COGENERATION:

A FEASIBILITY STUDY FOR THE ARTISTIC GLASS COMPANIES OF MURANO, ITALY

Sponsored by Vetreria Archimede Seguso S.R.L.

An Interactive Qualifying Project in partial fulfillment of the requirements for the Degree of Bachelor of Science
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Abstract

This project, sponsored by Vetreria Archimede Seguso, a glass company located in Murano, Italy, assessed the feasibility of generating electricity from the waste heat of artistic glass furnaces. The project team collected data on heat loss, gas consumption, comparative costs and efficiencies involved, leading to the creation of a new mathematical models for furnace operation as well as determining feasibility for various generating efficiencies and payback periods for cogeneration. The project concludes by suggesting follow up studies utilizing Stirling engines.

Executive Summary

The focus of this project is on the island of Murano, which lies 1200 meters north of Venice, Italy. Murano is made up of seven islands separated by a canal system. It is home to approximately 5700 people, most of whom are employed in some manner by the thriving artistic glass manufacturing industry. Murano has been a glass-manufacturing center since the craft moved to the island from Venice in the late thirteenth century. Glassmaking traditions and practices have been passed down through the family lineage. There are currently 155 artistic glass factories located on the island.

The sponsor, *Vetreria Artistica Archimede Seguso S.R.L* is an artistic glass company located in the southern portion of Murano. The owner and operator of the factory, Antonio Seguso was the project liaison.

The artistic glass process used in the factories on Murano has been unchanged for many years. The traditional furnaces and methods allow large quantities of waste heat to dissipate into the environment. Capturing this waste heat would result in a more responsible usage of the earth's resources as well as possibly help with global pollution abatement efforts, especially recent mandatory EU regulations. Reutilizing lost heat could produce economic benefits for the factories by reducing energy cost The goal of the project was to conduct a feasibility study and cost benefit analysis for the implementation of cogeneration technology in the glassworks on Murano.

Artistic glass is produced by heating large amounts of sand and soda (sodium carbonate) along with small amounts of calcium carbonate, potassium carbonate and sodium nitrate. Adding metal oxides to the base recipe results in colored glass. These additives, which include nickel, lead and arsenic, harm the environment when released. There are three phases in the glass making process: melting, working and annealing.

The melting phase uses the most energy. Natural gas is combusted to create heat and raise the temperature inside the furnace to approximately 1400°C, which is the melting temperature of glass. During this 10-12 hour phase, the most heat is lost.

The second phase is the working phase that lasts approximately 14-16 hours. In this phase the combustion of natural gas only produces to enough heat to maintain the glass in its molten form. Because less heat is needed to maintain the liquid state than to melt the glass, less natural gas is used during this process. Heat loss continues in large quantities because the furnace doors remain open so that artisans may work the glass. Figure 1 is an infrared picture showing the heat lost through the door of the furnace.

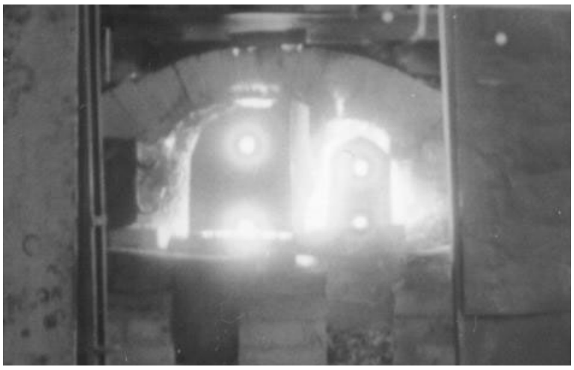

Figure 1:Infrared Picture of a Furnace

In the final phase, annealing, the finished glass product is cooled very slowly. A piece of glass can remain in an annealing furnace for over 50 hours before it is removed. This process requires little gas consumption and therefore only a small amount of heat is dissipated. The glass is cooled slowly to ensure that the finished shape is maintained.

Currently, many factories use a traditional furnace design that does not incorporate a flue hood or chimney. The lack of flue hoods and chimneys allows harmful fumes to linger in the work environment detrimentally affecting the health of the artisans. This is slowly changing as manufacturers are trying to meet the requirements of the *Accordo del Vetro* (Glass Accord). This agreement was municipally brokered and states that by Dec. 31, 2002 all glass factories on Murano must install pollution abatement equipment that carries the waste gas away from the work area and removes the toxins before exiting to the outside environment. Now is the ideal time to look at ways of recovering lost heat by exploring the potential implementation of cogeneration and other sustainable technologies.

Cogeneration is defined as combined heat and power production (CHP). Generally, heat and electricity are independent processes. However, most forms of industrial electricity production require the use of heat. Rather than separating these two methods of energy production, on Murano, it is possible to use existing heat to produce electrical energy (see Figure 2).

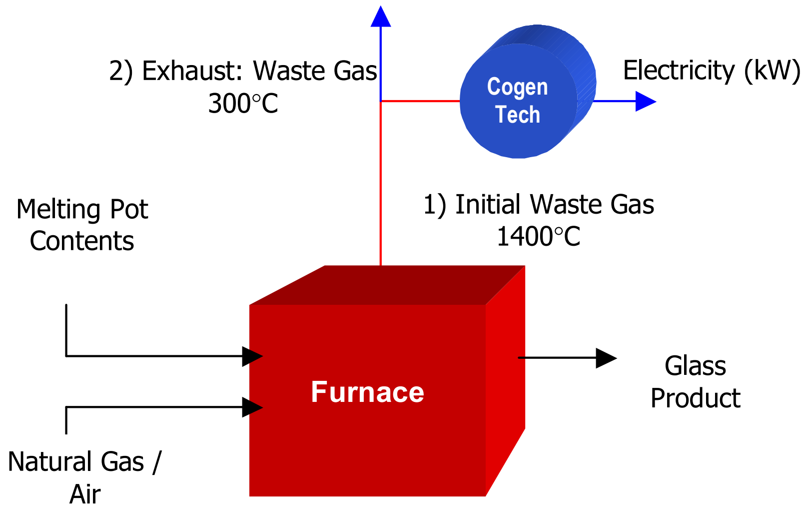

Figure 2: Cogeneration for Artistic Glass

The factories on Murano burn natural gas to melt glass, and the excess heat that would otherwise be lost through the waste gas can be converted into electricity.

There are many kinds of cogeneration technologies, but there are only limited solutions that can be applied to the glass making process on Murano. The two applicable technologies that have been researched in depth are Stirling engines and Steam Cycles.

A Stirling engine is an external combustion engine, meaning that it runs off of an external heat supply. Stirling engines work by trapping a gas between two pistons. Creating a temperature difference across the two pistons expands and contracts the gas trapped inside which then moves the pistons and creates mechanical energy. This mechanical energy is then converted to electricity. Stirling engines could be implemented on Murano simply by putting the "hot end" of the engine inside the stream of escaping exhaust gas from the furnace providing a temperature difference of 1400°C (internal furnace temperature) to 25°C (room temperature).

A steam cycle could also be used. Heat lost from the furnace could be transferred to a boiler that produces steam, which, in turn spins a turbine. Mechanical energy from the turbine can then be converted to electrical energy. The steam must then be condensed back into a liquid so it can be reused.

Both of these technologies could potentially recoup lost heat from the artistic glass process. Electricity gained from cogeneration could then be sold back to the electric company at market price.

Antonio Seguso explained that the ideal application of cogeneration technology would consist of a modular unit that could easily attach to the furnace exhaust. It would also have to be small, quiet, easy to maintain and operate, and convert heat into electricity efficiently in a cost effective manner. These are the parameters for an ideal cogeneration solution on Murano.

The first step of the project was to understand the glass manufacturing process and the typical factory environment. Using Archimede Seguso as an example, the furnaces were mapped and temperatures related to furnace operation were collected. The temperatures measured included: inside furnace temperature, flue temperatures, and the ambient air surrounding the furnaces. To graphically show heat loss, a temperature gradient map (Figure 3) was created with the recorded data.

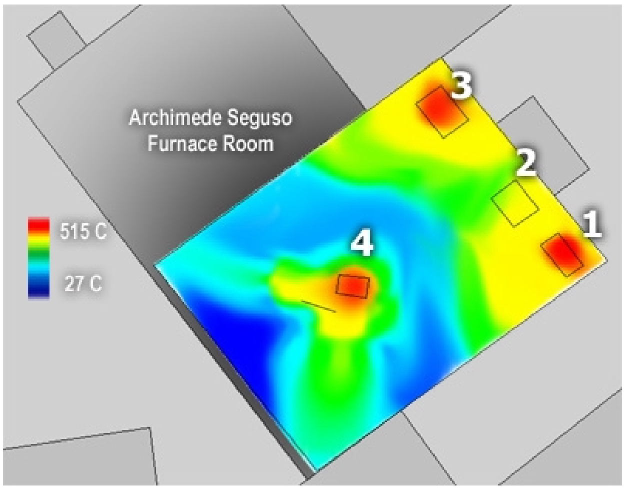

Figure 3: Heat Dissipation in the Archimede Seguso Glass Factory

In addition to the field data collection, experts in the areas of glass production, cogeneration, and pollution abatement were contacted and were able to provide additional information about the glass factories, the glass manufacturing process, the chimney installations on Murano, and on cogeneration technologies.

Information such as the number of furnaces in a factory, the number of melting cycles that take place each week and the amount of sand consumed were used to determine the total heat lost in the glass making process. These data were obtained through Archimede Seguso S.R.L., the City of Venice's Environmental Department and also from the *Stazione Sperimentale del Vetro* (Experimental Glass Laboratory) on Murano. Scientists at the Experimental Laboratory also provided us with data on the manufacturing process. They were able to provide estimates for the amount natural gas it takes to produce one kilogram of glass product, typical internal furnace temperatures, and the melting point of the raw materials. A pollution abatement specialist and a cogeneration specialist from the private sector supplied data on the chimney system that will be installed in the Archimede Seguso factory. They also provided information such as the expected temperatures in the chimney system as well as the heat contained in the waste gas.

In order to determine if installing a cogeneration system will be cost effective, it was necessary to calculate the theoretical amount of heat that is lost to the environment through the artistic glass process, which made it possible to estimate how much electricity could be obtained by converting the lost heat. It was necessary to create this mathematical heat to electricity model as one did not exist that suited the application.

The furnace is the central part of the glass factory and the glass making process. To properly analyze the process, it was necessary to create a mathematical furnace operation model (Figure 4), which is a substantial component of the heat to electricity model. The furnace operation model uses the natural gas consumed, the amount of material melted, the amount of glass produced and the temperatures achieved to calculate the amount of heat generated from combustion and the amount needed to melt the raw

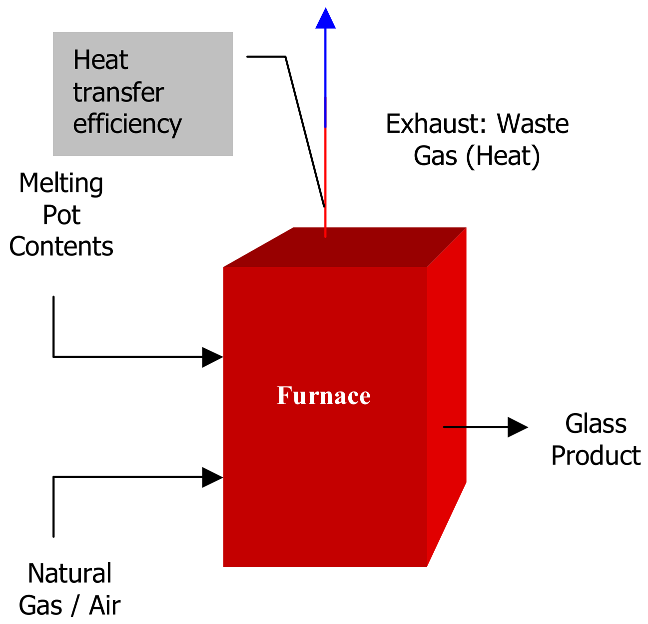

Figure 4: Basic Input/Output of a Furnace

materials. The model uses a basis of one furnace producing one kilogram of glass product and is scaled up from there.

Once the two outputs from the furnace operation model are obtained, estimation of the final electrical output becomes a matter of simple arithmetic as shown in Equation 1.

Heat lost = Heat acquired from combustion of natural gas – Heat required to liquefy melting pot contents

Heat contained in exhaust waste gas = Heat lost * Heat transfer efficiency

Electrical output = Heat contained in exhaust waste gas * cogeneration technology efficiency

Equation 1: Simple Heat Loss Calculation

The total heat lost is calculated by subtracting the heat needed in the process from the heat generated, and then electrical output is calculated by multiplying by the percentage of heat that gets to the cogeneration equipment and the efficiency of that equipment.

These equations were applied to the set of 71 factories for which data was received from the Environmental Department of the City of Venice. After calculating gas usage per glass kilogram of glass (m^3 NG/Kg), it was concluded that data on only 27 of the factories was usable and the rest had a m^3 NG/Kg that was unusually high or low. All of the outputs for all 71 factories were compiled and datasheets (Appendix F) were created.

A cost analysis using the outputs of the heat to electricity model was developed to determine the economic feasibility of cogeneration technologies. The feasibility section of the cost analysis utilizes total investment over the selected payback period to provide a set of flue and cogeneration system efficiencies that would be feasible (Appendix C.3). The tables are constructed in a flexible manner. If the efficiencies are known, a total investment can be found. Also, if the total investment and flue efficiencies are known then the efficiency of the cogeneration system can be determined. A traditional cost benefit analysis was also generated to show the year-by-year annual savings and to compensate for neglecting of tax, depreciation and inflation in the feasibility section.

Both steam and Stirling engine systems were explored in depth and the feasibility table in the cost analysis was applied to these technologies. While both systems tend to have similar efficiencies (approximately 30%), they each have their advantages and disadvantages. Steam systems are applied in many industries around the world, but tend to be very expensive and possess other disadvantages, such as the size of the system and the number of components required (heat exchanger, boiler, turbine, generator, condenser and pump). Stirling engines tend to need little maintenance, are relatively quiet and could possibly be designed to take up little room. But unlike steam systems, are not in wide use and are not currently commercially available for this application. An exact price for steam was not found but the price for a suitable turbine-generator combination would be approximately $55 thousand. Since this cost is only one part of the initial investment, the total investment over any payback period would be much greater. When the feasibility tables were consulted, using a 5-year payback period and 55% flue efficiency, the maximum total investment for economic feasibility was found to be approximately $52 thousand dollars. Since $55 thousand is greater than $52 thousand, steam would not be feasible. A price for a Stirling engine system could not be estimated. It is conceivable, however, that the cost would be considerably less than steam because there are fewer components.

Utilizing the datasheets that were generated from the heat to electricity model and the method of calculating total investment from the feasibility section of the cost analysis, an extrapolation was made to determine the feasibility of implementing cogeneration on all of Murano and to determine if the factories would be capable of generating enough electricity to "self-sustain" with their only energy intake being natural gas. It was calculated that an overall efficiency (flue and cogeneration technology efficiencies combined) of only 3.95% would be needed for all of the factories on Murano to self sustain as a group, and if an efficiency of 6.1% could be achieved, the electrical needs of Murano's entire 5700 person population wouyld be met. A range of overall efficiencies (6%-24%) was calculated and used to give allowable overall investment values for economic feasibility Appendix E. These values range from L. 13.7 billion (€7.1 million[1]) for a 6% overall efficiency to be

[1] €1.00 = L.1936.27

recouped over 3 years to L. 183.0 billion (€ 94 million) for a 24% overall efficiency to be recouped over 10 years.

After the analysis recommending a specific cogeneration technology for immediate installation became impossible, but a future implementation looked promising. A steam system, the only system currently available, is obviously a bad choice due to high cost and the large size. Stirling engines on the other hand have potential, but, although the technology is old, they are not yet commercially available. Hopefully, through further research and development, a system can be created that will meet the requirements of the glass factories on Murano. Until this happens, other methods of increasing efficiency should be explored such as redesigning the door on the furnaces where the most heat is lost.

While a solid recommendation cannot be made for a cogeneration implementation on the island of Murano, the project took major steps in easing the analysis of future and current technologies. The heat to electricity model, furnace operation model, cost analysis, and extrapolation are all relatively simple methods of quantification, yet they are all very flexible. The written document alone is useful, but the electronic tools developed along the way are more so. With these tools any factory on Murano as well as any other factory with a similar process could easily determine whether cogeneration is an acceptable method of more responsibly using natural resources.

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1. Introduction

The origins of the art of glass blowing in Venice date back to before the first millennium. Venetians used instruments that late Roman glass blowers passed down through the ages. It is presumed, that the later techniques were developed in Venice more than anywhere else in Europe because of the trading contacts that the Venetians had with the Orient and above all with countries that already had an ancient tradition in glass blowing such as the Phoenicians, the Syrians and the Egyptians. Such traditions were later improved by the emergence of furnaces created by the Islamic people. From this exposure, a fusion of Eastern and Western techniques emerged in the form of a unique Venetian method. Today, Venetian glass is produced almost entirely on the island of Murano and still ranks among the best glass produced in the world.

The resemblance between Venice and Murano is plainly seen in the urban development consisting of similar public squares, streets, internal canals and even the same "Grand Canal" which runs through it. By edict of Doge Tiepolo in 1291, the island of Murano was declared a true industrial area and soon became the capital of glass production in the world.

Murano glass has known moments of glory over the centuries as well as moments of decline. However it has always been characterized by an obsessive search for quality. In fact, Murano's pride has always been its artistic quality, which has often contrasted with its competition and has frustrated attempts at imitation. Throughout the history of the art, the hollow blown glass of Murano has forged its own path, quickly rising to world-class status.

However, even though Murano’s glass products have been well known around the world for their uniqueness and exquisiteness, Murano is currently facing a serious dilemma. Murano glass factories as a whole are not just producing an excellent piece of art, but are polluting the environment, because the materials used to color glass are harmful. Their glass processes creates heavy metal emissions. Since 1998, the Venetian and Italian governments have laid down strict regulations about pollution abatement.

Venice has always been concerned about the environment. Through the days of the Republic, pollution was a crime. In fact, it was punishable by death. It comes as no surprise that efforts are being made to stop the glass factories on Murano, characterized by the secretive and stubborn nature of their owners, from polluting the air and water. Implementing pollution abatement techniques will require the factories to begin moving away from tradition. Now is the perfect time for them to start exploring ways to more efficiently use of the natural resources they consume.

"A Cogeneration Feasibility Study of Murano Glass Factories" is intended to aid the Archimede Seguso Glass Factory and other similar manufacturing plants in deciding whether or not to implement a cogeneration system. The investigation focused on providing a simple and easy to use method for analyzing the usefulness of a cogeneration technology as well as looking at a few select technologies in depth.

Applied to the entire island of Murano, the implementation of a cogeneration technology becomes extremely advantageous. The island could be brought to the point of producing enough electricity such that the whole island could become self-sustaining, only having to take in natural gas. A sustaining Murano island is a more responsible user of the world's natural resources.

The remainder of this document is divided into three areas. Chapter 2 discusses the background knowledge required to propose a methodology for the feasibility study. This information includes island of Murano, artistic glass manufacturing, the Archimede Seguso factory, legislation that affects the project, and information about the cogeneration process.

The methodology found in chapter 3 discusses the processes by which we acquired all the information that was needed to conduct our feasibility inquiry. We acquired detailed information about the Archimede glass factory, it's operations and its resource consumption. At the same time, we obtained information from cogeneration experts so that we could build a mathematical model to calculate the amount of heat lost to the environment. Using this heat loss number and efficiencies the amount of producible electricity can be calculated. With the help of a cost analysis and this mathematical model, the feasibility of a cogeneration technology will be in the form of an easy-to-use table.

Chapter 4 comprises the results and analysis portion of this report. In this chapter we analyzed all the data we obtained through our methodology. Based on two cogeneration technologies that we have decided to consider, the Stirling engine and the steam system, we relate our cost analysis to a real world prices.

Chapter 5 includes conclusions based upon the results and analysis portion of this report. We include a range of efficiencies and investments that will result in a self-sustaining Murano. It also contains recommendations on possible methods to increase furnace efficiency as well as suggestions for future projects.

2. Background

The background chapter gives general information that will help the reader to understand the remainder of this project. We include information concerning the geography of Murano. The Glass Manufacturing section includes traditional, modern, and the coloring of glass. Next is a description of *Archimede Seguso s.r.l.* Revelant Laws and Regulations explain energy resale and environmental policies, as well as regulations on Murano glass manufactures. The Cogeneration section includes uses of cogeneration, advantages of cogeneration, and cogeneration components. In the Heat Engine section, steam and Stirling systems are explained.

2.1. Murano

This section discusses several different aspects of Murano. These include the geography, economics and utilities of the island.

2.1.1 Geography

Murano, shown in Figure 5, is an island in the Venetian lagoon located just north of Venice proper and is part of the municipality of Venice. The 1134-acre island was founded between the 5th and 7th centuries with major development not taking place until the 13th century. The population peaked in the 16th century when were over 30,000 people living on the Island[3].

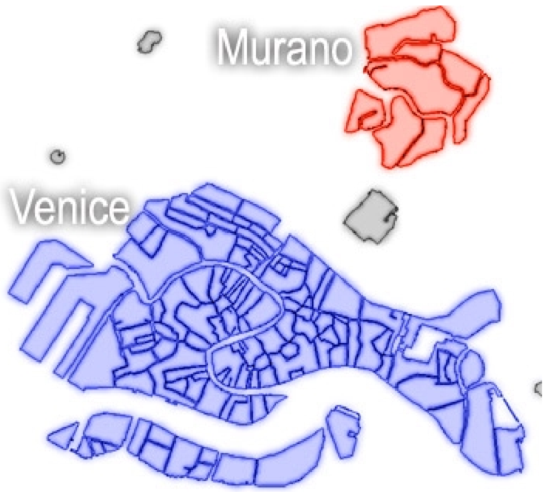

Figure 5: The island of Murano in relation to Venice[2]

[2] Black, Joshua C., Brian Cavanna and Nicholas J. Cottreau. Monitoring Pollution on Murano: An Analysis of the Artistic Glass Industry of Murano, Italy
July 31, 2000
[3] Encyclopedia Britannica. Murano
http://www.britannica.com/bcom/eb/article/6/0,5716,55686+1+54321,00.html?query=murano (March 25, 2001)

2.2 Glass Manufacturing

Glass is produced through melting raw materials at high temperatures, shaping the molten solution, and finally allowing it to cool. Sometimes glass is also shaped through processes that occur after it has cooled. This section on glass manufacturing details the methods used to form glass. The education department of the Corning Museum of Glass supplied the information below[4].

2.2.1 Traditional Glassmaking

Traditional methods of glass manufacturing include: casting, cutting, core forming, and blowing. With these processes craftsmen create many shapes.

2.2.1.1 Casting

Casting is a process in which the glass shape is formed using a mold. First, the ingredients of the glass are mixed and then heated until they fuse. The mixture is ground back into a powder and then poured into the mold. The mold is placed in a hot furnace where the powder melts. As the powder melts it takes up less space in the mold and more powder must be added. After the mold is full of molten glass, it is taken out of the furnace and left to cool. Once cool, the glass piece is removed from the mold.

2.2.1.2 Cutting

Cutting is a process used to shape glass that is already cooled. Abrasives are used to wear away the unwanted sections of glass. Cutting can be done with a spinning abrasive wheel, a lathe or even hand tools.

2.2.1.3 Core Forming

Core forming involves melting glass around an object, usually made of clay, that has the same shape as the desired shape for the final piece. The core is covered with glass and the product is cooled. Removal of the core is accomplished by scraping away the clay. A craftsman will often decorate these objects by melting bands of other colors over the base color.

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[4] Education Department of the Corning Museum of Glass. A Resource For Glass. http://www.cmog.org/pdf/aroglass.pdf (March 25, 2001)

2.2.1.4 Blowing

Glass blowing involves putting a small amount of melted glass on the end of a hollow tube and pushing air through the glass to create a hollow object. This method was discovered around 50 B.C. and significantly reduced the amount of time it took to create a glass product. The other methods (cutting, core forming, and casting) were very labor intensive and time consuming. The advent of glass blowing is the main reason for glass products becoming inexpensive and available to the masses

2.2.1 Modern

Modern glassmakers still use traditional methods of forming but they also use techniques such as pressing, drawing, rolling and centrifugal casting. They also employ methods of automating the traditional methods of production.

2.2.1.1 Pressing

Pressing is a fast and easy way to make dimensionally accurate pieces that have relatively large cross sections. Molten glass is placed in the bottom section of a mold and the other half of the mold is lowered onto the glass. Pressure is then applied and he glass takes the shape of the mold.

2.2.1.2 Drawing

Drawing is used to produce rods, tubes and sheets of glass. The glass is drawn out over a mandrel, cone or hollow cylinder. When making tubes, pressurized air keeps them from caving in until the glass has cooled. With the air turned off, the same setup produces rods.

2.2.1.3 Rolling

Rolling is also used to make sheet glass. The molten glass in squeezed between rollers that form it into a flat sheet. The rollers are made of metal alloys that will not melt at the high temperatures required for glass making. With this process, glass is produced quicker than by drawing, but will not have as smooth a surface finish.

2.2.1.4 Centrifugal Casting

Centrifugal casting involves placing molten glass in a mold spinning at high speed forcing the glass to move toward the outside of the mold. This process is used in making the conical sections of cathode ray tubes that are used in televisions.

2.2.1.5 Automation

Modernization of the glass manufacturing industry has resulted in the automation of several forming techniques. Development of these machines started in 1913 with the commercial release of a machine to produce the light bulb. The machine increased production from a couple of hundred bulbs per day to 42 bulbs per minute. This machine was improved upon and in 1922 the first ribbon type machine was built and raised the production numbers to 250 bulbs per minute. This method is currently used today but has been significantly improved to produce up to 2,000 bulbs per minute.

2.2.2 Coloring Of Glass

Normally, glassmakers introduce metal oxides into the mixture in order to color the glass. Different metals produce different colors and the intensity of the colors is determined by the amount added to the glass. Table 1 shows some of the metals that are used and the colors they generate.

Metal	**Color**
Cerium	Yellow
Chromium	Green
Cobalt	Blue
Copper	Blue
Gold	Red
Iron	Green
Lead	White
Manganese	Purple
Nickel	Purple
Uranium	Yellow

Table 1: Metals used to color glass[5]

2.3 The Archimede Seguso Glass Factory

The sponsor of this project is *Archimede Seguso s.r.l.* Archimede Seguso is a glass-making company placed on the island of Murano, located in the city of Venice Italy. Over the years the factory has built up a solid reputation for itself. It has become known as one of the finest producers of Murano glass.

[5] Black, Joshua C., Brian Cavanna and Nicholas J. Cottreau. Monitoring Pollution on Murano: An Analysis of the Artistic Glass Industry of Murano, Italy July 31, 2000

Archimede Seguso, (Figure 6) founded *Archimede Seguso s.r.l.* He was born on the Venetian island of Murano in 1909[7]. Antonio Seguso, his father, worked as a glass craftsman at *Vetri Artistici Fratelli Barovier*. By the age of 11, Archimede's interest in glassmaking began to grow. By the age of 14, Archimede was training at the factory.

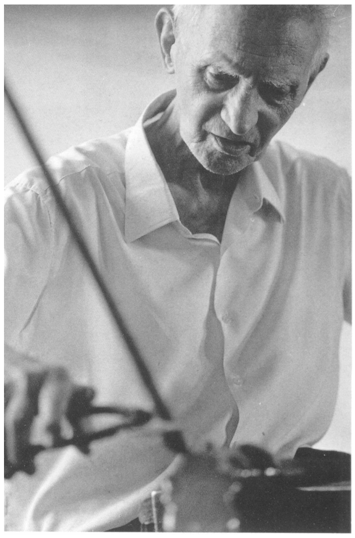

Figure 6: Archimede Seguso[6]

In 1929, the *Vetri Artistici Fratelli Barovier* dissolved and Archimede left with his brother and father to open a studio of their own. Ultimately, this studio became the present day company. Throughout this time period, Archimede was able to establish himself as one of the glass masters of Murano. Archimede Seguso died in 1998, at the age of 89[8].

