to saving energy, efficient transformers reduce emissions of sulfur hexafluoride (SF_6), which is a powerful greenhouse gas.

At the same OSRAM Sylvania facility it was estimated that replacing the transformers by high-efficiency transformers would lead to savings of 10% of the transformer losses (equivalent to 1% of total onsite electricity use) resulting in annual savings of \$24,000 (D'Antonio et al. 2003).

Combined heat and power (CHP) or cogeneration. For industries with heat, steam and electricity requirements, the combined heat and power (CHP) systems may be one approach to save energy and reduce pollution. Cogeneration plants are more efficient than standard power plants since they are able to utilize waste heat. Furthermore, distribution and transportation losses are minimized when CHP systems are located at or near the plant. Combined heat and power is also used as backup supply; Guardian's float glass plant in Geneva, New York, has 2 MW generators set up to supply the facility in the case of a supply failure (Anon. 1998a).

However, since steam use in the glass industry is very limited (see above), the traditional application of CHP may not be attractive. Presently, the steam demand in a glass factory is too small to use a gas turbine-based CHP system cost-effectively in most areas in the United States. However, continuously developing technology and specific heat applications may change this in the future.

Innovative CHP applications use the waste heat of the gas turbine directly to dry raw materials or use as preheated combustion air (if sufficient oxygen is left in the flue gas). An audit of Corning's plant in Greenville, Ohio, identified the potential use of a gas turbine to produce power for onsite use and to use the exhaust gas of the turbine to preheat the glass batch as well as supply heat to the annealing lehrs. This project would result in savings of 20,000 MMBtu/year of fuel and 6.7 MWh of electricity (U.S. DOE 2004), equivalent to savings of \$270,000/year. With investments estimated at \$732,000, the simple payback period is estimated at 2.7 years.

The air-bottoming cycle is another example of an innovative CHP application (Korobitsyn 2002). However, this technology is not yet commercially available nor demonstrated in the glass industry. Therefore, this specific application is not described further in this section.

In addition to the energy savings, CHP also has comparable or better availability of service than utility generation. In the automobile industry, for example, typical CHP units are reported to function successfully for 95 to 98% of planned operating hours (Price and Ross 1989). For installations where initial investment is large, potential multiple small-scale CHP units distributed to points of need could be used cost effectively. Generally, the energy savings of replacing a traditional system of a boiler for steam generation and power production in a stand-alone power plant, by a standard gas turbine-based CHP-unit is estimated at 20-30%. The efficiency gain will be higher when replacing older or less maintained boilers.

5.7 Batch Preparation

All glass manufacture begins with the weighing and mechanical mixing of ingredients to create a batch for the melting furnace. Many different chemical compositions can be used to create glass, and each formula affects the mechanical, electrical, chemical, and thermal properties of the final glass product. The glass batch contains formers, fluxes, stabilizers, and sometimes colorants.

Some of the raw materials are ground onsite. Grinding to very fine particle sizes can be an energy intensive process, as grinding is an inherently inefficient process, where most of the energy is lost as heat.

Efficient blending of the ingredients is of critical importance for the quality of the glass product. If the batch is not properly blended, in-homogeneities may increase the melting time and cause product quality problems. In fact, the melting time is dominated by the need to homogenize the melt in the furnace. To ensure homogeneity, extreme care is taken to ensure materials are of proper grain size, carefully weighed, and well blended. In larger plants, with computer controlled weighing equipment, materials are generally weighed directly onto a conveyor belt, which feeds into a solids mixer. Non-automated mixing, which mostly occurs at smaller plants is the most inefficient method.

Electricity is used in batch preparation for bucket elevators, (pneumatic) conveyors, batch mixers, and agglomeration of materials. The batch mixer accounts for the greatest share of electricity use in this process step. In general, electricity used for batch preparation is about 4% of a glass plant's total energy demand (U.S. DOE 2002a).

Grinding. Most grinding technology uses rotating equipment. Several studies for different types of grinding equipment designs have shown that energy efficiency increases with low rotational speeds and high feed rates (Wang et al. 2004), without reducing the throughput.

Grinding – new technology. Energy losses in grinding can be large with most energy lost as heat. Efficient grinding technology combines energy-efficient communition and classification technologies to achieve an even, reproducible particle size distribution at low energy costs. New grinding technologies are regularly introduced in the market. MaxxMill® is an innovative, agitated medium grinding technology manufactured by Eirich. Eirich claims lower specific energy consumption for grinding with the new technology. There are no case studies available to substantiate an estimate of energy savings for glass industry applications from the new grinding technology.

Mixing. Various types of batch mixes exist, e.g. rotating pan, ribbon, orbiting screw, ploughshare, and ring trough mixers. Mixing is extremely important to determine the quality of the glass and the melting process. Hence, optimal control of the mixing process is essential to control batch quality. Mixing technology can be subdivided in non-intensive and intensive mixing. Non-intensive mixers may have varying energy consumption. Screw orbit, ribbon mixers have a specific energy consumption of 10 kW/tonne, while ring through and rotating pan mixers have a typical consumption of 20 kW/tonne. Intensive mixers can have an energy consumption of 50 kW/tonne or higher (Rikken 2004). Based on tests at Philips in The Netherlands, rotating pan mixers showed the least variability in composition at the shortest mixing period (Rikken 2004). The additional electricity use in the mixing may be more than offset by energy savings in the furnace due to more efficient melting and improved product quality.

Fluxing agents. Fluxes are added to lower the temperature at which the batch melts. Soda ash and potash are commonly used fluxes. The use of lithium compounds as fluxing materials has been increasing over the last 5 to 10 years (U.S. DOE 2002a). Glass producers using lithium compounds report lower melting temperatures at equivalent melting energy and cullet input, improved forming properties and increased nominal furnace capacity. Recent estimates suggest that adding lithium to glass batches can reduce furnace energy consumption by as much as 5-10% while also decreasing NO_X emissions (Grahl 2002).

Reduce batch wetting to a minimum. 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 (U.S. DOE 2002a). Occasionally agglomeration of the batch into pellets or briquettes is also used as a means of ensuring consistency and reducing dust. However, the water content increases energy consumption in the glass tank as the water is evaporated in the furnace. Hence, wetting should be reduced to a minimum. Depending on the share of cullet, a reduction of the moisture content of the batch by one percent will result in fuel savings in the furnace of 0.5% (Beerkens et al. 2004; Lindig 2004).

Selective batching. Preferential reactions between alkali and alkaline-earth carbonates can promote segregation of the batch. Combined with large particle size, this can lead to increased reaction and melting times (Carty et al. 2004). Selective batching is a technique that can be used to optimize melting efficiency by decreasing the chemical reaction of alkali and alkaline-earth carbonates, and promoting reactions between the fluxes and quartz earlier. This reduces the melting time. First experiments suggest that the melting time can be reduced by 50%, resulting in fuel savings of 20-33% (Carty et al. 2004). The development is now focusing on spray drying to pre-mix the different raw materials, and will first focus on the use for the production of (textile) glass fibers. To spray dry the material, the material needs to be ground very finely, which is already done for the production of glass fibers. The technology is undergoing further testing at a larger scale, and not yet commercially available.

Conveyor belts. The different methods of conveying are pneumatic conveying, screw conveying or belt conveying. The most energy-efficient conveying is through belt conveyors. During design stage consideration should be given for layout to minimize transportation. This will result in power savings. Planning of belt conveying systems for transport will also reduce maintenance cost (due to lower wear and tear compared to pneumatic conveying systems) and reduce atmospheric emissions from chippers. Energy efficiency improvements in conveyor belt systems are possible by re-sizing motors, using more efficient motors, ASDs (see also Section 5.3), more efficient belts, as well as new conveyor system designs.

Re-sizing of motors. Motors and pumps that are sized inappropriately result in unnecessary energy losses. In conveyor systems, motors are often over-sized. If a motor runs at 25-50% of its capacity the energy losses may be between 4 and 8%. If peak loads can be reduced, motor size can also be reduced. Note that motors can run a limited time at about 15% over capacity. Hence, if peak loads are limited to a few occasions, a smaller motor may still perform well. When replacing the motor, a smaller motor should be considered, resulting in immediate savings at no additional costs. Alternatively, an ASD (see below) may reduce energy consumption of oversized motor systems.

High-efficiency motors. High-efficiency motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. See Section 5.3 for a detailed discussion of high-efficiency motors.

Adjustable speed drives (ASDs)/ variable speed drives (VSDs). ASDs better match speed to load requirements for motor operations. The power required to move material is set by the rate of flow of the material. Slowing the speed of the belt with an ASD to reduce the amount of material transported will reduce the energy consumption when compared to part-load operation. Hence, there is potential for saving energy by using ASDs for conveyors, however, this will be limited when compared to the savings typically found on pump and fan systems (Nadel et al. 2002). The installation of ASDs improves overall productivity, control and product quality, and reduces wear on equipment, thereby reducing future maintenance costs.

The typical energy savings from ASDs for conveyor belt systems are estimated at 8-15% (De Almeida et al. 2002). However, the cost-effective savings potential will differ from application to application.

A special system, attractive to conveyor systems, is the MagnaDrive system, in which a magnetic coupling between the motor and system allows the speed to vary (MagnaDrive 2005). The MagnaDrive is aimed at constant speed applications on 20-1000 hp motors that require overload and failure protection and reduced vibration and maintenance. The MagnaDrive system automatically disconnects at system overloads, reducing the risk of damage to the motor or other system parts. The system is currently typically used for large-scale conveyor systems. MagnaDrive ASDs has been used in various material conveying applications, e.g., a bucket elevator at a cement plant, and conveyor belts at a coal mine and a coal-fired power station. No MagnaDrive ASDs have yet been installed at glass plants.

High efficiency belts (cog belts). Belts make up a variable, but significant portion of the total motor drive in most plants. Standard vee belts tend to stretch, slip, bend, and compress, which leads to a loss of efficiency (CIPEC 2001b). Replacing standard vee belts with cog belts can save energy and money, even as a retrofit. Cog belts run cooler, last longer, require less maintenance and have an efficiency that is about 2% higher than standard vee belts (CIPEC 2001b). Upgrading to high-torque cog belts results in savings of up to 6% over standard vee belts (CIPEC 2001b). Motor load reductions of 2 to 10% have been shown from replacing vee belts with cog belts (Price and Ross 1989). CIPEC (2001b) estimates the payback for replacing standard belts with more efficient ones to be 6 months to 3 years. A case study in the corn wet milling industry (US) estimated the cost for using more efficient belts at $29,660, savings of $17,250 in electricity (or 1%) per year, and an average payback of about 1.7 years (IAC 2005). Another case study in the IAC database estimated a smaller system would cost $1,406 and save $709 annually in electricity (0.2%), but also have a payback of less than 2 years.

Conveyor belt systems. Sicon Roulunds (Sweden) claims to produce environmental friendly enclosed belt conveyors that transport bulk material, without transfers, spillage, or generation of dust. The flexibility of the system allows taking 90° corners without using multiple conveyors and the associated losses. The conveyor system is said to need less maintenance and have lower power consumption (Sicon 2005) when compared to pneumatic, screw, and chain conveyors, but similar to that of ordinary belt conveyors. For the glass industry systems have been sold to ACI (Australia), Glava A/S (Norway), Glasuld A/S (Denmark), Gullfiber AB (Sweden), G+H Isover, and Schott Glaswerke (Germany).

Cullet separation and grinding. Use of recycled glass (cullet) in the melt will reduce the energy intensity in glassmaking (see section 5.8 for a further discussion of increased cullet use in the glass tank). To control and guarantee the quality of the glass, companies often prefer the in-house cullet over contaminated and/or mixed post-consumer glass. To allow higher recycling rates, cullet needs to be cleaned from contaminants (e.g. metals, ceramics, and organic material) and separated on color. Traditional cleaning and separation systems can be very labor-intensive processes. No data on energy consumption for cullet preparation could be found for the U.S. glass industry. Total electricity use for batch preparation is estimated at 200 kWh/ton, varying between 80 kWh/ton for flat glass, 155 kWh/ton for container glass, and up to 337 kWh/ton for glass fiber (U.S. DOE 2002a).

New technology developed in the United States uses grinding to clean the cullet (Führ et al. 1995). Cullet is first pre-sorted in three colors: clear, brown, and green. Other colors are separated. In grinding, only the cullet is ground, while other contaminants are not reduced in size (autogenous grinding). This makes it easier to remove the contaminants from the cullet. A 99% clean cullet product is produced. The grinding technology is developed and marketed by RemCo from Livermore, California, under the trade name *GlassMax*. The installation reduces the costs for cullet pretreatment and reduces energy use. Grinding is the largest energy consumer in the process and is estimated at 5.0 to 5.6 kWh/ton of glass powder, depending on the capacity of the installation, operation, glass quality, and moisture content of the glass (Führ et al. 1995). The operation costs are estimated at $0.04/ton of glass powder. Capital investment data for this technology were not available in the literature. By 1995, 10 plants in the United States used the *GlassMax* technology to prepare cullet, as well as two plants in Germany and Switzerland (Führ et al. 1995).

The proper sizing of cullet pieces can also be important for some products, such as blown glass. At Royal Doulton Crystal, a maker of blown leaded glass specialty products, the ideal cullet size was found to be 12-20 mm to provide uniform melt and to prevent faults in the blown glass (ETBPP 1997). However, only about 30% of in-house cullet generation met this criterion, which led to approximately 560 tonnes of cullet disposal per year. In 1997, Royal Doulton Crystal invested in a cullet crushing system that allowed the plant to improve its in-house cullet recycling rate to around 75%. Annual savings in avoided waste disposal and avoided raw materials purchases alone were estimated at $190,000 (1997). The payback period for this measure was only 3 weeks.

