# Energy Efficiency Opportunities in the Glass Manufacturing Industry

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## ABSTRACT

The glass manufacturing industry is a highly energy-intensive industry that has been one of the focal sectors of the US Department of Energy's Industries of the Future (DOE-IOF) initiative. This paper will provide an overview of energy intensity, and energy and environmental opportunities in this industrial sector. First, we will provide an overview of the glass manufacturing process, with a critical focus on both traditional and recent process systems and their energy intensity. While the glass manufacturing process is very simple in concept (involving the melting of fine silica sand and formation into specific geometries), there are a broad range of process and power supply variations, all of which can have profound effects on the net energy efficiency and energy density (BTUs per lb of product). Attempts to improve glass manufacturing energy efficiency are complicated by the complexity of some of the process equipment, particularly since many glass-manufacturing systems are custom engineered, one-of-a-kind systems. Consequently, costs associated with upgrades for efficiency can be very high.

Opportunities for energy efficiency improvement will then be discussed, first in general for the glass manufacturing industry as a whole, and then for a specific case study example facility. The selected case study will address an Osram Sylvania plant that manufactures glass tubing for both Osram internal operations and for other lamp manufacturers. This facility is currently the focus of a DOE-IOF plant-wide assessment. This study will address the complete glass manufacturing operations, including melting and glass forming, power supplies for the glass melting process, post-formation shaping and handling, and auxiliary services and processes. The key findings of the study will be presented, with a critical eye on improvements that are not only applicable to this facility, but also to the glass manufacturing industry as a whole.

## Overview of Glass Manufacturing in the US

Glass is one of the oldest and most important materials known to man. Its desirable properties – low-cost, durable, transparent, thermally and chemically tolerant, abundance of raw materials and easy to recycle – have stimulated the development of a myriad of products used throughout society.

Today the US glass industry is divided into four sub-sectors – container, flat, specialty and fiberglass – producing over 20 million tons of glass a year (Table 1). Its uses include containers, lighting, buildings, communication, transportation and many other applications.

**Table 1. US Glass Sectors by Product Type**

| | |
|---|---|
| **Flat Glass** | Windows, car windshields, picture glass |
| **Container Glass** | Bottles, jars and packaging |
| **Specialty Glass (Pressed/Blown)** | Food service, flat panel display, light bulbs, televisions, scientific and medical glassware |
| **Glass Fiber** | Insulation, textile reinforcement, optical fibers |
| **Manufactured Glass Products** | Assembled items, e.g. table tops, aquariums, mirrors, lab apparatus, ornaments, art glass |

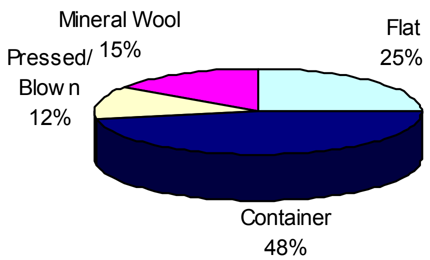
Glass end products and raw materials are heavy and expensive to ship, so production and consumption is generally concentrated near major cities. The majority of glass manufacturing plants are in the Northeast, Midwest and California. The leading states are Ohio, Pennsylvania, North Carolina and California. (Pellegrino, 2002)

**Table 2. Summary of 1999 Glass Industry Statistics**

| Sector | Shipments ($million) | Tons | Establish-ments | Employees | Capital Expenses ($millions) |
|---|---|---|---|---|---|
| **Flat** | 2,746 | 5,000,521 | 36 | 11,053 | 322.7 |
| **Container** | 4,215 | 9,586,500 | 61 | 19,220 | 349.3 |
| **Pressed/Blown** | 5,787 | 2,484,182 | 515 | 35,013 | 636.8 |
| **Mineral Wool** | 4,844 | 3,04,000 | 298 | 22,823 | 285.8 |
| **Purchased Glass Products** | 10,847 | not avail. | 1,657 | 62,405 | not avail. |
| **INDUSTRY TOTAL** | 28,439 | 20,111,203 | 2,567 | 150,514 | 1,594.60 |

(DOC ASM 93-99, DOC MP 93-00-, USITC 2001)

**Figure 1. Breakdown of Glass Production in the U.S. by Ton, 1999 Estimate**




(Pellegrino 2002)

The glass industry is a cornerstone of the US economy, with nearly $30 billion in products shipped annually and close to 150,000 employees. It is also an energy-intensive industry, consuming an estimated 250 trillion Btu a year, at a cost of $1.7 billion (Pellegrino 2002).