In his own studio, Archimede was able to apply his technical skill to his emerging creativity[9]. He created vases, animals, and figurines, earning the title of "master of animals" for his versatility and technique in crafting the miniatures. He also produced sculptured nudes in a style that influences Muranese glassmaking. His success with human and animal figures rests in his perfection of a technique known as "*a masello"*, in which the glass is modeled while it still hot, producing a fluid and seamless figure. In 1947, he perfected another technique, *" a merletto"*, which incorporated a three-dimensional web of threads encased in the walls of the piece to create a lacework effect. Many of Archimede's creations have been displayed in museums throughout the world.

Over the years Archimede has trained many of the new masters of glass making[10], such as Mario Gambaro and Bruno Poggi. The work of these two men has also been shown in art museums all over the world.

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[6] www.fiftiesglass.com/designers/
[7] Saravalle, Madeline; *Connoisseur*; "Glass in the blood" August 1990; Vol 220; n943 p94
[8] Alderman, Lesley*; Money*, New York; Jul 1994; Vol 23, Issue 7 pg 80
[9] Zigerlig, Katja,"Glassmaking" http://www.axa-artinsurance.com/cw/aspects/artglass/#Innovators
[10] Unknown, *New York Times*, "Graceful Glass, Shaped by a Master" May 4, 1989

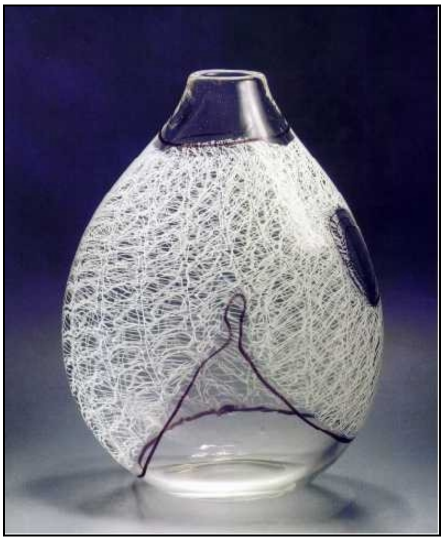

Figure 7: "a merletto" Vase[11]

The company produces a vast assortment of objects for interior decorating, lamps of all kinds, gifts and fine jewelry, and chandeliers[12]. Included in the interior decorating section are vases and bowls. One of the most popular designs is the "*a merletto*" glass, for which Archimede Seguso was famous. The "*a merletto*" type of glass remains the most popular and sought after glass made by Archimede Seguso. Lamps of all shapes and sizes produced also include this type of glass, and are intended for use as desk lamps. This allows them to be used and admired at the same time. As for gifts and fine jewelry, the company produces many types. The most popular are pins and broaches. The chandeliers produced by the Archimede Seguso factory are present in some of the most respected and famous hotels in the world.

The company, characterized by its reduced management, has total control over the production[13]. It has a considerable capacity to organize its production, which, together with impressive implementation, can guarantee the buyer a highly artistic product of fine quality.

2.4 Laws and Regulations

This section will cover relevant laws and regulations that are enforced in Europe, Italy, Veneto, Venice, and Murano.

2.4.1 Energy Resale and Environmental Policies

One of the goals of this project is to explore the possibility of reselling the reclaimed energy back to the electrical supplier. Therefore, finding the policies that govern this matter, such as energy resale and environmental policy, is crucial.

[11] www.arthema.com/ExnRoom.asp?ExID=1&RmID=8
[12] www.aseguso.com
[13] Zigerlig, Katja,"Glassmaking" http://www.axa-artinsurance.com/cw/aspects/artglass/#Innovators

2.4.1.1 Energy Resale Policy

In Europe, the European Union (EU) directives currently require member countries to open their electricity markets to competition and also require that no single company generate more than 50% of any member country's electricity by 2003.

EU membership has initiated important changes in Italy's energy sector, requiring privatization of Italy's dominant energy monopolies. Hence, Italy's energy sector has been undergoing considerable restructuring in recent years. ENI, the state-held oil and gas conglomerate, along with its main subsidiaries, Agip (hydrocarbons exploration and production) and Snam (gas supplies and distribution), and the state-owned electricity company, ENEL, are in the process of privatization. Both ENEL and ENI became joint stock companies in 1992. The Italian government sold off shares of ENI between 1995 and 1998, and now holds 35% of the company. Privatization of ENEL stalled, but then moved ahead with a 34.5% sale in November 1999. With limited domestic energy sources, Italy is highly dependent on energy imports. As of 1998, Italy was estimated to be less than 20% self sufficient in terms of energy [14].

2.4.1.2 Environmental Policy

In December 1997, the Parties to the UN Framework Convention on Climate Change agreed to the terms of the Kyoto Protocol. This historical agreement sets legally binding greenhouse gas emission objectives over the 2008-2012. This agreement sets a clear signal for action now, and a challenge to governments, citizens and private companies alike. The energy sector, from supply to end-uses, is responsible for the majority of greenhouse gas emissions in the developed world, through the combustion of fossil fuels and the emission of CO_2, N_2O and CH_4, three of the six gases covered by the protocol.

The International Energy Agency (IEA) has been mandated by its member countries to provide sound analytical work on the energy dimension of climate change and the implications of the Kyoto agreement on the energy sector. Beyond national policies and measures that help promote lower greenhouse gas emissions from energy

[14] Grubb, Michael. "Energy Policies and the Greenhouse Effect: Policy Appraisal." Great Britain, Worcester: Billing & Sons Ltd, 1991.

and develop climate-friendly technology, the IEA is also working on international cooperation mechanisms to help achieve greenhouse gas objectives at the lowest possible cost [15].

2.4.2 Regulations on Murano Glass Manufacturers

For hundreds of years, the Venetian government laid down strict regulations about the production of glass and workers were forbidden, on penalty of death, to leave Venice or to reveal the secrets of their trade. Despite this law many Murano glassmakers left Italy to set up glassworks elsewhere in Europe. Italy's supremacy weakened in the 17th century by the development of new glass recipes in Germany and England[16].

The latest regulation that has been laid down by the Venetian government is called the *Accordo di Programma per il Miglioamento Dell'impatto Ambientale Generato dale Aziende Produttrici di Vetro Artistico Situate Sull'isola di Murano-Venezia* (Accord for the Program to Minimize the Environmental Impact of the Businesses who Produce Artistic Glass on the Island of Murano, Venice). Better known as "*Accordo del Vetro*", the agreement was signed by the Italian government on April 18, 1998. It states that companies who signed the agreement must comply with all existing environmental legislation by December 31, 2002. Furthermore, these companies must also comply with new, stricter, atmospheric emissions instituted by the Italian government. The companies who have not signed the agreement would be expected to meet the new regulations immediately or be closed down[17].

2.5 Energy Production and Consumption in Italy

In order to investigate the possibility of reselling the reclaimed energy, the state of the energy market in Italy must be known. Therefore, energy production and consumption was examined. This section covers the two-most widely used types of energy in Italy: natural gas and electricity.

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[15] Boehmer-Christiansen, Sonja. "Acid Politics." Great Britain, London: Belhaven Press, 1998.
[16] http://www.cia.gov/cia/publications/factbook/geos/it.html
[17] Black

The Italian government is undertaking major reforms in the energy sector. It has started to decentralize energy policy, giving more responsibilities to regions and local authorities. Thus, coordination across regions and with the national government is becoming an important issue. In February 1999, competition was introduced in the electricity sector. The government is also preparing a legislative decree to implement the EU directive on natural gas. In enforcing competition, attention needs to be given to the dominant position of national companies in the electricity and natural gas sectors. Italy's high tax on energy in comparison with other IEA countries has encouraged the country's low energy consumption. In addition, in December 1998, the government introduced a carbon dioxide (CO_2) tax. Tax policy needs a long-term strategy that would better reflect the external cost of using energy and make the tax structure consistent across the different sectors and fuels.

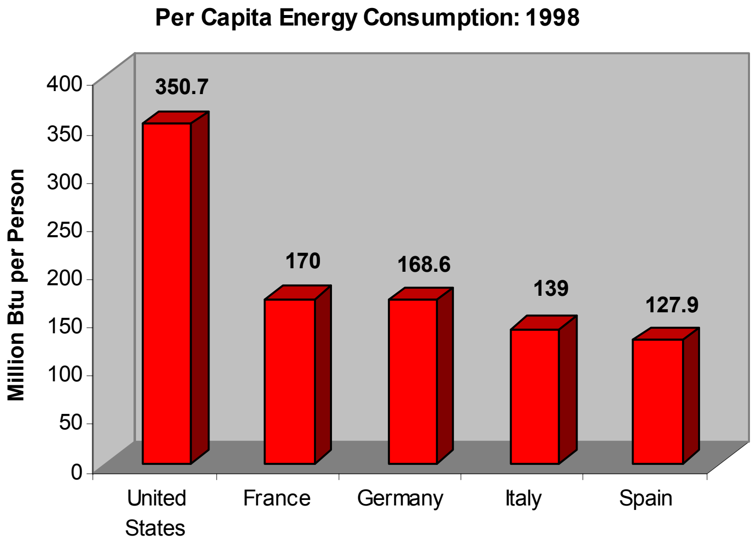

Figure 8: Energy Consumption [18]

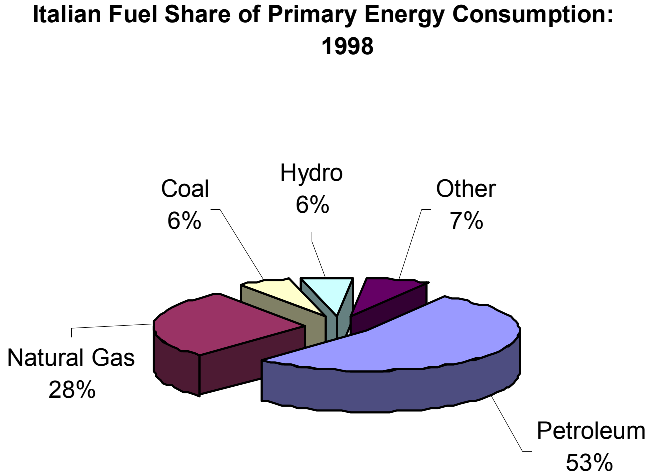

Figure 9: Italian Energy Consumption [19]

In 1998, Italy consumed 8.0 quadrillion Btu's (quads) of energy,

[18] http://www.iea.org/statist/index.htm

[19] http://www.iea.org/statist/index.htm

the fourth highest energy consumption level in Europe, behind Germany (13.8 quads), and France (10.0 quads), as seen in Figure 8. Petroleum consumption accounts for a significant portion of Italy's energy consumption (53.0%) followed by natural gas (28%), coal (6%) and hydroelectricity (6%) (See Figure 9). Renewable fuels comprise the remaining 7%[20].

2.5.1 Natural Gas Consumption in Italy

Historically, the country has relied heavily on imported oil, much of it from North Africa. In recent years, oil consumption has declined (although Italy remains one of the largest oil consumers in Western Europe) in favor of natural gas. Natural gas not only aids Italy in achieving its goal of energy diversification, but it also helps Italy to meet its domestic and European environmental requirements for a cleaner environment. In order to support this conversion, the Italian government has indicated that the tax on natural gas will rise by only 2%-7% by 2004, while the tax on oil will rise 33%-61%[21].

The conversion to natural gas also will help Italy achieve its obligations under the Kyoto Protocol, under which the nations of the European Union as a whole must reduce greenhouse gas emissions 8% below 1990 levels by 2008-2012. In 1998, Italy emitted 120 million metric tons of carbon, 8% higher than 1990 levels. Table 2 is the summary production and consumption of natural gas in 1998 in Italy.

[20] http://www.eia.doe.gov/cabs/itenv.html
[21] http://www.rri.org/envatlas/europe/europe.html

Gross Production (Billion Cubic Feet)	617.69	**Dry Imports** (Billion Cubic Feet)	1747.53
Vented and Flared (Billion Cubic Feet)	0.00	**Dry Exports** (Billion Cubic Feet)	1.48
Reinjected (Billion Cubic Feet)	0.00		
Marketed Producton (Billion Cubic Feet)	617.69		
Dry Production (Billion Cubic Feet)	617.69	**Dry Production** (Quadrillion Btu)	0.6319
Dry Consumption (Billion Cubic Feet)	2395.91	**Dry Consumption** (Quadrillion Btu)	2.4510

Table 2: Natural Gas Production and Consumption in Italy in 1998[22]

2.5.2 Electricity Consumption in Italy

In 1998, Italy generated 247.68 billion kilowatt hours (bkwh) and consumed 272.35 bkwh. Generation is shifting away from oil and toward gas, and to a smaller extent toward coal. Non-hydro renewable electricity generation (mostly solar and geothermal) almost doubled in the 1990s.

Italy's extensive electricity network is linked to its neighbors. Electricity imports come mostly from France and Switzerland. Construction on a new 164-kilometer (102-mile) underwater cable to link Italy and Greece was underway in January 2000 and could be complete by the end of 2001.Table 3 summary capacity, generation and consumption of electricity in 1998 in Italy.

[22] The estimates contained in this table are those published by the *Oil and Gas Journal*. More info can be found in the BP Amoco *"Statistical Review of World Energy 1999"*.

	Capacity	Generation				
	(Million kw)	(Billion kwh)	(Quads)		(Billion kwh)	(Quads)
Hydroelectric	13.058	44.788	0.4658	**Total Imports**	42.539	0.4424
Nuclear	0.000	0.000	0.000	**Total Exports**	0.530	0.0055
Geothermal and Other	0.872	7.009	0.1173	**Losses**	17.338	
Thermal	51.583	195.882				
Totals	**65.513**	**247.679**		**Consumption**	**272.350**	

Table 3: Electricity Capacity, Generation and Consumption in Italy in 1998 [23]

2.6 Cogeneration

Cogeneration, or CHP (combined heat and power) is the simultaneous production of thermal and electrical energy from a fuel such as natural gas. The heat produced from an electricity generating process is captured and used to produce steam. The steam can then be used as a heat source in industrial processes or for domestic uses. It can also be utilized to generate more electricity if needed. In industry, many facilities are upgrading their plants to include cogeneration processes. [24] In essence, cogeneration is the best way to increase the efficiency of current industrial procedures by capturing energy which otherwise would be lost.

[23] The estimates contained in this table are those published by the *Oil and Gas Journal*. More info can be found in the BP Amoco *"Statistical Review of World Energy 1999"*.

[24] Marecki, J. "Combined heat and power generating systems" Exeter: Short Run Press Ltd. 1988

2.6.1 Uses of Cogeneration

Cogeneration is not recommended unless there is a nearby useful purpose for the captured heat. Electricity can be transmitted over great distances with relatively minor losses (10%) but heat from cogeneration cannot travel very far without losing its usefulness. Heat captured by cogeneration power plants can produce steam, which then can be used in industrial processes, such as space and water heating. The ideal applications for cogeneration are for industries where manufacturers require a steady demand for both electricity and steam heat, allowing the cogeneration plant to work at an optimum efficiency[25].

Figure 10 shows two separate cases of electrical and heat production. For the

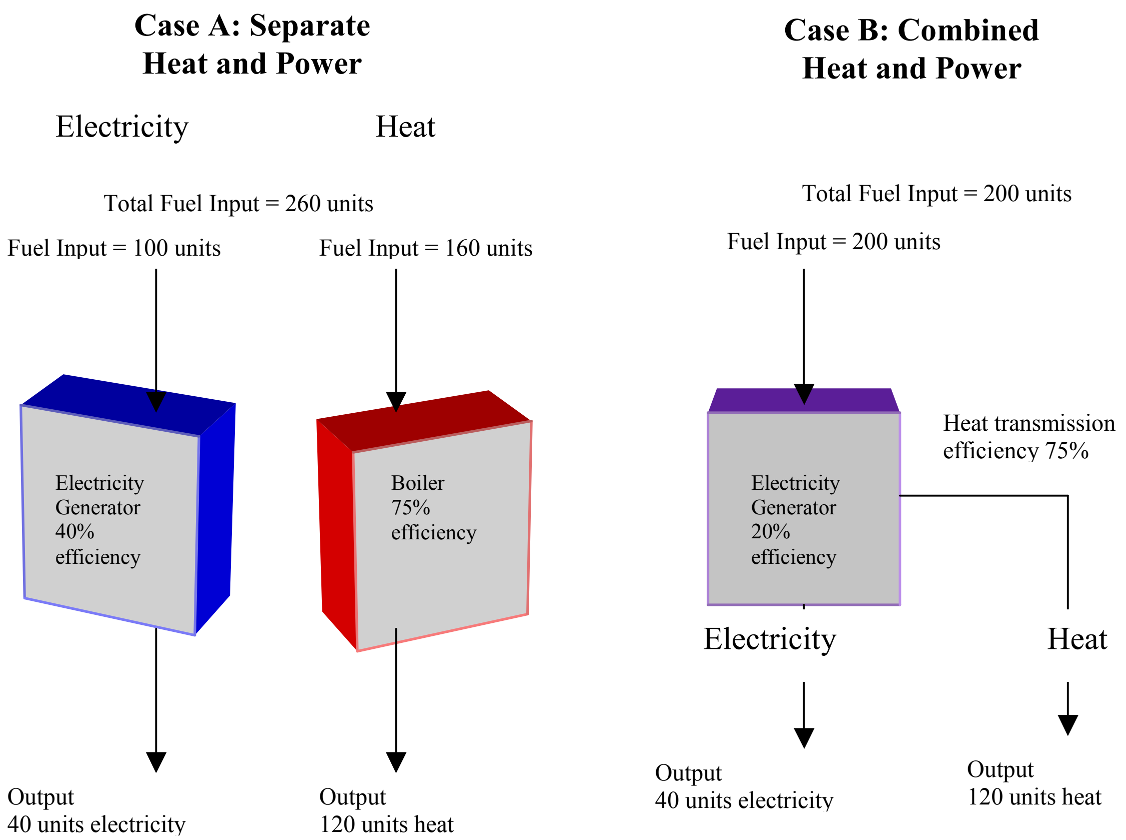

Figure 10: Electrical and Thermal Energy Production

[25] http://www.iclei.org/efacts/cogen.htm

electrical operation, 100 units of fuel are supplied to an electric generator; most generators operate with 40% efficiency. From 100 units of fuel it is possible to get an output of exactly 40 units of electricity. Similarly, for a heat process, 160 units of fuel are supplied to a boiler running with an efficiency of 75%. From this process it is possible to receive 120 units of heat energy. Total fuel input to the generator is 100 units with a return of 40; this would give an efficiency of 40%. However, if both forms of energy were produced simultaneously, a fuel input of 200 units would yield 160 units of total energy. This cogeneration process would give a total efficiency of 160/200, or 80%. Clearly the advantages of cogeneration in industry are apparent. In order for maximum efficiency and cost effectiveness to be reached, there must be a demand for both heat and electrical energy in the manufacturing process.

"The demand for both electricity and heat in individual houses is so variable over time (day & season) that these applications are not as efficient because they may rarely be called on to produce an optimum ratio of electricity/heat. A more effective use of cogeneration in the residential sector is for power plants to produce electricity for a utility grid, and heat for a district heating system. District heating systems use underground pipes to transmit either steam or hot water to individual buildings where heat exchangers capture this heat for space heating. Most countries in Europe have extensive district heating systems for both commercial and residential buildings. In Denmark, 40% of the country's space heating needs are met by district heating and half of this was provided by cogeneration technology. In the United States, district heating systems are common for large commercial buildings in cities downtown, but are virtually non-existent in residential areas. The reason for this difference is urban density. There are more people per square km in Europe than in the United States, so heat produced by cogeneration would not have to travel a long distance before it could be put to use. Italy has the fifth highest population density in Europe with about 200 persons per square kilometer (490/sq mi)." [26] Since the population density in Murano and Venice is so great, district heating would be advantageous to implement in this area.

[26] http://www.iclei.org/efacts/cogen.htm

2.6.2 Advantages of Cogeneration

The main benefit of cogeneration is plain and simple: efficiency. Cogeneration promotes more efficient use of fossil fuels because two forms of energy may be created from fuel combustion: heat and electricity. By capturing and using heat that would otherwise be discarded, cogeneration eliminates the need to burn additional fuel for the sole purpose of heating. The increase in efficiency reduces the amount of fuel needed to produce the same amount of energy. Reducing the fuel consumed decreases overall emission of atmospheric pollutants associated with combustion of fossil fuels. Some examples of pollutants associated with combustion of fossil fuels are carbon dioxide, a greenhouse gas and sulphur dioxide, which can cause acid rain[28]. A cogeneration system can virtually pay for itself within 3-5 years depending on the installation. It will save fuel costs as well as heating costs and electrical costs, just because it is much more efficient.

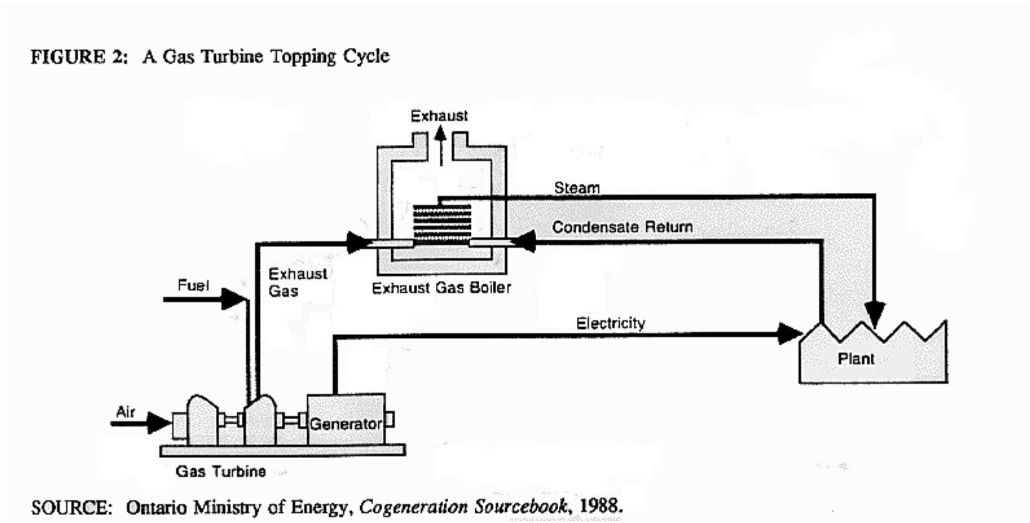

Figure 11: Model of Basic Cogeneration Process[27]

2.6.3 Cogeneration Components

There are a variety of cogeneration implementation configurations because most applications are site specific. Different technologies have been engineered based

[27] Ontario Ministry of Energy, *Cogeneration Sourcebook, 1988*
[28] http://www.iclei.org/efacts/cogen.htm

on the needs of the manufacturer, however all of them consist of these elemental parts, the prime mover, cogeneration technology, and the cogeneration system. [29]

2.6.3.1 Prime Mover

Prime mover is a term used in industry that defines a machine that drives the generator to produce electricity (e. g., a gas turbine).

2.6.3.2 Cogeneration Technology

Cogeneration technology refers to the engineering and design of any dual-use system capable of generating electric power and heat energy from the same fuel source (e. g., a furnace, boiler, generator).

2.6.3.3 Cogeneration System

A cogeneration system is a specific configuration of cogeneration technologies that will exhibit the optimal electricity/heat ratio for a manufacturing process. Cogeneration systems consist of one or more cogeneration technologies and a series of heat exchangers, such as heat recovery boilers or heat pumps, designed for certain applications (e. g., a diesel engine with a heat recovery steam generator and open-cycle heat pump).

2.6.4 Heat Engines

To capture heat from the artistic glass factory, researching heat engines was important. A heat engine is a device or machine that produces work from heat in a cyclic process. Essential to all heat engine cycles are the absorption of heat at a high temperature, the rejection of heat at a lower temperature, and the production of work. In the theoretical treatment of heat engines, the two temperature levels that characterize their operation are maintained by heat reservoirs. These heat reservoirs are capable of absorbing or rejecting an infinite quantity of heat without temperature change. In operation, the working fluid of a heat engine absorbs heat (Q_H) from a hot reservoir, produces a net amount of work (W), discards heat (Q_C) to a cold reservoir, and returns to its initial state.[30]

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[29] Hu, David S., Cogeneration Reston Publishing Company, Inc. pp 4-5
[30] Smith Van Ness Abbott Introduction to Chemical Engineering Thermodynamics New York: McGraw-Hill, 1996

2.6.4.1 Steam Turbine

An example of a heat engine is a steam power plant in which the working fluid (steam) periodically returns to its original state. In such a power plant the cycle consists of the following steps[31].(Figure 12)

1. Liquid water at approximately ambient temperature is pumped into a boiler at high pressure.
2. Heat from a fuel (heat of combustion of a fossil fuel) is transferred in the boiler to the water, converting it to high-temperature steam at the boiler pressure.
3. Energy is transferred as shaft work from the steam to the surroundings by a device such as a turbine, in which the steam expands to reduced pressure and temperature.
4. Exhaust steam from the turbine is condensed at low temperature and pressure by the transfer of its heat to the cooling water, thus completing the cycle.

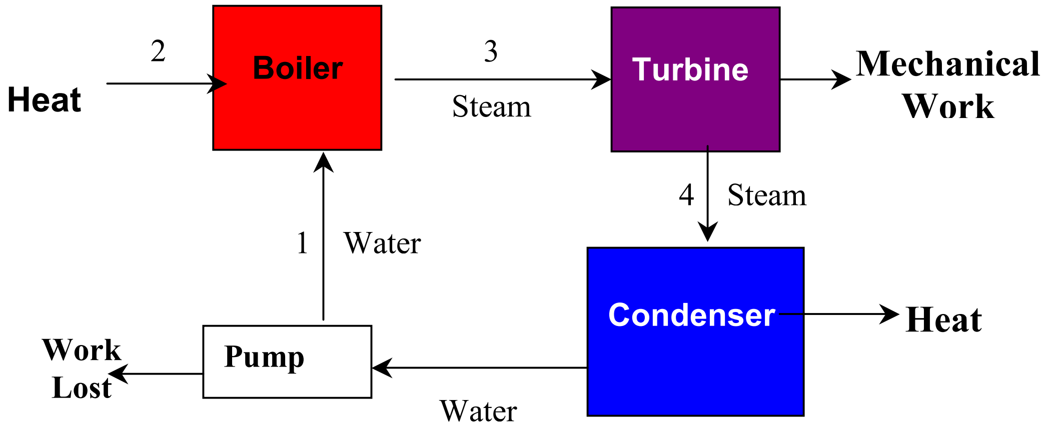


Figure 12:Steam Cycle

Steam systems are currently in use in many places in the world and off-the-shelf parts can be found to create a system for almost any application. However, these systems are usually very large and require a lot of excess heat. There are also

[31] Moran, Michael J. and Howard N. Shapiro. *Fundamentals of Engineering Thermodynamics.* Danvers, MA: John Wiley & Sons Inc., 2000

many physical components to the system that could potentially break or need maintenance.

2.6.4.2 Stirling Engine

A Scottish clergyman named Robert Stirling invented the Stirling engine in 1816. His engines were manufactured from 1818 to 1922, during which they were mainly used to pump water on farms and to produce electricity.[32] The Stirling engine is an external combustion engine (Figure 13). It uses the heat generated by an external combustion process to operate. The Stirling engine can be constructed in two forms, the two-piston type and displacer type.

Figure 13: A Model Stirling Engine in Operation at Archimede Seguso

[32] The Stirling Engine: http://campus.fortunecity.com/chemistry/187/s/

Two Piston Stirling Engine

The Two Piston Stirling engine is characterized by having two working pistons, a hot piston and a cold piston. Heat is delivered to the hot piston by the external heat source. The gas pressure in that cylinder increases due to the increase in temperature of the gas in a closed volume. This increase in pressure pushes the hot piston. The gas is then cooled and contracts, pulling on another piston, the cold piston, before returning to be heated and repeat the cycle.