Cullet preparation. The use of cullet is limited by the type and color of the glass product made, and the color of the cullet. Hence, color separation of cullet is essential to optimize the use of cullet. Improved technology has made it easier to separate glass cullet on color. Several companies market separation technologies to remove contaminants (e.g. ceramics) and separate glass cullet on color, e.g. MSS (US), Countec (US), Toyo (Japan), and Zippe (Germany). Generally, these separators are operated by municipal or commercial recycling facilities and not at the glass plant.

However, there may still be the possibility of colored cullet in a batch, or an inbalance in cullet color and products. Traditional decolorizing additions to the melt allow the use of up to 0.5% green cullet for the production of clear glass. For the production of amber (brown) glass up to 30% green cullet can be used. Several techniques have been investigated to increase the use of green cullet in clear glass up to 3%, for example, phase separation, reductive melting, electrochemistry, wet chemical extraction, and the use of alternative coloring systems (Dalbey and Purser 1996; WRAP 2004). However, none of them has yet been used in commercial practice (WRAP 2004). Hence, besides efficient and optimized cullet separation on color no commercial technologies are available to increase the use of colored cullet in the mix or batch.

5.8 Melting Tank

Glass melting, refining and conditioning are the most energy-consuming steps in the glass making process; considerable effort has therefore been placed on the optimization of the melting tank as the major piece of equipment. This section starts with a discussion of measures that can be implemented at existing furnaces, after which new furnace designs and oxy-fuel technology are discussed. These opportunities should be considered at the end of the campaign life of an existing furnace or when constructing a new furnace. This section first focuses on combustion furnaces, then discusses electric furnaces. Finally, options to increase cullet use and impact on energy consumption are discussed (including cullet preheating).

New furnaces are typically designed for a specific composition of raw materials and, hence, glass type (Clark-Monks 2001) to optimize product quality and efficiency. Therefore, the discussion of new melting technologies below should be viewed from this perspective. General guidance on (new) furnace technologies is provided, as well as the application of such technologies in specific plants. Evaluation of a specific technology should always account for the specific product mix and raw materials used in the specific plant for which the technology is considered.

Also, changes in other parts of the process (e.g. batch preparation) may affect the energy consumption of the glass tank. Section 5.7 discussed changes in batch preparation that may result in energy savings in the glass tank. These measures will not be repeated in this section. As the residence time in the glass tank is an important factor in the energy intensity of glass production, the pull rate of the furnace should be optimized. Improvements in the annealing and forming of the product may affect the pull rate, reduce reject rates, and hence reduce the energy intensity of the glass tank and final product (see Section 5.10). When evaluating energy efficiency measures, the interactions between the different production steps should be carefully considered.

5.8.1 Changes to Existing Furnaces

Process control systems. It is estimated that more than 80% of melting furnaces in the world use manual temperature control or just one single loop PID controller (Chmelar et al. 2000). In the United States, a 2002 survey conducted by the EIA found that less than 48% of the establishments in the glass industry report the use of computer process controls (EIA 2005). However, it is likely that most large U.S. furnaces have computer controls installed, while especially smaller furnaces may not have computer controls. Still, new improved process control systems and strategies are developed continuously. Process control for energy efficiency of a glass melting tank is difficult. Most process control systems measure the process parameters indirectly, while heat transfer is more difficult to measure. Below, some of the modern systems developed and applied in the glass industry are discussed.

Efficient process control systems depend on the development of accurate control strategies (software) and appropriate data collection on process performance (sensors). In this section, the focus is on the control strategies. However, sensor development is important to further improve the accuracy of information on temperature distribution, material composition, and characteristics in the furnace (and other process steps). Various research and development projects are undertaken in the United States, Europe, and Japan to develop new sensors that may become commercially available over time. Development aims at the use of optical, ultrasonic, acoustic, and microwave systems, that should be resistant to aggressive environments (e.g. oxidizing environments in furnace or chemicals in chemical processes) and withstand high temperatures.

Modern control systems are often not solely designed for energy efficiency, but rather at improving productivity, product quality, and efficiency of a production line. Applications of advanced control and energy management systems in varying development stages can be found in all industrial sectors. Control systems result in shorter residence time, reduced downtime, reduced maintenance costs, reduced processing time, and increased resource and energy efficiency, as well as improved emissions control. Application of process control systems is growing rapidly, and modern process control systems exist for virtually any industrial process. However, still large potentials exist to implement control systems, and more modern systems enter the market continuously. Model based process control systems (MPC, see below), for example, are widely used in oil processing, but are still emerging in the glass industry (Backx et al. 2000).

Control systems can principally be subdivided in mathematical "rule"-based models and neural networks/fuzzy logic models. In a rule based model, a detailed understanding of the process is used to design rules and decision parameters to optimize the process parameters. In a fuzzy logic system, a more "loose" programming environment is used to optimize the process by simulating the best operators, and "learn by doing" using information from the process. Various organizations and companies have developed expert and fuzzy logic systems. The U.S. DOE has supported the development of control systems for glass furnaces (e.g., for specialty glass melting to isolate radioactive material). Also, the European Union funded an R&D project to develop an expert system for high-temperature kilns, which was tested at the Santos Barosa container glass plant in Portugal (Carvalho et al. 1999).

Various control systems are marketed in the glass industry for control of the melting process. While all systems will lead to energy savings directly (due to improved temperature control and reduced residence time) or indirectly (e.g., reduced reject rates or improved capacity utilization), the energy savings are not always clearly determined. Table 12 provides an overview of some of the systems marketed in the global glass industry. This overview is not exhaustive. Below, the experiences of some specific plants or technologies are discussed. The 2004 GMIC report provides an excellent overview of the basic principles of glass process control technology (GMIC 2004).

Table 12. Overview of commercially available control systems for glass melting (not exhaustive)

Control System	Developer/Supplier
Expert System II	Glass Service, Czech Republic
GlassMax	Universal Dynamics, Canada
MeltingExpert	IPCOS, The Netherlands/Belgium
SIGLAS- Expert	Siemens, Germany

Glass Service has developed an advanced control system called *Expert System II* (ES II™) that controls the glass melter, the working end, the forehearth, and forming equipment (Chmelar et al. 2000). It has several important features including multi input—multi output (MiMo) options, incorporation of several set points (SP) and parameters, model-based predictive control (MPC)—a dynamic numerical model of the process, control with feedback, and fuzzy logic control. Continuously optimized heat input distribution produces the fuel savings. In addition, the furnace can operate continuously with little action from operators, and resulting stability leads to fewer defects, increased yields, increased product quality, more stable crown and bottom glass temperatures (with less risk for corrosion), and increased lifetime. Installed furnace applications show energy savings of about 2 to 3%, improved yields of about 8%, and payback periods of less than 6 months. The system has been installed in television, fiber, float, container and specialty glass plants in both air-fuel and oxy-fuel furnaces.

MeltingExpert developers IPCOS do not claim specific energy savings, but claim a reduction in the need for electric boosting to maintain production output. A reduction in electric boosting has a strong economic benefit due to the high price of electricity. They also claim increased throughput due to reduced downtime and improved temperature stability, which may lead to additional energy savings. Other control systems exist for other areas of the plant (such as Tubing Expert, Profile Expert).

Consumers Glass has installed the *GlassMax* control system at their container glass plant in Lavington, British Columbia, Canada. The system not only controls the furnace but also the forehearth. This has led to reduced downtime, improved product quality, and reduced product losses (Cassidy 2000). The developers Universal Dynamics claims a 4% increase in annual production. The payback period was estimated at less than 1 year with an investment of $150,000 (Universal Dynamics 2003).

Siemens has supplied control systems (*SIGlas*, *SIMATIC*) to plants around the world. Process control systems were supplied to float glass (e.g., Saint-Gobain, Mannheim, Germany), container glass (e.g. Heye-Glas, Moerdijk, and The Netherlands), hollow glass (e.g., OSRAM, Augsburg, Germany) and (insulation) glass fiber (e.g., Isover, Gliwice, Poland) plants around the world. The Siemens technology has been used for different furnaces. The systems typically control not just the furnace but also the forehearth and other parts of the production. SIGLAS Lambda (marketed by STG Cottbus in Germany) has been developed to control NO_x and energy use for regenerative glass furnaces. The technology keeps NO_x emission levels between 500 and 800 mg/Nm^3 and achieves energy savings of 2 to 8%.

Minimize excess air/reduce air leakage. Many furnaces still operate with less than optimal air/fuel ratios and air infiltration (Backhausen 2000). Generally, furnaces operate with 5-10% excess air (1-2% excess oxygen). Operating at near-stochiometric levels will result in reduced energy losses and reduced NO_x emissions. Savings depend on the level of excess air but are generally around 10% (EC-JRC 2000). On-line assessment of NO_x, O_2, and CO levels is necessary to achieve near-stochiometric combustion conditions. Decreasing excess air from 15% to 5% has been shown to reduce NO_x emissions by 35% (Backhausen 2000).

Air leakages may exist in older furnaces, and may lead to losses in excess of the common excess air supplied to the furnace. Sealing either the furnace structure or the burner system to prevent the ingress of ambient air can contribute to better energy efficiency. Lax & Shaw, a container glass manufacturer in Leeds, United Kingdom, replaced one furnace with this principle in mind. The new furnace incorporated several features that each improved its thermal efficiency. The furnace saved a total of 12.2% of the primary energy used by the furnace and 33% of its energy costs (EEBPP 1998b). Of the 12.2% of the furnace energy that was saved, upgraded regenerator packing saved 30%, sealed doghouse saved 20%, increased crown insulation saved 11% and other furnace insulation saved 10%. The investment on energy saving adjustments for this furnace cost approximately $320,000 (1998), while energy savings totaled $517,000, yielding a payback of 7 months. According to the study, however, a more typical payback for large glass operators who do not use oxygen and electric boosting would be just less than 1 year at today's (2004) U.S. natural gas prices.

Premix burners. Premix burners are a way to reduce the infiltration of excess air. Premixing has been in use in the glass industry for many years and has been applied in glass forehearths, feeders, furnaces, and lehrs. Separate air-gas burners usually operate at 10% excess air and are often difficult to control. Using pre-mix burners allows a reduction of excess air, which can potentially result in energy savings of up to 11% (Anon. 2005), depending on the reduction in excess air achieved. Various manufacturers supply pre-mix burners.

Adjustable speed drives on combustion air fans. Often the cooling air and stack blowers run continuously, while variations in demand are not met or met by using variable inlet vanes. The application of ASDs on the fan systems may be an opportunity if there are variations in demand for air from the furnace. The savings (and hence payback period) will depend on the operating conditions of the fan system and the size of the furnace.

An audit of the Anchor Glass plant in Warner Robins, Georgia, found potential electricity savings by installing ASDs on the furnace air blowers of over 800,000 kWh/year with a payback period of 1.7 years (OIT 2002).

With large variations in heating demand (e.g., in small-scale intermittently used furnaces) installing an ASD may lead to savings in fuel use as well, as it reduces excess combustion air.

Waste heat boiler. The temperature of the flue gases leaving the regenerator is between 600 and 1100°F (300 and 600°C), and can be used to recover steam. Capturing the waste heat can be done before the flue gas cleaning (with subsequent cleaning) or after gas cleanup. Economics vary. Boilers are mainly found on float glass furnaces and recuperative furnaces. All float glass furnaces in Germany have waste-heat boilers installed. Capital costs could exceed $1 million.

The steam can be used to generate power (using steam turbines), drive blowers or compressors, and/or preheat and dry cullet.

Bubbler. Development of fluid dynamics modeling and improved understanding of the melting process now makes it possible to improve the location of bubblers in order to improve heat transfer and uniform product quality (Clark-Monks 2001). These new design technologies make it possible to reduce the negative effects of electrode location on uniform mixing and melting.

The use of oxygen is preferred for the bubbler, as it minimizes the impact of nitrogen and other inert gases on the glass batch. Oxygen bubblers can increase the heat exchange efficiency by 10-15% (SenterNovem 2005b).

When rebuilding an existing regenerative furnace with an oxy-fuel fired furnace, Philips Lighting in Roosendaal, The Netherlands (a manufacturer of fluorescent lamps), also introduced an oxygen bubbler to replace the relatively expensive electric booster in the furnace (SenterNovem 2005b). The replacement of the booster led to savings of 4 million KWh, or equivalent to 170 kWh/ton glass produced. The specific payback period of the bubbler cannot be estimated as it was included in the total project costs to introduce an oxy-fuel fired furnace.

Refractories/Insulation. To be economic, any changes in the insulation of an existing furnace should be considered at the time of furnace design, or at the end of the campaign life when rebuilding a furnace. Insulation reduces heat losses by about 55 to 65% (Lutskanov 1996). Problems exist with furnace insulation, including higher corrosion rates and “rat holes” in the silica crown. Over the lifetime of the furnace (or campaign), insulation material is wearing off, increasing the heat losses. New refractories are being developed that demonstrate a better resistance to the aggressive environment in the glass tank, increase lifetime (and hence campaign life) while providing improved insulation over the campaign life. Research and development is ongoing in this field to develop improved refractories accounting for different glass compositions.

It is estimated that deteriorating refractories may lead to increasing energy losses of 0.1-0.2%/month (GMIC 2004).

Replacement of refractory bricks in the regenerator by specially shaped fusion materials can increase the heat exchange intensity of the regenerator. Typical energy savings are 7%. To date, 320 furnaces around the world have installed corrugated cruciforms (EC-JRC 2000).