Glass has been produced en mass since the industrial revolution in this country. It has boomed and struggled with the rest of the economy, through the prosperity of the 1950s, the technological advances of the 1960s, the fuel shortages and recession of the 1970s, the slow-down and consolidation of the 1980s, the increased foreign competition and industrial downsizing of the 1990s. Throughout these times, adversity has inspired creativity, from more efficient use of energy and raw materials, to expansion into new markets such as fiber optics, architectural design and electronics.

Into the 21st century, prospects for market growth are moderate but steady. Finding new ways to improve process reliability, curtail energy use and reduce pollution will help US glass manufacturers stay competitive in a changing global market.

**Process and Materials**

The basic raw material and method for making glass is the same as it was when Egyptians were making it 7,000 years ago: melting and forming sand. Today, highly controlled processes and formulas allow for glass in an endless array of shapes, densities, strengths, colors, etc. Whether manufacturing containers, flat, specialty or fiberglass, the steps are essentially the same. There are four phases of production: batch preparation, melting and refining, forming, and post-forming.

During **batch preparation**, raw materials are selected and blended. The main ingredients are high-quality silica (sand), limestone and soda ash, and (for container glass) feldspar with many other substances that can be added. The composition of the batch can greatly influence the outcome of the final product, in terms of its chemical, electrical, mechanical and thermal properties. Therefore, proper proportioning and mixing of these materials is critical to the product characteristics. To generate a ton of

Next the batch is **melted** in a furnace at very high temperature (between 2,600 $^o$ F and 3,100$^o$ F) to remove impurities and transform the raw materials from the batch. As these crystalline materials become molten, chemical reactions associated with melting, dissolution, volatilization and oxidation-reduction occur that turn it into glass.

Melting can be done in many different types and sizes of furnaces incorporating different fuels and energy intensities. This depends on the end product desired. About 90% of the glass produced in the US is melted in regenerative furnaces. These furnaces include electric boosters that increase output, reduce fuel consumption and emissions at the manufacturing plant (Ruth 1997).