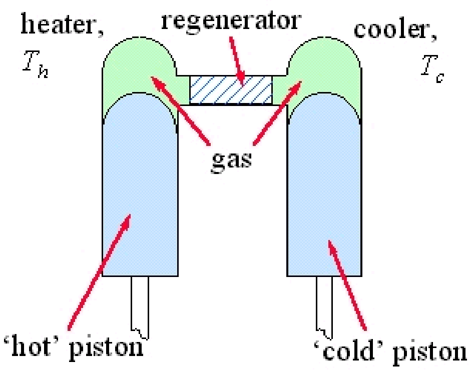


Figure 14: Two Piston Type Stirling Engine

Displacer Stirling Engine

The Displacer Stirling engine uses the same method; except that the displacer piston, or cold piston, is not sealed within its own cylinder and simply moves the hot gas from below to the cooler area above, see Figure 15. Allowing the gas to cool and contract forcing the hot piston down. The displacer piston then moves again allowing the gas to be reheated and the process repeats.

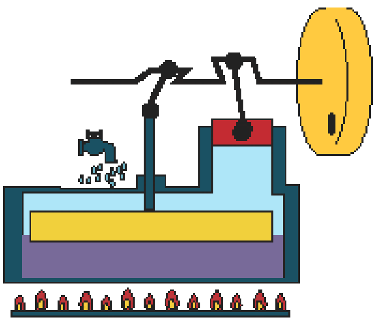


Figure 15:Displacer Stirling engine

In each type of engine, the work done per cycle is the work done during the expansion phase, less the work required to move the gas from one area to another. If the pressure increase in the hot part produces sufficient force to overcome frictional losses, work can be acquired through the rotating shaft[33].

Advantages and Disadvantages

The advantages for a Stirling engine are numerous. The first advantage is that the engine requires only a temperature difference between the hot and cold pistons to

[33] Australian Energy News 12-6-00

operate. Therefore the fuel used to obtain the heat on the hot piston is not a factor, so any fuel is possible. When compared to an internal combustion engine the Stirling engine is much more efficient. Typical internal combustion engines have an efficiency of 8%, while a Stirling engines have been known to have efficiencies between 30-35%. Stirling engines are very quiet during operation, since there are no valves or periodic explosions.

However, there are also disadvantages to Stirling engines. The main disadvantage to Stirling engines is the cost. The heat sink of the engine, in most applications, is constructed out of expensive materials. Stirling engines also require the use of seals that are necessary to prevent lubricants from entering the cylinder. The use of highly pressurized gases makes these seals difficult to maintain[34].

[34] "The Stirling Engine for Cars" Nick Batchelor, Jonathan Merritt, Steven Murcott: University of Melbourne, Australia

3. Methodology

This project is intended to aid the Archimede Seguso glass factory in determining the feasibility of a cogeneration system. The investigation will focus on the implementation and cost effectiveness of a cogeneration system to reclaim waste heat produced by artistic glass manufacturing.

The primary objectives for our project are as follows:

1) Understand Archimede Seguso's Plant Layout and Glass Manufacturing Process
2) Analyze the Feasibility for Cogeneration Implementation in the Archimede Seguso Glass Factory
3) Extrapolate results from the Archimede Seguso Glass Factory to all of Murano

Section 3.1 defines the scope of our project.
Section 3.2 describes the physical boundaries for our project.
Section 3.3 shows the process of acquiring data from the Archimede Seguso factory, including the plant layout and temperature data.
Section 3.4 addresses the acquisition of data needed to quantify the possibility of integrating cogeneration into Archimede Seguso's glass making process. The information was obtained from experts intimately involved with the glass process in their respective fields.
Section 3.5 provides a strategy for mathematically modeling heat loss in a glass factory.
Section 3.6 shows the process behind analyzing all parameters behind cogeneration implementation.
Section 3.7 explains the method extrapolation to all of Murano.

Figure 16 is a flow chart showing the breakdown of the steps followed throughout the data collection and analysis phases of the project.

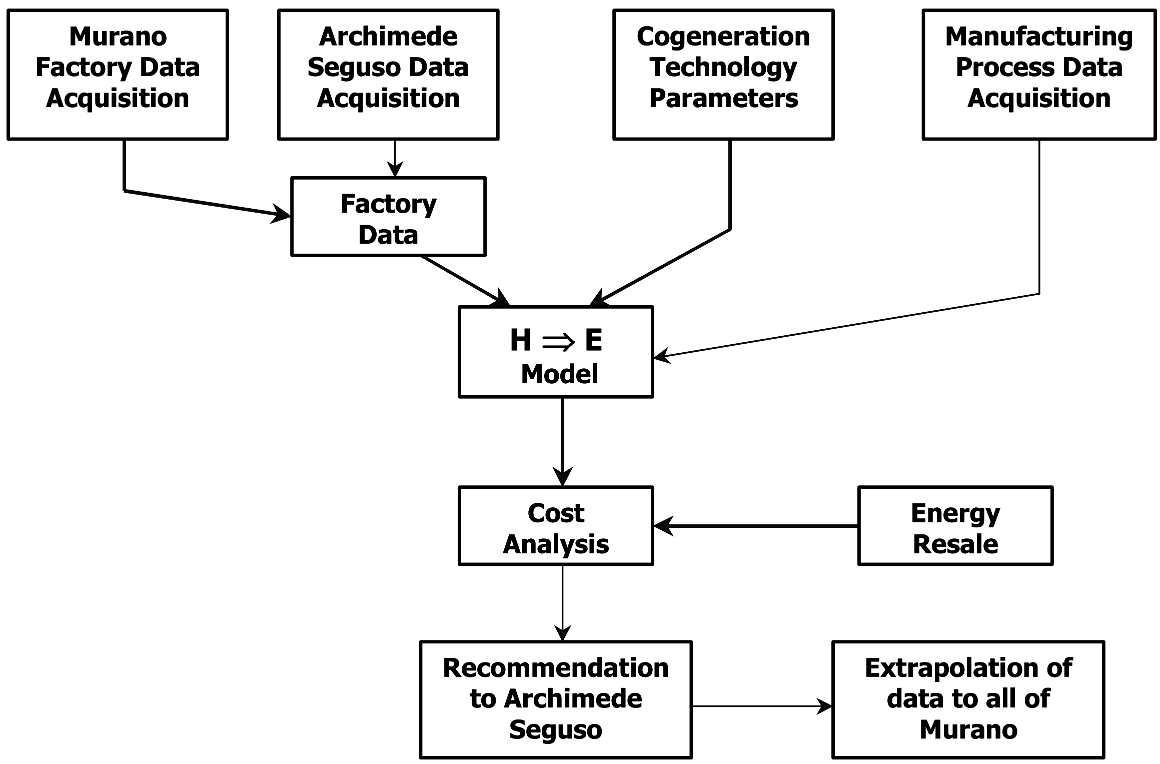


Figure 16: Methodology Flow Chart

3.1 Domain of Inquiry and Definitions

The study will focus on the feasibility of implementing cogeneration technologies in the Archimede Seguso glass factory located in Murano to reclaim waste heat. Cogeneration is defined as simultaneous production of both heat and power. In order for cogeneration to be useful, there must be a use for both heat and electric power. In artistic glass factories there are uses for large amounts of heat as well as electricity.

3.2 Study Area

The study area of the project was the island of Murano in Venice, Italy. The project centered on the Archimede Seguso factory but also encompassed neighboring glass factories and Murano as a whole.

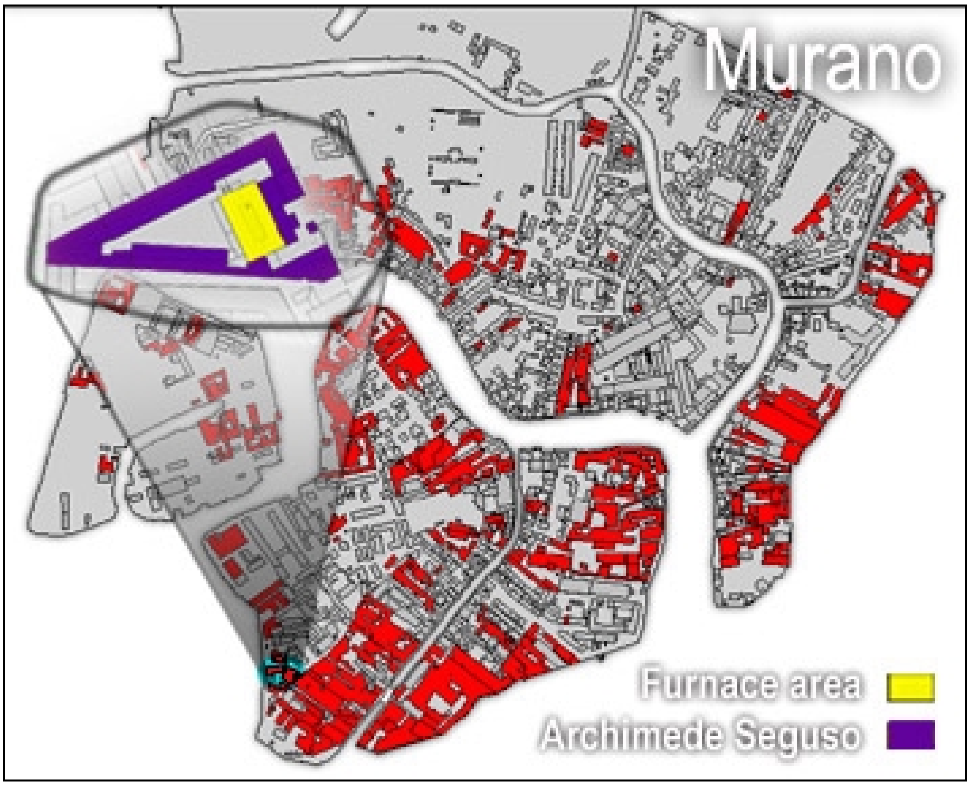


Figure 17: Buildings Occupied by Glass Manufacturers on Murano[35]

3.3 Inspection of the Artistic Glass Factory Environment

Our investigation focuses on the implementation and cost effectiveness of a cogeneration system as well as the possible resale of excess reclaimed heat energy. The data retrieved from the Archimede Seguso factory was then extrapolated to all other Murano glass manufacturers to analyze the impact of a total cogeneration solution on the island. The liaison, Antonio Seguso, has communicated the need for a device that is small, modular, and inexpensive which can be easily implemented into his current system as well as added to newly built furnaces. The device should be able to convert heat into electricity with an acceptable level of efficiency. The efficiency must also be high enough so that the initial investment by the glass manufacturer can be recouped in a reasonable amount of time.

In order to completely understand the artistic glass factory environment, we started our data collection at the Archimede Seguso Glass Factory. While at the

[35] Monitoring Pollution on Murano: An Analysis of the Artistic Glass Industry of Murano, Italy

factory we collected physical measurements of the plant layout. We also collected heat loss temperatures for the furnaces to be able to show how the excess heat created by the furnaces is lost to the ambient air. The study area was limited to approximately half of the plant, choosing the half that contained three out of the four active furnaces. Each of the furnaces was in a different state: melting, working, and cool down from previous melt. We chose to limit our study area because the plant was in operation during our data collection and the factory owner requested that we stay out of the way of the workers. Choosing the side with three out of the four furnaces was the best option.

3.3.1 Plant Layout

The plant layout of the Archimede Seguso glass factory, gives the reader a visual representation of the study site (Figure 18). The general layout of the factory was drawn in AutoCAD and subsequently included in a specific Geographical Information System (G.I.S) layer using MapInfo.

Figure 18: Inside the Factory

Since we were unable to obtain blueprints for the plant, we took measurements and produced our own plans. To perform all of our measurements, we used a 50m surveyors tape with accuracy to the half centimeter. The first step was to measure the dimensions of our study area. Next, we established reference points from which we could determine the physical position of each furnace. For the reference points we choose the left outside wall and the rear outside wall. Working off of these reference points we were able to determine where and in what orientation each furnace was positioned within our study area. The measurements were recorded on a grid pattern in which a rough sketch of the furnaces and the study area was created. In order to have an accurate layout, we also measured the physical dimensions of each furnace.

3.3.2 Temperature Measurement

The overall heat loss of the furnaces was obtained through measuring the temperature of the ambient air and the temperature of the exhaust of the furnace. The temperature of the ambient air was measured in a radial pattern around each furnace. For the furnace located in the center of the of study area, the ranged from 1 meter to 3 meters. To measure the temperature we used a digital thermometer produced by Ceramic Instruments S.R.L, model Roline 305. Along each radius 4 temperature readings were taken, one at each corner of the furnace. In addition to these 12 readings the temperature 10cm away from each side of the furnace was also taken. However, for the other two furnaces located near the rear wall, this radial pattern was only possible on two of the four sides of the furnaces. Once again the same radii were used for the readings.

To measure the temperature of the exhaust of the furnace, the thermometer was placed approximately 20 cm from the top of the furnace. The inside temperature of the furnace was also taken, this reading was collected by inserting the thermometer through the small hole in the front door as pictured in Figure 19. These two temperature readings were taken for all 3 furnaces in our study area. With these temperatures we were able to characterize the amount of heat that each furnace produces, and so how much heat is available for cogeneration use.

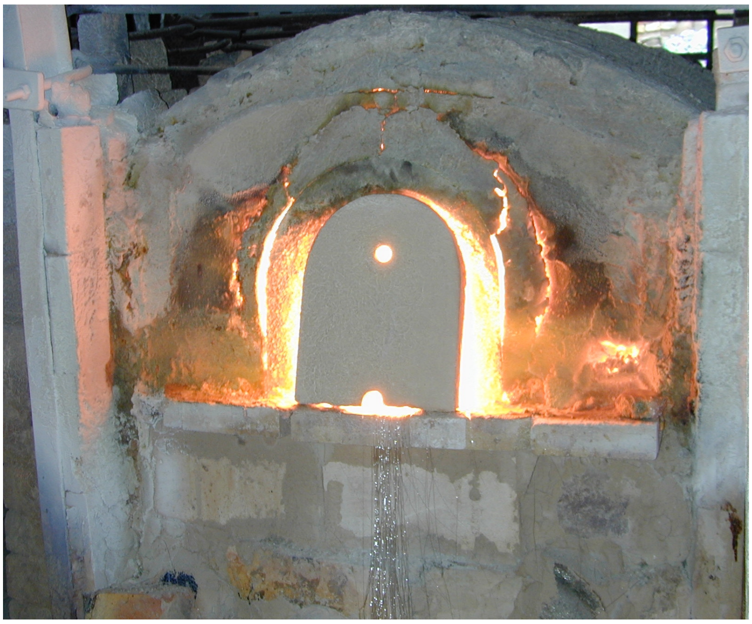
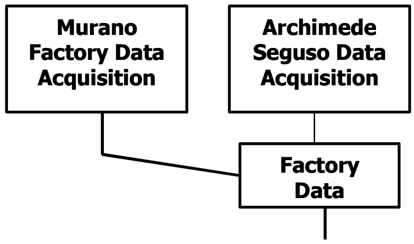


Figure 19: Furnace at *Archimede Seguso*

3.4 Third Party Data Acquisition

Much of the data needed to determine the feasibility of implementing a cogeneration system in the artistic glass factories on Murano was not collected through field work but was compiled through communication with several experts in the fields of glass production, cogeneration and pollution abatement. The information gathered falls into three main categories: factory data, cogeneration technology data and manufacturing process data.

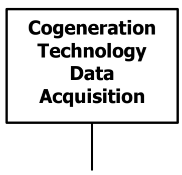
3.4.1 Factory Data



Factory data consists of the number of furnaces, the number of melting cycles that happen per week, and the consumption of resources. The number of furnaces and melting cycles per week are used in conjunction with natural gas usage and sand consumption to determine the total heat that is lost during the glass making process. The electricity utilization of the factory is used as a benchmark to compare to the output of a cogeneration system.

The data for Archimede Seguso was obtained through Antonio Seguso. He provided paper spreadsheets with the factories consumption of natural gas, sand and electricity. Dr. Maria Bianca Scalett of the *Stazione Sperimentale del Vetro* (Experimental Glass Center) provided this type of data for companies of smaller and larger sizes than Archimede Seguso. The *Stazione Sperimentale del Vetro* is one of two institutions in Europe that studies and tests glass and is located on Murano. Data on 70 additional factories was also supplied by the Environmental Department of the City of Venice. This data was translated into English and reentered into a new Access database in order to make data sheets for each company (Appendix F), and to provide data for an accurate extrapolation.

3.4.2 Cogeneration Technology Data



For each cogeneration technology that was considered, many factors need to be known. These include efficiency, minimum and maximum outputs and cost. Cost includes both implementation cost and other related costs such as maintenance. Information on the chimney and pollution abatement systems also falls into this category because the cogeneration implementation must coexist with the required pollution control measures.

Most of the needed information about the chimney system was obtained through a meeting that took place at the Archimede Seguso factory with Clementino Poppi, a pollution abatement specialist, and a cogeneration expert. They were able to provide details on the chimney system. Among the items discussed were the expected exhaust gas temperatures at different points in the system as well as the amount of heat contained in the exhaust gas as compared to the total heat lost. They were also able to provide an estimate for the maximum output of a steam system.

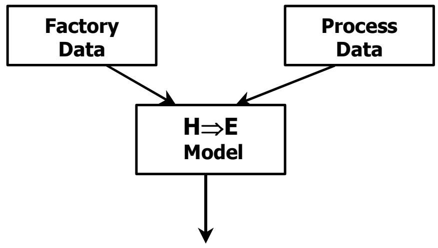
Alex Trenta, a cogeneration engineer based in Worcester, MA, USA, was able to provide cost information on a steam system. He quoted the cost of a turbine and generator combination that would fit the output that the furnaces could produce.

A trip to the Edicuaghi ceramics factory was used to view a working cogeneration system and gain a better understanding of the traditional methods currently used industries. The factory utilizes a gas turbine generation unit to produce electrical power and the waste heat is used in an atomization drying process necessary to the creation of the final product. Making ceramic products also requires the use of very high temperatures inside a kiln several hundred degrees Celsius higher than in the artistic glass making process. Although there was a very small amount of numerical data obtained, the stark contrast of the amount of wasted heat from modern equipment as compared to that lost from furnaces used in traditional artistic glass production was noted.

3.4.3 Manufacturing Process Data

Manufacturing process data includes things: natural gas needed to produce one kilogram of product, internal furnace temperatures, and the melting point of the raw materials. This information was obtained from Antonio Seguso as well as Dr. Scalet and Dr. Roberto Dall'Igna of the *Stazione Sperimentale del Vetro*. Dr. Scalet and Dr. Dall'Igna were both invaluable in helping to validate the calculations used to generate the results of this report.

3.5 Heat to Electricity Model



In order to analyze the feasibility of a cogeneration system applicable to Archimede Seguso's glass making process, knowledge had to be acquired about the specific needs of the glass factory. The information required was received through further inspection of the factory environment. The following sections describe the information acquired in order to understand the specifics of the artistic glass process so that it could be analyzed with accuracy. From the proposed framework of the Heat to Electricity model, meaningful results can be obtained through analysis.

3.5.1 Furnace Operation

At the heart of the artistic glass factory is the furnace. The heat loss problem is attributed to inefficiencies in furnace design based on old methods of hand-made construction. In order to understand the heat loss problems of artistic glass factories it is important to take furnace design into consideration. Also, it is essential to know operational parameters for these furnaces. It is then possible to see where the furnace design is flawed and where it can be improved. Operational parameters were acquired from the Archimede Seguso glass factory from information obtained by Antonio Seguso. By defining the furnace as the area of inquiry, it will be possible to use it as a basis for all artistic glass furnace designs and thus will enable us to extrapolate data with reasonable accuracy.

3.5.2 Operational Model

The first step taken to understand furnace operation was the creation of a furnace model including basic operational parameters. Figure 20 shows the most elemental operational model. These are all the basic input and output values for an artistic glass furnace.

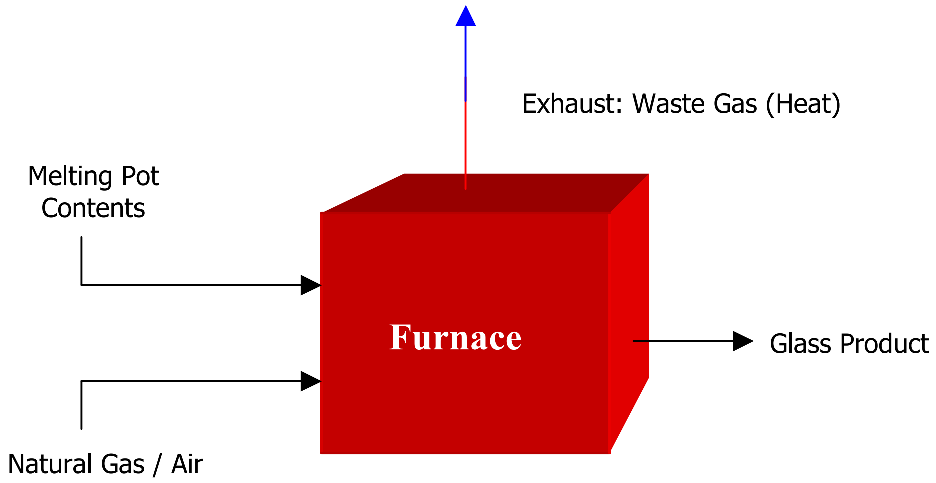
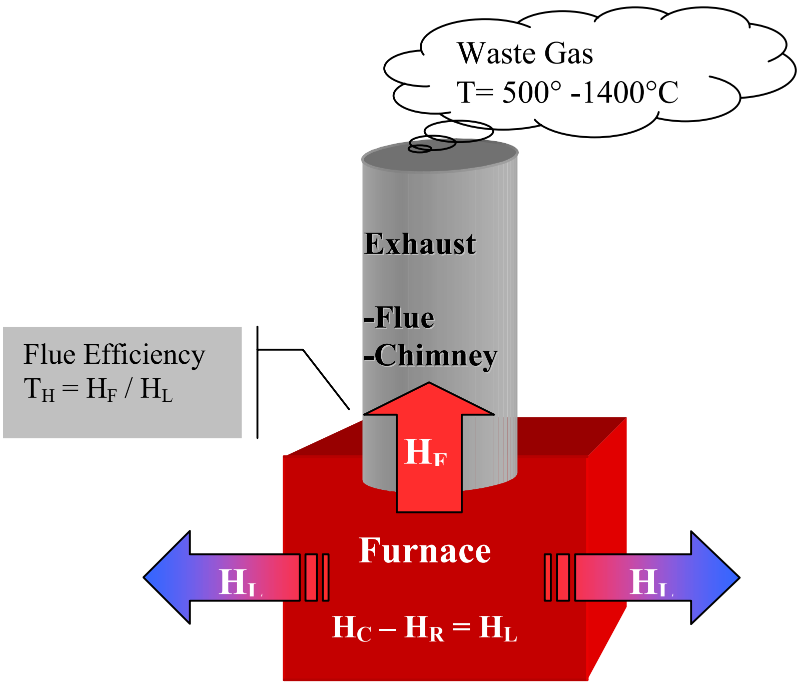


Figure 20: Furnace Operational Model (Basic Input / Output)

We will make the basis of all our calculations on the operational model. Every artistic glass furnace inputs a certain amount of sand and natural gas combined with air. Inside the furnace, the combustion of the natural gas in presence of the melting pots. The products of the combustion of natural gas in the presence of the sand mixture are heat, waste gas and amorphous glass that can be worked to form glass product. The purpose of our project is to analyze the feasibility of capturing the lost heat and using it for another application. Figure 21 depicts how heat is dissipated from the furnace and how we quantify how much heat we have available for our cogeneration application.



H_C = Heat created from combustion of Natural Gas & Air

H_R = Heat required to liquefy melting pot contents

H_L = Heat Lost: The extra heat produced that is not used for melting goes into warming up the waste gas. Some of this gas escapes from the furnace door, some through the walls. The remainder goes up the exhaust. We will call this exhaust value H_F.

Figure 21: Furnace Operational Model (Heat Loss)

On Murano, the best use for this escaped heat according to our liaison and sponsor, Antonio Seguso, would be converting it into electricity. The electricity produced could be sold to the electrical company, ENEL, at market price as soon as it is produced. It is possible for a cogeneration technology to tap into the exhaust gas, which contains a usable amount of heat (see Figure 21). The reason to tap into the exhaust gas and not into the furnace itself is because we do not want to interrupt the artistic glass process. It is possible, however, that more heat could be pulled out of the furnace than would be required for melting and maintaining, resulting in a higher natural gas consumption rate. Figure 22 shows the model used to describe reclamation of the waste gas heat. Realize that H_L , the total amount of heat lost, is the highest theoretical amount of energy that can be converted into electricity. In reality the total conversion of H_L to electricity can never be attained. The total amount of heat that can be converted to electricity is dependent upon the heat transmission efficiency (T_H) and the heat to electricity conversion efficiency (E_M). These efficiencies multiplied together result in an overall efficiency.

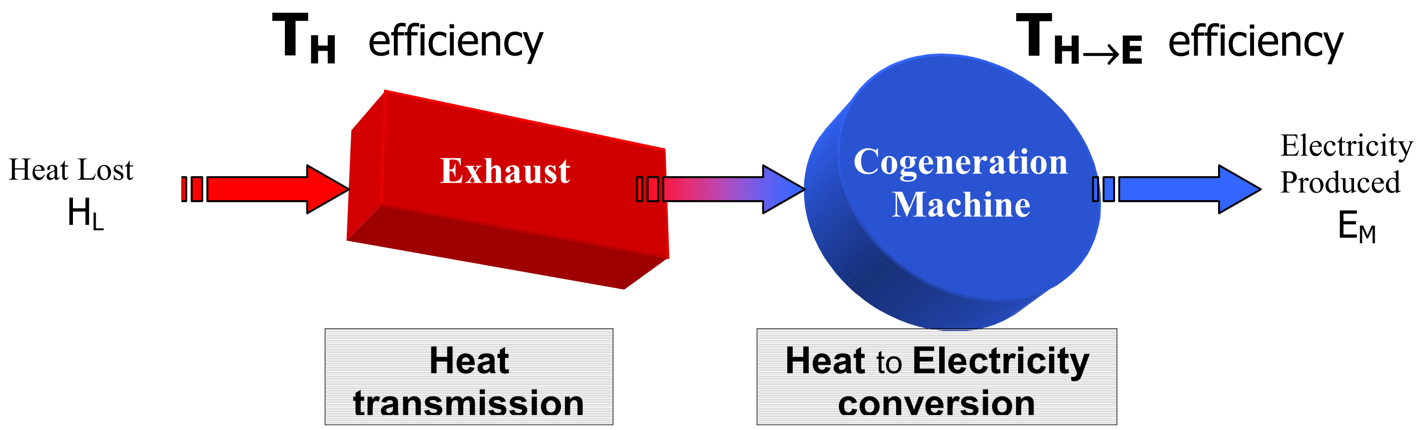


Figure 22: Furnace Operational Model (Heat Reclamation)

By studying the glass manufacturing process and from information provided from various sources, all input and output operational parameters were integrated into the model and assigned variables. The complex furnace operational model with all input, output, and transmission variables and a methodological breakdown can be found in Appendix B.