Lubisol Engineering Co. has developed new crown insulation that has both a higher efficiency and a longer service life (Lutskanov 2003). They claim that Lubisol crown insulation uses a high quality silica refractory and eliminates loose joints to avoid negative effects on the furnace. According to its developers, the heat losses from the silica crown are about 5% of the total heat loss in a glass-melting furnace. With the implementation of efficient crown insulation on their furnaces, the glass producing companies can reduce their total fuel budget between 1.0 and 1.5%, when the crown insulation is upgraded, and up to 4.5% when the crown insulation is newly applied (Lutskanov 2003). Two furnaces in the U.S. fiber and specialty glass industries installed crown insulation and found payback periods of less than 2 years (IAC 2005).

Kanthal AB (Sweden) has developed heating elements with fiber insulation in complete modules that have demonstrated energy savings, increased pot furnace life, and improved product quality and flexibility (Frisk and Linder 2001).

Properly positioned burners. Furnaces should have the proper angle between the burner axis and the glass surface. The burner angle not only affects the efficiency of heat transfer to the melt, but may also affect NO_x formation and dust emissions. The burner angle should be optimized for heat transfer to the melt.

Sealed burners. Burners may be sealed in the furnace burner block to avert outside air that is normally drawn into the furnace through the furnace block. This air can make up as much as 15% of the total stochiometric air, but is typically 3 to 5% (EEBPP 2001). If 5% cold air is eliminated, energy savings are 2 to 3%. Other advantages include reduced NO_x levels, a burner block with a longer life and reduced maintenance. One possible disadvantage is a new need for alternative cooling to replace the outside cooling air. In 1996 and again in 1998-1999, Rockware Glass of Knottingley, United Kingdom, performed trails with burner sealing rings supplied by Laidlaw Drew. During the trial periods, the system proved to be reliable and easily switched from gas to oil firings with no changeover problems. Melting costs were reduced by 1.75% and gas by 1%. Total savings were $6,440 (1998 U.S. $) and the payback period was about 4 months. Currently many glass manufacturers use sealed burners, such as Lax and Shaw (Leeds, UK), Greggs (Knottingley, UK), Beatson Clark (Barnsley and Rotherham, UK) and others. The applications have included both cross and end fired furnaces.

Low-NO_x burner. Low NO_x burners are specialized regenerative or recuperative burners that modify the fuel prior to combustion and then form and burn the soot in the flame. Increased heat transfer rates and decreased flame temperatures result in increased furnace production rates and thermal efficiency.

A low NO_x burner prototype, the Sorg LoNOx® Melter was set up and put into operation at the container glass plant of Bayerische Flaschen Glashüttenwerke Wiegand & Söhne GmbH & Co. KG in Steinback (Germany) in 1987 (Ehrig et al. 1995). The furnace is heated with natural gas but can also be heated with heavy oil. The LoNOx Melter with cullet preheating consumes 3.1 MMBtu/ton (3234 kJ/kg), 14.4% less energy than regenerative end-fired furnaces (Pieper et al.

1995). It also discharges approximately 45% less NO_x emissions than regenerative end-fired furnaces.

The Cleanfire™ low NO_x burner by Air Products combines oxy-fuel burners with the elimination of nitrogen, thus reducing fuel use and NO_x emissions further (Brown 1995). Flue gases are reduced over 80%. Compared to recuperative furnaces, Cleanfire burners can reduce fuel use by up to 40%. Compared to regenerative furnaces, Cleanfire can reduce fuel use by about 20%. In addition, product impurities like stones and seeds are reduced.

Air Liquide (France) has developed an oxy-fuel furnace with a low-NO_x flame (Legiret et al. 1997). According to the producers, ALGLASS FC™ is an oxy-oil burner with a wide, low-NO_x flame detached from the block, so that it has no hot spots, and a reduced flame temperature. Air Liquide claims 5% energy savings compared to conventional oxy-burners (GMIC 2000). The NO_x produced is 20% of a traditional optimized burner. It also has very little maintenance due to the simplicity of the design. Because flame momentum is low, alkali volatilization is decreased compared to a conventional burner, which decreases refractory wear and increases life of the furnace and reduces particulate emissions. Over 100 ALGLASS FC burners have been installed worldwide. BOC Gases has also developed a flat flame burner that is being used in nonferrous metal melting furnaces and scheduled to be installed in one glass melting furnace (AlChalabi et al. 1995). Praxair has developed a WideFlame™ burner that saved one manufacturer 6.1% energy over previous models and reduces NO_x emissions by 50% (GMIC 2000). Five WideFlame burners had been installed as of 2000.

Energy Saving DeNOx (EsDeNOx) Technology of Software & Technology Glass GmbH (STG) from Cottbus in Germany has developed a method to reduce NO_x formation and energy consumption by controlling air consumption and flame turbulence (Birle 2005). The payback time for the system is less than one year. The reduction of NO_x emissions can be up to 86% and are typically 40%. The energy savings are up to 5% for natural gas fired furnaces and range from 2 to 7% for oil-fired furnaces (Birle 2005).

Recuperative burners (mainly used for fiber glass production). Recuperative burners use a “recuperator” or heat exchanger to heat the incoming combustion air with outgoing exhaust gases. Recuperative burners are mainly used in fiberglass production. Recuperative burners are generally less fuel efficient than regenerative furnaces but tend to have better temperature uniformity since there is no rise and fall of checker temperature (see regenerative furnaces) (GTI 2002).

The Energy Efficiency Best Practice Programme in the UK estimates energy savings up to 30% compared to cold-air furnaces, and, based on fuel costs of $4.3/MMBtu for natural gas, a payback of 7 to 14 months (EEBPP 1998a).

Vertically-fired furnaces. Instead of firing horizontally, these furnaces direct the flames almost vertically down onto the batch surface. This melting system can supply more energy per square foot of batch surface area without increasing refractory temperatures beyond normal operation limits. Hence, the furnace can melt more glass and/or a higher quality glass in a given size furnace. In 1996, BOC and Owens Corning converted an oxy-fuel furnace without interrupting production (LeBlanc et al. 2002). In its four months of operational testing, it showed a pure rate increase greater than 50% over conventional capacities, no increase in emissions per ton, no change in glass chemistry and a decrease in glass defects. These results were primarily due to the oxygen boost, and not solely attributable to the vertical burner. Other trials produced similar results.

5.8.2 Furnace Designs

End-fired furnaces. End-fired furnaces have a higher thermal efficiency than cross-fired furnaces by about 10%, but are limited in capacity to about 150 tonnes/day (EC-JRC 2000). Investment costs for end-fired furnaces are about 20% lower than for cross-fired furnaces (Pieper 1994). A modern end-fired regenerative melter replaced a cross-fired regenerative furnace at Vetropack's Croatian Straza Glass plant, with a capacity of 150 tonnes of green soda lime glass per day and a melting area of $60m^2$ (Stieglitz 2000). Instead of a full repair of the existing failing melter, they decided to switch to a new end-fired melter. They estimated a payback of 1 year in comparison to a full repair, which incorporated not only energy savings but also an improvement in total tank loads across the whole plant. The furnace has reduced energy consumption by 25 to 30% and a specific energy consumption averaging 4000 kJ/kg of glass. In addition, the plant consumed less electricity due to lower ventilation needs. NO_x emissions have been reduced as well.

Lax and Shaw in Leeds (UK) manufactures white flint glass bottles mainly used for liquor bottles. In 1996, they replaced their furnace with an end-fired regenerative furnace, with large efficiency regenerators, an enclosed doghouse, increased crown insulation, upgraded furnace, flue and regenerator insulation, sealed low NO_x burners, and a deeper glass bath (CADDET 2000). They found the furnace used less energy to produce more glass. Running costs were reduced because electric and oxygen boosting was eliminated. Savings amounted to \$6.6 (1997)/tonne on energy savings, a 12.2% reduction in energy consumption, and 33% decrease in energy costs. Upgrades related to energy efficiency cost approximately \$305,000 (1997) and savings were \$507,000 (1997), resulting in a payback period of 7 months. For plants without electric and oxygen boosting, payback periods will likely be 16 months.

Regenerative furnaces. Regenerative furnaces operate the furnace in two cycles. There are two chambers, each containing refractory material, called the checker. Combustion gases are passed through the checker and exhaust air through the other, where the checker is heated or regenerated for subsequent combustion gases. About every 20 minutes, the flow is reversed so that the new combustion air can be heated by the checker. Ninety percent of all glass is melted in regenerative furnaces, and 42% of U.S. furnaces are regenerative (U.S. DOE 2002a). Two types exist, side port and end port. Side ports are most common, although end-port furnaces are generally more efficient (Beerkens et al. 2004).

Multi-pass regenerators recover the energy in the flue gases more efficiently, and can reduce the intensity of the furnace by 15%. This will only be possible at the construction of a new furnace, when larger heat exchangers (i.e. more refractory bricks) are added (EC-JRC 2000).

Improvements in regenerative furnaces decrease the ratio of primary to secondary air. One pilot study found a reduction of 33% NO_x emissions when using a new regenerative burner with 50:50 primary to secondary air, replacing an older model that used only 85:15 primary to secondary air (Flamme et al. 2001).

Increase size of the regenerator. When rebuilding a furnace after the campaign life ended it may be worthwhile to expand the size of the regenerator to improve the heat recovery efficiency. A larger regenerator will allow increased heat recovery from the flue gases, and will release the flue gas at a lower temperature to the environment. With increasing fuel prices, a larger regenerator may be more cost-effective than past assessments may have shown.

SORG® Flex Melter (replacing small-scale pot furnaces). This furnace is used for high quality glass and discontinuous operation though it can be used for continuous operation. According to SORG®, these furnaces are more energy efficient than other furnaces of similar size (SORG 2002).

5.8.3 Oxy-Fuel Furnaces

Synthetic air. Synthetic air is produced by mixing the oxygen required for combustion with recirculated waste gas leaving the regenerator systems and then preheating the mixture as normal (Mattocks 1998). Compared to an oxy-fuel fired furnace with no direct heat recovery system, using synthetic air can be more efficient. Synthetic air is similar to that of the equivalent air supply system, so the same burners and port design can be used, which makes retrofits easy. Fuel savings are at least 15% compared to conventional air-fired burner systems. Synthetic air systems also have improved combustion control but may experience increased refractory wear.

Oxygen enriched air staging (OEAS). By decreasing oxygen in the flame's high temperature zone and improving uniformity of the flame temperature, NO_x emissions are reduced and heat transfer to the glass is increased. The technology mainly aims to reduce NO_x emissions by 40-70%. Energy savings are secondary and result from reduced energy use for flue gas treatment for NO_x reduction. OEAS has been successfully demonstrated at 10 U.S. plants; 7 endport and 3 sideport.

Oxy-fuel furnace. Virtually in all segments of the glass industry, 100% oxy-fuel combustion technology has been successfully demonstrated. Over 150 major glass melting plants worldwide have implemented oxy-fuel technology (Damsell et al. 1996), and nearly 30% of U.S. glass furnaces now use oxygen enriched air (U.S. DOE 2002a). The flat glass industry has the least amount of conversions to oxy-fuel furnaces due to higher oxygen use and therefore higher operating costs when implementing this measure. Specialty glass has the most oxy-fuel furnace applications (GMIC 1999).

The energy savings of converting to an oxy-fuel furnace depend on the energy use of the current furnace, use of electric boosting, air leakage, glass type, and cullet use. Energy savings are typically between 20 and 45% (45% for replacing energy inefficient furnaces) (Sauer and Lauwers 1994). Even for large efficient regenerative furnaces, savings would be between 5 and 20% (Sauer and Lauwers 1994; EC-JRC 2000).

Energy savings also depend on the energy required to produce oxygen. While cryogenic systems are the most energy efficient (consuming about 0.84 – 1.36 MMBtu/ton) they are typically used for large scale plants. For smaller facilities vacuum swing absorption (VSA; between 20 and 90 tons/day) or pressure swing adsorption (PSA) is used (less than 20 tons/day). Energy use for VSA is estimated at 2.08 MMBtu/ton and for PSA at 2.6 MMBtu/ton (Rue et al. 2006).

Using oxy-fuel furnaces reduces NO_x emissions by about 70-90% and particulate emissions by 25-80%, compared to traditional air-firing systems (Lauwers and Stohberg 1994; GTI 2002). Overall, the exhaust volume is decreased by roughly 80%; however, the plume is much denser (Damsell et al. 1996). An oxy-fuel furnace has generally also lower particulate matter (PM) emissions. Reductions between 20 and 70% have been measured (Sauer and Lauwers 1994).

Advantages of oxy-fuel technology include noise reduction, reduced melting times, and glass quality improvements due to smaller variations in the product (Ebeling and Bobbit 2000). Industry reports claim an average of 15 to 20% increase in production after conversion, particularly important in areas where space is limited (Anon. 1998b). Disadvantages may include increased refractory wear and decreased furnace life (or increased refractory costs), oxygen production costs, and potential problems related to conversions from regenerative furnaces (Argent and Dickinson 1995). Increased refractory wear may affect the product quality, as found by Philips Lighting in The Netherlands, where increased wear increased the corrosion of silica in the crown of the furnace (SenterNovem 2005b).

The capital costs of a new oxy-fuel furnace are reduced by 20% compared to recuperative furnaces, and 30-40% compared to regenerative furnaces. The costs of the on-site oxygen plant are about 10% of the capital costs of the plant. Oxy-fuel furnaces also benefit from reduced costs for flue gas treatment (EC-JRC 2000) and significantly reduced maintenance costs (Damsell et al. 1996). Overall, cost-effectiveness varies widely, and depends strongly on location-specific circumstances, such as the current system's fuel efficiency, costs of NO_x emissions, cost of fuel, and electricity. The technology is most effective when installed at a furnace rebuild after its campaign life.