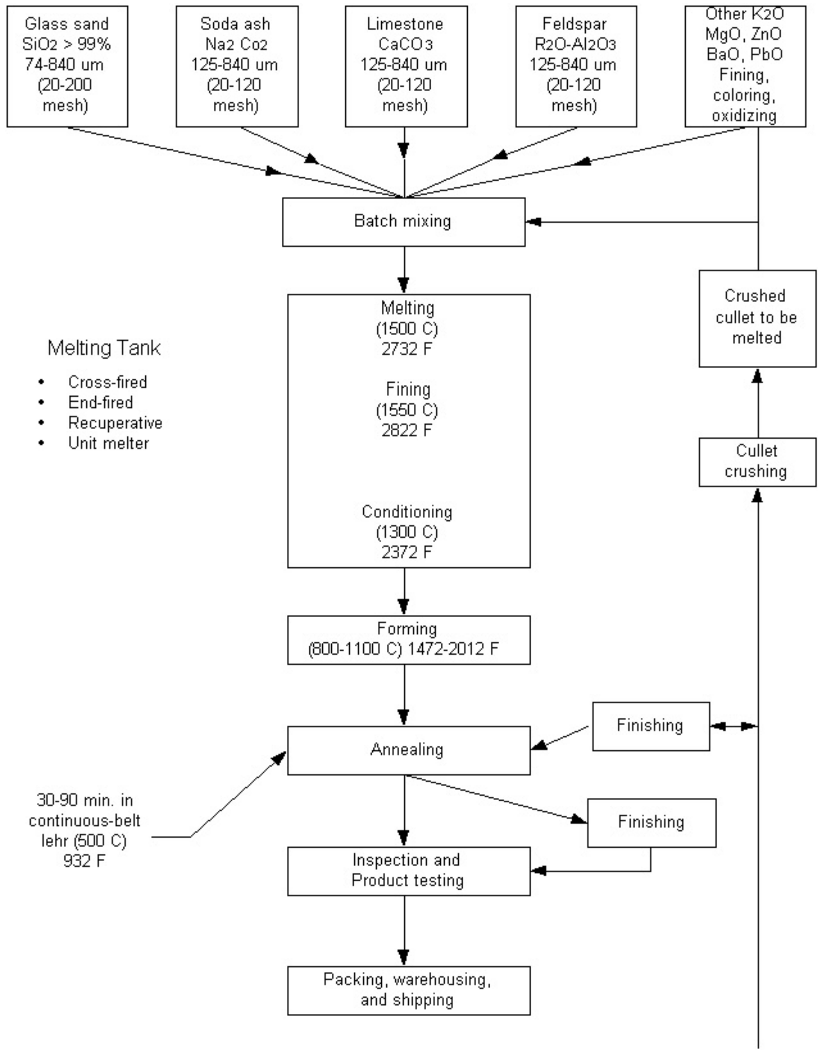
**Refining** is the stage where the molten glass is freed of bubbles, homogenized and heat conditioned. This chemical and physical process occurs in the melting chamber. The desired quality and properties of the glass determines how much refining is done. Flat and specialty glass must have fewer imperfections than container glass, therefore it requires more time and energy. Melting of raw materials consumes about 60-70 percent of the total energy used to make glass. It is a very inefficient process, with as much as 30 percent of the energy lost through the furnace and an additional 30 percent lost up the stack. (Pellegrino 2002)

The final product takes shape during **forming**. As it moves from the melting tank to the forming machine, the molten hot glass looks like a thick orangey syrup. The forming must take place quickly, since the glass become rigid as it cools. Depending on the final product, the forming process can vary widely. This may involve blowing, casting, fiberization, sheet forming, or other processes.

### Diagram of a Generalized Glass-making Process

The general steps in the glass making process are shown in Figure 2. This diagram outlines the process that relates to all sectors of glass manufacturing.

**Figure 2. Overview of the Glass Manufacturing Process**




(Adapted from the Glass Industries of the Future Report, Pellegrino 2002)

### Energy Use

The majority of energy used in glass production goes toward melting and refining. Subsequently, this is where the greatest opportunity for savings can be found. These steps account for about 70% of energy use. Melting one ton of glass theoretically requires about 2.2 million Btu. Due to a variety of inefficiencies and quality standards, it generally takes about twice that much. The US glass industry seeks to close that gap by the year 2020 (Jamison, et al 2002).

In total, approximately 60% of the energy used to generate heat is lost and only about 40% actually goes into heating the batch and driving the thermodynamic reactions (Vision 1996, EPA 1994). Aside from making furnaces more efficient, heat recovery is a significant opportunity for energy savings.

Before the oil crisis of the 1970s, oil was the major source of power in the glass industry. Today natural gas accounts for about 80% of the energy input, with 17% coming from electricity, and the remaining 3% from fuel oil and other fuels. Energy is a major cost for glass manufacturing with purchased energy accounting for about 14% of all manufacturing costs. (MECS 1994). Table 3 shows a breakdown of energy use by sector based on information from the Energy Information Administration of the U.S. Department of Energy.

Process heating accounts for approximately half of the electricity used in glassmaking, mainly for electric boosting of furnaces. The rest is consumed by compressors, conveyors, pumps, blowers, and HVAC and lighting.