	Elemental Variables in the Heat to Electricity Model
Factory Specific Variables	**Archimede Seguso S.R.L. Factory Data**
$NG_{Ta} := 513168 \frac{m^3}{yr}$	NG_{Ta} is the total amount of natural gas consumed / yr for the factory. This is multiplied by MMf because this excludes annealing gas consumption.
$Sc_{Ta} := 32450 \frac{kg}{yr}$	Sc_{Ta} is the sand consumption for the glass factory. It is divided by the sand composition ratio of the total mixture to give the kg/yr for the total weight of material also known as the melting pot contents.
$Gp_{Ta} = 37020 \frac{kg}{yr}$	Gp_{Ta} is the glass production for the glass factory. It can be divided by .81 (weight loss) to find the initial melting pot contents.
$M_f := 4$	M_f is the number of melting / working furnaces employed in the factory. (any furnace that is not used in the annealing process)
$W_o := 45.7 \cdot \frac{weeks}{yr}$	W_o value is the number of weeks that the factory is "operating" per year. (Days of operation) / (7 Days / week)
Artistic Glass Variables	
$MM_f := .9$	MMf is 90%, the amount of natural gas / kg that is used during the melting and maintaining cycles. We are not looking at cogeneration for the annealing phase.
$WG_{Ta} := 11 \cdot NG_{Ta}$	WG_{Ta} denotes the amount of waste gas that is produced annually from combustion of natural gas.
$Hc_{NG} := 8400 \frac{kcal}{m^3}$	Hc_{NG} is the amount of energy that can be attained from combustion of 1 m^3 natural gas.
$Sh_{WG} := 0.38 \cdot \frac{kcal}{m^3 \cdot K}$	Sh_{WG} is the specific heat capacity of the waste gas exhaust stream.
$WG_t := 1623 \cdot K$	WG_t is the temperature of the waste gas exhaust (Kelvin)
$T_H := .55$	T_H is the heat transmission efficiency: The ratio of heat in flue to heat lost to the environment. This is based on furnace and exhaust design.
$T_{H\_E} := .30$	T_{H_E} is the efficiency which heat can be converted to useful electricity. This is based on the cogeneration application.
	See Appendix B for Calculation Methodology

Table 4: Definition of Variables for the Heat ⇒ Electricity Model

These values can be calculated from data supplied by the Archimede Seguso Glass Company. Other values required that could not be supplied by the factory were provided by the *Stazione Sperimentale Del Vetro* and other sources discussed in our information section (Section 3.4).

3.5.2.1 Assumptions

In order to provide a framework for calculations based upon the furnace model it was necessary to make some assumptions about the glass process and details of Archimede Seguso's production methods. We expect these assumptions to hold true for any artistic glass factory on Murano.

- Basing each calculation on one kg of glass produced, inconsistencies in the glass process over time, such as heat fluctuations due to different production phases, will not have to be calculated.
- Max Total Power Output of any cogeneration solution can be based on these specific variables:
  - Heat created when combusting 1 m^3 of natural gas (kcal/ m^3)
  - Energy contained in the waste gas flow annually (kcal/yr)
  - Natural gas consumed to create 1 kg of glass product (m^3/kg)
  - Weeks in operation per year
  - Number of Melting Furnaces
  - Waste Gas Temperature (K)
  - Total amount of natural gas consumed annually (m^3/yr)
  - Total amount of sand expended annually (kg/yr) <u>or</u> glass produced annually (kg/yr)
  - Efficiency (ratio) of heat that enters exhaust stream compared to Heat Lost to surroundings.
  - Efficiency (ratio) of exhaust heat that can be converted into useful electrical power, or the cogeneration solution efficiency.

  All other variables can be calculated by relating any of these fundamental base values.
- The Annealing Process only uses a fraction (10%) of the fuel consumed by a working/melting furnace.

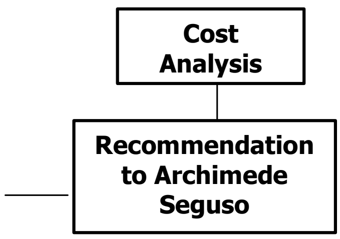
- AS does not use natural gas for anything else but melting glass.
- Total amount of sand consumed / year is divided evenly among the 4 melting furnaces.
- Heat Lost is a linear relationship between the heat provided by combustion and the heat it takes to melt the glass and keep it amorphous.
- T_H efficiency is dependent on the furnace and flue design
- $T_{H\rightarrow E}$ efficiency is dependent upon the cogeneration technology
- The Power Output will be valid for any cogeneration technology as long as we know the overall efficiency of its conversion from heat to electricity.
- Max Total Power Output can never be fully attained and it is only the maximum possible value. Total Power Output is below this value.
- The method takes the broadest approach possible when analyzing the glass melting process and heat transfer. Values attained by this calculation are not be precise, but provide a ballpark figure within a degree of magnitude.

3.5.2.2 Calculations

In order to perform many simultaneous calculations based on fundamental variables, sets of equations were related in MathCAD (Appendix B). MathCAD allows easy manipulation of the variables from which we were able to extrapolate any data required. The data sheets created in MathCAD contain equations based on our research and the assumptions listed in the previous section. Once the basic model was built in MathCAD, calculations were exported to Microsoft Excel in order to conduct calculations needed to extrapolate the data to all artistic glass factories. Efficiencies must be calculated separately according to furnace design and specific cogeneration applications. The purpose of the furnace calculation model is to give a workable electricity (kWh) figure on which to base our cost analysis. All calculations are done in respect to one elemental process in the glass making tradition, the furnace.

3.6 Creation of Feasibility Tables

The definition of feasibility that this project is centered around is the ability of the cogeneration system to



pay for itself with a certain payback period. For the sake of flexibility, a table was generated that automatically adjusts to any desired payback period. It is necessary to examine the parameters of a cogeneration system in order to determine its feasibility. These parameters include: flue efficiency, electrical efficiency, investment, and payback. To analyze all of these factors, a set of tables that relates all of these constraints together was the most logical method. The following sections describe how these tables were created.

3.6.1 Cost Analysis: Varying Investment

By setting the payback period as the constant value, we were able to calculate the annual savings that could be attained. The cost of selling back 1 kWh of electrical output was found to be L. 300 (€ 0.15)[36]. Using this value it is possible for us to calculate the amount of electricity that needs to be produce annually in order to regain the total investment during a specific time frame. This total investment includes all the maintenance cost and any other expenses required. However, for each different total investment, the value of the electrical production required varies accordingly: the higher the investment, the more electricity that needs to be produced in order to reach the specified payback. Therefore, we created a table (Appendix C.1) that displays several investment amounts with the amounts of electricity needed to be produced annually to make back the investment. The table calculates total investments by incrementing a minimum value by a certain percentage through 35 iterations. Both the minimum value and incrementing percentage are values set by the user. For the purposes of this project

3.6.2 Cost Analysis: Varying Payback

In this section, total investment was not used as a variable instead the payback period was used as the variable. This means that the total investment was held constant and the payback was incremented at a rate of 5%. The longer the payback period, the least amount of saving is needed annually.

[36] This value was attained from Dr. Bianca Maria Scalet, a scientist currently employed by the the *Stazione Sperimentale del Vetro.*

The purpose of performing the cost analysis in two different methods was to increase the flexibility and usability of our analysis method. Having a method that is flexible increases the possibility for future use.

3.6.3 Rework of the Heat to Electricity Model

From the cost analysis, the total amount of electricity required is generated, which represents the amount of electricity that needs to be produced so that the investment is recouped in the desired amount of time. Even though we performed the cost analysis using two different methods, the end result of both is an electricity output value. Therefore, we can use the same method to calculate the flue and electrical efficiencies. Reworking the heat to electricity model allows us to complete this calculation.

The heat to electricity model has already been explained and can be seen in Appendix D. The output of the model is an electricity production value determined from a calculated heat loss value and two efficiencies, flue and electricity. Therefore, if we were to know the electricity that needs to be produced from the cost analysis and the heat loss calculated using Archimede Seguso consumption data (Appendix D.1) and the heat to electricity model, then the efficiency values can be derived. In order to calculate the two efficiencies, it was necessary to combine the two into a single overall efficiency, which is the efficiency of the total amount of heat lost to the amount of electricity produced. Efficiencies are combined by simple multiplication. For example, if the flue efficiency is 30% and the electrical efficiency is 20%, then the overall efficiency is 30%×20% or 6%. Using the equations that make up the Heat to Electricity Model, the Overall efficiency was determined to be equal to $\frac{E_M}{H_L}$.

However, electricity produced is measured in kilowatt-hours (kWh) and E_M is measured in Watts (W), necessitating a unit conversion. The unit conversion from kWh to W is as follows, since there are a thousand Watts in a kilowatt the kWh value needs to be multiplied by one thousand making the unit watt-hours (Wh). To eliminate the hour value out of the label, the unit is divided by the number of hours in a year. The H_L value is calculated using the heat to electricity model and inputting

Archimede Seguso data, and is a constant for all of the efficiency calculations. Now that the units are correct and the division is completed, the new value is the overall efficiency. In order to calculate the electricity efficiency, it is necessary for us to assume a flue (exhaust) efficiency. We vary the flue efficiency so that for the same overall efficiency different electricity efficiencies are calculated.

Programming this method into a Microsoft Excel spreadsheet, allowed for automation of the calculations. The output of this method was reformatted into an easy-to-read and understandable table (Appendix C.3) that highlights unrealistic efficiencies in red. The realistic efficiency value will change over the years as technology improves and present solutions become more efficient. Just as internal combustion engines have gained increased output for the same displacement, cogeneration equipment designs will inevitable evolve and higher efficiencies will be improved. However, based on thermodynamics and the average temperatures of the glass process, the greatest efficiency that is possible as stipulated by the thermodynamics of the Carnot cycle is 82.18%. This value is based on the ideal thermodynamic efficiency that is $1 - \frac{\text{Temperature}_{\text{cold}}}{\text{Temperature}_{\text{hot}}}$. For the glass factories, the temperature $_{\text{cold}}$ value is taken to be 25°C or 298K and the temperature $_{\text{hot}}$ value is 1400°C or 1673K (Appendix B). This gives an overall efficiency of 82.18%. Therefore, if the flue efficiency were 100% then the electrical efficiency would be 82.18%. So, if the chosen investment and payback force the electrical efficiency of any cogeneration technology to be equal to or greater than 82.18%, then that set of parameters is not feasible.

3.6.4 Cost Benefit Analysis

After finding a total investment and efficiencies that are reasonable, it is necessary to further analyze the investment value. Since the investment is the entire amount spent over the payback period, the initial and maintenance costs are separated via a cost benefit analysis.

Our cost benefit analysis has two parts, the first being the capital budgeting analysis and the second being the investment cash flow pattern. There are three factors that could greatly affect our cost benefit analysis: taxes, inflation, and depreciation value. Tax is definitely one factor that must be considered in making capital budgeting decisions because a project that looks good on a before-tax basis may not be acceptable on an after-tax basis. However, since tax rates vary greatly and depend on a wide range of variables, we assume that the tax rate is zero. As for the inflation, better estimates of future cash flows will be obtained by assuming growth of both benefits and costs at the general rate of inflation, which in this case is 2.5%. And finally, for the depreciation, there are two types of depreciation values that we use. The first type is the normal depreciation value that is obtained by dividing the initial amount of investment on machines, divided by the life expectancy of the machines. This depreciation value would be used in the capital budgeting analysis. The second type of depreciation is the Modified Accelerated Cost Recovery System (MACRS) depreciation value and is used for the investment cash flow pattern. MACRS is a standard system of decreasing depreciation percentages that allows for total depreciation over 10 years. All of the equations that we created in the Excel spreadsheet located in Appendix C.4 and were based on the research that we did on both Internet resources and book resources[37].

After inserting the total investment amount, the amount of electricity production needed, the selling price of electricity, the annual savings was calculated. Once the annual savings value is obtained, we can then use this value for our capital budgeting analysis. By using the capital budgeting analysis, we would be able to estimate the return on investment (ROI) and the payback period. From here, we can then tell whether it is viable for Archimede Seguso s.r.l to implement this cogeneration project. If the payback period were above 7 years, then serious consideration would have to be given as to whether implementation should take place. For easy manipulation, the capital budgeting analysis would was created in a Microsoft Excel spreadsheet located in Appendix C.4.

However, the capital budgeting analysis would only show the percentage of the return on investment, and the number of years for the payback period, but not the

[37] Handbook of Financial Analysis, Forecasting, and Modeling, http://www.wpi.edu/Academics/Depts/IGSD/IQPHbook/

annual savings or annual cash inflow that Archimede Seguso s.r.l. would receive by implementing this project. Therefore, we calculated an investment cash flow pattern that shows the annual savings and cash inflow that Archimede Seguso s.r.l. would receive in the following years.

To easily present our findings, the investment cash flow pattern laid out in a Microsoft Excel spreadsheet. This spreadsheet is presented in Appendix C.4. It shows the amount of money that Archimede Seguso could save annually until the desired final year.

Using this method of analysis, not only Archimede Seguso, but any company considering installing any cogeneration technology will be able to assess the feasibility of implementing that technology.

3.7 Extrapolation for Electricity Production to all of Murano

The first necessary step in making the extrapolation was to calculate the annual total heat lost for all the traditional glass factories in Murano that data was received for. Instead of calculating for all the glass factories on Murano, we are basing our calculations on the 27 factories that we have complete, non-deviant (section 4.2.3) data for. By doing this, we were able to find the total amount of electricity that could be produced annually from all these factories.

Once we found the electricity that can be produced annually from all these factories, we calculated the total electricity consumption for all of the factories. If the electricity consumed is smaller than the value of the total electricity produced annually, then the Murano's traditional glass factories as a whole will be able to self sustain in terms of electrical needs. We have provided a table that shows the overall amount of electricity produced vs. the overall amount of electricity consumed based on the varying overall efficiencies values. It is presented in two colors, green and red. The green color denotes that the factories as a whole are self-sustaining, while the red cells show that the factories cannot meet their own electrical requirements. From the annual electricity that can be produced the total allowable investment for a payback period can be calculated by multiplying by the price of electricity, amount of electricity produced, and the number of years in the payback period. This investment can then be extrapolated to all of Murano by multiplying by the ratio of the total number of glass factories on Murano (156) to the number of factories in the dataset (27).

4. Results and Analysis

The following section will consist of the direct outcomes of the Methodology. Each result will be thoroughly discussed and explained so that when these outcomes are used in an analysis, the concepts are already completely understood. The following is a breakdown of this section:

1) Discuss the consumption habits of the Archimede Seguso as well as explore the heat dissipation characteristics of the furnace room.
2) The outputs of the heat to electricity model are put into understandable terms and applied to each factory.
3) The use of the feasibility table is explained, by following an example from beginning to end, including a cost benefit analysis. The trends that follow the feasibility table are explored.
4) A full, in-depth analysis of both steam and Stirling engine systems is included.
5) Finally, an extrapolation is performed to determine the feasibility of cogeneration allowing the glass factories on Murano to only consume natural gas for all their energy needs.

4.1 Discussion of Archimede Seguso Factory

We used Archimede Seguso as a means to understand the consumption habits and heat loss of a typical Murano glass factory in order to get a better idea of what the natural gas and electricity usage values mean. Without this basis, the natural gas, electricity, and heat loss values would only be a set of numbers and would have no relation to reality.

4.1.1 Consumption

Figure 23 shows the consumption data for Archimede Seguso in a single year.

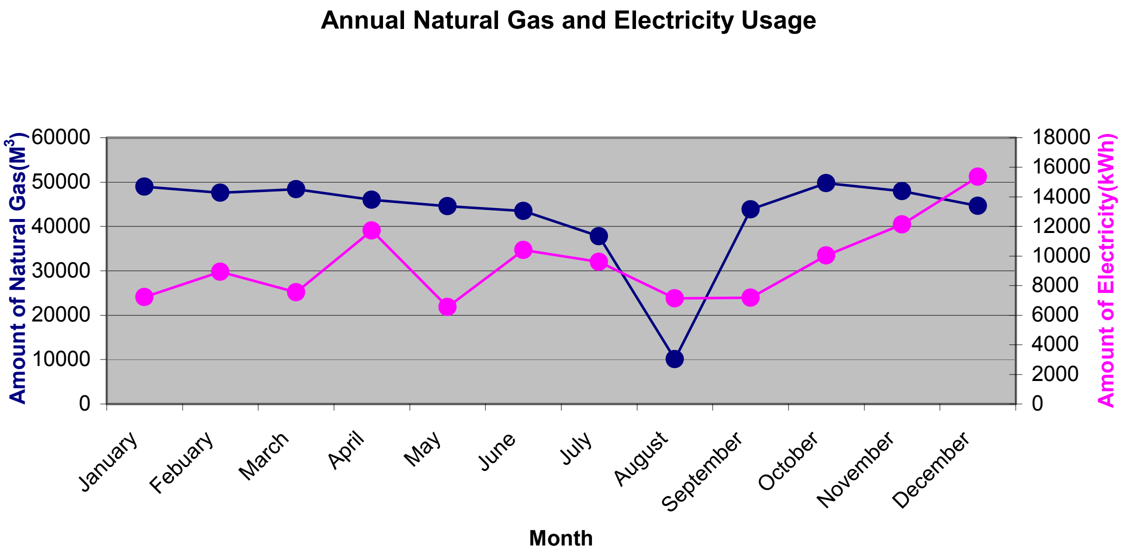


Figure 23:Annual Natural Gas and Electricity Usage for Archimede Seguso

Overall the natural gas consumption is stable, however during the month of August the natural gas usage drops as the factories close and production ceases. The combination of hot weather and the heat loss from the furnaces creates an environment of extreme heat that the artisans cannot work in. The electricity trend is more erratic, however. During the winter months there is a concrete trend: as the winter progresses the consumption of electricity increases. This tendency most likely exists because the shortened days require Archimede Seguso to increase the amount of time that the lights are on in the building.

4.1.2 Heat Dissipation

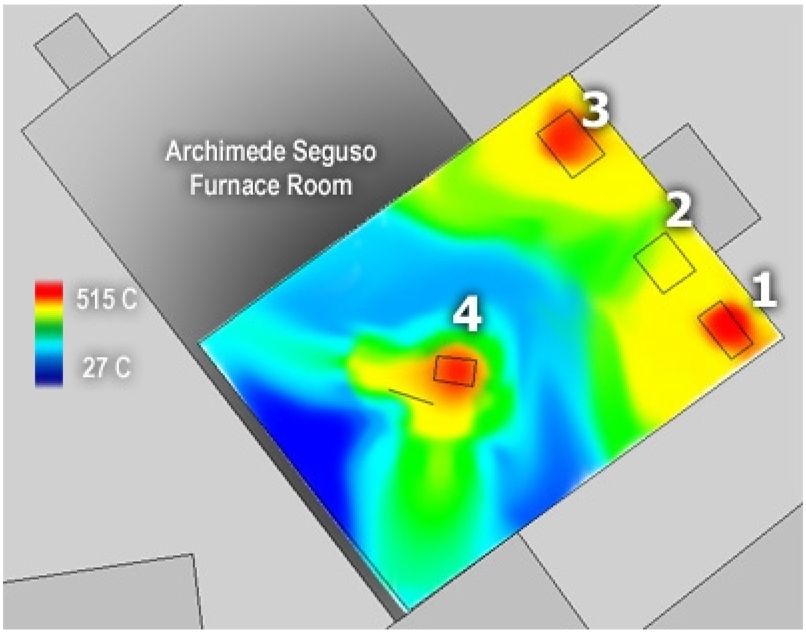


Figure 24: Heat Dissipation Map

In order to visualize the heat loss in the factory a heat dissipation map was created from our temperature readings (see Figure 24). Since our project is based around the idea of heat loss, it is necessary to have a complete understanding of how this heat is lost. The boxes in the map represent the furnaces in our study area. Furnaces 1,2, and 3 are melting furnaces, while furnace 4 is a working furnace. The colors on the map show the temperature of the air, the coldest in blue and the hottest in red. Notice that the hottest temperatures are directly above the furnaces where the flues are constructed. This means that the greatest heat loss occurs through the top of the furnace. Furnace 2 does not have a “red spot” because it is still under construction and so is not in use. The second area of greatest heat loss is directly in front of the furnace. This loss is due to the inefficient design of the door to the furnace, and the fact that during the working of the glass the artists often leave the door complete open allowing a large amount of heat to be lost. This trend can be seen in furnace 4, which was in the working cycle when we collect the temperature data. In the map, furnace 4 has a large amount of green and yellow color around the position of the door. Since green and yellow represent higher temperatures than blue (see legend) it is clear that the door allows for a great amount of heat loss. The upper portion of the map has higher temperatures because of the close proximity of furnace 1 and furnace 3.

4.2 Heat to Electricity Model

The purpose of the heat to electricity model was to calculate how much electricity could be obtained from the furnaces in the artistic glass factories throughout Murano. Besides an electrical output there are many other useful calculations that are integrated into the model and it is important to present all the data to see how they vary for each factory.

Once the heat to electricity model was constructed and assumptions were stated, useful results were obtained from the output of the model. In essence, what the model does is allow you to calculate an estimated electrical output from basic factory information. This information includes the number of melting furnaces, natural gas consumption, glass production, overall efficiency for heat transfer and electrical production, flue gas temperature, and the number of workweeks per year the factory operates. For a breakdown of all calculations based on this simple information please refer to Appendix B.

4.2.1 Archimede Seguso Factory Information

In order to do a feasibility study it was vital to understand Archimede Seguso's glass making process from beginning to end. Understanding the glass process included knowing the different phases of production, material contents of melting pots, furnace temperatures, consumption data, and thermodynamic characteristics of glass. All retrieved information was compiled and calculations were made using the heat to electricity model. Results from this model for the Archimede Seguso Glass Factory are shown in Table 5.

Archimede Seguso Factory Data Results

Factory Specific Variables	
$NG_{Ta} := 513168 \frac{m^3}{yr}$	NG_{Ta} is the total amount of natural gas consumed / yr for the factory. This is multiplied by MMf because this excludes annealing gas consumption.
$Sc_{Ta} := 32450 \frac{kg}{yr}$	Sc_{Ta} is the sand consumption for the glass factory. It is divided by the sand composition ratio of the total mixture to give the kg/yr for the total weight of material.
$Gp_{Ta} = 37020 \frac{kg}{yr}$	Gp_{Ta} is the glass production for the glass factory. It can be divided by .81 (weight loss) to find the initial melting pot contents.
$M_f := 4$	M_f is the number of melting / working furnaces employed in the factory. (any furnace that is not used in the annealing process)
$W_o := 45.7 \cdot \frac{weeks}{yr}$	W_o value is the number of weeks that the factory is "operating" per year. (Days of operation) / (7 Days / week)
Energy Calculations	
$EWG_{Ta} = 2.842 \times 10^9 \frac{kcal}{yr}$	Energy Contained in the waste gas annually.
$NG_{kgG} = 3.825 \frac{m^3}{kg}$	Volume of natural gas that is required to produce 1 kg of glass.
$NGc_{Ta} = 4.311 \times 10^9 \frac{kcal}{yr}$	Energy attained from combustion of natural gas annually.
$HMpc_{Ta} = 1.468 \times 10^9 \frac{kcal}{yr}$	Energy required to liquefy contents of melting pots annually.
$HL_{Ta} = 2.842 \times 10^9 \frac{kcal}{yr}$	Energy lost through dissipation to the environment annually.
$HL_f = 6.395 \times 10^8 \frac{kcal}{yr}$	Energy lost through dissipation to the environment per furnace annually.
$HF_f = 3.517 \times 10^8 \frac{kcal}{yr}$	Energy that goes through the exhaust waste gas stream with a flue efficiency of 55% per furnace annually.
$EM_f = 1.4 \times 10^4 W$	Electricity that can be produced from cogeneration with a 30% efficiency per furnace annually.
Output Calculations	
$kWh = 122298$	Electricity that can be sold back to ENEL per furnace annually.
$M_f \cdot kWh = 489191$	Electricity that can be sold back to ENEL for the entire factory annually.
$WG_{Ta} = 5.645 \times 10^6 \frac{m^3}{yr}$	Waste gas produced for the entire factory annually.
$Gp_{Ta} = 37020 \frac{kg}{yr}$	Glass Produced for the entire factory annually.
	See Appendix B for Calculation Methodology

Table 5: Quantification of the Archimede Seguso Glass Process

4.2.2 Murano Artistic Glass Factory Data Sheets

We used the Archimede Seguso data to develop the heat to electricity model, and then used it to calculate results for the factories that had complete sets of data available. Despite receiving data on 71 factories, they were only complete for 50. See Table 6 for an example data sheet of the Ongaro Fuga Glass Factory. Data sheets

Ongaro Fuga di Fuga G. e C. # 92

Furnace Operating Times

Days of Operation per Year	217
Weeks of Opertaion per Year	31.00

Factory Data

Number of Furnaces	9
Glass Production	5.58E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	336000 KWh
Yearly Natural Gas Usage	1,707,066.67 m^3
Mass of Material Melted per Year	68,888.89 Kg
Natural Gas Usage per Unit of Glass	8.44 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.43E+10 Kcal/Yr
Heat Needed to Melt Pot Contents	4.88E+09 Kcal/Yr
Total Heat Loss	9.45E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	1.88E+07 m^3
Total Recoverable Energy (55% Flue Efficiency)	5.20E+09 Kcal/Yr
Electricity Production	1.63E+06 KWh/Yr

Table 6: Example Data Sheet

for all factories that signed the *Accordo del Vetro* are located in Appendix F.

4.2.3 Electrical Output Analysis

Once electrical output values were obtained, the first step was to determine if a usable amount of electricity could be created. We did this by comparing the electricity that could be produced to the electricity that the factories used annually. From these 50 factories, we calculated the electrical output we could hope to attain based on an overall efficiency of 16.5% and a flue gas temperature of 1350°C that we obtained from a working furnace during data collection at the Archimede Seguso glass factory. Appendix D.2 shows the calculations for all 50 factories when the information was inputted into the heat to electricity model. Please refer to the appendix for further reference for this section.

The electrical output value is dependent on all variables involved in the calculation. However, it was found that certain variables greatly affected the outcome of this value. Natural gas consumption, exhaust temperature, and overall efficiency had the greatest affect on kWh output. When natural gas consumption is high compared to the glass product, more energy can be lost to the environment. More energy can be recovered through cogeneration since a larger amount of energy is wasted. Figure 25 shows how kWh can vary when specific variables are manipulated.

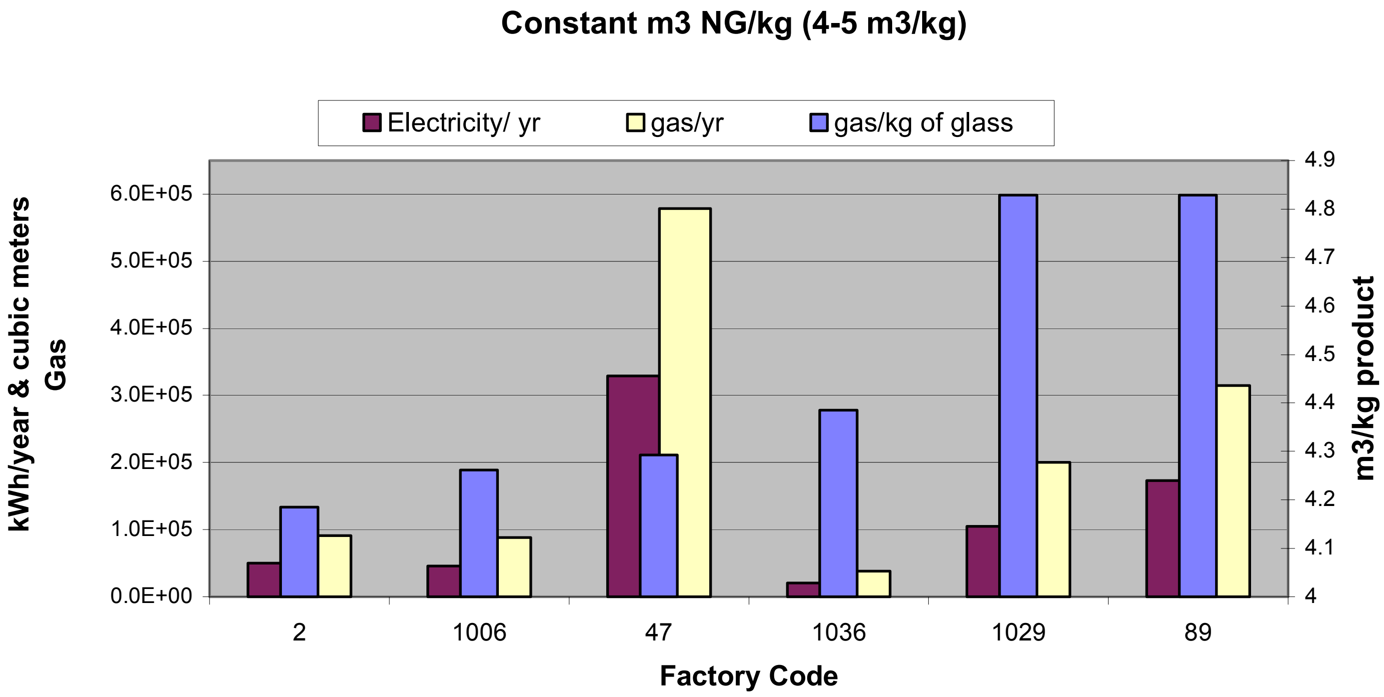


Figure 25: Consumption – kWh Correlation

In order to see how electrical production varies from factory to factory we picked with a range between 4-5 m^3 natural gas required to produce 1 kg of glass product (shown in blue). Once this variable is held within a range, it is possible to compare consumption data with electrical production results. Factory code 47 has much higher natural gas consumption than the other factories in this range, but it also is the largest producer, producing over 37 tons of glass annually. This graph shows that factories with larger natural gas consumption and less efficiency can produce more electricity.