The oxy-fuel burner has been successfully applied to furnaces with capacities over 90 tonnes/day (GTI 2002). It is not used extensively yet in container glass production, but has been adopted to a greater degree in glass fiber production. Pilkington LIF (Ohio) operated the only oxy-fuel float glass plant in the world as of 2000. Germany's first oxy-fuel furnace melting for flint glass containers was installed in 1996 at Heye Glas's Obernkirchen plant (Portner 1999). Average energy consumption was 3.35 MJ/kg (3.1-3.2 MMBtu/ton), having lower melting costs than those for any conventional furnaces in operation.

Glashütte Gerresheim GmbH in Dusseldorf (Germany) produces container glass. In 1997, the plant replaced its regenerative heated cross-fired furnace with an oxy-fuel melter with batch and cullet preheating (Lubitz 1999). The specific energy consumption for the oxy-fuel melter with preheater was about 3.02 MJ/kg of glass (2.9 MMBtu/ton). Including the energy required for oxygen consumption (231 kJ/kg), the oxy-fuel melter reduced fuel use by 35% (compared to the old furnace energy consumption of 5028 kJ/kg (4.8 MMBtu/ton)). NO_x emissions were also reduced significantly, to 180 mg/m^3. They also found excellent workability of the glass and improved glass quality with fewer seeds and inclusions.

The Schott plant in Mainz (Germany) converted its regenerative furnace to oxy-fuel firing (Lindig and Wachter 2000). They found that energy savings were strongly related to the pull of the tank, and above a specific load (1.65 t/m^2-d), savings of over 35% were achieved. Average energy savings were estimated at about 20% (Anon. 1997). In addition, temperature stability was significantly better and NO_x emissions were reduced. Plugging problems occurred initially, but dilution air added in the vertical portion to reduce the temperature of the horizontal portion entrance avoided this problem. Because no air preheaters were needed for the new oxy-fuel furnace, the new furnace fit the space of the older furnace, while providing 25% higher production capacity (Anon. 1997).

At another plant producing television glass, the furnace fuel use was reduced by 40% when converting from an air-fueled to an oxy-fueled furnace (Damsell et al. 1996). Workers found lower operating costs and less than half the particulate and NO_x emissions. Another pilot study found a reduction of up to 52% in NO_x emissions using an oxy-fuel burner over an older regenerative furnace that used 85:15 primary to secondary air (Flamme et al. 2001).

Fenton Art Glass (West Virginia), the largest manufacturer of hand-made colored glass in the United States, recently installed a remote controlled on-site oxygen generating system to supply its oxy-fuel melters (Ebeling and Bobbit 2000). They have been using oxy-fueled furnaces since 1976, but recently contracted with AGA Gas in Cleveland, Ohio, to supply their oxygen using on-site generation. The system uses pressure vacuum swing absorption (PVSA) to produce 26 tons of oxygen a day (Ebeling and Bobbit 2000; Joshi et al. 1996). Installment of the system cost $200,000 and has an expected payback of just over one year. In addition to energy savings, in the tanks they tested, Fenton found a reduction of particulate emissions from 11 lb/hr to 0.53 lb/hr, a reduction of 79%. They also experienced less noise, decreased melting times, improved process control and reduced variations in product. Praxair, Inc. also developed an oxy-fuel firing system that uses PVSA. In 1992, they teamed with Corning, Inc. and Gallo Glass Company to demonstrate the technologies at Gallo's Modesto, California, facility, with great success. NO_x emissions were reduced by 85%, PM by 25%, and fuel savings were 25% (OIT 1999a). Gallo has since converted all melters to oxy-fuel firing. Other plants in the United States have also adopted this technology (Joshi et al. 1996; Schatz 1996).

An oxy-fuel glass melter has been developed with a regenerative heat recovery process that preheats the incoming oxygen (Browning and Nabors 1997). Test results show using an oxygen preheat temperature of 2200°F, results in fuel savings of 15% compared to traditional oxy-fuel furnaces. In addition, NO_x emissions are further reduced.

Heat recovery of oxy-fuel furnaces. Heat in the flue gas is often not recovered in many oxy-fuel furnaces. Without heat recovery an oxy-fuel furnace could be as or less efficient as an end-port fired furnace (Beerkens et al. 2004), due to the energy needed for oxygen production. However, the flue gases exiting the oxy-fuel furnace are cooled before they can be emitted to the atmosphere. This heat can be recovered by producing high-pressure steam and/or pre-heating cullet.

Heye Glas, a container glass producer in Moerdijk, The Netherlands, implemented a system to produce high-pressure steam from the flue gases of their 300 tonne/day oxy-fuel furnace. The heat is first used to generate high-pressure steam. The steam is used in two turbines that drive the blowers supplying air to the plant. Low-pressure steam extracted from the back-pressure turbines is used to pre-heat and dry the cullet. The system was completed in 2000. Based on the performance of the system, changes were proposed to optimize the system by using multi-stage steam turbines and pre-heating the cullet to 230°F, instead of the original 194°F (SenterNovem 2005a). The optimized system has a simple payback period of 3.5 years at a natural gas price of $4.1/MMBtu (SenterNovem 2005a), while the original system had a payback period of 6.2 years.

Horn Glasanlagen (Germany) has developed a new furnace design that combines oxy-fuel combustion with recuperative burners, the so-called Combined Oxyfired System® (CO System®). Horn claims lower operation costs (as less oxygen is needed), while corrosion of the crown of the furnace is reduced due to lower moisture content of the gas streams. The energy consumption of the design is comparable to that of oxy-fuel fired furnaces.

Oxy-fuel furnaces – high luminosity burners. Current oxy-fuel burners have a relatively low flame luminosity, while air leakage may lead to increased NO_x emissions due to the high flame temperatures. The Gas Technology Institute and Eclipse Combustion have been working with Owens Corning (fiberglass plant, 2002) and PPG (float glass plant, 2003) to test a new design for a high-luminosity burner (Wishnick et al. 2003). The burner "pre-burns" part of the fuel to generate soot that is burned in a second stage to provide a high luminosity flame. The lower flame temperature leads to lower NO_x emissions, extended furnace life (Smirnov and Allen 2005), and increased thermal efficiency by approximately 4%. The tests of the burner finished in 2004, and commercialization is expected soon.

Oxy-fuel furnaces – tall crown furnace technology. In some oxy-fuel furnaces, silica corrosion has led to decreased campaign lives and even reduced product quality. Praxair and Heye Glass have developed the so-called "tall crown furnace", which combines a Praxair JL burner with a new design of the furnace. It has shown no or limited silica corrosion, even after a campaign life of 9 years (Kobayashi et al. 2005). The furnace life is estimated at 10 to 11 years. Two other furnaces have reached campaign lives of 7 and 5 years. The energy intensity of the new design is comparable to that of a conventional oxy-fuel furnace. The energy intensity of the "tall crown furnace" has reached an energy intensity of 3.3 MMBtu/ton for flint glass with 60% cullet.

5.8.4 Cullet Use and Preheating

Use more cullet and/or filter dust. Cullet and filter dust can be used in all sectors of glass manufacturing. Glass containers are 100% recyclable (GPI 2002). In container glass manufacturing, cullet use can vary from 10% to over 90%. Currently, the United States uses about 30% cullet in container glass manufacturing (Ruth and Dell'Anno 1997). In the European Union, the average cullet use in container glass production is 60% and ranges from 95% for Belgium and 90% for Germany to 34% for the UK and 27% for Greece (Glass Gazette 2003). Part of the reason for the lower use of cullet in the United States is that only 37.4% of glass containers are recycled (GPI 1996). The U.S. EPA reports that in 2003, only 22% of all glass containers in municipal solid waste are recycled (U.S. EPA 2004). This is low compared to other countries. In Europe, around 60% of all glass container waste is recycled (2003), varying from 96% in Switzerland, 92% in Sweden, 88% in Germany, but a low of 22% in Turkey.

The non-homogeneity of the glass colors and contaminants and impurities mixed with recycled glass present problems for manufacturers. In Europe container glass plants use up to 100% cullet for green-colored container glass, typically up to 80% cullet for brown, and 70% for clear container glass (Beutinger 1995). For flat glass production, cullet can be as high as 20-40% for green flat glass and lower for clear flat glass (Fleischmann 1997). Beneficiation and intermediate processing facilities are being built and improved to deal with these problems, but currently the technologies are still costly and operation of these facilities requires a steady supply of cullet at stable prices (Ruth and Dell'Anno 1997). Regulated ingredients such as lead oxide must also be avoided when using recycled cullet. Improved data, chemical analyses, and process control systems should overcome these and other quality issues.

Contamination of the cullet should also be minimized. Ceramic parts larger than 1 cm (0.4 inch) are not easily melted, and metal parts may damage the bottom refractories in the glass tank (Gebhardt 1997). Organic material should be limited, as it may affect foaming, mixing, and color (Beutinger 1995; Enneking 1994). On the other hand, larger cullet pieces affect mixing in the furnace positively. Modern separation technology helps to maintain a high quality cullet.

If problems in acquiring quality cullet are overcome, energy savings are significant. Because no chemical reactions take place in melting the cullet, energy consumption is reduced. The energy savings are partly offset by additional energy requirements in crushing, cleaning, sorting, and transportation of the cullet (Anon. 1984). Increasing the cullet share by 10% (based on weight) reduces net energy consumption by 2-3.5% (Beerkens et al. 2004). A 1993 survey of furnaces in German-speaking countries in Europe proved a reduction of 3.3% in specific energy consumption for each additional 10% increase in cullet share (Fleischman 1997), estimating energy savings equivalent to 7.6 kBtu/ton of glass for each additional percent of cullet added.

In addition, raw materials use will be reduced, energy in producing the raw materials will be decreased, and the life of the furnace will increase up to 30% due to decreased melting temperatures and a less corrosive batch (Ruth and Dell'Anno 1997; GPI 2002). Owens Corning reports that compared to 100% raw materials, using 30% cullet reduces silica use by 60%, soda ash by 40%, and saves 10% in energy costs (Papke 1993).

At Pilkington's float glass manufacturing facility in St. Helens, England, a new raw materials storage bay, distribution silo, and control system were installed to increase the use of in-house glass waste. The total cost savings of these measures amounted to 40,300 GBP in avoided raw materials costs and 13,000 GBP in avoided waste disposal costs per year (ETBPP 1999). Total investment costs were 140,000 GBP, leading to a payback period of 32 months.

Increased cullet use will also lead to reduced emissions. NO_x emissions will be reduced because less fuel is used, while the SO_x emissions are also reduced due to the lower consumption of sodium sulfate (Enneking 1994).

Batch and cullet preheating. In a cullet-preheater, the waste heat of the fuel-fired furnace is used to preheat the incoming cullet batch. Cullet preheaters are marketed by a number of companies, and are either direct or indirect preheaters. In the direct preheater, the cullet is in direct contact with the flue gas, and is heated to about 400°C. A bypass is available in case the preheater cannot be used. The indirect preheater is a cross-flow plate heat exchanger. The cullet moves through the heat exchangers that preheat the cullet to a temperature of approximately 300°C. A new system has been developed by Edmeston, which combines an electrostatic precipitator with a direct preheater, preheating the cullet and dust from the furnace to 400°C.

Batch preheating is more difficult than cullet preheating, as clumping of incoming materials can affect the product quality and melter efficiency.

Energy savings of cullet preheaters are estimated to be between 12 and 20% (EC-JRC 2000) depending on the cullet share and pre-heating temperature. McGrath (1996) found significant fuel savings could be achieved only if 35% or more cullet is preheated. Enninga et al. (1992) report on an installed preheater achieving an energy efficiency improvement of 20% at a cullet share of 55%. However, others report lower savings of 8-12% at a cullet share of 50% or higher and a preheating temperature of 500°C (930°F) (Fleischmann 1997). In theory, any system with over 50% cullet in the batch can install preheaters. Batch-only preheaters are not considered proven technology (EC-JRC 2000).

Installing a preheater will result in a reduction of NO_x emissions, while direct preheaters also reduce the emissions of SO_2, HF and HCl. Installing a preheater may increase furnace capacity by 10-15%, without compromising the furnace life.

Cullet preheaters are currently only found in container furnaces. Most are found in Europe (6 installations as of 2000), and some in United States. In the United States, Leone Industries (New Jersey) uses the Edmeston EGB-filter cullet preheater on an oxy-fuel fired furnace. Interprojekt (Germany) has been installing preheater systems since the late 1980s (Anon. 1999). PLM Glas Industrie Dongen BV (now called Remax, The Netherlands), a packaging glass company, installed a cullet/batch preheating heat exchanger at its plant (NOVEM 1993). In the preheater, cullet is preheated to 530°F, reducing electric boosting by 60% (or 90 kWh/tonne) and natural gas use by 8% per year (or 0.3 MMBtu/ton). The project cost was approximately $1.4 million (1996 USD), resulting in a payback period of 2.6 years at natural gas prices of $3.8/MMBtu and electricity prices of 0.05 $/kWh.

Problems can occur with very fine cullet, which can bind under heat and pressure from the cullet bed and form lumps that restrict flow. Slow cullet flow can also cause problems in the build up of fines, restricting the flow of waste gas. A control system may be able to adjust the flow to avoid this problem (McGrath 1996).

In 1997, the Glashütte Gerresheim GmbH of Dusseldorf plant (of Gerresheimer Glas AG, Germany) replaced its regenerative heated cross-fired furnace with an oxy-fuel melter with batch cullet preheating (see oxygen enrichment/oxy-fuel furnace, this section) (Lubitz 1999). The specific energy consumption for the oxy-fuel melter with preheater was about 3,017 kJ/kg (2.6 MMBtu/ton) of glass. Without batch and cullet preheating, the energy consumption is about 3,436 kJ/kg (3.0 MMBtu/ton), a savings of about 419 kcal/kg (0.36 MMBtu/ton) or 12%.