**Table 3. U.S. Glass Industry Energy Use, MECs Estimates (Trillion BTU)***

| | Purchased Electricity | Fuels | Net Energy Use | Losses | Total Energy Use |
|---|---|---|---|---|---|
| Flat | 5 | 47 | 52 | 10.4 | 62.4 |
| Container | 15 | 68 | 83 | 31.2 | 114.2 |
| Pressed/ Blown | 11 | 52 | 63 | 22.9 | 85.9 |
| Mineral Wool | 12 | 39 | 51 | 24.9 | 75.9 |
| INDUSTRY TOTAL | 43 | 206 | 249 | 89.4 | 338.4 |

*The most recent complete data available by sector is from 1994.
In 1998, total energy use was 293 Trillion BTU.

Significant improvements have been made in reducing the energy intensity of glass production in recent years, resulting in a 25 percent reduction in fuel consumed in melting since the early 1980s. Advances include computerized process control and inspection, the development of advanced refractory materials, and technologies such as oxy-fuel firing and electric and chemical boosting, which increase production capacity. (Pellegrino 2002, Ruth 1997)

Increased efficiency will help lower costs and make the US glass industry stronger in the face of global competition, substitute materials and economic downturns. Today, over 50% of glassmaking establishments conduct energy-management activities (Pellegrino, 2002).

## Current and Future Opportunities for Energy Saving

Though the glass industry is considered "mature," because it is so large and energy-intensive, any improvements to efficiency can result in substantial savings with quick payback periods. There are some key emerging technologies that hold potential for the industry to realize significant savings in the future. These include heat recovery systems, improved process controls, more efficient use of raw materials and proper furnace tuning.

According to the EIA, the most popular energy-saving technologies in the glass industry are computer control of manufacturing processes and building equipment, waste heat recovery and adjustable speed motors (Pellegrino, 2002).

## Recent Advances in Technology

### Minimization of Excess Air and Proper Burner Position

According to Glasscon Associates, fuel efficiency and production of glass can be improved by carefully tuning the burner and controlling gas input (Glasscon 2003). When burners are properly positioned (adjusting the angle between the burner axis and the glass surface), significant changes can occur in the amount of natural gas required to melt a ton of glass. In tests, Glasscon says, 6.8 million BTU were required to melt each ton of glass. As the burners were adjusted, gas consumption per unit of output changed significantly.

### Batch or Cullet Preheating

One of the most promising technologies to emerge in the glass industry in recent years involves preheating the glass virgin batch materials or cullet before it enters the furnace. Cullet is recycled glass broken into pieces, either from in-house processes or purchased. This is a high-efficiency method involving filtering the pre-glass materials through hot exhaust gases to preheat it prior to melting. Cullet and batch preheating is not yet at a market-ready stage, although government projections have indicated it could have major implications for energy and resource savings.

A fact sheet from the Office of Industrial Technologies at the DOE estimates that this technology could reduce consumption of fuel and oxygen by 25 percent in oxyfuel glass furnaces, increase production by up to 25 percent, reduce overall production costs, and increase the life of furnaces (EIA 2000).

### Oxy-fuel Furnaces

By adding oxygen specific points in the melting process, manufacturers can lower the BTU/ton ratio by either increasing output or reducing fuel input. Increased oxygen enables hotter burn temperatures. It has been reported that by increasing the oxygen content of combustion air from 21 to 23 percent, an increase in glass production of 12 percent can be achieved (Glasscon Associates, 2003). This process must be carefully controlled, as burning of unnecessary oxygen is costly, increases $NO_x$ and particulate matter, and increases wear-and-tear on the furnace, particularly the silica crown roof. About 20-25 percent of all glass furnaces used today are oxy-fuel furnaces.

### Increase in the Use of Recycled Glass

Cullet typically makes up about 20 percent of the materials that go into glass making. Most glass manufacturers use about ten percent of “house” cullet that is recycled during the manufacturing process (Pellegrino, 2002). Many can also use post-consumer recycled glass, where strict purity is not an issue. Though it is less energy-intensive to process cullet into glass than it is to begin with raw materials, there are economic and energy concerns involved with collecting and transporting the recovered glass. Still, in many cases, increasing the percentage of post-consumer glass can have a positive impact on plant energy consumption and overall costs, as well as reduced inputs and emissions.