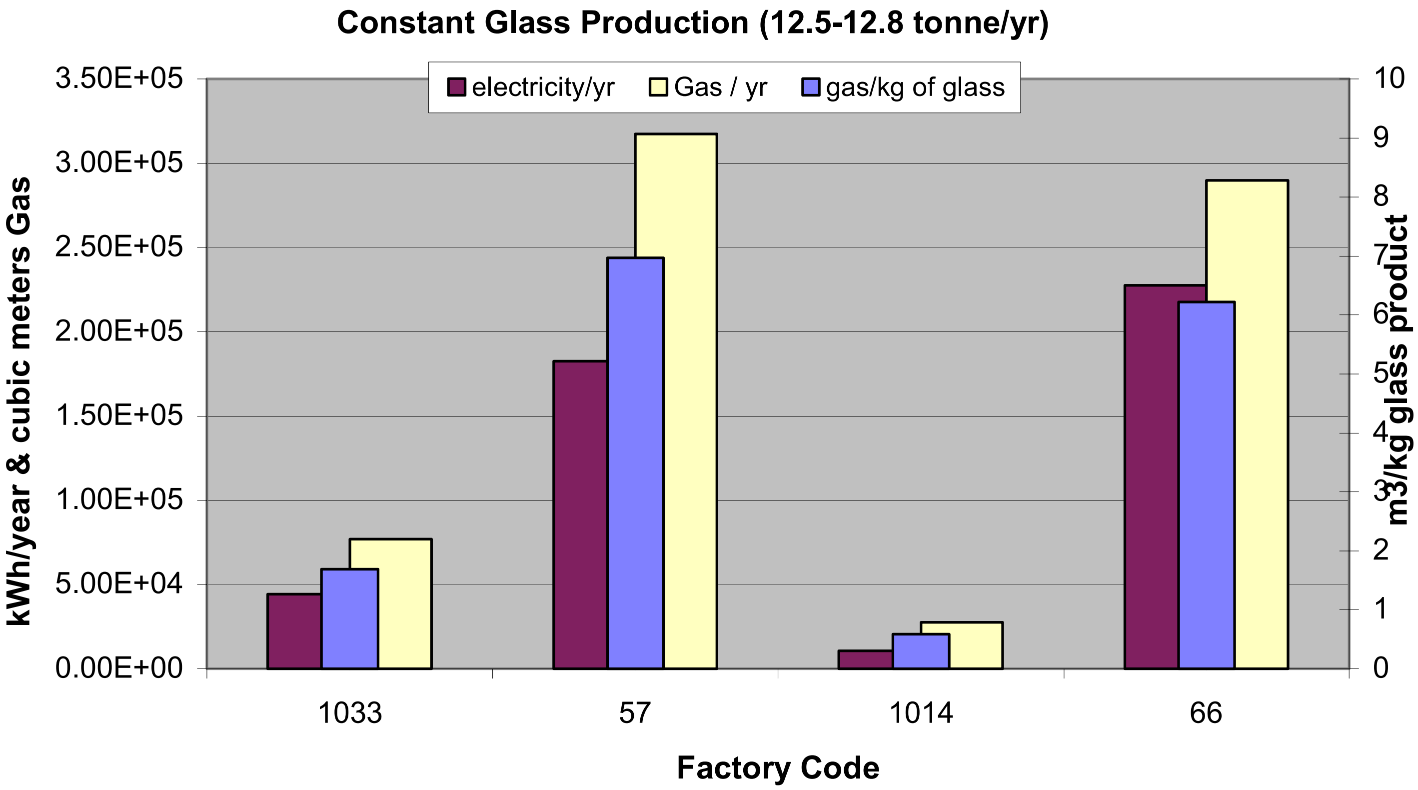


Figure 26: Constant Glass Production – kWh Correlation

To show how efficiently various glass factories operate; we found 4 factories that produced approximately 12.5 metric tons of glass per year each. According to the data provided, factories 1014 and 1033 operate much more efficiently than factories 57 and 66. They use much less natural gas to produce the same amount of product. These results show that there are major inconsistencies in the glass-making process from factory to factory. The following lists some possible explanations for the inconsistencies in data.

- Chimney - Factories 57 and 66 may have chimneys attached to their furnaces requiring them to burn more natural gas to maintain temperature.
- Heat exchanger - Factories 1014 and 1033 may have heat exchangers installed. A heat exchanger increases the temperature of the intake air by recapturing some of the lost heat to preheat the air for combustion. When the intake air is a higher temperature, less natural gas is consumed in the combustion process.
- Furnace door - another possibility is that factories 1014 and 1033 have a furnace door installed that inhibits heat loss during the working phase of the glass process.

- Insulation - factories 1014 and 1033 may have insulated furnaces. If the furnaces were insulated natural gas consumption would be reduced.
- Incorrect Data – data used to calculate these results could have been incorrect.

The major difference between factories 57 and 66 with high natural gas consumption compared with 1014 and 1033 with lower consumption are the electrical output values. The correlation is valid because when more natural gas is consumed to create the same amount of glass product there is a larger heat loss value. However, the larger the heat loss value, the more inefficient the factory's glassmaking process. Thus, for the purpose of a cogeneration feasibility study, factories that are more inefficient in their energy usage are better candidates for cogeneration systems. When we compare factory 57 with factory 1014, we find that their gas consumption values are 317,409 m3 natural gas/yr and 27,500 m3 natural gas/yr respectively. To create the same amount of glass product, factory 57 consumes precisely 289,909 m3 natural gas/yr more than factory 1014. Once it is multiplied by the current market price for natural gas on Murano (L. 400/ m3 natural gas) we find that factory 57 spends approximately L. 115,963,600/yr more than factory 1014 on natural gas expenditures.

In order to reduce inconsistent information, it was necessary to filter the data. From meetings with glass experts we were told that a range between 2-10 m3 natural gas (NG) / kg glass product should be expected for all factories. Data we had obtained and calculated showed that there were many outliers from this data range. Using conditional formatting it is possible to color-code the data fields. Red was used to denote 0-2 m3 NG/kg, green 2-10 m3 NG/kg, and for values greater than 10 m3 NG/kg we used yellow. Please refer to Appendix D.2. By keeping these results distinguishable it is possible to hold values denoted in green with higher than those calculated in red (see Table 7). The factories that are not between the specified 2-10 m3 NG/kg data range deviate from the normal range. They will be referred to as deviant. Factories lying in the specified data range will be referred to as non-deviant.

Legal Name	factory_code	CH4/KG glass
Ongaro Fuga di Fuga G. e C.	92	8.4
Nuova Marco Polo SRL	90	10.7
Name Unknown	1053	1.8

Table 7: Sample of deviant and non-deviant data

Table 8 shows how dealing with different flue temperatures can change the electrical yield. When the waste gas temperature decreases, the amount of heat that can be converted into electricity drops dramatically. These results are calculated just to test the mathematical validity of the model. Factories 1052 and 1053 were chosen because they provided the minimum and maximum extreme electrical output values calculated from the 50 factories. Notice that the cubic meters natural gas used per

Legal Name	Code	Glass Product (metric ton)	CH4/KG Product (1350 C)		1350 C	1150 C	950 C	750 C
Name Unknown	1052	15.000	0.1	KWH Total / yr	3.33E+03	2.83E+03	2.33E+03	1.82E+03
Name Unknown	1053	282.857	1.8		1.75E+06	1.48E+06	1.22E+06	9.56E+05

Table 8: Temperature affects on Electrical Output

kilogram glass produced (m^3 NG/kg) values for both factories are deviant. They are not within the desired range of 2-10 m3 NG/kg. Operating exhaust temperatures for a furnace range from 1350°C to 750°C. Internal furnace temperatures below 1400 °C are not applicable in the artistic glass industry. However, as soon as waste gas leaves the furnace (whether dissipated or through an exhaust stream) the temperature begins to drop dramatically; therefore it is important that the cogeneration technology be integrated as close to the start of the exhaust stream as possible. At this location waste gas temperature is highest and the most heat can be recovered. Figure 27 depicts electrical production based on various waste gas temperatures for each factory that shows non-deviant behavior.

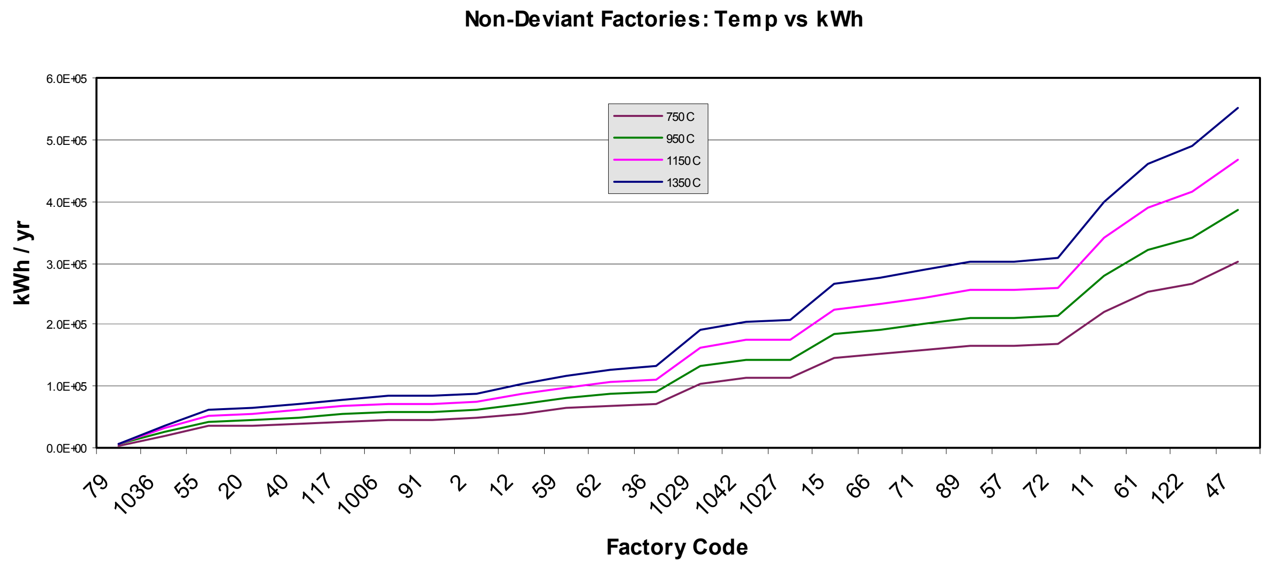


Figure 27: Temperature affects on kWh for Non- Deviant Factories

Results from the heat to electricity model when applied to all of Murano showed a large range of electricity could be produced. A range between 1820 – 1.75 x 10^6 kWh was found for factory codes 1052 and 1053 respectively. Factory 1053 would earn the most profit from installing a cogeneration system because it currently produces the most waste heat. See Appendix D.3 for details. The minimum amount of money that could be earned on Murano was for factory 1052. After the installation of a cogeneration system, income from resale of electricity was calculated to be L. 546000 / yr. The monetary amount is found by multiplying the kWh by the current market cost of electricity (300 Lire/ kWh) .The maximum amount of money that could be earned from cogeneration on Murano in factory 1053 would be approximately L. 525,000,000 annually. These minimum and maximum extremes show that there is a huge range from which to evaluate cogeneration due to discrepancies in the glass manufacturing process on Murano.

Flue and electrical efficiencies can also affect the final electrical output. These values can be viewed as percentages of the ideal kWh output. It is impossible to truly define the efficiencies because they will depend on the furnace, flue, cogeneration application, and glass company.

4.3 Feasibility Table

With a feasibility table, the glass producers on the Murano will be able to look up the amount of investment needed and efficiencies that the technology purchased will need to meet such that the glass producer will recoup the investment, including maintenance, in a certain period of time. When new and innovative technologies arrive in the future, the Murano producers will be able to make an informed and well-based decision on whether or not to implement this new technology in their factories.

The procedure above leads to a table that relates investment, payback period, electricity produced, flue efficiency, and electricity efficiency. An excerpt of this table can be seen in Figure 28.

In Lire (L)	In Euro (€)	Electrictity Produced (kWh)	Flue Efficiency 5%	10%	15%	20%
52,500,000.00	27,103.77	35000	107.46%	53.73%	35.82%	26.86%
55,125,000.00	28,458.96	36750	112.83%	56.42%	37.61%	28.21%
57,881,250.00	29,881.91	38588	118.47%	59.24%	39.49%	29.62%
60,775,312.50	31,376.00	40517	124.40%	62.20%	41.47%	31.10%
63,814,078.13	32,944.80	42543	130.62%	65.31%	43.54%	32.65%
67,004,782.03	34,592.04	44670	137.15%	68.57%	45.72%	34.29%
70,355,021.13	36,321.64	46903	144.00%	72.00%	48.00%	36.00%

Electricity Efficiency

Figure 28:Portion of a Feasibility Table

4.3.1 Method 1: Finding Electrical Efficiency

With the flexibility of this table it is possible to determine the feasibility of a technology in several different methods. The first method finds electrical efficiency from the known values of investment, desired payback period, and flue efficiency. If the technology does not currently meet that electricity efficiency, then the technology is not recommended. The recommendation is based on the desire of the investor to recoup all of the investment in a payback period. If the technology does not meet the needed electricity efficiency value, and the investor did implement the technology, he/she would not recover the entire investment and at the end of the payback period there would be a loss of money. For example, if the glass producer knew that his furnaces have a flue efficiency of 20% and that the total investment that he was willing to spend over the entire payback period, again including maintenance, was around L. 58,000,000.00 (€ 30,000[38]). Then by using the table the glass producer would know that the cogeneration technology would have to have an efficiency of 29.62%, see Figure 29.

[38] 1€=1936.27

			Flue Efficiency			
In Lire (L)	In Euro (€)	Electrictity Produced (kWh)	5%	10%	15%	20%
52,500,000.00	27,103.77	35000	107.46%	53.73%	35.82%	26.86%
55,125,000.00	28,458.96	36750	112.83%	56.42%	37.61%	28.21%
57,881,250.00	29,881.91	38588	118.47%	59.24%	39.49%	29.62%
60,775,312.50	31,376.00	40517	124.40%	62.20%	41.47%	31.10%
63,814,078.13	32,944.80	42543	130.62%	65.31%	43.54%	32.65%
67,004,782.03	34,592.04	44670	137.15%	68.57%	45.72%	34.29%
70,355,021.13	36,321.64	46903	144.00%	72.00%	48.00%	36.00%

Electricity Efficiency

Figure 29: Method 1 for using Feasibility Table: Finding Electrical Efficiency

The electrical efficiencies that are in red are efficiencies that are over a realistic efficiency value. For this and the following example this realistic value is set at 35%. Therefore, any investment that requires a technology have an efficiency of greater than 35% is not recommendable. The investor may then decide to extend the payback period thereby lowering the required electrical efficiencies. However, if the electrical efficiency is too high, the investor may be forced to extend the payback period far longer than desired, making that technology not recommendable.

4.3.2 Method 2: Finding Investment

The second method for using the table is as follows. If the glass producer knows the flue efficiency and the electricity efficiency for a particular cogeneration technology, then the investor will be able to find out what the maximum investment value of that technology needs to be in order to regain that entire investment in the payback period. For example, if the glass producer knows that his furnaces have a flue efficiency of 20% and that the cogeneration technology that the factory is considering investing in has an efficiency of 29.62%, then the total investment for that technology needs to be approximately L. 58,000,000. If the investment needed to implement and maintain that technology over the desired payback period is smaller than L. 58,000,000, then the technology is recommended. (Figure 30).

In Lire (L)	In Euro (€)	Electrictity Produced (kWh)	Electricity Efficiency	Flue Efficiency 5%	10%	15%	20%
52,500,000.00	27,103.77	35000		107.46%	53.73%	35.82%	26.86%
55,125,000.00	28,458.96	36750		112.83%	56.42%	37.61%	28.21%
57,881,250.00	29,881.91	38588		118.47%	59.24%	39.49%	29.62%
60,775,312.50	31,376.00	40517		124.40%	62.20%	41.47%	31.10%
63,814,078.13	32,944.80	42543		130.62%	65.31%	43.54%	32.65%
67,004,782.03	34,592.04	44670		137.15%	68.57%	45.72%	34.29%
70,355,021.13	36,321.64	46903		144.00%	72.00%	48.00%	36.00%

Figure 30:Method 2 for using Feasibility Table: Finding Investment

After determining the total investment, that investment value could be used in a Cost Benefit Analysis to calculate the actual initial investment and maintenance cost for the technology. This new analysis also provides a Return On Investment (ROI) value.

4.3.3 Cost Benefit Analysis

For our final part of our analysis, there are a couple of assumptions that we made. The first assumption that we made was that we assume that the conversion rate is € 1.00 to L. 1,936.27 for the initial investment, which means that the value of L.57,881,250.00 would be around € 29,893.17. Second, for the purpose of easier comparison, we assume that the corporation's marginal federal and state income tax are both 0%. Finally, we also assume that there is an inflation of 2.5% for the first year, and a depreciation rate of 4% annually. The reason we use these two values as our inflation and depreciation rate is because these are the typical values that are currently used by accountants.

Furthermore, since the effect of inflation is very uncertain, better estimates of future cash flows will be obtained by assuming growth of both benefits and costs at the general rate of inflation. Also, the increase in future incomes due to inflation is forecast by assuming that the incomes grow at a constant annual compound rate. Please refer to Figure 31 for a clearer picture.

Total Investment in Euro	€ 29,893.17
Initial Investment	€ 27,175.61
Maintenance Cost for 5 Years	€ 2,717.56
Electricity Produced (kWh)	38587.5
Desired Payback Period	5
Tax	0.00%
Inflation	2.50%
Depreciation	4.00%

Figure 31. Assumption and Inputs for Cost Benefit Ananlysis

The total investment and the electricity output values that are shown in Figure 31 are based on the feasibility table that we created using a desired payback period of 5 years. As for the value of the initial investment cost, it was calculated from the total investment cost. The initial investment cost is 90% of the total investment cost, and the remaining value is left for the maintenance cost, which is 10% of the total investment cost. With all the assumptions, together with the information from the feasibility table that we entered in Figure 31, we have provided an example of the cost benefit analysis (Figure 32).

Capital Budgeting Analysis

	Income		Expenses
Electricity Sales	€ 5,978.63		
Direct Materials			-€ 271.76
Variable Overhead			-€ 108.70
Fixed Overhead			-€ 163.05
Income	€ 5,435.12		

	Net Income		Net Cash Inflow	
Inflation (2.5%)	€ 135.88			
Net Savings	€ 5,571.00		€ 5,435.12	
Tax (0%)		-€ 0.00		-€ 0.00
Net Savings After Tax	€ 5,706.88			
Depreciation (4%)		-€ 228.28		
Net Income	€ 5,478.60			
Tax Shield			€ 0.00	
Net Cash Inflow			€ 5,435.12	

Return On Investment

$$\frac{\text{Net Income}}{\text{Total Investment}} = \frac{€\ 5{,}478.60}{€\ 29{,}893.17} = 18.33\%$$

Payback Period

$$\frac{\text{Total Investment}}{\text{Net Cash Inflow}} = \frac{€\ 29{,}893.17}{€\ 5{,}435.12} = 5.50 \text{ years}$$

Figure 32. Cost Benefit Analysis

The electricity sales in the capital budgeting analysis are calculated by using the current selling of electricity price in Italy, which is € 0,155/kWh (L.300.00/kWh). Net income is found by subtracting the sum of direct materials, variable overhead and fixed overhead from the total income, which, in the example on the previous page, is only the total amount of electricity sales.

However, since the purpose of generating a capital budgeting analysis is to find out the return on investment and the payback period value, it is therefore inevitable for us to calculate the net income and the net cash inflow value, because the formula for the return on investment is (Net Income/Total Investment) and the formula for the Payback Period is (Total Investment/Net Cash Inflow).

The only difference between net income and net cash inflow is that net income takes into account the inflation and the depreciation rate, while the net cash inflow only takes into account the tax shield. However, since we assumed that the corporate federal income tax is 0%, the tax shield is therefore 0% also. This also means that the net cash inflow would be the same as the income value.

By having these two values (net income and net cash flow), we are then be able to calculate the return on investment and the payback period as shown in Figure 32. We now know that a net income of € 5,478.60 with total investment of € 29,893.17 will give us a return on investment of 18.33%. And with a total investment of € 29,893.17 and a net cash inflow of € 5,435.12 it yields a payback period of 5 years and 6 months.

We now move on to the Investment Cash Flow Pattern. The purpose of having this table is to show the annual maintenance cost, the annual net savings, as well as the annual cash inflow if the project were implemented.

As mentioned before, in this illustration, the tax rate is assumed to be 0% and the inflation rate would still remain the same as before, at 2.5%. However, for the investment cash flow pattern (Appendix C.4), we use a different depreciation value, because the investment cash flow pattern requires a 10 year depreciation scheme, while capital budgeting only requires a one year depreciation rate. Instead of using 4% for the annual depreciation value, we will be using the MACRS depreciation value. And as for the maintenance cost, it will increase at the rate of the inflation. The maintenance cost in this case is the sum of the direct materials, variable overhead, and the fixed overhead (see Figure 32), which is about 10% of the initial investment value. Therefore, the maintenance cost is equal to:

€ 271.76
€ 108.70
<u>€ 163.05 +</u>
€ 543.51

Since the calculation in the Investment Cash Flow Pattern uses a different depreciation value (MACRS) than the previous capital budgeting analysis, there is therefore a different in the net cash inflow between the one in the Capital Budgeting Analysis and the one in the Investment Cash Flow Pattern (Appendix C.4). Therefore, with the help of our cost benefit analysis we now have a picture of how the annual net savings and the annual net cash inflow would look if a company decided to invest in this project. Furthermore, in order to have a payback period of 5 years, the maximum amount of total investment is € 29,893.17. If the initial investment is above this value, then the payback period might be longer than 5 years. Therefore, the optimal solution in this example is to find a Cogeneration system that will cost less than € 29,893.17.

4.3.4 Relationships between Payback Period, Investment and Overall efficiency

With any set of data there are trends that develop. The following section will cover the trends that are involved with the feasibility table. These trends include how investment affects electricity produced and how investment affects overall efficiency, as well as how the payback period affects electricity produced and overall efficiency.

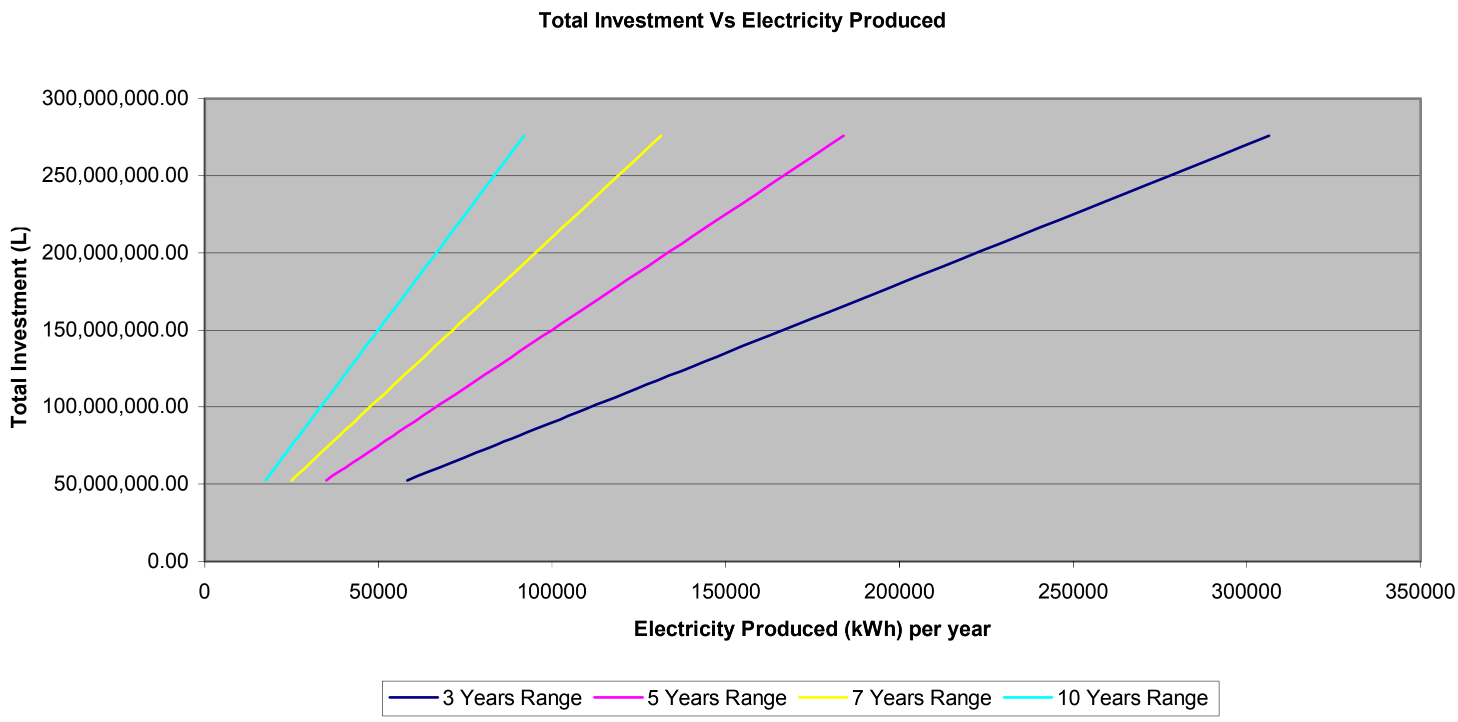


Figure 33: Total Investment Vs Electricity Produced

As investment is varied so will the electricity that needs to be produced as seen in Figure 33.

The relationship between investment and electricity produced is a linear relationship. Being linear means that the only calculations involved are simple multiplication and division. Notice that there are several lines graphed. Each line denotes a separate payback period. The light blue line (10yrs) has the steepest slope because the amount of electricity that needs to be produced for a payback period of 10 years is going to be smaller than the amount of electricity that needs to be produced for any of the other 3 payback periods. For a similar reason the dark blue line (3 yrs) has the smallest slope, the amount of electricity that needs to be produced for a payback period of 3 years is larger than the amount that needs to be produced for any of the other 3 paybacks.

It is also possible to graph investment versus overall efficiency, see Figure 34.