The developers of the raining bed concept for batch/cullet preheating (Tecogen) claim a better performance and economics than those described above (OIT 1999b; Breault et al. 1996). In the raining bed process, batch and cullet fall freely through the heat exchanger increasing in temperature as they contact the rising hot combustion gases. Laboratory testing of the Raining Bed Batch/Cullet Preheater heat exchange system by Corning, Thermo-Power, and Praxair demonstrated the ability to preheat soda – lime batch/cullet to greater than 1000°F (500°C) (OIT 1999b). This process recovers about 0.5 MMBtu/ton of glass. Experience from demonstration projects in the United States show that with preheat temperatures of only 850°F (450°C), payback periods of 1 to 4 years are predicted; preheat temperatures of 1000°F (500°C) would reduce payback even further (Breault et al. 1996). For oxy-fuel glass furnaces using the Raining Bed Preheater, the developers claim a reduction of energy use by as much as 25% as well as an increased furnace lifetime (OIT 1999b). In addition, because material falls freely in the raining process, the problems of plugging are eliminated.

5.8.5 Electric Furnaces

Electric glass melting tanks are mainly used for the production of specialty products or for small batches of products (e.g., tableware). Historically, the relatively high cost of electricity made the use of large-scale fuel fired furnaces more attractive (i.e. the energy costs of an electric furnace may have been up to a factor of 2 higher compared to natural gas fired furnaces, depending on the natural gas and electricity rates). However, the recent sharp increases in natural gas prices may have made electricity a more economically attractive option for specific plants, depending on the local power rates. Electric furnaces do not produce any onsite NO_x and PM emissions. Due to the improved emission control opportunities, electric furnaces are the key alternative for otherwise polluting production routes for glass products such as lead crystal and opal glass.

State-of-the-art electric melters consume 780-800 kWh/ton soda-lime and sodium borate glass (Hibscher et al. 2005). However, based on surveys (see Chapter 4) it is assumed that currently operating melters typically use 30-40% more power, demonstrating a considerable potential for energy efficiency improvement.

All-electric furnaces are typically used for smaller capacities, e.g. generally smaller than 75 ton/day. However, larger furnaces may be economically attractive depending on local electricity prices.

Top-heating. Most electric furnaces use electrodes in the batch to melt the raw materials into glass. Sandvik Glassworks and Ramco in Sweden rebuilt a batch pot furnace and equipped it with top-mounted electrodes to improve and maintain product quality, and obtain a higher share of salable glass (Thureson and Persson 1997). The furnace was tested for the production of lead-free crystal, and the results were compared to a similar furnace that was not rebuilt. The results show a slight reduction of electricity consumption (3-4%) and an increased production of salable glass of 4% (Thureson and Persson 1997). The specific electricity savings were within the uncertainty bound. Still, the improved product quality leads to 4% lower material losses. Hence, net energy savings are estimated at 4%. The payback period was 1.3 years for the plant operating in Sweden. The exact electricity price for the Sandvik plant is not public, but the average Swedish industrial electricity prices were 20-30% lower than in the United States (energy price data provided by the International Energy Agency). Hence, the payback period under U.S. conditions would be around 1 year (depending on the local electricity rates).

Optimize electrode placement. While energy losses through the wall of an electric furnace are much smaller, heat distribution within electric furnaces is of key importance to reduce overheating and cold spots. Two major types of electrodes are used, i.e. molybdenum or tin oxide. While tin oxide electrodes are typically stacked blocks in the melter wall, (cooled) molybdenum electrodes are immersed in the melt and allowing for flexible location of the electrodes (Hibscher et al., 2005). Tin oxide electrodes are mainly used in lead crystal melters. Uneven heating will lead to increased power use as well as potential reduction in product quality. Hence, electrode placement optimization for the geometry of the specific furnace is an important design element.

Replace by fuel firing. Depending on the relative price differences between fuel (natural gas) and electricity, as well as product quality impacts, it may be worthwhile to replace part of the electricity use in the furnace by fuel firing. Depending on the furnace design, it is possible to change this within the existing furnace design, or it may only be possible with a substantial rebuild.

Corning preformed an audit of its Greenville, Ohio, specialty glass plant and found that the conversion of an all-electric furnace to a combined electric melter with a gas-fired batch preheater would result in a reduction of electricity use by 9 MWh/year at additional gas use of 12,000 MMBtu/year. At 2003 energy prices, this would have resulted in savings of $208,000/year and a payback period of 1.2 years (U.S. DOE 2005b).

5.9 Forehearths and Forming

Process controls. Forehearth and furnace control in the glass industry is difficult due to the changes in the physical properties of the glass as a function of temperature (see also Furnace Controls in Section 5.8). For container glass facilities, it is especially important to control not only the temperature but also a constant gob weight. This reduces the number of rejects, and hence increases productivity and saves energy. In float glass plants, it is especially important to control the temperature of the tin bath by controlling the various zones of the tin bath roof.

Universal Dynamics Technologies, Inc. and Glass Consumers have produced an advanced adaptive process controller (APC) called BrainWave for forehearths (Kay et al. 2000). Developers claim the APC system reduces the time required for typical control systems to settle the glass temperature by 50%, with increases in production ranging from 3.75 to 20% (for common containers) to 40% (for specialty containers). With decreases in scrapped glass, specific energy consumption is reduced. In addition, maintenance is reduced; unlike PID controls, re-tuning is not necessary for the APC system. Paybacks are estimated to be 2 to 9 months.

An alternative control system has been developed by XPAR Vision in The Netherlands. An infrared analysis system analyzes the product quality before leaving the forehearth allowing real-time control to maintain continuous product quality. The system can be combined with automatic control of the gob weight, to further increase productivity (Kats and Holtkamp 2004). The infrared inspection and control system has been installed in over 20 container glass plants worldwide, of which two are U.S. plants (Longhorn Glass (Anheuser-Busch) and Saint-Gobain containers). Typical energy savings are estimated at 2-3% of total plants energy use through reduction of the reject rate. The Rexam container glass plant in Dongen (The Netherlands) installed one of the first of these systems, and was able to reduce fuel consumption of the plant by 5%. Total annual benefits were estimated at over $3 million/year, of which $200,000 was due to energy savings (SenterNovem 2000).

Lewis and Towers Ltd. installed improved container weight control for its forming machines in its glass container manufacturing plant in Kent, United Kingdom (EEBPP 1994b). The continuous gob monitoring system (CGMS) was developed by British Glass and can be applied to any system in which a pre-formed gob is delivered to a forming machine. The CGMS monitors the weight of the gob for each container so that corrective action can be taken if the containers are overweight or underweight. This reduces both specific energy consumption and material waste. In addition, the production process is stabilized, the target weights can be specified more exactly, and equipment redundancy can be reduced. Lewis and Towers found reduced primary energy savings of 2.4 TJ/year (2.3 GBtu/year), savings $8,600/year (1993). Material savings were 151 tonnes/year or $8,500/year (1993). With a total investment of $26,000 (1993) (and no downtime for installation), payback was 18 months.

Siemens and AEG have developed an energy control system for the float glass process. The tin bath is heated in up to 40 different zones, which are carefully controlled to sustain high product quality. Together, the power consumption for the electric heating of the bath is considerable, making control also essential for control of energy use and production costs. The system minimizes power fluctuation, reduces start-up time, and increases the energy efficiency. No information is available on the specific energy efficiency improvement that can be attained by better control of the tin bath temperature.

More efficient forehearths. Forehearths are the channels that transport molten glass to the forming machine. Performance of the forehearth is rated by the range of pull rates and gob temperatures able to maintain an acceptable degree of homogeneity, the speed of response of the forehearth, and its ability to maintain temperature stability. Its roofblock shape, the number, the position and the size of exhausts, the degree of controllability of the combustion and cooling exhausts, and uniformity in temperature and viscosity distribution are important parameters in designing an efficient forehearth. In general, electric or new forehearths are more energy efficient than older models.

Moss Glassverk A/S, a container glass manufacturer in Norway, installed their first new electric forehearth with indirect cooling in 1985 (CADDET 1989). Heat is generated by electrodes in the glass melt while cooling is provided via indirect radiation by feeding cool air through the forehearth in ducts. Control systems regulate both the heating and cooling. Prior to its installation, the old forehearth used 230 tons per year of natural gas, equivalent to 3,000 MWh/year per unit. The new system uses only 350 MWh electricity per year per unit, equivalent to 1,078 MWh per year per unit of primary energy. This equates to an energy savings of 64%. The project saved 495,000 NOK (or $95,000 1987 US/year). With total additional investment costs of 750,000 NOK/year ($120,000 1987 US), this gives a payback of about 1.5 years.

Oxy-fuel fired forehearth. Owens Corning, with the support of the U.S. Department of Energy, is investigating the use of oxy-fuel fired forehearths. Especially in fiber manufacture the forehearths may be major energy consumers (up to 40% of total fuel use). Similar to oxy-fuel firing in furnaces (see section 5.8.3), the use of oxygen may reduce fuel use and emissions. This technology is not yet commercialized, and therefore, not further discussed here.

Improved insulation. See insulation in Section 5.8.1.

5.10 Annealing and Finishing

Controls. Efficient process control systems depend on the development of accurate control strategies (software) and appropriate data collection on process performance (sensors). A Furnace Scheduling Advisory System was installed at Pfaudler Balfour Ltd., the leading manufacturer of glass-lined steel vessels and parts for the chemicals and pharmaceutical industries in the UK, in its electric glass coating ("glassing") furnaces (EEBPP 1994a). The expert system saved $55,000 /year (1989) in electricity, $43,000 (1989) in reduced labor, maintenance and repair and $74,000 (1989) for reduced work in progress (one-time savings). The energy savings were 12% of the original furnace electricity use. The total system cost was $161,000 (1987), yielding a payback of 10 months. In addition to the above savings and benefits, scheduling controls enabled Pfaudler Balfour to meet customer deadlines more readily and minimize work in progress inventory.

Plant layout. Material and products entering the lehr will need to be reheated if the temperature has declined due to long internal transport distances in the plant. To reduce the need for reheating the incoming material, the distance between the glass furnace and the lehr should be as short as possible. When re-building a furnace at the end of the campaign life, reconsidering the layout of the plant may be an option to increase the productivity and energy efficiency of the plant.

Remax in Dongen (The Netherlands) used the construction of a new oxy-fuel furnace (see Section 5.8.3) to reorganize the layout of the container forming, annealing, and packaging production steps to minimize transport distances and optimize productivity.

Air leakage. Cold air may leak into the annealing lehr, disturbing the heat distribution in the lehr. This may not only affect energy use, but also product quality due to uneven cooling. The leakage of cold air into the lehr should be reduced to a minimum by installing a damper or insulating curtains, as well as reducing the losses around the belt or rollers used to transport materials to and through the lehr.

Insulation. The annealing lehr loses energy through the walls. Selection of insulation materials with a low thermal mass will reduce the heat losses through the walls, and reduce start-up losses. Section 5.8.1 discusses some other issues in selection of insulation materials.

Similarly, materials are transported through the lehr on a belt or rollers. Using low-thermal mass materials for the rollers will reduce heat losses. Metal belts may be set up in such a way that they stay as much in the furnace (e.g., internal belt returns through the bottom of the furnace) as possible.

Product drying system upgrade. In some specialty glass manufacturing plants, molten glass is cooled by quenching in a water bath. Water must then be removed. Normally this is done by several annealing ovens. Better drying devices using a combination of gravity, filtration and forced air evaporation can reduce the drying time, decrease fuel use and increase production capacity.

Viox Corporation produces glass products that are used in the electronics industry at their Seattle, Washington, plant. With the financial help of the Bonneville Power Administration, they designed water-quenching baths that reduced the drying time from 58 to 72 hours to only 11 hours per batch (CADDET 2000b). Energy savings were 179,200 kWh/year; non-energy benefits, including reduced operation and maintenance costs, were $14,637 per year. Costs for the project were $43,630. With energy costs of 5 cents/kWh, this would yield a payback of less than 2 years.

Flat Glass - glass coating. To improve the energy efficiency of windows, increasingly more window glass is being coated. The coating allows solar radiation to pass through the window, but reduces the transfer of heat through the window. Various coating systems are available or under development.

In-line coating is possible using a microwave-cathode system. The advantage of microwave heating is that only the glass is heated and not the furnace atmosphere. Interpane in Lauenförde, Germany, installed a microwave-vacuum coating installation with an annual capacity of 3 million m^2 (32 million ft^2) in 1995. The investment costs for the whole production line were estimated at $15 million (Anon. 1995). No information could be found on the energy efficiency benefits of microwave coating versus that of other systems.

5.11 Emerging Technologies

The Energy Guide focuses on commercially available practices and technologies. However, new and emerging technologies are continuously being tested and developed. In this section, a few emerging technologies are discussed. The technologies under development are not limited to the technologies described in this section. The reader is referred to other publications for more detail on emerging process technologies (e.g. GMIC 2004).

Oscillating combustion. Oscillating combustion is a new technology currently being field tested by the Gas Technology Institute (GTI). This technology forces the oscillation of the burner fuel to create successive, fuel-rich and fuel-lean zones within the flame. This increases heat transfer by enhancing flame luminosity and turbulence. It also reduces NO_x emissions by avoiding stochiometric combustion conditions that create maximum flame temperatures that are ideal for NO_x creation. Oscillating combustion can be retrofitted onto existing burners by installing an oscillating valve on the fuel line to each burner and an electronic controller that handles several valves simultaneously. It can be retrofitted on systems fired with ambient air, preheated air, enriched air and oxygen. Several field demonstrations have been completed to date, including four stack annealing and fiberglass melting furnaces. Reported fuels savings are 2 to 5% and reduced NO_x emissions 30 to 50% (Wagner and Schrecengost 2002; GMIC 2000). One conversion on a glass melter had been in operation for 33 months at the time of publication.