### Energy Management Activities

More than half of all U.S. glass manufacturers are involved in one or more energy management activities. According to the Manufacturing Energy Consumption Survey (EIA 2000) the top four activities were energy audits, purchase of electricity under special programs such as peak load reduction, modifications to improve machine drives and improvements to facility lighting. Improving glass processes and supporting end-uses efficiencies Plantwide can have considerable impacts on energy consumption.

### Obstacles to Improvements

Due to the wide variety of glass applications and types of manufacturers, glass-making furnaces come in a variety of sizes and types. This makes it difficult to standardize potential energy savings measures in the plants, specifically in the furnaces. These custom-engineered systems are costly to upgrade. Furnaces are not typically shut down until a major rebuild is required, which can take up to two years and cost millions of dollars. Once placed into service, a glass furnace may operate continually for up to fifteen years. Subsequently, it is capital-intensive and represents a major project to replace existing furnaces.

## Case Study: Osram Sylvania Glass Manufacturing Plant

### Introduction

The Osram Sylvania facility in Exeter, New Hampshire, in conjunction with its technical consulting partner, Energy & Resource Solutions (**ERS**), was awarded a Plantwide Assessment project under the DOE-IOF Program. This project was awarded in the fall of 2002, and at the time of this writing – due to DOE's budget approval cycle – is just commencing. The final version of this paper will update the case study to include the most recent findings and related activities for the project. By nature of the program, the Plantwide Assessment will address all end-uses in the facility. Specific attention, however, will be placed on the energy intense process associates with the glass manufacturing operations within the plant.

### Facility Overview

The Osram Sylvania glass manufacturing facility is comprised of multiple adjacent buildings that incorporate different aspects of the manufacturing process and related business operations. Two primary buildings are the focus of the study, Building A and Building B. Building A is the original building in the complex and was built in 1962. Building B was constructed later in an expansion period during the early 1980s. Together, these two buildings occupy a total area of 170,000 square feet. The majority of area in the facility is dedicated to manufacturing and engineering functions. Manufacturing processes are conducted 24 hours per day, seven days per week throughout the year.

The facility conducts energy-intensive operations associated with the conversion of raw silica into highly pure glass and ceramic products intended for use in commercial lighting systems and semiconductor manufacturing processes. The industrial processes used to develop these products use substantial electric energy and numerous (purchased) industrial gases (Hydrogen, Nitrogen, Oxygen, Argon and Helium) and include the use of specialized sand processing equipment, high temperature electric melters, and electric vacuum baking ovens. In addition to the specialized processes heating systems, more typical industrial systems are present in the facilities such as process cooling loops, space heating/cooling equipment (for manufacturing, clean room and office environments), compressed air systems, motor driven equipment, and lighting systems.

**Glass Manufacturing Process Overview**

Raw materials are received in the form of quartz sand. This material goes through a variety of processes to develop a glass tube with the required end product characteristics. The primary process categories of the glass manufacturing operation are as follows:

**Sand processing (cleaning, calcification and cracking).** This operation incorporates the raw silica and breaks it down into a finer form. Considerable heat energy is required for the process in conjunction with a variety of process equipment. The crystalline structure of the sand is altered, impurities are cleared and the overall material is washed.

**Glass melters.** There are a total of nine electrically fueled melters that are used to develop molten sand that is processed into extruded glass tubes of various diameters. A container tube with a controlled gas environment is heated by the electrical energy input. A mandrel inside the container tube controls the outside diameter of the tube to be extruded. Inert gases are forced down the center of the container tube to control the internal diameter. These melter systems are typically maintained at 2,000 C and operate continuously around the clock. Low voltage, high current electrical energy is used to maintain the high temperatures in the container tube. The tubes are cut to the desired length and sent to the bakers for additional processing.

**Vacuum bakers.** After the glass tubes leave the melting process, they are put through an annealing process to further establish the desired material properties of the product. This process also incorporates the use of low voltage, high current electrical energy to maintain high temperature (1000 C). Further purification of the material, outgasing, and in some cases, additional washing occurs at this stage.