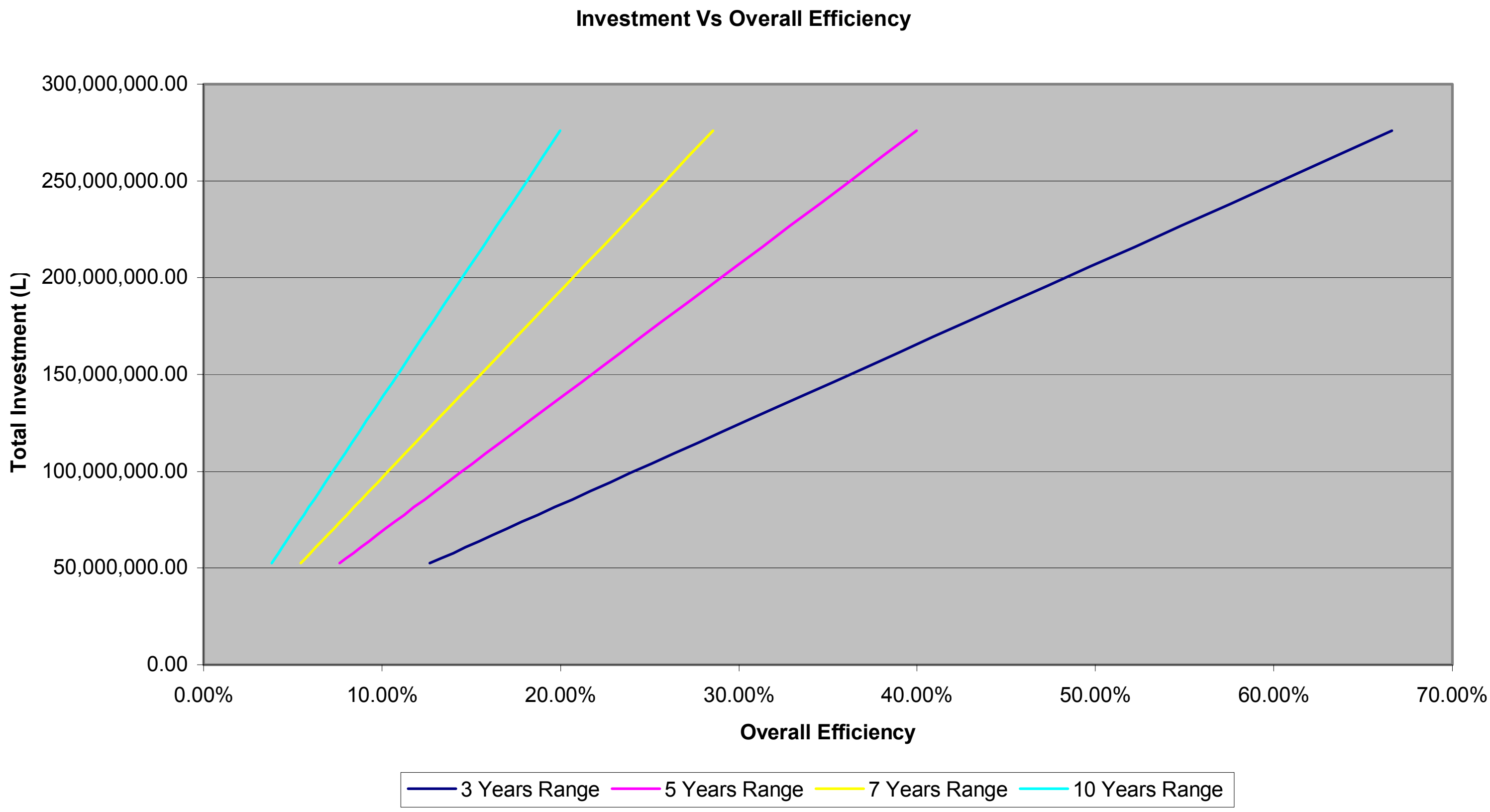


Figure 34:Investment Vs Overall Efficiency

The graph of Investment versus electricity output (Figure 33) and Investment versus Overall Efficiency (Figure 34) have the same trends because the calculations converting electricity output to overall efficiency is a matter of division (refer to section 3.6.3) therefore Figure 34 is a scaled version of Figure 33.

All of the above graphs have had a varying investment and a static payback period. Now we will look at the opposite, having a static payback period and a varying investment. Figure 35 is a graph showing a varying payback, based on an investment of L.146,263,036 (€75,538.60), versus electricity produced.

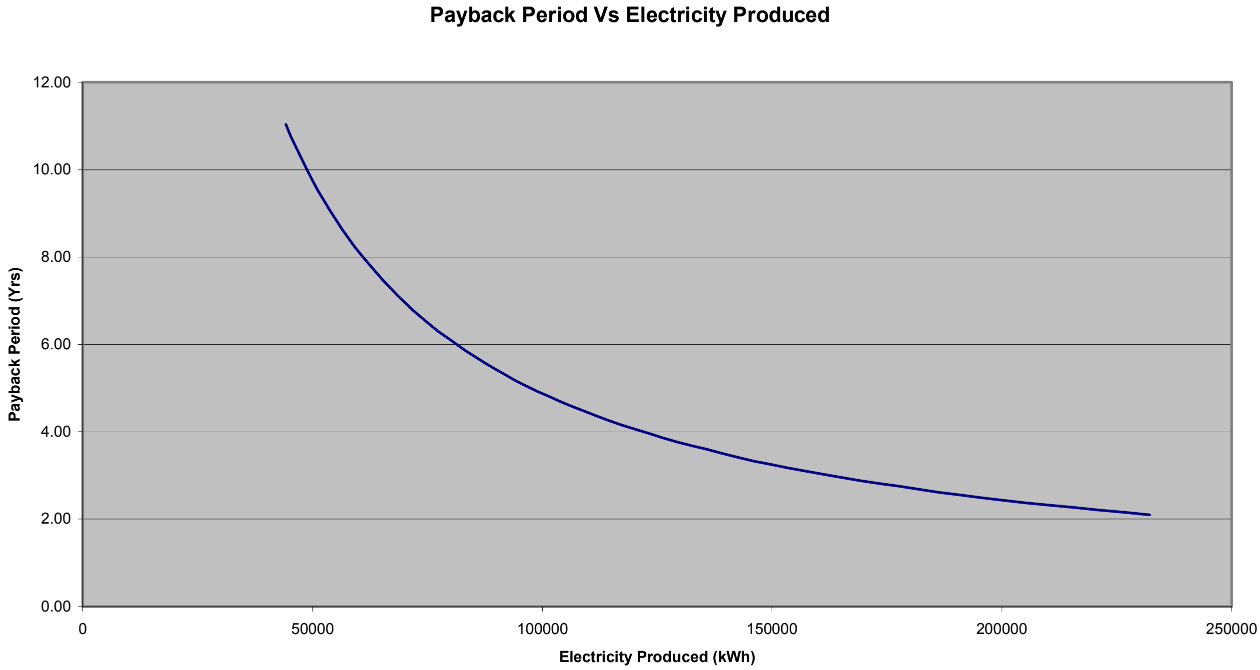


Figure 35:Payback Vs Electricity Produced

Figure 35 is an inverse graph. This means that a constant investment value is being divided by an increasing payback period, this produces the inverse trend then simply scaled by the cost of electricity. This graph tells us that as the payback period increases the electricity production needed increases exponentially. This trend can also be seen in Figure 33. The distance between the different payback period lines decreases and the payback years increase. Payback versus overall efficiency could be graphed, however as explained earlier it would only be a scaled version of Figure 35

4.4 Technology Analysis

An in-depth analysis of both steam and Stirling systems is provided in the next few sections. Using the feasibility table generated in section 3.6, efficiencies and investment values were found that provide for a payback of 5 years. Since this investment value includes maintenance, it is necessary to do a cost benefit analysis to separate the initial investment and maintenance. With a range of initial investment values set, a comparison to real life setup costs can be done. Now that a technology has an appropriate investment number, that technology needs to be able to fit into the glass manufacturing process without any interruptions or be affected by inconsistencies in heat. Finally, with a technology that has an appropriate investment and fits well into the glass production process, it needs to meet the personal requirement of our sponsor, Archimede Seguso.

4.4.1 Application of the Feasibility Table

For both steam and Stirling systems a flue efficiency of 55% and an electrical production efficiency of 30% should be possible. Since the method of cost analysis used is technology independent and the efficiencies are equal, the resulting outputs will be the same. Plugging these values into the feasibility table shown in Figure 36 (Appendix C.3) returns a maximum allowable investment over 5 years of L.114,600,915.89 or €59,186.40. There equivalent to a total electricity production of 76401 KWh per year. By inserting the electricity production and initial investment into the cost benefit analysis spreadsheet (sections 3.6, 4.3.3 and Appendix C.4) an actual payback period of 5.5 years is obtained. In the first full fiscal year after recouping the investment (year 7) a net profit of L. 23,034,320.50 (€ 11896.2) is received.

	Total Investment		
In Lire (L)	103,946,408.97	109,143,729.42	114,600,915.89
In US ($)	47,248.37	49,610.79	52,091.33
ctricitity Produced (k	69298	72762	76401
Flue Efficiency			
5.00%	301.27%	316.34%	332.15%
10.00%	150.64%	158.17%	166.08%
15.00%	100.42%	105.45%	110.72%
20.00%	75.32%	79.08%	83.04%
25.00%	60.25%	63.27%	66.43%
30.00%	50.21%	52.72%	55.36%
35.00%	43.04%	45.19%	47.45%
40.00%	37.66%	39.54%	41.52%
45.00%	33.47%	35.15%	36.91%
50.00%	30.13%	31.63%	33.22%
55.00%	27.39%	28.76%	30.20%
60.00%	25.11%	26.36%	27.68%
65.00%	23.17%	24.33%	25.55%
70.00%	21.52%	22.60%	23.73%
75.00%	20.08%	21.09%	22.14%
80.00%	18.83%	19.77%	20.76%
85.00%	17.72%	18.61%	19.54%

Figure 36:Excerpt of 5 Year payback Feasibility Table

4.4.2 Relation of Cost Analysis to Real World Prices

A steam system is a very expensive option. The proper turbine and electric generator combination would cost between L. 1.1 billion and L. 1.21 billion (€568102.59 - € 624912.85). This does not include the other 4 parts of that system (heat exchanger, boiler, condenser, and pump) that would be necessary. It also does not include the cost of the piping or the engineering cost to design the layout of the system. Overall the total initial investment would greatly exceed the total allowable investment over five years.

While the cost of implementing steam is high, the cost for Stirling is unknown. There are currently no Stirling engines commercially available that could be used for the Murano application and estimating the cost is nearly impossible without having a design. For this technology the cost analysis output should be used as a design parameter. If a Stirling engine is designed with an efficiency of 30% that is applicable to the Murano application then the price should be less than L.114,600,915.89 (€ 59186.43).

4.4.3 How Cogeneration Technology is affected by the Glass Manufacturing Process.

When installing a cogeneration system in a glass manufacturing facility, it is necessary understand how that system will affect and be affected by the characteristics of the manufacturing process. For example, any system that is installed would have to allow for the employees to work and complete their jobs. In this way, Steam and Stirling have to be analyzed.

A Steam system is characterized by its large size due to the number of components that are necessary, so a large amount of space is needed for its installation. Different components means people with different expertise are needed to service the system. The Murano glass factories are not equipped with personnel that are experienced in the service of a steam system. Steam also requires the heating of water to steam so that a turbine can be turned and electricity produced. In order to heat the water, piping must be placed in or around the furnace, which may change the internal heat characteristic of the furnace. Changing these characteristics could have an affect on the way the glass melts. Since the production of glass is in three separate stages, in each stage the furnace is used for a different purpose. In these different stages, the heat produced by the furnace varies. This variation makes a consistent production of electricity by steam difficult.

The main advantage to a Stirling engine is the small size of the device. With a small size, it is possible to integrate the engine in the position that is most beneficial. The position of the Stirling engine is very important. If the “hot end” of the engine is installed into the furnace then the heat characteristics of the furnace will change the way the glass is melted. However, since a Stirling engine works on a temperature difference and not a specific temperature value, the engine can be installed in the flue waste stream, then the whole problem of changing the characteristics of the melting glass is avoided. A Stirling engine is very reliable and so special personnel are not needed. Stirling engines can also be designed to be relatively quiet. Noise pollution from a cogeneration system is a major concern and must be considered.

Steam systems are a proven way to generate electrical power from heat, but there are many disadvantages and prohibitive costs. A Stirling engine system seems promising in theory, but one suited to the application at hand has not been developed yet. It is clear that neither of these technologies is a perfect solution to the problem and some compromises will have to made if any form of cogeneration is to be implemented.

4.5 Analysis of factory Data Sheets for Extrapolation

Information from the 49 complete factory datasheets (Appendix F) was used to determine whether or not it is possible for the factories on Murano as a whole to produce enough electricity to meet their needs. Thus becoming self-sustaining in terms of electricity, only taking in natural gas. For the methodology used refer to section 3.7.

4.5.1 Initial Calculations for Extrapolating

The initial calculations on the data set were simple totals. The total heat loss for all 27 factories (Appendix E) was calculated to be 3.78E+10 Kilocalories per year (Kcal/yr), the equivalent of the heating needs of approximately 4700[39] people. This value converts to 4.40E+07 Kilowatt-hours per year (KWh/yr). The amount electricity consumed by the 27 factories in one year totals to 1.74E+06 KWh.

[39] Assumed 500m^3 Natural Gas consumed by each person per year

Next the range of useable overall efficiencies was determined to be 6%-24%. The minimum efficiency value was chosen because the product of a very low flue efficiency of 30% (.3) and a very low cogeneration efficiency of 20% (.2) is 6% (.6). The maximum value used was 24%. This was determined in a similar fashion to the minimum efficiency using 60% and 40%.

4.5.2 Analysis of Self Sustainability and Cost for All of Murano

Table 9 shows an excerpt of the spreadsheet used to determine the total allowable investment as well as the possibility of the factories on Murano getting all of their energy needs from natural gas and not having to pay for electricity. The electricity column is automatically color coded to green if the value exceeds the total electricity consumed and red if the consumption is greater than the production. Green fields mean that self-sustainability is possible and red fields mean that it is not. Assuming that the 27 factories used are an accurate representation of the all the factories on the island, if a cogeneration unit with a reasonable overall efficiency was installed on every furnace in every factory, the factories on Murano would no longer be paying for electricity. Dividing the total electricity consumed by the total heat loss in KWh/yr shows that the overall efficiency only has to be above 3.95% for self-sustainability to be possible. With an overall efficiency of 6% the factories on Murano would not only provide electricity for themselves, but they would

Overall Efficiency	Electricity KWh/Year	Total Allowable Investment Over 3 Years
6%	2.64E+06	€ 7,087,268.38
8%	3.52E+06	€ 9,449,691.17
10%	4.40E+06	€ 11,812,113.96
12%	5.28E+06	€ 14,174,536.76
14%	6.16E+06	€ 16,536,959.55
16%	7.04E+06	€ 18,899,382.34
18%	7.92E+06	€ 21,261,805.14
20%	8.80E+06	€ 23,624,227.93
22%	9.68E+06	€ 25,986,650.72
24%	1.06E+07	€ 28,349,073.52

green = self sustaining

red = not self sustaining

Table 9: Excerpt from Appendix E showing efficiency self sustainability and allowable investment for a 3 year return

be able to meet the electrical needs of approximately 5400[40] people. 16% overall efficiency is likely to be achieved and enough electricity would be produced for the factories and 32000 people. Since the island of Murano only has a population of 5700, the whole island would could be supplied the co-generated electricity in the glass factories.

The table calculates the allowable total investment for a payback period of three, five, seven and ten years for all of Murano. These investments range from L. 13.7 billion (€ 7.09 million) for a 6% overall efficiency to be recouped over 3 years to L. 183.0 billion (€ 94.5 million) for a 24% overall efficiency to be recouped over 10 years.

[40] Assumed 950 kWh consumed by each person per year.

5. Conclusions and Recommendations

This chapter presents our conclusions and recommendations to our sponsor *Vetreria Archimede Seguso S.R.L.* as well as all the other glass producers on Murano. We discuss how the various models in our project are useful and can be applied to future feasibility studies. The recommendations include improvements in energy efficiency in the glass factories through other means besides cogeneration.

5.1 Heat to Electricity Model and Cost Analysis Methodology

The most important element of our project was the methodology that we created to prepare the feasibility study. The process by which we analyzed the feasibility of cogeneration technologies included creating a mathematical model that could calculate heat loss and convert it into an electrical value that is used to analyze the feasibility of implementation based on a cost analysis.

The heat to electricity model was created after gaining a complete understanding of all the components of the glass-making process and the artistic glass business. In essence, it is a tool for analyzing the energy requirements for any glass making process. Once energy requirements are found, it is then possible to see how much excess energy is created that can be used for energy reclamation. The model breaks everything down into the most elemental parameters of the glass making process, making it possible to calculate useful results from basic factory data. The data includes natural gas consumption, glass production and electrical consumption. Furthermore, since the model only makes calculations on basic data, it is therefore very flexible.

The cost analysis is based on the preliminary results of the heat to electricity model. These results lead to a total investment value and a payback period in the cost analysis. The heat to electricity model is then worked in reverse, based on natural gas consumption and glass production, to get efficiency values that the specified technology will have to operate at in order to meet that particular payback period. If the payback period is met, then the cogeneration application will be financially feasible. It is then just a matter of knowing the correct operational efficiencies to see if the application is technologically feasible.

The utility of our method is the fact that it is not dependent upon any specific cogeneration technology, and can be modified to apply to any process that generates heat. The Heat to Electricity Model is based upon the artistic glass process practiced on Murano. However, the Heat to Electricity Model can be modified and applied to any other process that involves heat loss by studying it. In addition, the method only uses the efficiency value of a cogeneration process; therefore any cogeneration has equal validity in the method. The combination of these two characteristics provides for a method that is incredibly flexible and very useful.

The results of our model are best demonstrated in the Microsoft Excel spreadsheet files provided in the CD version of this report. The Excel spreadsheets have a graphical presentation. When a value indicates different conclusions, for example self-sustaining or not self-sustaining, the values are then presented as different colors. This graphical presentation is automatic and will change as the values do and so do the conclusions based on those values. In short, the Excel file will make all the conclusions for you, and represent them as different colors. Once the method for analyzing any cogeneration technology was developed, we could then use the method to analyze the current two most applicable cogeneration technologies: the steam cycles and the Stirling engines.

5.2 Cogeneration Technology

From our analysis in section 4.4, we are able to make one solid conclusion. Steam is not a feasible technology for Murano. The cost of a typical steam system is too high and combining this high price with the amount of electricity produced, it is not possible to regain the total investment in 5 years. Since steam consists of individual components, and space is an important factor on the island of Murano, there simply is not enough space needed for such a system. It is possible to interconnect multiple furnaces together in a steam system, and by doing this, it maybe possible to recoup the investment. However it was a requirement set by our sponsor that the technology be individual, compact and able to be attached to any furnace easily. Such a concept is not possible with steam.

Applying a Stirling engine to our analysis provides a different conclusion. Since Stirling engines are an underdeveloped technology, no prices are currently available. Therefore, a financial requirement does not apply. So, the only requirements that do apply are the efficiencies, the requirements of the glass process and our sponsor. Efficiency values for Stirling engines are available and are within the 30% value that we used. Stirling engines are easy to operate, relatively reliable and compact, meeting all the requirements of the glass process and our sponsor. As stated earlier, Stirling engines do not have a known price, and for that reason, we are unable to make a recommendation. We are only able to determine the minimum efficiency that it must operate and the maximum possible cost that it could be in order to be feasible.

It is possible to recommend a realistic range of investment and efficiencies needed for Stirling engines. A realistic overall efficiency range was found to be between 6-24%. The 6% overall efficiency was based on a 30% flue efficiency and a 20% cogeneration technology efficiency. As for the 24% overall efficiency, it was based on a flue efficiency of 60% and a cogeneration technology efficiency of 40%. With the realistic overall efficiency range, it was possible to determine the total investment amounts based on a payback year of 5. The total investment amounts were found to be in the range of € 27,104 - € 87,412 per furnace for the given efficiency range. If the installation and maintenance for each Stirling engine is within this range (based on the stated efficiencies) then a Stirling engine application on Murano would be feasible. These payback periods are based on Archimede Seguso's heat loss and, using our tools, must be calculated separately for each factory on Murano.

One aspect of heat reclamation that we looked into is whether Murano glass factories would be able to supply enough electricity for their day-to-day operation if they used cogeneration technologies. Section 4.5 researches the possibility of an electrically self-sustaining Murano glass industry. Analysis showed that with a minimum overall efficiency of 3.95% it was possible for factories within our data pool to be self-sustaining. Calculations also show that only a little over 6% overall efficiency is needed for cogeneration in the glass factories to produce enough electricity for the whole population of Murano. Since 6% is the lowest in the range of realistic efficiencies, it is possible for the glass factories to produce much more electricity than the needs of Murano. Any conversion to electricity from lost heat in the glass factories would be an improvement, but calculating self-sustainability is used as a comparison in order to understand the magnitude of heat loss on Murano.

5.3 Recommendations

In order to reduce heat loss in the artistic glass factories on Murano, measures must be taken to improve the furnace design. Old methods of furnace construction are the major reasons for the current excess amount of heat loss.

One method factories could implement that some of the larger factories currently facilitate is implementing separate melting and working furnaces. The melting process would then only take place in certain furnaces and then molten glass is transported to the working furnaces. When they are separated in such a fashion it would be possible to insulate the working furnaces to reduce heat loss. Insulation is not used for furnaces that melt. After a melting cycle, a cool-down period is required before the contents of another melting pot can be added. Insulation lengthens the cool-down period of the melting cycle impeding productivity. During the working cycle a large amount of heat is also lost to the surroundings through the open furnace door. The reason the door must remain open is so that the artisans can work with the glass in the open furnace. It is this hands-on approach that makes artistic glass so valuable, yet energy intensive. When the artisan is at his bench working the glass, the door is still open allowing large quantities of heat to escape. We propose that the current artistic furnace doors be redesigned to prevent heat loss during the working phase. Perhaps this can be accomplished through the installation of a foot-pedal operated furnace door. It would prevent heat loss without interrupting the artisan's normal practices.

The best method for recapturing lost heat is through the use of a flue or chimney system. For this reason, most cogeneration technologies will involve some type of attachment to the flue/chimney to reclaim heat. It is therefore, beneficial to try to increase the amount of heat in the flue. In order to do this, we recommend a study be conducted to investigate possible methods to maximize the heat transfer efficiency to the flue, without causing more natural gas to be consumed.

5.4 Future Projects

After completion of this project, we realize that there are more opportunities to help the glass manufactures on Murano. Our ideas for future projects are as follows:

1) Stirling Project tailored to Murano

   Since we were unable to exclude Stirling and it holds the greatest amount of potential as a possible applicable cogeneration technology, a project that makes further advances in developing a working Stirling engine for the glass manufactures of Murano is recommended.

2) Artistic glass furnace design

   Previously in this section we discussed ways of improving furnace design. A project that researches ways to improve natural gas fired artistic furnaces on Murano would be very beneficial to the industry.

All of these upgrades and technologies involve a large amount of investment. Since the European Union promotes technological innovations in the field of energy conservation, it is therefore very possible that funding could be obtained from the EU. From our extrapolation and factory data (both on the attached CD) it is possible to decide in what order factories should install cogeneration technologies. In some cases a factory can produce three times the electricity that it consumes. Logically these factories should install such a system first.

5.5 Project Conclusions

The previous recommendations were made to expand upon our findings for cogeneration possibilities on Murano. The major problem we discovered was the factories excessive use of natural gas to create artistic glass. If steps can be taken to dramatically reduce their heat loss, then the heat reclamation techniques provided by cogeneration may not be necessary. Perhaps a cogeneration application is the best solution to the problem if large amounts of heat loss in the artistic glass process are inevitable. The methodology for analyzing cogeneration technologies will be invaluable. In industry, making a choice that is economically feasible as well as socially beneficial guides all business models.

If used successfully, the products of this project, especially the methodology for choosing an acceptable cogeneration application, will preserve the traditional glass industry of Murano while making it more efficient in its energy usage and natural resource consumption. Hopefully, our project will aid in the preservation of the tradition of Murano glass for many more centuries while making them more efficient energy users in the process.

6. Bibliography

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Australian Energy News: www.isr.gov.au/resources/netenergy/aen/back_issue.html

Black, Joshua C., Brian Cavanna and Nicholas J. Cottreau. Monitoring Pollution on Murano: An Analysis of the Artistic Glass Industry of Murano, Italy July 31, 2000

Boehmer-Christiansen, Sonja. "Acid Politics." Great Britain, London: Belhaven Press, 1998.

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Grubb, Michael. "Energy Policies and the Greenhouse Effect: Policy Appraisal." Great Britain, Worcester: Billing & Sons Ltd, 1991.

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Kato, Takeyoshi; "Introduction Feasibility of DHC with CGS in Residential Sectors"; *Electrical Eng. In Japan*;Vol 133, No 2, 2000

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Saravalle, Madeline; *Connoisseur*; ”Glass in the blood” August 1990; Vol 220; n943 p94

Smith Van Ness Abbott Introduction to Chemical Engineering Thermodynamics New York: McGraw-Hill, 1996

“The Stirling Engine”: http://campus.fortunecity.com/chemistry/187/s/ (July 2001)

“The Stirling Engine for Cars” Nick Batchelor, Jonathan Merritt, Steven Murcott: University of Melbourne, Australia: www.

Thermal Ventures; http://thermalventuresinc.com/energyinfo.htm (April 2001)

Werner, Sven; http://www.chalmers.se/HyperText/Prof-E/Werner-E.html (April 2001)

www.arthema.com/ExnRoom.asp?ExID=1&RmID=8 (March 2001)

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www.femcos.de/strukturanalysen_e.html#90gradbogen

www.fiftiesglass.com/designers/ (March 2001)

www.umanitoba.ca/academic/faculties/architecture/la/sustainable/design/energy/enrg001.htm (April 2001)

Zigerlig, Katja,“Glassmaking” http://www.axa-artinsurance.com/cw/aspects/artglass/#Innovators

7. Appendices

Appendix A – Bibliography

Appendix B – Calculation Methodology

Complex Furnace Operational Model with Calculation Methodology (MCAD)
- **“Data Sheet Calculations Exp.mcd”**

Appendix C – Feasibility Tables

Feasibility Tables
- **“Technology Analysis.xls”**

C.1 Cost Analysis
- Cost analysis (static investment)
- Cost analysis (varying investment)

C.2 HE Model
- HE Model (varying investment)

C.3 Automated-Payback Efficiency Analysis
- Automated-Payback Efficiency

C.4 Cost Benefit Analysis
- Cost Benefit Analysis

Appendix D – Heat to Electricity Model Analysis

Heat to Electricity Model Analysis
- **“Heat to Electricity Model Analysis.xls”**

D.1 50 Factory HE Model Calc (raw data)
D.2 50 Factory HE Model Calc (conditional formatting)
D.3 27 Non-Deviated Factories
D.4 kWh Temp (temperature affect on kWh for all factories)

Appendix E – Extrapolation

Extrapolation
- **“Extrapolation.xls”**

E.1 Extrapolation Data
E.2 Extrapolation Analysis

Appendix F – Factory Data Sheets

Factory Data Sheets
- **“Factory Data.mdb”**

Appendix A – Bibliography

Appendix A: Annotated Bibliography

7.1.1 Background

Murano

Black, Joshua C., Brian Cavanna and Nicholas J. Cottreau. Monitoring Pollution on Murano: An Analysis of the Artistic Glass Industry of Murano, Italy July 31, 2000

This Interactive Qualifying Project focused on pollution caused by the glass factories on Murano and contains a lot of useful background information as well as an example for formatting. The accompanying compact disc contains map layers and a database that will be helpful during the project.

Encyclopedia Britannica. Murano http://www.britannica.com/bcom/eb/article/6/0,5716,55686+1+54321,00.html?query=murano (March 25, 2001)

Encyclopedia article on Murano. Mostly has geographic data.

Lane, Frederic C. Venice A Maritime Republic. Baltimore MD: Johns Hopkins University Press, 1973.

This source provides some general historical information on the island of Murano.

Glass Making

British Glass: British Glass Homepage http://www.britglass.com/ (March 25, 2001)

Has detailed information on modern glass manufacturing processes and different types of glass. It also has some history.