Segmented melter (seg-melter). In the segmented melter, the batch is melted in an electric melter, after which the cullet is added in a separate oxy-fuel fired melter. This results in lower emissions, and increased thermal efficiency. Maintenance requirements are higher, restricting campaign life to 15 years, with repairs every 3 years (EC-JRC 2000). Both Saint Gobain and Owens-Illinois have considered segmented melter designs, but neither have been commercialized (GMIC 2004).

PPG's P-10 melter consists of four segmented devices (batch preheating/precalcining, primary melting, secondary melting and refining). The process was developed and commercialized by PPG in the 1980's and implemented at two plants. Ultimately, the design reached fuel use of 4.0 MMBtu/ton in a flat glass furnace (GMIC 2004). The plants were taken out of operation to reduce overcapacity in the market, as they did not achieve the expected cost reduction relative to state-of-the-art traditional furnaces.

There is still considerable interest in the further development of the segmented melter to develop a more energy-efficient glass melting process (e.g. TNO, The Netherlands; Alfred University, New York).

Plasma melter. Various attempts to develop a plasma glass melting system have been made around the world (e.g. British Glass, Johns Mansville, and PPG). Patented by PPG Industries in the U.S. (Patent # 4,545,798) and currently under development in the UK, an argon plasma melter allows the rapid melting of glass. It is mainly of interest to small scale production of glass using batch processes. Tetronics / Johns Manville developed a twin-torch plasma melter while British Glass uses a triple-torch plasma melter for glass. However, both systems were never commercialized for glass melting. With support from the U.S. Department of Energy, the Plasmelt process is further investigated. It is not expected to be a viable technology for capacities over 20 tonnes/day (EC-JRC 2000).

High speed convection. Under development by Tamglass, Finland, this new HSC™ high-speed convection heater transfers more of the heat by convection (over 50%) using a lengthwise system of heating elements in the furnace. It allows the focusing of uniform heat and thus temperature control and increased product quality. In addition, Tamglass claims production increases of as much as 40%, lower energy costs, and increased process reliability (Tamglass 2003).

Reengineer process to spend less time in tank. Although there is a minimum time required for a certain quality of glass, most of the time in the tank is spent on the final 10% of quality. If this time can be reduced, energy savings can be achieved. Various designs have aimed at reducing the residence time in the furnace, e.g. the AGA scarp fiber melter, Saint Gobain's SPEED process, and the Pilkington Melter. Neither of the technologies has been offered commercially.

Submerged Combustion Melting (SCM). SCM has been under development since the 1960's. SCM is based on enhancing heat transfer by mixing the fuels and oxidant with the raw materials. In submerged combustion melting, fuels are fired directly into and under the surface of the batch material being melted. Placing the burners in the bottom of the glass furnace results in improved heat transfer and vigorous convective stirring of the melt. The reduction in energy intensity is mainly achieved by a reduction in residence time in the furnace, as the system allows for a segmented melting approach (Rue 2004). The savings are estimated at 5-7.5% when compared to a state-of-the-art oxy-fuel furnace, and depend on the utilization of heat losses from the furnace wall.

This technology can only be used with natural gas. Drawbacks of earlier designs included poor quality of the glass because of excessive bubbling, excessive refractory wear, and a shallow bed. Advantages include fast and easy start-up (four hours) and shut-downs (with empty or full chamber), rapid product composition and pull rate switching (while maintaining a homogenous melt), and safer operation with cooled walls and no need of hot repairs. All solid wastes can be recycled to the melter. In addition, the melter is compact and has low capital and maintenance costs and has flexibility of feeds (the batch can be blended or not). Five commercial 75 ton/day mineral wool units are in use in the Ukraine (two) and Belarus (three). A consortium of U.S.

based companies is developing the technology further. The Gas Technology Institute is now testing the system at a 1 tonne/hour pilot facility, started up in the summer of 2006.

Advanced Glass Melter (AGM). AGM has been developed by the Gas Technology Institute since the 1980's. A more compact furnace design in combination with batch preheating reduces energy losses, as well as capital costs. The AGM system may be most useful for insulation glass fiber and sodium silicate glasses (GMIC 2004). However, the AGM system has not been proven yet on a commercial scale.

Air bottoming cycle. Limited steam use in the glass production process limits the use of cogeneration or combined heat and power generation in the glass industry. An alternative may be the use of an air-bottoming cycle. In this cycle, the waste heat from a gas turbine is used to preheat the combustion air of the glass furnace. Korobitsyn (2002) studied the application of an air-bottoming cycle for various types of furnaces (regenerative, recuperative, and oxy-fuel) and found varying fuel savings for the different types of furnaces. The average energy savings were estimated at 10% with an estimated payback periods of 3 to 4 years (at price conditions in The Netherlands). While demonstration projects have been proposed for this technology, no commercial applications are known in the glass industry.

Glass fiber recycling. In the glass fiber industry, the recycling of in-house glass waste has proven particularly challenging as impurities in the waste material can often lead to a high rate of filament breakage in fiber forming processes. It has been estimated that around 260,000 tons of glass waste are generated each year in U.S. fiber glass production and that in-house recycling of this waste would save the U.S. glass industry over $7 million per year in avoided energy and waste disposal costs (ANL 2003). Argonne National Laboratory has developed a glass fiber recycling process based on thermal treatment that is estimated to have a potential payback period of 2 years. At the time of this writing, this technology had yet to be commercialized.

Using waste glass for cutting. An abrasive water jet cutting technique has been developed for finishing flat architectural and automotive glass, which uses waste glass as the abrasive media. At roughly $0.0035 per pound, the waste glass media is nearly 100 times cheaper than the garnet media that has been traditionally used in this application (U.S. DOE 2001a). While no quantitative data are yet available for this technology, the use of waste glass is projected to lead to significant savings in glass cutting costs, while providing an important outlet for waste glass that would otherwise be landfilled.

Other emerging melting technologies. The Glass Manufacturing Industry Council held a workshop entitled Glass Melting Technologies of the Future in February 2001 (GMIC 2001). At this conference, several emerging technologies were discussed, such as the arc furnace designed by M. P. Schlienger, using the batch for thermal insulation instead of the refractory sidewalls (U.S. Patent # 3,328,149, 01/27/67), cyclone melters (U.S. Patent # 3,510,289, 05/05/70), rapid refining, a process separated out from the melting stage, in development by Praxair, and microwave heating with energy savings from 30 to 50%.

6. Summary and Conclusions

Glass manufacturing consumes a considerable amount of energy. In 2003, the four primary segments of the U.S. glass industry—flat glass, container glass, specialty glass, and fiberglass—spent over $1.6 billion on energy. On average, energy costs in the U.S. glass industry account for around 14% of total glass production costs, making energy a significant cost driver. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings, especially in times of high energy price volatility.

Significant potential exists for energy efficiency improvement in the U.S. glass industry. A focused and strategic energy management program will help to identify and implement energy efficiency measures and practices across an organization. Many companies in the U.S. glass industry have already accepted the challenge to improve their energy efficiency in response to steadily-rising energy prices; these companies have also begun to reap the rewards of energy efficiency investments.

There are a variety of opportunities available at individual plants in the U.S. glass industry to reduce energy consumption in a cost-effective manner. This Energy Guide has identified many energy efficiency practices and energy-efficient technologies that can be implemented at the component, process, system, and organizational levels. Tables 10 and 11 summarized the cross-cutting and the process-specific energy efficiency opportunities, respectively. Expected savings in energy and energy-related costs have been provided for many energy efficiency measures, based on case study data from real-world industrial applications. Additionally, typical payback periods and references to further information in the technical literature have been provided, when available.

While the expected savings associated with some of the individual measures presented in this Energy Guide may be relatively small, the cumulative effect of these measures across an entire plant may potentially be quite large. Additionally, the majority of these measures have relatively short payback periods. The degree of implementation of these measures will vary by plant and end use; continuous evaluation of these measures will help to identify further cost savings in ongoing energy management programs.

For all energy efficiency measures presented in this Energy Guide, individual glass plants should pursue further research on the economics of the measures, as well as on the applicability of different measures to their own unique production practices, in order to assess the feasibility of measure implementation.

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8. Glossary

Al	Aluminum
APC	Adaptive process control
ASD	Adjustable speed drive
ASM	Annual Survey of Manufactures (of the U.S. Census)
B	Boron
Btu	British Thermal Unit
CAC	Compressed Air Challenge®
CaO	Calcium oxide (lime)
CDA	Copper Development Association
CFL	Compact fluorescent lamp
cfm	Cubic feet per minute
CGMS	Continuous Gob Monitoring System
CHP	Combined heat and power
CIPEC	Canadian Industry Program for Energy Conservation
CO	Carbon monoxide
CO_2	Carbon dioxide
EASA	Electric Apparatus Service Association
EIA	Energy Information Agency (U.S. Department of Energy)
ft^2	Square feet
ft^3	Cubic feet
GTI	Gas Technology Institute
HCl	Hydrochloric acid
HF	Hydrofluoric acid
HID	High-intensity discharge
hp	Horsepower
HVAC	Heating, ventilation, and air conditioning
IAC	Industrial Assessment Center
ISO	International Organization for Standardization
kBtu	Thousand British Thermal Unit
kcal	Kilocalorie
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour

LBNL	Lawrence Berkeley National Laboratory
LED	Light-emitting diode
m^2	Square meters
MASIS	Mobile aerosol-sealant injection system
MMBtu	Million British Thermal Units
MECS	Manufacturing Energy Consumption Survey
mm	Millimeter
MPC	Model-based predictive control
MW	Megawatt
MWh	Megawatt-hour
Na_2O	Sodium oxide
NAICS	North American Industrial Classification System
NBER	National Bureau of Economic Research
NEMA	National Electrical Manufacturers Association
NLG	Dutch Guilder
NO_X	Nitrogen oxides
O_2	Oxygen
OEAS	Oxygen enriched air staging
Pb	Lead
PID	Proportional, integral, derivative (controller)
PLC	Programmable Logic Controller
PM	Particulate matter
PSA	Pressure swing absorption
psi	Pounds per square inch
psig	Pounds per square inch (gauge)
PVSA	Pressure vacuum swing absorption
R&D	Research and development
SCM	Submerged combustion melting
SIC	Standard Industry Classification
SF_6	Sulfur hexafluoride
SiO_2	Silicon dioxide (quartz)
SO_2	Sulfur dioxide
TBtu	Trillion British Thermal Units
UNIDO	United Nations Industrial Development Organization

U.S. DOE	United States Department of Energy
U.S. EPA	Unites States Environmental Protection Agency
VSD	Variable speed drive
VVC	Variable voltage control

Appendix A: Location of Major Glass Plants in the United States

Major Flat Glass Plants in the United States (2004).[29]

Company	Location - City	State	Company	Location - City	State
AFG Industries	Victorville	CA	*Pilkington*	Lathrop	CA
	Spring Hill	KS		Ottawa	IL
	Richmond	KY		Laurinburg	NC
	Cinnaminson	NJ		Rossford	OH
	Kingsport	TN	*PPG Industries*	Fresno	CA
	Church Hill	TN		Mount Zion	IL
	Flemington	WV		Carlisle	PA
Cardinal FG	Mooresville	NC		Meadville	PA
	Durant	OK		Wichita Falls	TX
	Chehalis	WA	*Automotive Components Holdings, LLC*	Tulsa	OK
	Menomenie	WI		Nashville	TN
	Portage	WI			
Guardian Industries	Kingsburg	CA			
	DeWitt	IA			
	Carleton	MI			
	Geneva	NY			
	Floreffe	PA			
	Richburg	SC			
	Corsicana	TX			

[29] Major flat glass plants were defined as those operated by companies designated as "major manufacturers" of flat glass in the United States by the *2001 Glass Factory Directory* (National Glass Budget 2001) and the Office of Industrial Technology's *Energy and Environmental Profile of the U.S. Glass Industry* (U.S. DOE 2002). The locations of major plants were obtained from the *2004 Glass Factory Directory* (National Glass Budget 2004) and company websites.

Major Container Glass Plants in the United States (2004).[30]

Company	Location - City	State	Company	Location - City	State
Anchor Glass	Jacksonville	FL	*Saint-Gobain Containers*	Madera	CA
	Warner Robins	GA		Dolton	IL
	Lawrenceburg	IN		Lincoln	IL
	Winchester	IN		Dunkirk	IN
	Shakopee	MN		Ruston	LA
	Salem	NJ		Millford	MA
	Elmira Heights	NY		Pevely	MO
	Henryetta	OK		Henderson	NC
Owens-Illinois	Los Angeles	CA		Wilson	NC
	Oakland	CA		Sapulpa	OK
	Tracy	CA		Port Allegany	PA
	Windsor	CO		Waxahachie	TX
	Atlanta	GA		Seattle	WA
	Streator	IL		Burlington	WI
	Lapel	IN			
	Charlotte	MI			
	Auburn	NY			
	Winston-Salem	NC			
	Zanesville	OH			
	Muskogee	OK			
	Portland	OR			
	Brockway	PA			
	Clarion	PA			
	Crenshaw	PA			
	Waco	TX			
	Danville	VA			
	Toano	VA			

[30] Major container glass plants were defined as those operated by companies designated as "major manufacturers" of container glass in the United States by the *2001 Glass Factory Directory* (National Glass Budget 2001) and the Office of Industrial Technology's *Energy and Environmental Profile of the U.S. Glass Industry* (U.S. DOE 2002). The locations of major plants were obtained from the *2004 Glass Factory Directory* (National Glass Budget 2004) and company websites.