**Key Findings and Opportunities for Energy Savings**

In addition to the process categories discussed above for the primary glass operations at the plant, numerous other energy-using end-uses are present in the facility in support of the overall plant operations. An end-use breakdown for the facility is presented in Table 4 that shows the energy using technologies in the facility, including the glass operations.

**Table 4. End-Use Breakdown of Energy Consumption at Osram Sylvania's Exeter Glass Plant**

| | Electric (kWh) | Gas (MCF) |
|---|---|---|
| Glass Manufacturing | 13,741,245 | 22,289 |
| Transformers | 2,862,759 | - |
| Compressed Air | 657,000 | - |
| HVAC | 1,155,000 | 133,731 |
| Process Cooling | 1,030,593 | - |
| Clean Room HVAC | 866,250 | 66,866 |
| Motor Systems | 1,145,104 | - |
| Lighting | 1,916,250 | - |
| Totals | 23,374,202 | 222,885 |

During a preliminary plant wide assessment of the facility, several opportunities were identified that would yield considerable energy savings, improve process efficiency and subsequently reduce environmental impacts of the production process. This section outlines the efficiency measures (EM) that will be assessed in detail under the proposed study.

**EM-1: Glass production process and efficiency improvement.** The glass manufacturing operation at the plant involves three major steps, all of which are energy intensive.

- **Sand processing (cleaning, calcification and cracking)**. This operation incorporates the raw silica and breaks it down into a finer form. Considerable heat energy is required for the process in conjunction with a variety of process equipment.
- **Glass melters**. There are a total of nine melters that are used to melt raw silica and develop extruded glass tubes. These melters are typically maintained at 2,000 C and operate continuously around the clock. These systems use low voltage, high current electrical energy to maintain high temperatures. Additionally, industrial gases are used to maintain the internal orifice of the tube.
- **Vacuum bakers**. After the glass tubes leave the melting process, they are put through an annealing process to further establish the desired material properties of the product. This process incorporates the use of low voltage, high current electrical energy to maintain high temperature (1000 C).

Each of these areas will be studied in detail to determine process and energy improvements to facilitate reduced consumption of energy and industrial gases. Several emerging technologies will be studied to optimize process efficiency, including laser sensing to adjust draw speeds, optimize industrial gas utilization, and dynamically establish product quality. Heat recovery opportunities for cogeneration and space heating utilization will also be evaluated as will the potential of dual fuel heating (melting or baking) to reduce electrical energy consumption.

**EM-2: Installation of high efficiency transformers for primary plant transformer and designated process transformers.** At the plant-wide level, several of the transformers that are fed by the power company (but owned by the facility) are older, inefficient models. Additionally, numerous transformers are used at the process level to supply the melters, bakers, and ovens with low voltage, high amperage electrical energy to achieve the high temperatures required. Many of these transformers are old, air-cooled, and oversized for the process. Consequently, they are operating inefficiently. Improved system efficiencies could be achieved with correctly sized, variable load capable, high efficiency, water-cooled transformers.

**EM-3: Comparative assessment of purchased vs. site manufactured gases.** The plant uses a variety of purchased gas products, including hydrogen, nitrogen, oxygen, and argon. Many of these gases can be site-manufactured in lieu of direct purchase. This measure will evaluate opportunities to develop systems for on-site production of some gases. In addition, we will investigate additional opportunities to reduce demand for these gas products.

**EM-4: Compressed air system evaluation.** This effort will apply the principles of the DOE's Compressed Air Challenge program to assess opportunities in the supply and demand side components of the compressed air system. This measure will evaluate compressor plant operation and control strategies, develop an inventory of leaks through ultrasonic detection, identify inappropriate end uses, establish opportunities for flow control devices such as nozzles and solenoid valves, and evaluate reducing artificial demand in the facility.