Education Department of the Corning Museum of Glass. A Resource For Glass.
http://www.cmog.org/pdf/aroglass.pdf (March 25, 2001)

Has a good overview of both historic and modern glass forming processes.

Encyclopedia Britannica. Glass.
http://www.britannica.com/bcom/eb/article/3/0,5716,37723+1+36988,00.html?query=glass (March 25, 2001)

Encyclopedia article on glass. Has information on melting temperatures as well as different uses of glass.

The Glass http://www.fiamitalia.it/uk/ve.htm (March 25, 2001)

Provides a brief history of glass making.

Paul A. Chemistry of Glasses. NY: Chapman and Hill 1982

This book contains a detailed explanation of the chemistry of glass including thermal properties

Archimede Seguso Factory

Alderman, Lesley; *Money*, New York; Jul 1994; Vol 23, Issue 7 pg 80

This source focused on Archimede Seguso and his glasswork. It was helpful with some biographical information as well as products. However it was not very helpful in describing the particulars about the Archimede Seguso factory.

Sheldon Barr, *Antiques*," Venetian art nouveau glass."; Feb, 2000

This source was helpful with a little biographical information. However it focused more on the Venetian glass community as a whole rather than focusing on Archimede Seguso himself. It would have been more helpful had it done that.

Douglas, R.W; *A history of glassmaking;* Henley-on-Thames: Foulis, 1972

This source was used more for my own personal benefit. It was not very helpful with researching Archimede Seguso. However, it did help me in understanding exactly what the climate was like in glass making during his lifetime and the major advances that occurred.

Duncan, Alastair; *House and Garden*; "Master of Murano"; May 1989; Vol 161; pg 118

This source focused on Archimede Seguso and his glasswork. It was helpful with some biographical information as well as products. However it was not very helpful in describing the particulars about the Archimede Seguso factory.

McCray, Patrick; *Journal of European Economic History*; "Creating Networks of Skill: Technology transfer and the glass industry of Venice"; fall 1999; Vol 28 no2; pg 301-33

This source was very helpful in understanding how the glassmaking process came Murano. Unfortunately, the source does not get into any specifics about Archimede Seguso. It was also interesting to understand how the old techniques are being transferred to technology.

Saravalle, Madeline; *Connoisseur*; "Glass in the blood" August 1990; Vol 220; n943 p94

This source was helpful with a little biographical information. However it focused more on the Venetian glass community as a whole rather than focusing on Archimede Seguso himself. It would have been more helpful had it done that.

Unknown;“Italian Glass 1930- 1970”, http://www.arthema.com/ExnRoom.asp?ExID=1&RmID=8

This source was very helpful in focusing on the products that the Archimede Seguso factory offered during this time period. However, it was not very helpful in discussing the history of the company or of Archimede Seguso himself.

Unknown, *New York Times*, “Graceful Glass, Shaped by a Master” May 4, 1989

This source discusses the importance of Archimede Seguso as an artist. An interesting note that this source revealed is that Archimede Seguso has trained many of the new and upcoming artists. However this source does not mention any information about the Archimede Seguso factory.

Zampedri, Michele; “History of Glass making”, http://www.doge.it/murano/muranoi.htm

This source was very helpful in understanding how the glassmaking process came Murano. Unfortunately, the source does not get into any specifics about the Archimede Seguso Company.

Zigerlig, Katja,“Glassmaking” http://www.axa-artinsurance.com/cw/aspects/artglass/#Innovators

This source revealed the historical importance of Archimede Seguso. It was interesting to know that he started his apprenticeship at the age of 14. However the source

was lacking any specific information. It did however; point me in several new directions, which was helpful.

Cogeneration

Cogeneration Consultants, Inc. 2001. http://cogeneration.net

This site was sort of useful because it gave a base price for a fully portable cogeneration plant and installation costs of this unit. It was also useful to see how they marketed their cogeneration solutions to appeal to the consumer. It helped us to see what are the most important attributes of a cogeneration plant.

edugreen 2000. *Co-generation*
http://edugreen.teri.res.in/explore/renew/cogen.htm

This was a short article that spoke of the potential for cogeneration use in India's sugar plants. It was not very useful, but is a good example of the global movement towards cogeneration.

grinet@gri.org 1999. *Glass Industry Description*
http://www.gri.org/pub/oldcontent/tech/ind-eu/mrktinfo/glass/glmrkt.htm

This article talks of the US glass industry and gives some numbers. It mentions cogeneration briefly, but it is still useful to use as a comparison for Europe and Italy. It could also potentially show how the US differs in it's glass production from Europe.

Horlock, J. H. 1997. *Cogeneration- Combined Heat and Power.* Florida: Krieger Publishing Company

It has a few figures that may be useful, but overall not a very functional source because again, it concentrates on the thermodynamics and math behind cogeneration.

Hu, S. David. 1982. *Cogeneration.* Reston, Virginia: Reston Publishing Company

This book is a good source for the cogeneration process from the first step. It talks about selecting the right kind of cogeneration technology as well as analysis for cost of implementation. Some things that will be useful in this book are a few of the flow charts of cogeneration processes and steps.

iclei.org 1993. *Energy Facts: Cogeneration* http://www.iclei.org/efacts/cogen.htm Energy Educators of Ontario

This was a very useful source. They did an excellent job of explaining the complicated process of cogeneration so that anyone could understand the concept. Figures found on this site are also useful. This acts as a good basis from which to expand upon.

localpower.org 1999. *Cogeneration: What & Why?* http://www.localpower.org/cogen.html

This is a very brief and basic abstract. It was not very useful for my purposes.

Marecki, Jacek. 1988. *Combined Heat and Power Systems*. London, UK: Peter Peregrinus Ltd.

This book was not very useful for my purposes. The first chapter may be helpful somewhat because it talks about the theory behind combined heat and power. This book is mainly for doing calculations in a cogeneration system.

Mills, A.E. *Heat Transfer*. Upper Saddle River, NJ: Prentice Hall 1999

This heat transfer textbook contains the formulas necessary to calculate the maximum distance that heat can be carried and still be effective.

Moran, Michael J. and Howard N. Shapiro. *Fundamentals of Engineering Thermodynamics.* Danvers, MA: John Wiley & Sons Inc., 2000

This thermodynamics text book explains cogeneration and gives the formulas necessary to compute efficiencies.

Payne, F. William. 1997. *Cogeneration Management Reference Guide.* Georgia: The Fairmont Press, Inc.

This book is very useful, and up-to-date. It even has a chapter called "A Cogeneration Feasibility Study". Also, it contains a chapter geared precisely towards cogeneration from a feed of natural gas which is what we will be concentrating researching. This book would also be useful in when we are in Venice because it covers all aspects of cogeneration.

Roarty, M. 1999. *Cogeneration – Combined Heat and Power (Electricity) Generation* http://www.aph.gov.au/library/pubs/rn/1998-99/99rn21.htm Science, Technology, Environment and Resources Group: Parliament of Australia

Includes basic description of cogeneration. It was useful because it shows trends as well as predictions for cogeneration. It also explains what Australia is going to do to implement cogeneration further.

Laws and Regulations

Boehmer-Christiansen, Sonja. "Acid Politics." Great Britain, London: Belhaven

Press,1991.

This book is a case study of the efforts made to resolve major international environmental problem, in two West European countries, the UK and the Federal Republic of Germany. It also stated the international agreement on the type of steps required to combat this matter. This book should be very useful for comparing/benchmarking the international agreement with the local (Venice/Italy) agreement.

Council on Environmental Quality. “Energy and the Environment.” Washington, D.C: U.S. Government Printing Office, 1973.

This book considers the elements underlying the growing demand for energy and the environmental implications of the complex energy systems for meeting this demand. This book should be very useful in finding the information needed to obtain a perpetual demand for energy.

Fact Book: Italy. “Demand and Supply of Natural Gas in Italy.” http://www.eni.it/english/notizie/rapporti/fact_99/gas/sistema.html 4/27/01

This site shows the demand and consumption of Natural Gas in Italy and the graphical interface of the distribution. It should be very useful for Natural Gas Consumption section since it has both the demand and the consumption level of natural gas.

Fact Book: Italy. “The World Fact book 2000.” http://www.cia.gov/cia/publications/factbook/geos/it.html 4/26/01

This site provides the detail information about the background information of Italy, It also provides the production and the consumption of electricity in Italy. It should

be very useful for the Electricity section since it has both the production and the consumption level of electricity.

Grubb, Michael. “Energy Policies and the Greenhouse Effect: Policy Appraisal.” Great Britain, Worcester: Billing & Sons Ltd, 1991.

This book represents the culmination of two years of research on the Greenhouse Effect by the Energy and Environmental Programmed. It concentrates on the policy issues arising from attempts to reduce the greenhouse gas emissions from the energy sector. The policy issues should become a very useful resource for the Laws and Regulations Section as a benchmarking tools for the Venetian Laws and Regulations.

Grubb, Michael. “Energy Policies and the Greenhouse Effect: Country Studies and Technical Options.” Great Britain, Worcester: Billing & Sons Ltd, 1991.

This is the second series of the book that basically provides the detailed analysis on which the conclusions of this book have been based on. It should has the same usefulness as the first series.

International Energy Policy (IEA). “Energy Policies in Italy.” http://www.iea.org/pubs/reviews/files/italy99/italy.htm 3/26/01

This site contained the IEA report that provides a comprehensive, in-depth assessment of the energy policies of Italy, including recommendations on future policy developments. This should be very useful for finding out what types of energy policies does Italy has.

International Energy Policy (IEA). “Energy Efficiency.” http://www.iea.org/effi/index.htm 3/21/01

This site showed the IEA activities which are intended to assist Member countries in monitoring and improving their present energy efficiency policies in identifying and exploiting new opportunities for improving energy efficiency. It should become very useful when our project has reached the energy efficiency part.

Resource Renewal. " Environmental Atlas in Europe."
http://www.rri.org/envatlas/europe/europe.html 3/25/01

This site cited all the environmental policy set by the European Union (EU) in Europe.It should be useful as a reference resource for the environmental policy in the Laws and Regulation section.

Vogel, David. "National Styles of Regulation." New York: Cornell University Press, 1986.

This book provide an overview of British environmental policy, compare the patterns of government regulation in Great Britain and the United States, and link the study of government regulation of business with that of comparative politics. It should be useful as a benchmarking tools to compare the policy they have in Europe to the policy they have in the United states.

7.1.2 Methodology

1995-2001, *Cogeneration System Businesses in Italy*
http://energy.sourceguides.com/businesses/byGeo/byC/Italy/byP/cogen/cogen.shtml Momentum Technologies LLC 3/26/01

I went to the individual sites of the businesses listed in this resource, it was useful to know such companies exist in Italy, but failed to find direct information about cogeneration applications on their websites. However this was a useful stepping-stone to find cogeneration system businesses in Italy.

Amarnath, K. R. et al. "Benchmarks for industrial Energy Efficiency" IECE 96. Proceedings of the 31st Intersociety Energy Engineering Conference 1996. Volume 3 pp.1558-1562 1996.

This source discusses the validity of a specific method of benchmarking manufacturing plants for efficiency. It also contains references that will outline the technique.

Energy Information Administration; "Official Energy Statistics from the U.S. Government"; http://eia.doe.gov/indexnjava.html 3/28/01

This source is useful for finding the needed information about the fuel and energy consumption in Italy. However, the source does not give specifics information about the fuel and energy consumption in Murano. There are however, links to web sites and email addresses, which I think might be very helpful for our references when we were actually in Venice.

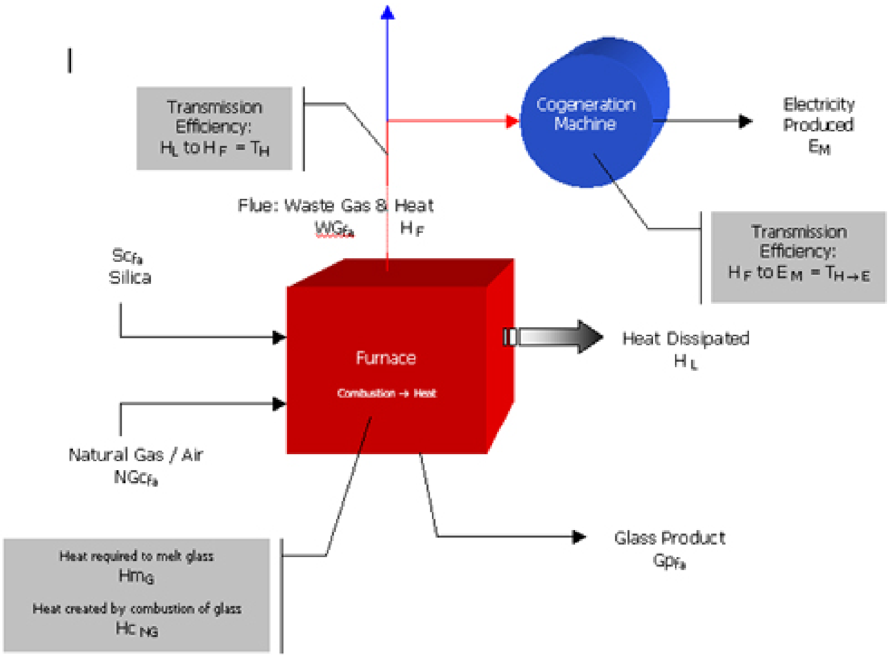
Momentum Technologies; "Cogeneration System Component Businesses in the World"; http://energy.sourceguides.com/businesses/byP/cogencomp/cogencomp.shtml (March 29, 2001)

This source was helpful in determining what companies produce cogeneration machines that could be added into the Archimede Seguso Factory. However, the source was not very helpful in giving specifics about the products produced by each company. There are however, links to web sites and email addresses, which is very helpful.

Appendix B – Calculation Methodology

Complex Furnace Operational Model with Calculation Methodology (MathCAD)

“Data Sheet Calculations Exp.mcd”



Archimede Seguso Calculations

$$\text{days} := \frac{\text{yr}}{365}$$

$$\text{weeks} := \frac{\text{yr}}{52}$$

$$\text{UkWh} := 3.600 \times 10^{6}\,\text{J}$$

$$W_{yr} := 52$$

- days defines the amount of days in 1 year
- weeks defines the amount of weeks in 1 year
- UkWh is the conversion factor we to convert into the kWh unit that the elctrical company uses to bill its customers.
- W_{yr} value is the number of weeks per year.

Factory Specific Variables

$$NG_{Ta} := 513168\,\frac{\text{m}^3}{\text{yr}}$$

$$Sc_{Ta} := 32450\,\frac{\text{kg}}{\text{yr}}$$

$$Ec_{Ta} := 113859\,\frac{\text{UkWh}}{\text{yr}}$$

- NG_{Ta} this is the total amount of natural gas consumed / yr for the factory. This is multiplied by MMf because this excludes annealing gas consumption.
- Sc_{Ta} is the sand consumption for the glass factory. It is divided by the sand composition ratio of the total mixture to give the kg/yr for the total weight of material.
- Ec_{Ta} is the electrical consumption for the factory

$Mpc := \frac{Sc_{Ta}}{.71}$

- Mpc calculates the total weight of the contents of the melting pots annually. We can make this calculation because the weight of the sand is approximately 71 % of the total mixture.

$Mpc = 45704 \frac{kg}{yr}$

- M_f is the number of melting / working furnaces employed in the factory. (any furnace that is not used in the annealing process)

$M_f := 4$

- D_o value is the number of days that the factory is "operating" per year

$D_o := 320 \cdot \frac{days}{yr}$

- W_o value is the number of weeks that the factory is "operating" per year. (Days of operation) / (7 Days / week)

$W_o := 45.7 \cdot \frac{weeks}{yr}$

- Wu_{Ta} is water consumption for the factory annually

$Wu_{Ta} := 1006 \cdot \frac{m^3}{yr}$

Artistic Glass Variables

$MM_f := .9$

- MMf is 90%, the amount of natural gas / kg that is used during the melting and maintaining cycles. W e are not looking at cogeneration for the annealing phase.

$WG_{Ta} := 11 \cdot NG_{Ta}$

- WG_{Ta} denotes the amount of waste gas that is produced annually from combustion of natural gas.

$Hc_{NG} := 8400 \cdot \frac{kcal}{m^3}$

- Hc_{NG} is the amount of energy that can be attained from combustion of 1 m^3 natural gas.

$Sh_{WG} := 0.38 \cdot \frac{kcal}{m^3 \cdot K}$

- Sh_{WG} is the heat capacity of the waste gas exhaust stream.
- WG_t is the temperature of the waste gas exhaust (kelvin)

$WG_t := 1623 \cdot K$

- T_H is the heat transmission efficiency: The ratio of heat in flue to heat lost to the environment. This is based on furnace and exhaust design.

$T_H := .55$

- T_{H_E} is the efficiency which heat can be converted to useful electricity. This is based on the cogeneration application.

$T_{H\_E} := .30$

Energy Calculations

The first step in the process is to see how much energy is lost annually. We accomplish this by calculating the energy that escapes through the waste gas. EWG_{Ta} is the amount of energy that is lost annually.

$$EWG_{Ta} := Sh_{WG} \cdot WG_{Ta} \cdot \left(WG_t - 298 \cdot K\right)$$

$$EWG_{Ta} = 2.842 \times 10^9 \frac{kcal}{yr}$$

Once we know how much heat is lost annually we can calculate how much natural gas is actually used to melt the pot contents to work the glass from start to finish. When we take this basis, it is possible to forego the complex calculations that the different cycles (melting and working) would introduce.

$$NG_{kgG} := \frac{\left[EWG_{Ta} - \left(NG_{Ta} \cdot Hc_{NG}\right)\right]}{\left(-Mpc \cdot Hc_{NG}\right)}$$

$$NG_{kgG} = 3.825 \frac{m^3}{kg}$$

The next step once NG_{kgG} is known, is to calculate how much energy actually goes into producing the glass. Hm_g is the energy kcal/ kg glass.

$$Hm_g := Hc_{NG} \cdot NG_{kgG}$$

We need to calculate NGc_{Ta} so that we know how much energy we are dealing with in total. NGc_{Ta} calculates how much energy is acquired from burning all of the factorys gas consumption for the entire year.

$$NGc_{Ta} := NG_{Ta} \cdot Hc_{NG}$$

$$NGc_{Ta} = 4.311 \times 10^9 \frac{kcal}{yr}$$

When NGc_{Ta} is found the next step is to calculate how much of that heat actually goes into creating the glass product. We know how many kgs are in the melting pot and thanks to our NG_{kgG} calculation we know how much energy it takes to melt all of the glass, $HMpc_{Ta}$.

$$HMpc_{Ta} := Mpc \cdot Hm_g$$

$$HMpc_{Ta} = 1.468 \times 10^9 \frac{kcal}{yr}$$

Once calculated, $HMpc_{Ta}$ tells us how much of the total energy (NGc_{Ta}) is used for melting all the glass. The difference of these two values is the total amount of heat lost annually. This value should coincide with the total heat lost through the waste gas because in fact that is where all the heat is transferred. Combustion of the gas raises the temperature of the air inside the furnace. The air then transfers the heat into the pot mixture which creates the amorphous glass. Meanwhile, all the heat that goes out the furnace door and up the chimney/flue or through the walls; any of this "dissipated heat" is actually contained in the waste gas. Waste gas is the medium for heat transfer in the furnace. We then find $HL_{Ta} = EWG_{Ta}$.

$$HL_{Ta} := NGc_{Ta} - HMpc_{Ta}$$ $$HL_{Ta} = 2.842 \times 10^{9} \frac{kcal}{yr}$$

Once we have calculated the total amount of heat lost annually, it is important to realize that this is the total. In order to extrapolate properly and analyze the cost benefit it is important to relate everything *per furnace*. HL_f calculates heat lost during the melting and working phases per furnace.

$$HL_f := \frac{(HL_{Ta} \cdot MM_f)}{M_f}$$ $$HL_f = 6.395 \times 10^{8} \frac{kcal}{yr}$$

Although this value is all the heat that is lost per furnace, it is actually not the heat that we are able to capture. Therefore we implement a Flue (chimney) efficiency and conclude that only a % of the heat lost actually goes up the exhaust pipe, HF_f.

$$HF_f := T_H \cdot HL_f$$ $$HF_f = 3.517 \times 10^{8} \frac{kcal}{yr}$$

The cogeneration unit will be attached to the exhaust in order to capture the escaping heat. The closer the unit is to the furnace-> exhaust opening, the better. The reason for this is because heat dissipates quickly when it exits the furnace and in order to capture as much heat as possible the cogeneration unit must be in close proximity to the furnace. The next step is converting the heat to electricity. We use another efficiency for this denoted T_{H_E}, which is called the efficiency of the cogeneration application.

$$EM_f := T_{H\_E} \cdot HF_f$$ $$EM_f = 1.4 \times 10^{4}\ W$$

Output Calculations

At the end of the energy calculations we know how many watts the cogeneration application can produce annually. However, this is not useful when analyzing the cost because the electrical company ENEL would buy back electricity in kWh. Therefore we must convert Watts to kWh in order to do a cost benefit analysis on any application. The following equations convert EM_f to kWh.

$$Whr_{yr} := 24 \cdot 7 \cdot W_{yr} \cdot hr$$ $$kWh := \frac{(EM_f \cdot Whr_{yr})}{UkWh}$$ $$EM_f \cdot Whr_{yr} = 4.403 \times 10^{11}\ J$$

$kWh = 122298$ per furnace $M_f \cdot kWh = 489191$ total

Other useful information canbe calculated from factory data. The waste gas volume: WG_{Ta} and the glass production annually, Gp_{Ta} can be calculated. Natural gas flow is multiplied by the stoichiometric coefficients of the combustion reaction to give the volume of the waste gas per year. Glass production annually can be calculated because typically, the melting pot contents (Mpc) lose approximately 19% of their weight in the melting process. Therefore we can say glass product is 81% of the weight of the contents contained in the melting pots.

$$WG_{Ta} := 11 \cdot NG_{Ta}$$

$$WG_{Ta} = 5.645 \times 10^{6} \frac{m^3}{yr}$$

$$Gp_{Ta} := .81 \cdot Mpc$$

$$Gp_{Ta} = 37020 \frac{kg}{yr}$$

Appendix C – Feasibility Tables

Feasibility Tables

"Technology Analysis.xls"

C.1 Cost Analysis

Cost analysis (Static Investment)

Cost analysis (Varying Investment)

C.2 HE Model

HE Model (Varying Investment)

C.3 Automated-Payback Efficiency Analysis

Automated-Payback Efficiency

C.4 Cost Benefit Analysis

Cost Benefit Analysis

C.1 Cost Analysis

Cost analysis (static investment)
Cost analysis (varying investment)

Technology Analysis

Legend =	Input Value

Total Investment	**L. 146,263,036.00**		
Percentage Increase	**5.00%**		
Payback Period (Yrs)	**5**		
Electricity Price		**L. 300.00**	
Euro to Italian Exchange Rate	**1**	**:**	**1,936.27**

	Percentage Increase	Payback Period (Yrs)	Investment in Lire	Investment in Euro	Annual Savings in Lire	Annual Savings in Euro	Electricity Price	Electricity Produced (kWh)
Case 1	5.00%	5.25	L. 146,263,036.00	€ 75,538.55	L. 27,859,625.90	€ 14,388.30	L. 300.00	92865
Case 2	5.00%	5.51	L. 146,263,036.00	€ 75,538.55	L. 26,532,977.05	€ 13,703.14	L. 300.00	88443
Case 3	5.00%	5.79	L. 146,263,036.00	€ 75,538.55	L. 25,269,501.95	€ 13,050.61	L. 300.00	84232
Case 4	5.00%	6.08	L. 146,263,036.00	€ 75,538.55	L. 24,066,192.34	€ 12,429.15	L. 300.00	80221
Case 5	5.00%	6.38	L. 146,263,036.00	€ 75,538.55	L. 22,920,183.18	€ 11,837.29	L. 300.00	76401
Case 6	5.00%	6.70	L. 146,263,036.00	€ 75,538.55	L. 21,828,745.88	€ 11,273.61	L. 300.00	72762
Case 7	5.00%	7.04	L. 146,263,036.00	€ 75,538.55	L. 20,789,281.79	€ 10,736.77	L. 300.00	69298
Case 8	5.00%	7.39	L. 146,263,036.00	€ 75,538.55	L. 19,799,315.99	€ 10,225.49	L. 300.00	65998
Case 9	5.00%	7.76	L. 146,263,036.00	€ 75,538.55	L. 18,856,491.42	€ 9,738.57	L. 300.00	62855
Case 10	5.00%	8.14	L. 146,263,036.00	€ 75,538.55	L. 17,958,563.26	€ 9,274.82	L. 300.00	59862
Case 11	5.00%	8.55	L. 146,263,036.00	€ 75,538.55	L. 17,103,393.58	€ 8,833.17	L. 300.00	57011
Case 12	5.00%	8.98	L. 146,263,036.00	€ 75,538.55	L. 16,288,946.27	€ 8,412.54	L. 300.00	54296
Case 13	5.00%	9.43	L. 146,263,036.00	€ 75,538.55	L. 15,513,282.16	€ 8,011.94	L. 300.00	51711
Case 14	5.00%	9.90	L. 146,263,036.00	€ 75,538.55	L. 14,774,554.44	€ 7,630.42	L. 300.00	49249
Case 15	5.00%	10.39	L. 146,263,036.00	€ 75,538.55	L. 14,071,004.23	€ 7,267.07	L. 300.00	46903
Case 16	5.00%	10.91	L. 146,263,036.00	€ 75,538.55	L. 13,400,956.41	€ 6,921.02	L. 300.00	44670

Case 17	5.00%	11.46	L. 146,263,036.00	€ 75,538.55	L. 12,762,815.63	€ 6,591.44	L. 300.00	42543
Case 18	5.00%	12.03	L. 146,263,036.00	€ 75,538.55	L. 12,155,062.50	€ 6,277.57	L. 300.00	40517
Case 19	5.00%	12.63	L. 146,263,036.00	€ 75,538.55	L. 11,576,250.00	€ 5,978.63	L. 300.00	38588
Case 20	5.00%	13.27	L. 146,263,036.00	€ 75,538.55	L. 11,025,000.00	€ 5,693.94	L. 300.00	36750
Case 21	5.00%	13.93	L. 146,263,036.00	€ 75,538.55	L. 10,500,000.00	€ 5,422.80	L. 300.00	35000
Case 22	5.00%	14.63	L. 146,263,036.00	€ 75,538.55	L. 10,000,000.00	€ 5,164.57	L. 300.00	33333
Case 23	5.00%	15.36	L. 146,263,036.00	€ 75,538.55	L. 9,523,809.52	€ 4,918.64	L. 300.00	31746
Case 24	5.00%	16.13	L. 146,263,036.00	€ 75,538.55	L. 9,070,294.78	€ 4,684.42	L. 300.00	30234
Case 25	5.00%	16.93	L. 146,263,036.00	€ 75,538.55	L. 8,638,375.99	€ 4,461.35	L. 300.00	28795
Case 26	5.00%	17.78	L. 146,263,036.00	€ 75,538.55	L. 8,227,024.75	€ 4,248.90	L. 300.00	27423
Case 27	5.00%	18.67	L. 146,263,036.00	€ 75,538.55	L. 7,835,261.66	€ 4,046.57	L. 300.00	26118
Case 28	5.00%	19.60	L. 146,263,036.00	€ 75,538.55	L. 7,462,153.97	€ 3,853.88	L. 300.00	24874
Case 29	5.00%	20.58	L. 146,263,036.00	€ 75,538.55	L. 7,106,813.30	€ 3,670.36	L. 300.00	23689
Case 30	5.00%	21.61	L. 146,263,036.00	€ 75,538.55	L. 6,768,393.62	€ 3,495.58	L. 300.00	22561
Case 31	5.00%	22.69	L. 146,263,036.00	€ 75,538.55	L. 6,446,089.16	€ 3,329.13	L. 300.00	21487
Case 32	5.00%	23.82	L. 146,263,036.00	€ 75,538.55	L. 6,139,132.54	€ 3,170.60	L. 300.00	20464
Case 33	5.00%	25.02	L. 146,263,036.00	€ 75,538.55	L. 5,846,792.89	€ 3,019.62	L. 300.00	19489
Case 34	5.00%	26.27	L. 146,263,036.00	€ 75,538.55	L. 5,568,374.18	€ 2,875.83	L. 300.00	18561
Case 35	5.00%	27.58	L. 146,263,036.00	€ 75,538.55	L. 5,303,213.51	€ 2,738.88	L. 300.00	17677