Major Fiberglass Plants in the United States (2004).[31]

Company	Location – City	State	Company	Location – City	State
CertainTeed Corp.	Chowchilla	CA	*Owens Corning*	Eloy	AZ
	Athens	GA		Fort Smith	AR
	Kansas City	KS		Santa Clara	CA
	Mountaintop	PA		Fairburn	GA
	Sherman	TX		Kansas City	KS
GAF Materials	Chester	SC		Delmar	NY
	Nashville	TN		Mt. Vernon	OH
Guardian Industries	Kingman	AZ		Newark	OH
	Albion	MI		Huntingdon	PA
	Mineral Wells	MS		Aiken	SC
	Inwood	WV		Anderson	SC
Johns Manville	Tucson	AZ		Jackson	TN
	Corona	CA		Amarillo	TX
	Willows	CA		New Braunfels	TX
	Winder (2)	GA		Waxahachie	TX
	Richmond	IN		Salt Lake City	UT
	McPherson	KS	*PPG Industries*	Shelby	NC
	Berlin	NJ		Lexington	NC
	Edison	NJ		Chester	SC
	Defiance (4)	OH		Forest	VA
	Cleburne	TX			
	Richmond	VA			

[31] Major fiberglass plants were defined as those operated by companies designated as "major manufacturers" of fiberglass products in the United States by the *2001 Glass Factory Directory* (National Glass Budget 2001) and the Office of Industrial Technology's *Energy and Environmental Profile of the U.S. Glass Industry* (U.S. DOE 2002). The locations of major plants were obtained from the *2004 Glass Factory Directory* (National Glass Budget 2004) and company websites.

Major Specialty Glass Plants in the United States (2004).[32]

Company	Location – City	State	Company	Location – City	State
Corning	Harrodsburg	KY	*OSRAM Sylvania*	Versailles (2)	KY
	Canton	NY		Winchester	KY
	Corning (2)	NY		Lake Zurich	IL
	Blacksburg	VA		Hillsborough	NH
	Danville	VA		Manchester	NH
GE Lighting	Lexington	KY		St. Marys	PA
	Somerset	KY	*Philips Lighting*	Salina	KS
	Circleville	OH		Danville	KY
	Logan	OH		Bath	NY
	Niles	OH		Paris	TX
	Bridgeville	PA		Fairmont	WV
	Winchester	VA	*World Kitchen*	Corning	NY
GE Quartz	Cleveland	OH		Massillon	OH
	Willoughby	OH		Charleroi	PA
Libbey Glass	Shreveport	LA			
	Toledo	OH			

[32] Major specialty glass plants were defined as those operated by companies designated as "major manufacturers" of specialty glass in the United States by the *2001 Glass Factory Directory* (National Glass Budget 2001) and the Office of Industrial Technology's *Energy and Environmental Profile of the U.S. Glass Industry* (U.S. DOE 2002). The locations of major plants were obtained from the *2004 Glass Factory Directory* (National Glass Budget 2004) and company websites.

Appendix B: Basic Energy Efficiency Actions for Plant Personnel

Personnel at all levels should be aware of energy use and organizational goals for energy efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high achievement. Some examples of simple tasks employees can do are outlined below (Caffal 1995).

- Eliminate unnecessary energy consumption by equipment. Switch off motors, fans, and machines when they are not being used, especially at the end of the working day or shift, and during breaks, when it does not affect production, quality, or safety. Similarly, turn on equipment no earlier than needed to reach the correct settings (temperature, pressure) at the start time.

- Switch off unnecessary lights; rely on daylighting whenever possible.

- Use weekend and night setbacks on HVAC in offices or conditioned buildings.

- Report leaks of water (both process water and dripping taps), steam, and compressed air. Ensure they are repaired quickly. The best time to check for leaks is a quiet time like the weekend.

- Look for unoccupied areas being heated or cooled, and switch off heating or cooling.

- Check that heating controls are not set too high or cooling controls set too low. In this situation, windows and doors are often left open to lower temperatures instead of lowering the heating.

- Check to make sure the pressure and temperature of equipment is not set too high.

- Prevent drafts from badly fitting seals, windows and doors, and hence, leakage of cool or warm air.

- Carry out regular maintenance of energy-consuming equipment.

- Ensure that the insulation on process heating equipment is effective.

Appendix C: Guidelines for Energy Management Assessment Matrix

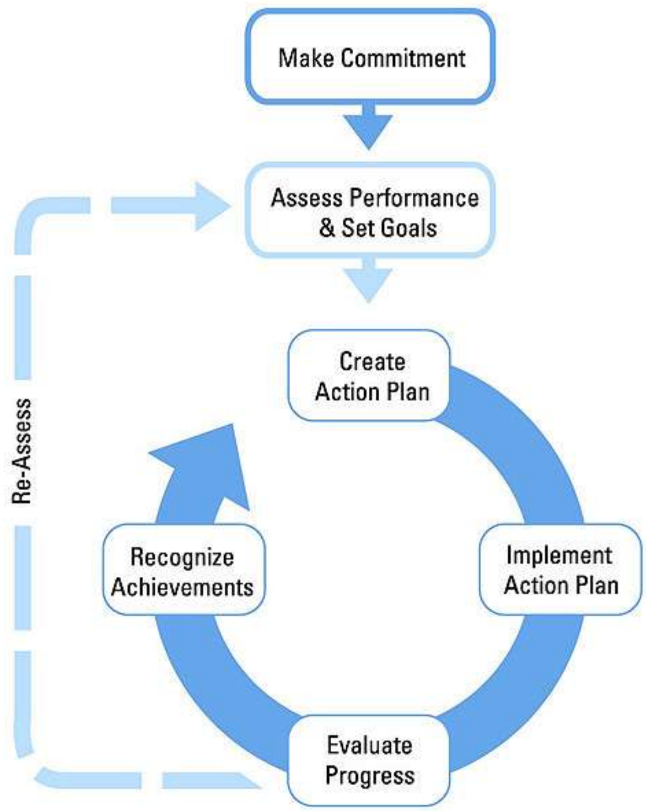
CHANGE FOR THE BETTER WITH ENERGY STAR

Energy Management Program Assessment Matrix

Introduction

The U.S. EPA has developed guidelines for establishing and conducting an effective energy management program based on the successful practices of ENERGY STAR partners.

These guidelines, illustrated in the graphic, are structured on seven fundamental management elements that encompass specific activities.



This assessment matrix is designed to help organizations and energy managers compare their energy management practices to those outlined in the Guidelines. The full Guidelines can be viewed on the ENERGY STAR web site – http://www.energystar.gov/.

How To Use The Assessment Matrix

The matrix outlines the key activities identified in the ENERGY STAR Guidelines for Energy Management and three levels of implementation:

- No evidence
- Most elements
- Fully Implemented

1. Print the assessment matrix.

2. Compare your program to the Guidelines by identifying the degree of implementation that most closely matches your organization's program.

3. Use a highlighter to fill in the cell that best characterizes the level of implementation of your program. You will now have a visual comparison of your program to the elements of the ENERGY STAR Guidelines for Energy Management.

4. Identify the steps needed to fully implement the energy management elements and record these in the Next Steps column.

Energy Management Program Assessment Matrix

	Little or no evidence	Some elements	Fully implemented	Next Steps
Make Commitment to Continuous Improvement				
Energy Director	No central corporate resource Decentralized management	Corporate or organizational resource not empowered	Empowered corporate leader with senior management support	
Energy Team	No company energy network	Informal organization	Active cross-functional team guiding energy program	
Energy Policy	No formal policy	Referenced in environmental or other policies	Formal stand-alone EE policy endorsed by senior mgmt.	
Assess Performance and Opportunities				
Gather and Track Data	Little metering/no tracking	Local or partial metering/tracking/ reporting	All facilities report for central consolidation/analysis	
Normalize	Not addressed	Some unit measures or weather adjustments	All meaningful adjustments for corporate analysis	
Establish baselines	No baselines	Various facility-established	Standardized corporate base year and metric established	
Benchmark	Not addressed or only same site historical comparisons	Some internal comparisons among company sites	Regular internal & external comparisons & analyses	
Analyze	Not addressed	Some attempt to identify and correct spikes	Profiles identifying trends, peaks, valleys & causes	
Technical assessments and audits	Not addressed	Internal facility reviews	Reviews by multi-functional team of professionals	
Set Performance Goals				
Determine scope	No quantifiable goals	Short term facility goals or nominal corporate goals	Short & long term facility and corporate goals	
Estimate potential for improvement	No process in place	Specific projects based on limited vendor projections	Facility & corporate defined based on experience	
Establish goals	Not addressed	Loosely defined or sporadically applied	Specific & quantifiable at various organizational levels	
Create Action Plan				
Define technical steps and targets	Not addressed	Facility-level consideration as opportunities occur	Detailed multi-level targets with timelines to close gaps	
Determine roles and resources	Not addressed or done on ad hoc basis	Informal interested person competes for funding	Internal/external roles defined & funding identified	

Energy Management Program Assessment Matrix				
	Little or no evidence	**Some elements**	**Fully implemented**	**Next Steps**
Implement Action Plan				
Create a communication plan	Not addressed	Tools targeted for some groups used occasionally	All stakeholders are addressed on regular basis	
Raise awareness	No promotion of energy efficiency	Periodic references to energy initiatives	All levels of organization support energy goals	
Build capacity	Indirect training only	Some training for key individuals	Broad training/certification in technology & best practices	
Motivate	No or occasional contact with energy users and staff	Threats for non-performance or periodic reminders	Recognition, financial & performance incentives	
Track and monitor	No system for monitoring progress	Annual reviews by facilities	Regular reviews & updates of centralized system	
Evaluate Progress				
Measure results	No reviews	Historical comparisons	Compare usage & costs vs. goals, plans, competitors	
Review action plan	No reviews	Informal check on progress	Revise plan based on results, feedback & business factors	
Recognize Achievements				
Provide internal recognition	Not addressed	Identify successful projects	Acknowledge contributions of individuals, teams, facilities	
Get external recognition	Not sought	Incidental or vendor acknowledgement	Government/third party highlighting achievements	

Interpreting Your Results

Comparing your program to the level of implementation identified in the Matrix should help you identify the strengths and weaknesses of your program.

The U.S. EPA has observed that organizations fully implementing the practices outlined in the Guidelines achieve the greatest results. Organizations are encouraged to implement the Guidelines as fully as possible.

By highlighting the cells of the matrix, you now can easily tell how well balanced your energy program is across the management elements of the Guidelines. Use this illustration of your energy management program for discussion with staff and management.

Use the "Next Steps" column of the Matrix to develop a plan of action for improving your energy management practices.

Resources and Help

ENERGY STAR offers a variety tools and resources to help organizations strengthen their energy management programs.

Here are some next steps you can take with ENERGY STAR:

1. Read the Guidelines sections for the areas of your program that are not fully implemented.

2. Become an ENERGY STAR Partner, if you are not already.

3. Review ENERGY STAR Tools and Resources.

4. Find more sector-specific energy management information at http://www.energystar.gov/industry.

5. Contact ENERGY STAR for additional resources.

Appendix D: Check List for Organizing Energy Teams

The following checklist can be used as a handy reference to key tasks for establishing and sustaining an effective energy team. For more detailed information on energy teams, consult the U.S. EPA's *Teaming Up to Save Energy* guide (U.S. EPA 2006), which is available at http://www.energystar.gov/.

ORGANIZE YOUR ENERGY TEAM		√
Energy Director	Able to work with all staff levels from maintenance to engineers to financial officers. Senior-level person empowered by top management support	
Senior Management	Energy director reports to senior executive or to a senior management council. Senior champion or council provides guidance and support	
Energy Team	Members from business units, operations/engineering, facilities, and regions. Energy networks formed. Support services (PR, IT, HR).	
Facility Involvement	Facility managers, electrical personnel. Two-way information flow on goals and opportunities. Facility-based energy teams with technical person as site champion.	
Partner Involvement	Consultants, vendors, customers, and joint venture partners. Energy savings passed on through lower prices.	
Energy Team Structure	Separate division and/or centralized leadership. Integrated into organization's structure and networks established.	
Resources & Responsibilities	Energy projects incorporated into normal budget cycle as line item. Energy director is empowered to make decisions on projects affecting energy use. Energy team members have dedicated time for the energy program.	
STARTING YOUR ENERGY TEAM		**√**
Management Briefing	Senior management briefed on benefits, proposed approach, and potential energy team members.	
Planning	Energy team met initially to prepare for official launch.	
Strategy	Energy team met initially to prepare for official launch.	
Program Launch	Organizational kickoff announced energy network, introduced energy director, unveiled energy policy, and showcased real-world proof.	
Energy Team Plans	Work plans, responsibilities, and annual action plan established.	
Facility Engagement	Facility audits and reports conducted. Energy efficiency opportunities identified.	

BUILDING CAPACITY		√
Tracking and Monitoring	Systems established for tracking energy performance and best practices implementation.	
Transferring Knowledge	Events for informal knowledge transfer, such as energy summits and energy fairs, implemented.	
Raising Awareness	Awareness of energy efficiency created through posters, intranet, surveys, and competitions.	
Formal Training	Participants identified, needs determined, training held. Involvement in ENERGY STAR Web conferences and meetings encouraged. Professional development objectives for key team members.	
Outsourcing	Use of outside help has been evaluated and policies established.	
Cross-Company Networking	Outside company successes sought and internal successes shared. Information exchanged to learn from experiences of others.	
SUSTAINING THE TEAM		√
Effective Communications	Awareness of energy efficiency created throughout company. Energy performance information is published in company reports and communications.	
Recognition and Rewards	Internal awards created and implemented. Senior management is involved in providing recognition.	
External Recognition	Credibility for your organization's energy program achieved. Awards from other organizations have added to your company's competitive advantage.	
MAINTAINING MOMENTUM		√
Succession	Built-in plan for continuity established. Energy efficiency integrated into organizational culture.	
Measures of Success	Sustainability of program and personnel achieved. Continuous improvement of your organization's energy performance attained.	