**EM-5: Install high efficiency HVAC systems.** Numerous old heating and cooling units are present at the facility that operate with lower efficiencies than could be achieved with newer equipment. This measure will quantify the savings associated with upgrading steam boilers and DX cooling systems used for space conditioning throughout the facility. Control systems, economizer cycles, and equipment efficiency will be optimized.

**EM-6: Installation of clean room heat recovery system.** Clean room operations are conducted in the facility for assembly of certain glass products. Environmental control of this space requires large volumes of outside air. Installation of an air-to-air heat exchanger would facilitate energy transfer from the conditioned exhaust air to the unconditioned outside air and would reduce the energy required to maintain desired space temperatures.

**EM-7: Process cooling system optimization.** Process cooling is required for all high temperature operations in the plant. Cooling water is used for process control and is provided by cooling tower systems. Implementation of better controls, variable speed drives, and flow balancing will enhance cooling system performance resulting in greater overall efficiencies.

**EM-8: Motor driven system optimization.** Numerous motor driven systems are present throughout the facility. These systems will be assessed for efficiency (of drives and driven equipment), control, and application improvements that will result in reduced energy consumption and better performance.

**EM-9: Install high efficiency lighting controls.** Recent technology improvements to many of the lighting systems at the facility have been implemented. This measure will assess lighting control opportunities and will also determine remaining high performance lighting opportunities in the facility.

## Projected Savings

Preliminary savings estimates associated with the measures described above are presented in Table 5. Electrical savings are for purchased electricity. As the project progresses further, findings will be updated for the final version of this paper.

**Table 5. Plantwide Energy Saving Opportunities for Osram Facility**

| | | Exeter Glass Manufacturing Facility | | | Projected Osram Glass Energy Savings | Projected Osram Lamp Mfg. Energy Savings | Projected Related US Mfg. Energy Savings |
|---|---|---|---|---|---|---|---|
| Energy Efficiency Measure | | Annual Electrical Savings (kWh) | Annual Natural Gas Savings (MMBTu) | Annual Energy Cost Savings | Annual Energy Cost Savings (MMBTu)* | Energy Savings (MMBTu)† | Energy Savings (MMBTu) |
| EM-1 | Glass Production Process and Efficiency Improvement | 687,062 | na | $57,588 | 7,003 | 1,362 | 62,743 |
| EM-2 | Installation of High Efficiency Transformers | 286,276 | na | $23,995 | 1,459 | 1,135 | 19,457 |
| EM-4 | Compressed Air System Evaluation | 164,250 | na | $13,767 | 1,674 | 6,513 | 163,746 |
| EM-5 | Install High Efficiency HVAC Systems | 202,125 | 2,340 | $32,154 | 1,545 | 4,508 | 151,341 |
| EM-6 | Installation of Clean Room Heat Recovery System | 129,938 | 1,003 | $17,410 | 331 | 26 | 892 |
| EM-7 | Process Cooling System Optimization | 154,589 | na | $12,957 | 1,339 | 3,908 | 78,709 |
| EM-8 | Motor Driven System Optimization | 57,255 | na | $4,799 | 496 | 1,833 | 34,941 |
| EM-9 | Install High Efficiency Lighting Controls | 95,813 | na | $8,031 | 1,953 | 7,219 | 183,439 |
| | Total | 1,777,307 | 3,343 | $170,702 | 15,802 | 26,504 | 695,268 |

* This column equals summation of annual primary energy savings from the end use electric savings plus the end use natural gas savings.
†This column represents projected energy savings corporate wide for glass manufacturing facilities.

# Conclusion

Glass manufacturing facilities are energy intensive and represent a significant opportunity for energy savings. Emerging technologies for glass manufacturing as well as available plantwide approaches can be applied to glass operations and supporting systems to facilitate energy savings and greater overall efficiencies. The application of new technologies such as oxy-fuel firing or the development of advanced refractory materials in combination with best practice implementation for supporting systems can reduce overall consumption considerably, impart environmental benefits and yield economic benefits for the facility. Increased efficiency will help lower costs and make the US glass industry stronger in the face of global competition, substitute materials and economic downturns.

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