Appendix E: Support Programs for Industrial Energy Efficiency Improvement

This appendix provides a list of energy efficiency support available to industry. A brief description of the program or tool is given, as well as information on its target audience and the URL for the program. Included are federal and state programs. Use the URL to obtain more information from each of these sources. An attempt was made to provide as complete a list as possible; however, information in this listing may change with the passage of time.

Tools for Self-Assessment

Steam System Assessment Tool

Description:	Software package to evaluate energy efficiency improvement projects for steam systems. It includes an economic analysis capability.
Target Group:	Any industry operating a steam system
Format:	Downloadable software package (13.6 MB)
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Steam System Scoping Tool

Description:	Spreadsheet tool for plant managers to identify energy efficiency opportunities in industrial steam systems.
Target Group:	Any industrial steam system operator
Format:	Downloadable software (Excel)
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

3E Plus: Optimization of Insulation of Boiler Steam Lines

Description:	Downloadable software to determine whether boiler systems can be optimized through the insulation of boiler steam lines. The program calculates the most economical thickness of industrial insulation for a variety of operating conditions. It makes calculations using thermal performance relationships of generic insulation materials included in the software.
Target Group:	Energy and plant managers
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

MotorMaster+

Description:	Energy-efficient motor selection and management tool, including a catalog of over 20,000 AC motors. It contains motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.
Target Group:	Any industry
Format:	Downloadable software (can also be ordered on CD)
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

ASDMaster: Adjustable Speed Drive Evaluation Methodology and Application

Description:	Software program helps to determine the economic feasibility of an adjustable speed drive application, predict how much electrical energy may be saved by using an ASD, and search a database of standard drives.
Target Group:	Any industry
Format:	Software package (not free)
Contact:	Electric Power Research Institute (EPRI), (800) 832-7322
URL:	http://www.epri-peac.com/products/asdmaster/asdmaster.html

The 1-2-3 Approach to Motor Management

Description:	A step-by-step motor management guide and spreadsheet tool that can help motor service centers, vendors, utilities, energy-efficiency organizations, and others convey the financial benefits of sound motor management.
Target Group:	Any industry
Format:	Downloadable Microsoft Excel spreadsheet
Contact:	Consortium for Energy Efficiency (CEE), (617) 589-3949
URL:	http://www.motorsmatter.org/tools/123approach.html

AirMaster+: Compressed Air System Assessment and Analysis Software

Description:	Modeling tool that maximizes the efficiency and performance of compressed air systems through improved operations and maintenance practices
Target Group:	Any industry operating a compressed air system
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Fan System Assessment Tool (FSAT)

Description:	The Fan System Assessment Tool (FSAT) helps to quantify the potential benefits of optimizing a fan system. FSAT calculates the amount of energy used by a fan system, determines system efficiency, and quantifies the savings potential of an upgraded system.
Target Group:	Any user of fans
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Combined Heat and Power Application tool (CHP)

Description:	The Combined Heat and Power Application Tool (CHP) helps industrial users evaluate the feasibility of CHP for heating systems such as fuel-fired furnaces, boilers, ovens, heaters, and heat exchangers.
Target Group:	Any industrial heat and electricity user
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Pump System Assessment Tool 2004 (PSAT)

Description:	The tool helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.
Target Group:	Any industrial pump user
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Quick Plant Energy Profiler

Description:	The Quick Plant Energy Profiler, or Quick PEP, is an online software tool provided by the U.S. Department of Energy to help industrial plant managers in the United States identify how energy is being purchased and consumed at their plant and also identify potential energy and cost savings. Quick PEP is designed so that the user can complete a plant profile in about an hour. The Quick PEP online tutorial explains what plant information is needed to complete a Quick PEP case.
Target Group:	Any industrial plant
Format:	Online software tool
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

ENERGY STAR Portfolio Manager

Description:	Online software tool helps to assess the energy performance of buildings by providing a 1-100 ranking of a building's energy performance relative to the national building market. Measured energy consumption forms the basis of the ranking of performance.
Target Group:	Any building user or owner
Format:	Online software tool
Contact:	U.S. Environmental Protection Agency
URL:	http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager

Assessment and Technical Assistance

Industrial Assessment Centers

Description:	Small- to medium-sized manufacturing facilities can obtain a free energy and waste assessment. The audit is performed by a team of engineering faculty and students from 30 participating universities in the U.S. and assesses the plant's performance and recommends ways to improve efficiency.
Target Group:	Small- to medium-sized manufacturing facilities with gross annual sales below $75 million and fewer than 500 employees at the plant site.
Format:	A team of engineering faculty and students visits the plant and prepares a written report with energy efficiency, waste reduction and productivity recommendations.
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/iacs.html

Save Energy Now Assessments

Description:	The U.S. DOE conducts plant energy assessments to help manufacturing facilities across the nation identify immediate opportunities to save energy and money, primarily by focusing on energy-intensive systems, including process heating, steam, pumps, fans, and compressed air.
Target Group:	Large plants
Format:	Online request
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/saveenergynow/

Manufacturing Extension Partnership (MEP)

Description:	MEP is a nationwide network of not-for-profit centers in over 400 locations providing small- and medium-sized manufacturers with technical assistance. A center provides expertise and services tailored to the plant, including a focus on clean production and energy-efficient technology.
Target Group:	Small- and medium-sized plants
Format:	Direct contact with local MEP Office
Contact:	National Institute of Standards and Technology, (301) 975-5020
URL:	http://www.mep.nist.gov/

Small Business Development Center (SBDC)

Description:	The U.S Small Business Administration (SBA) administers the Small Business Development Center Program to provide management assistance to small businesses through 58 local centers. The SBDC Program provides counseling, training and technical assistance in the areas of financial, marketing, production, organization, engineering and technical problems and feasibility studies, if a small business cannot afford consultants.
Target Group:	Small businesses
Format:	Direct contact with local SBDC
Contact:	Small Business Administration, (800) 8-ASK-SBA
URL:	http://www.sba.gov/sbdc/

ENERGY STAR – Selection and Procurement of Energy-Efficient Products for Business

Description:	ENERGY STAR identifies and labels energy-efficient office equipment. Look for products that have earned the ENERGY STAR. They meet strict energy efficiency guidelines set by the EPA. Office equipment included such items as computers, copiers, faxes, monitors, multifunction devices, printers, scanners, transformers and water coolers.
Target Group:	Any user of labeled equipment.
Format:	Website
Contact:	U.S. Environmental Protection Agency
URL:	http://www.energystar.gov/index.cfm?c=business.bus_index

Training

ENERGY STAR

Description:	As part of ENERGY STAR's work to promote superior energy management systems, energy managers for the companies that participate in ENERGY STAR are offered the opportunity to network with other energy managers in the partnership. The networking meetings are held monthly and focus on a specific strategic energy management topic to train and strengthen energy managers in the development and implementation of corporate energy management programs.
Target Group:	Corporate and plant energy managers
Format:	Web-based teleconference
Contact:	Climate Protection Partnerships Division, U.S. Environmental Protection Agency
URL:	http://www.energystar.gov/

Best Practices Program

Description:	The U.S. DOE Best Practices Program provides training and training materials to support the efforts of the program in efficiency improvement of utilities (compressed air, steam) and motor systems (including pumps). Training is provided regularly in different regions. One-day or multi-day trainings are provided for specific elements of the above systems. The Best Practices program also provides training on other industrial energy equipment, often in coordination with conferences.
Target Group:	Technical support staff, energy and plant managers
Format:	Various training workshops (one day and multi-day workshops)
Contact:	Office of Industrial Technologies, U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/training.html

Compressed Air Challenge®

Description:	The not-for-profit Compressed Air Challenge® develops and provides training on compressed air system energy efficiency via a network of sponsoring organizations in the United States and Canada. Three levels of training are available: (1) Fundamentals (1 day); (2) Advanced (2 days); and (3) Qualified Specialist (3-1/2 days plus an exam). Training is oriented to support implementation of an action plan at an industrial facility.
Target Group:	Compressed air system managers, plant engineers
Format:	Training workshops
Contact:	Compressed Air Challenge: Info@compressedairchallenge.org
URL:	http://www.compressedairchallenge.org/

Financial Assistance

Below major federal programs are summarized that provide assistance for energy efficiency investments. Many states also offer funds or tax benefits to assist with energy efficiency projects (see below for State Programs). However, these programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

Industries of the Future - U.S. Department of Energy

Description:	Collaborative R&D partnerships in nine vital industries. The partnership consists of the development of a technology roadmap for the specific sector and key technologies, and cost-shared funding of research and development projects in these sectors.
Target Group:	Nine selected industries: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum and steel.
Format:	Solicitations (by sector or technology)
Contact:	U.S. Department of Energy – Office of Industrial Technologies
URL:	http://www.eere.energy.gov/industry/technologies/industries.html

Inventions & Innovations (I&I)

Description:	The program provides financial assistance through cost-sharing of 1) early development and establishing technical performance of innovative energy-saving ideas and inventions (up to $75,000) and 2) prototype development or commercialization of a technology (up to $250,000). Projects are performed by collaborative partnerships and must address industry-specified priorities.
Target Group:	Any industry (with a focus on energy-intensive industries)
Format:	Solicitation
Contact:	U.S. Department of Energy – Office of Industrial Technologies
URL:	http://www.eere.energy.gov/inventions/

Small Business Administration (SBA)

Description:	The Small Business Administration provides several loan and loan guarantee programs for investments (including energy-efficient process technology) for small businesses.
Target Group:	Small businesses
Format:	Direct contact with SBA
Contact:	Small Business Administration
URL:	http://www.sba.gov/

State and Local Programs

Many state and local governments have general industry and business development programs that can be used to assist businesses in assessing or financing energy-efficient process technology or buildings. Please contact your state and local government to determine what tax benefits, funding grants, or other assistance they may be able to provide your organization. This list should not be considered comprehensive but instead merely a short list of places to start in the search for project funding. These programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

Summary of Motor and Drive Efficiency Programs by State

Description:	A report that provides an overview of state-level programs that support the use of NEMA Premium® motors, ASDs, motor management services, system optimization and other energy management strategies.
Target Group:	Any industry
Contact:	Consortium for Energy Efficiency (CEE), (617) 589-3949
URL:	http://www.motorsmatter.org/tools/123approach.html

California – Public Interest Energy Research (PIER)

Description:	PIER provides funding for energy efficiency, environmental, and renewable energy projects in the state of California. Although there is a focus on electricity, fossil fuel projects are also eligible.
Target Group:	Targeted industries (e.g. food industries) located in California
Format:	Solicitation
Contact:	California Energy Commission, (916) 654-4637
URL:	http://www.energy.ca.gov/pier/funding.html

California – Energy Innovations Small Grant Program (EISG)

Description:	EISG provides small grants for development of innovative energy technologies in California. Grants are limited to $75,000.
Target Group:	All businesses in California
Format:	Solicitation
Contact:	California Energy Commission, (619) 594-1049
URL:	http://www.energy.ca.gov/research/innovations/index.html/

California – Savings By Design

Description:	Design assistance is available to building owners and to their design teams for energy-efficient building design. Financial incentives are available to owners when the efficiency of the new building exceeds minimum thresholds, generally 10% better than California's Title 24 standards. The maximum owner incentive is $150,000 per free-standing building or individual meter. Design team incentives are offered when a building design saves at least 15%. The maximum design team incentive per project is $50,000.
Target Group:	Nonresidential new construction or major renovation projects
Format:	Open year round
URL:	http://www.savingsbydesign.com/

Indiana – Industrial Programs

Description:	The Energy Policy Division of the Indiana Department of Commerce operates two industrial programs. The Industrial Energy Efficiency Fund (IEEF) is a zero-interest loan program (up to $250,000) to help Indiana manufacturers increase the energy efficiency of manufacturing processes. The fund is used to replace or convert existing equipment, or to purchase new equipment as part of a process/plant expansion that will lower energy use. The Distributed Generation Grant Program (DGGP) offers grants of up to $30,000 or up to 30% of eligible costs for distributed generation with an efficiency over 50% to install and study distributed generation technologies such as fuel cells, micro turbines, co-generation, combined heat & power and renewable energy sources. Other programs support can support companies in the use of biomass for energy, research or building efficiency.
Target Group:	Any industry located in Indiana
Format:	Application year-round for IEEF and in direct contact for DGGP
Contact:	Energy Policy Division, (317) 232-8970.
URL:	http://www.iedc.in.gov/Grants/index.asp

Iowa – Alternate Energy Revolving Loan Program

Description:	The Alternate Energy Revolving Loan Program (AERLP) was created to promote the development of renewable energy production facilities in the state.
Target Group:	Any potential user of renewable energy
Format:	Proposals under $50,000 are accepted year-round. Larger proposals are accepted on a quarterly basis.
Contact:	Iowa Energy Center, (515) 294-3832
URL:	http://www.energy.iastate.edu/funding/aerlp-index.html

New York – Industry Research and Development Programs

Description:	The New York State Energy Research & Development Agency (NYSERDA) operates various financial assistance programs for New York businesses. Different programs focus on specific topics, including process technology, combined heat and power, peak load reduction and control systems.
Target Group:	Industries located in New York
Format:	Solicitation
Contact:	NYSERDA, (866) NYSERDA
URL:	http://www.nyserda.org/programs/Commercial_Industrial/default.asp?i=2

Wisconsin – Focus on Energy

Description:	Energy advisors offer free services to identify and evaluate energy-saving opportunities, recommend energy efficiency actions, develop an energy management plan for business; and integrate elements from national and state programs. It can also provide training.
Target Group:	Industries in Wisconsin
Format:	Open year round
Contact:	Wisconsin Department of Administration, (800) 762-7077
URL:	http://focusonenergy.com/portal.jsp?pageId=4