Technology Analysis

Legend =	Input Value

Total Investment	**L. 50,000,000.00**		
Percentage Increase	**5.00%**		
Payback Period (Yrs)	**5**		
Electricity Price	**L. 300.00**		
Euro to Italian Exchange Rate	**1**	**:**	**1,936.27**

	Percentage Increase	Investment in Lire	Investment in Euro	Payback Period (Yrs)	Annual Savings in Lire	Annual Savings in Euro	Electricity Price	Electricity Produced (kWh)
Case 1	5.00%	L. 52,500,000.00	€ 27,113.99	5	L. 10,500,000.00	€ 5,422.80	L. 300.00	35000
Case 2	5.00%	L. 55,125,000.00	€ 28,469.69	5	L. 11,025,000.00	€ 5,693.94	L. 300.00	36750
Case 3	5.00%	L. 57,881,250.00	€ 29,893.17	5	L. 11,576,250.00	€ 5,978.63	L. 300.00	38588
Case 4	5.00%	L. 60,775,312.50	€ 31,387.83	5	L. 12,155,062.50	€ 6,277.57	L. 300.00	40517
Case 5	5.00%	L. 63,814,078.13	€ 32,957.22	5	L. 12,762,815.63	€ 6,591.44	L. 300.00	42543
Case 6	5.00%	L. 67,004,782.03	€ 34,605.08	5	L. 13,400,956.41	€ 6,921.02	L. 300.00	44670
Case 7	5.00%	L. 70,355,021.13	€ 36,335.34	5	L. 14,071,004.23	€ 7,267.07	L. 300.00	46903
Case 8	5.00%	L. 73,872,772.19	€ 38,152.10	5	L. 14,774,554.44	€ 7,630.42	L. 300.00	49249
Case 9	5.00%	L. 77,566,410.80	€ 40,059.71	5	L. 15,513,282.16	€ 8,011.94	L. 300.00	51711
Case 10	5.00%	L. 81,444,731.34	€ 42,062.69	5	L. 16,288,946.27	€ 8,412.54	L. 300.00	54296
Case 11	5.00%	L. 85,516,967.91	€ 44,165.83	5	L. 17,103,393.58	€ 8,833.17	L. 300.00	57011
Case 12	5.00%	L. 89,792,816.30	€ 46,374.12	5	L. 17,958,563.26	€ 9,274.82	L. 300.00	59862
Case 13	5.00%	L. 94,282,457.12	€ 48,692.83	5	L. 18,856,491.42	€ 9,738.57	L. 300.00	62855
Case 14	5.00%	L. 98,996,579.97	€ 51,127.47	5	L. 19,799,315.99	€ 10,225.49	L. 300.00	65998
Case 15	5.00%	L. 103,946,408.97	€ 53,683.84	5	L. 20,789,281.79	€ 10,736.77	L. 300.00	69298
Case 16	5.00%	L. 109,143,729.42	€ 56,368.03	5	L. 21,828,745.88	€ 11,273.61	L. 300.00	72762

Case 17	5.00%	L. 114,600,915.89	€ 59,186.43	5	L. 22,920,183.18	€ 11,837.29	L. 300.00	76401
Case 18	5.00%	L. 120,330,961.68	€ 62,145.76	5	L. 24,066,192.34	€ 12,429.15	L. 300.00	80221
Case 19	5.00%	L. 126,347,509.77	€ 65,253.04	5	L. 25,269,501.95	€ 13,050.61	L. 300.00	84232
Case 20	5.00%	L. 132,664,885.26	€ 68,515.70	5	L. 26,532,977.05	€ 13,703.14	L. 300.00	88443
Case 21	5.00%	L. 139,298,129.52	€ 71,941.48	5	L. 27,859,625.90	€ 14,388.30	L. 300.00	92865
Case 22	5.00%	L. 146,263,036.00	€ 75,538.55	5	L. 29,252,607.20	€ 15,107.71	L. 300.00	97509
Case 23	5.00%	L. 153,576,187.80	€ 79,315.48	5	L. 30,715,237.56	€ 15,863.10	L. 300.00	102384
Case 24	5.00%	L. 161,254,997.19	€ 83,281.26	5	L. 32,250,999.44	€ 16,656.25	L. 300.00	107503
Case 25	5.00%	L. 169,317,747.04	€ 87,445.32	5	L. 33,863,549.41	€ 17,489.06	L. 300.00	112878
Case 26	5.00%	L. 177,783,634.40	€ 91,817.58	5	L. 35,556,726.88	€ 18,363.52	L. 300.00	118522
Case 27	5.00%	L. 186,672,816.12	€ 96,408.46	5	L. 37,334,563.22	€ 19,281.69	L. 300.00	124449
Case 28	5.00%	L. 196,006,456.92	€ 101,228.89	5	L. 39,201,291.38	€ 20,245.78	L. 300.00	130671
Case 29	5.00%	L. 205,806,779.77	€ 106,290.33	5	L. 41,161,355.95	€ 21,258.07	L. 300.00	137205
Case 30	5.00%	L. 216,097,118.76	€ 111,604.85	5	L. 43,219,423.75	€ 22,320.97	L. 300.00	144065
Case 31	5.00%	L. 226,901,974.70	€ 117,185.09	5	L. 45,380,394.94	€ 23,437.02	L. 300.00	151268
Case 32	5.00%	L. 238,247,073.43	€ 123,044.34	5	L. 47,649,414.69	€ 24,608.87	L. 300.00	158831
Case 33	5.00%	L. 250,159,427.10	€ 129,196.56	5	L. 50,031,885.42	€ 25,839.31	L. 300.00	166773
Case 34	5.00%	L. 262,667,398.46	€ 135,656.39	5	L. 52,533,479.69	€ 27,131.28	L. 300.00	175112
Case 35	5.00%	L. 275,800,768.38	€ 142,439.21	5	L. 55,160,153.68	€ 28,487.84	L. 300.00	183867

C.2 HE Model

HE Model (Varying Investment)

In

	Specific Heat	Natural Gas/kg of Glass	Heat Capacity of Natural Gas	Number of Melting Furnaces
	Kcal/m^{3}K	m3/kg	kcal/m3	
Factory Code				
122	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4
	0.38	3.442430215	8400	4

puts

Total Annual Comsumption of Natural Gas	Heat Transfer Efficiency	Output Electricity	Heat to Electricty Efficiency
m3/yr		kWh	
	Flue		
461851.2	0.55	35000	0.3
461851.2	0.55	36750	0.3
461851.2	0.55	38588	0.3
461851.2	0.55	40517	0.3
461851.2	0.55	42543	0.3
461851.2	0.55	44670	0.3
461851.2	0.55	46903	0.3
461851.2	0.55	49249	0.3
461851.2	0.55	51711	0.3
461851.2	0.55	54296	0.3
461851.2	0.55	57011	0.3
461851.2	0.55	59862	0.3
461851.2	0.55	62855	0.3
461851.2	0.55	65998	0.3
461851.2	0.55	69298	0.3
461851.2	0.55	72762	0.3
461851.2	0.55	76401	0.3
461851.2	0.55	80221	0.3
461851.2	0.55	84232	0.3
461851.2	0.55	88443	0.3
461851.2	0.55	92865	0.3
461851.2	0.55	97509	0.3
461851.2	0.55	102384	0.3
461851.2	0.55	107503	0.3
461851.2	0.55	112878	0.3
461851.2	0.55	118522	0.3
461851.2	0.55	124449	0.3
461851.2	0.55	130671	0.3
461851.2	0.55	137205	0.3
461851.2	0.55	144065	0.3
461851.2	0.55	151268	0.3
461851.2	0.55	158831	0.3
461851.2	0.55	166773	0.3
461851.2	0.55	175112	0.3
461851.2	0.55	183867	0.3

Melting Pot Contents/ Furnace	Annual Natural Gas Consumption/Furnace	Annual Waste Gas/Furnace
	m3/yr	m3/yr
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
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11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84
11425.92593	115462.8	1189266.84

Outputs

Energy in Waste Gas	Heat Required to Melt Glass	Heat Loss	Heat in Flue	Electica
kcal	kcal/kg	Watts	Watts	Watts
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917
2842180968	28916.41381	84848.17677	46666.49722	13999.94917

al Output	Overall Efficiency	Heat to Electricity Efficiency
kWh		
122303.5559	0.0537	0.0977
122303.5559	0.0564	0.1026
122303.5559	0.0592	0.1077
122303.5559	0.0622	0.1131
122303.5559	0.0653	0.1187
122303.5559	0.0686	0.1247
122303.5559	0.0720	0.1309
122303.5559	0.0756	0.1375
122303.5559	0.0794	0.1443
122303.5559	0.0833	0.1515
122303.5559	0.0875	0.1591
122303.5559	0.0919	0.1671
122303.5559	0.0965	0.1754
122303.5559	0.1013	0.1842
122303.5559	0.1064	0.1934
122303.5559	0.1117	0.2031
122303.5559	0.1173	0.2132
122303.5559	0.1231	0.2239
122303.5559	0.1293	0.2351
122303.5559	0.1358	0.2469
122303.5559	0.1426	0.2592
122303.5559	0.1497	0.2722
122303.5559	0.1572	0.2858
122303.5559	0.1650	0.3000
122303.5559	0.1733	0.3151
122303.5559	0.1819	0.3308
122303.5559	0.1910	0.3473
122303.5559	0.2006	0.3647
122303.5559	0.2106	0.3829
122303.5559	0.2212	0.4021
122303.5559	0.2322	0.4222
122303.5559	0.2438	0.4433
122303.5559	0.2560	0.4655
122303.5559	0.2688	0.4887
122303.5559	0.2823	0.5132

C.3 Automated-Payback Efficiency Analysis

Automated-Payback Efficiency

Automated-Payback Efficiency Analysis

Table

Euro to Italian Currency Exchange Rate	**1.00 €**	**:**	**L. 1,936**
Unrealistic Efficiency Value	**%**	**>**	**35.00%**

In Lire (L)	In Euro (€)	Electrictity Produced (kWh)	Electrical Efficiency	Flue Efficiency									
				5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
52,500,000.00	27,113.99	35000		107.46%	53.73%	35.82%	26.86%	21.49%	17.91%	15.35%	13.43%	11.94%	10.75%
55,125,000.00	28,469.69	36750		112.83%	56.41%	37.61%	28.21%	22.57%	18.80%	16.12%	14.10%	12.54%	11.28%
57,881,250.00	29,893.17	38588		118.47%	59.24%	39.49%	29.62%	23.69%	19.75%	16.92%	14.81%	13.16%	11.85%
60,775,312.50	31,387.83	40517		124.39%	62.20%	41.46%	31.10%	24.88%	20.73%	17.77%	15.55%	13.82%	12.44%
63,814,078.13	32,957.22	42543		130.61%	65.31%	43.54%	32.65%	26.12%	21.77%	18.66%	16.33%	14.51%	13.06%
67,004,782.03	34,605.08	44670		137.14%	68.57%	45.71%	34.29%	27.43%	22.86%	19.59%	17.14%	15.24%	13.71%
70,355,021.13	36,335.34	46903		144.00%	72.00%	48.00%	36.00%	28.80%	24.00%	20.57%	18.00%	16.00%	14.40%
73,872,772.19	38,152.10	49249		151.20%	75.60%	50.40%	37.80%	30.24%	25.20%	21.60%	18.90%	16.80%	15.12%
77,566,410.80	40,059.71	51711		158.76%	79.38%	52.92%	39.69%	31.75%	26.46%	22.68%	19.85%	17.64%	15.88%
81,444,731.34	42,062.69	54296		166.70%	83.35%	55.57%	41.67%	33.34%	27.78%	23.81%	20.84%	18.52%	16.67%
85,516,967.91	44,165.83	57011		175.03%	87.52%	58.34%	43.76%	35.01%	29.17%	25.00%	21.88%	19.45%	17.50%
89,792,816.30	46,374.12	59862		183.79%	91.89%	61.26%	45.95%	36.76%	30.63%	26.26%	22.97%	20.42%	18.38%
94,282,457.12	48,692.83	62855		192.98%	96.49%	64.33%	48.24%	38.60%	32.16%	27.57%	24.12%	21.44%	19.30%
98,996,579.97	51,127.47	65998		202.62%	101.31%	67.54%	50.66%	40.52%	33.77%	28.95%	25.33%	22.51%	20.26%
103,946,408.97	53,683.84	69298		212.76%	106.38%	70.92%	53.19%	42.55%	35.46%	30.39%	26.59%	23.64%	21.28%
109,143,729.42	56,368.03	72762		223.39%	111.70%	74.46%	55.85%	44.68%	37.23%	31.91%	27.92%	24.82%	22.34%
114,600,915.89	59,186.43	76401		234.56%	117.28%	78.19%	58.64%	46.91%	39.09%	33.51%	29.32%	26.06%	23.46%
120,330,961.68	62,145.76	80221		246.29%	123.15%	82.10%	61.57%	49.26%	41.05%	35.18%	30.79%	27.37%	24.63%
126,347,509.77	65,253.04	84232		258.61%	129.30%	86.20%	64.65%	51.72%	43.10%	36.94%	32.33%	28.73%	25.86%
132,664,885.26	68,515.70	88443		271.54%	135.77%	90.51%	67.88%	54.31%	45.26%	38.79%	33.94%	30.17%	27.15%
139,298,129.52	71,941.48	92865		285.11%	142.56%	95.04%	71.28%	57.02%	47.52%	40.73%	35.64%	31.68%	28.51%
146,263,036.00	75,538.55	97509		299.37%	149.68%	99.79%	74.84%	59.87%	49.89%	42.77%	37.42%	33.26%	29.94%
153,576,187.80	79,315.48	102384		314.34%	157.17%	104.78%	78.58%	62.87%	52.39%	44.91%	39.29%	34.93%	31.43%
161,254,997.19	83,281.26	107503		330.05%	165.03%	110.02%	82.51%	66.01%	55.01%	47.15%	41.26%	36.67%	33.01%
169,317,747.04	87,445.32	112878		346.56%	173.28%	115.52%	86.64%	69.31%	57.76%	49.51%	43.32%	38.51%	34.66%
177,783,634.40	91,817.58	118522		363.88%	181.94%	121.29%	90.97%	72.78%	60.65%	51.98%	45.49%	40.43%	36.39%
186,672,816.12	96,408.46	124449		382.08%	191.04%	127.36%	95.52%	76.42%	63.68%	54.58%	47.76%	42.45%	38.21%
196,006,456.92	101,228.89	130671		401.18%	200.59%	133.73%	100.30%	80.24%	66.86%	57.31%	50.15%	44.58%	40.12%
205,806,779.77	106,290.33	137205		421.24%	210.62%	140.41%	105.31%	84.25%	70.21%	60.18%	52.66%	46.80%	42.12%
216,097,118.76	111,604.85	144065		442.30%	221.15%	147.43%	110.58%	88.46%	73.72%	63.19%	55.29%	49.14%	44.23%
226,901,974.70	117,185.09	151268		464.42%	232.21%	154.81%	116.10%	92.88%	77.40%	66.35%	58.05%	51.60%	46.44%
238,247,073.43	123,044.34	158831		487.64%	243.82%	162.55%	121.91%	97.53%	81.27%	69.66%	60.95%	54.18%	48.76%
250,159,427.10	129,196.56	166773		512.02%	256.01%	170.67%	128.01%	102.40%	85.34%	73.15%	64.00%	56.89%	51.20%
262,667,398.46	135,656.39	175112		537.62%	268.81%	179.21%	134.41%	107.52%	89.60%	76.80%	67.20%	59.74%	53.76%
275,800,768.38	142,439.21	183867		564.50%	282.25%	188.17%	141.13%	112.90%	94.08%	80.64%	70.56%	62.72%	56.45%

55%	60%	65%	70%	75%	80%	85%	90%
9.77%	8.95%	8.27%	7.68%	7.16%	6.72%	6.32%	5.97%
10.26%	9.40%	8.68%	8.06%	7.52%	7.05%	6.64%	6.27%
10.77%	9.87%	9.11%	8.46%	7.90%	7.40%	6.97%	6.58%
11.31%	10.37%	9.57%	8.89%	8.29%	7.77%	7.32%	6.91%
11.87%	10.88%	10.05%	9.33%	8.71%	8.16%	7.68%	7.26%
12.47%	11.43%	10.55%	9.80%	9.14%	8.57%	8.07%	7.62%
13.09%	12.00%	11.08%	10.29%	9.60%	9.00%	8.47%	8.00%
13.75%	12.60%	11.63%	10.80%	10.08%	9.45%	8.89%	8.40%
14.43%	13.23%	12.21%	11.34%	10.58%	9.92%	9.34%	8.82%
15.15%	13.89%	12.82%	11.91%	11.11%	10.42%	9.81%	9.26%
15.91%	14.59%	13.46%	12.50%	11.67%	10.94%	10.30%	9.72%
16.71%	15.32%	14.14%	13.13%	12.25%	11.49%	10.81%	10.21%
17.54%	16.08%	14.84%	13.78%	12.87%	12.06%	11.35%	10.72%
18.42%	16.89%	15.59%	14.47%	13.51%	12.66%	11.92%	11.26%
19.34%	17.73%	16.37%	15.20%	14.18%	13.30%	12.52%	11.82%
20.31%	18.62%	17.18%	15.96%	14.89%	13.96%	13.14%	12.41%
21.32%	19.55%	18.04%	16.75%	15.64%	14.66%	13.80%	13.03%
22.39%	20.52%	18.95%	17.59%	16.42%	15.39%	14.49%	13.68%
23.51%	21.55%	19.89%	18.47%	17.24%	16.16%	15.21%	14.37%
24.69%	22.63%	20.89%	19.40%	18.10%	16.97%	15.97%	15.09%
25.92%	23.76%	21.93%	20.37%	19.01%	17.82%	16.77%	15.84%
27.22%	24.95%	23.03%	21.38%	19.96%	18.71%	17.61%	16.63%
28.58%	26.19%	24.18%	22.45%	20.96%	19.65%	18.49%	17.46%
30.00%	27.50%	25.39%	23.58%	22.00%	20.63%	19.41%	18.34%
31.51%	28.88%	26.66%	24.75%	23.10%	21.66%	20.39%	19.25%
33.08%	30.32%	27.99%	25.99%	24.26%	22.74%	21.40%	20.22%
34.73%	31.84%	29.39%	27.29%	25.47%	23.88%	22.48%	21.23%
36.47%	33.43%	30.86%	28.66%	26.75%	25.07%	23.60%	22.29%
38.29%	35.10%	32.40%	30.09%	28.08%	26.33%	24.78%	23.40%
40.21%	36.86%	34.02%	31.59%	29.49%	27.64%	26.02%	24.57%
42.22%	38.70%	35.72%	33.17%	30.96%	29.03%	27.32%	25.80%
44.33%	40.64%	37.51%	34.83%	32.51%	30.48%	28.68%	27.09%
46.55%	42.67%	39.39%	36.57%	34.13%	32.00%	30.12%	28.45%
48.87%	44.80%	41.36%	38.40%	35.84%	33.60%	31.62%	29.87%
51.32%	47.04%	43.42%	40.32%	37.63%	35.28%	33.21%	31.36%

C.4 Cost Benefit Analysis

Cost Benefit Analysis

Cost Benefits Analysis

In this illustration, assume that the investment is € 29,893.17 .The corperation's marginal federal plus state income tax rate is 0%, with a normal inflation rate of 2.5% and a depreciation rate of 4% annually. Since the effect of inflation is very uncertain, better estimates of future cash flows will be obtained by assuming growth of both benefits and costs at the general rate of inflation. Also, the increase in future cash flows due to inflation is forecast by assuming that the cash flows grow at a constant annual compound rate.

Legend =	Input Value

Total Investment in Euro	**€ 29,893.17**
Initial Investment	**€ 27,175.61**
Maintenance Cost for Payback Period	**€ 2,717.56**
Electricity Produced (kWh)	**38587.5**
The Desired Payback Period	**5**
Tax	**0.00%**
Inflation	**2.50%**
Depreciation	**4.00%**

Capital Budgeting Analysis

	Income		Expenses	
Electricity Sales	€ 5,978.63			
Direct Materials				-€ 271.76
Variable Overhead				-€ 108.70
Fixed Overhead				-€ 163.05
Income	€ 5,435.12			
	Net Income		**Cash Inflow**	
Inflation (2.5%)	€ 135.88			
Net Savings	€ 5,571.00		€ 5,435.12	
Tax (15%)		€ 0.00		€ 0.00
Net Savings After Tax	€ 5,706.88			
Depreciation (10%)		-€ 228.28		
Net Income	€ 5,478.60			
Tax Shield			€ 0.00	
Net Cash Inflow			€ 5,435.12	

Return On Investment

$$\frac{\text{Net Income}}{\text{Total Investment}} = \frac{€\ 5,478.60}{€\ 29,893.17} = \mathbf{18.33\%}$$

Payback Period

$$\frac{\text{Total Investment}}{\text{Annual Net Cash Inflow}} = \frac{€\ 29,893.17}{€\ 5,435.12} = \mathbf{5.50\ \ years}$$

Therefore, assuming that the data above are the real data, it will took 5.5 years to get the investment back.

Investment Cash Flow Pattern

As it has been mentioned before, in this illustration the corperation's marginal federal plus state income tax rate is assumed to be 0%.
and the inflation rate as 2.5%. However, the depreciation that we will be using for the investment cash flow pattern will be different. Instead of using 4% for the depreciation rate, we will be using the MACRS depreciation rate.
As for the annual maintenance cost, it will increase at the rate of the inflation. The annual maintenance cost in this case is the sum of the direct materials, variable overhead, and the fixed overhead. Therefore, the annual maintenance cost is equal to

€ 271.76 + € 108.70 + € 163.05 = € 543.51 which is about 10% of the initial investment.

Maint. Cost	**€ 543.51**

Year	Initial Cost	Annual Savings	Maint. Cost	Net Savings	Net Savings After Tax	MACRS Depr.%'s	Depr. Tax Shield	Net Cash Inflow
0	€ 29,893.17							
1		€ 6,128.10	€ 557.10	€ 5,571.00	€ 5,571.00	10.00%	€ 0.00	€ 5,013.90
2		€ 6,281.30	€ 571.03	€ 5,710.28	€ 5,710.28	18.00%	€ 0.00	€ 4,682.43
3		€ 6,438.34	€ 585.30	€ 5,853.03	€ 5,853.03	14.00%	€ 0.00	€ 5,033.61
4		€ 6,599.29	€ 599.94	€ 5,999.36	€ 5,999.36	12.00%	€ 0.00	€ 5,279.43
5		€ 6,764.28	€ 614.93	€ 6,149.34	€ 6,149.34	9.00%	€ 0.00	€ 5,595.90
6		€ 6,933.38	€ 630.31	€ 6,303.08	€ 6,303.08	7.00%	€ 0.00	€ 5,861.86
7		€ 7,106.72	€ 646.07	€ 6,460.65	€ 6,460.65	7.00%	€ 0.00	€ 6,008.41
8		€ 7,284.39	€ 662.22	€ 6,622.17	€ 6,622.17	7.00%	€ 0.00	€ 6,158.62
9		€ 7,466.49	€ 678.77	€ 6,787.72	€ 6,787.72	7.00%	€ 0.00	€ 6,312.58
10		€ 7,653.16	€ 695.74	€ 6,957.42	€ 6,957.42	6.00%	€ 0.00	€ 6,539.97
11		€ 7,844.49	€ 713.14	€ 7,131.35	€ 7,131.35	3.00%	€ 0.00	€ 6,917.41
12		€ 8,040.60	€ 730.96	€ 7,309.63	€ 7,309.63	0.00%	€ 0.00	€ 7,309.63
13		€ 8,241.61	€ 749.24	€ 7,492.38	€ 7,492.38	0.00%	€ 0.00	€ 7,492.38
14		€ 8,447.65	€ 767.97	€ 7,679.69	€ 7,679.69	0.00%	€ 0.00	€ 7,679.69
15		€ 8,658.84	€ 787.17	€ 7,871.68	€ 7,871.68	0.00%	€ 0.00	€ 7,871.68
16		€ 8,875.32	€ 806.85	€ 8,068.47	€ 8,068.47	0.00%	€ 0.00	€ 8,068.47
17		€ 9,097.20	€ 827.02	€ 8,270.18	€ 8,270.18	0.00%	€ 0.00	€ 8,270.18
18		€ 9,324.63	€ 847.69	€ 8,476.94	€ 8,476.94	0.00%	€ 0.00	€ 8,476.94
19		€ 9,557.74	€ 868.89	€ 8,688.86	€ 8,688.86	0.00%	€ 0.00	€ 8,688.86
20		€ 9,796.69	€ 890.61	€ 8,906.08	€ 8,906.08	0.00%	€ 0.00	€ 8,906.08

Appendix D – Heat to Electricity Model Analysis

Heat to Electricity Model Analysis

"Heat to Electricity Model Analysis.xls"

D.1 50 Factory HE Model Calc (Raw Data)
D.2 50 Factory HE Model Calc (Conditional Formatting)
D.3 27 Non-Deviated Factories
D.4 kWh Temp (Temperature affect on kWh for Non-Deviating Factories)

D.1 50 Factory HE Model Calc (Raw Data)

Legal Name	factory_code	Number Of Furnaces	days_operation/year	weeks_operation/year	Electricity_KWh/year	CH4/yr(m3)	Melting Pot Contents (kg/yr)
Mazzuccato di M. Daniele SRL	79	1	230.00	32.85714286	1560	8050	1014.109347
Name Unknown	1044	2	160.00	22.85714286	1056	12960	2821.869489
Barovier e Toso	20	3	200.00	28.57142857	9600	66666.66667	2821.869489
Name Unknown	1036	1	210.00	30	6696	38143	2962.962963
Fratelli Barbini di Barbini Cesare	55	1	218.00	31.14285714	12000	65400	4325.396825
Donà Guido	40	2	250.00	35.71428571	35400	75000	4409.171076
Nuova PIM Cristalleria SAS	91	1	335.00	47.85714286	35520	89333.33333	5908.289242
Name Unknown	1006	2	200.00	28.57142857	157620	88266.66667	7054.673721
A.V. Mazzega SRL	2	2	210.00	30	6000	91000	7407.407407
Vetreria Artistica Schiavon	133	6	210.00	30	182400	492100	7407.407407
D'este Bruno	36	2	218.00	31.14285714	12000	138066.6667	7689.594356
L'Artistica Muranese di Badioli M. e. C.	62	3	246.67	35.23809524	5652	132000	7760.141093
Tagliapietra Dino	117	2	240.00	34.28571429	122736	83376	8465.608466
Artigianto Artistico Veneziano	12	2	200.00	28.57142857	12960	108666.6667	10582.01058
Guarnieri Vetr. A.	59	3	200.00	28.57142857	14400	122000	10582.01058
Name Unknown	1055	6	200.00	28.57142857	168696	400000	10582.01058
Premiata Glass	97	5	210.00	30	27600	33600	11111.11111
Name Unknown	1043	1	220.00	31.42857143	5160	57200	11640.21164
Name Unknown	1029	2	200.00	28.57142857	11940	200000	14109.34744
Name Unknown	158	12	230.00	32.85714286	84000	920000	15008.81834
Linea Mazzuccato	71	8	217.00	31	50388	301991.6667	15308.64198
Name Unknown	1033	1	220.00	31.42857143	13200	77000	15520.28219
Gambaro e Poggi SNC	57	3	220.00	31.42857143	115488	317408.6667	15520.28219
Name Unknown	1014	1	150.00	21.42857143	3000	27500	15873.01587
La Murrina SRL	66	4	300.00	42.85714286	36000	290000	15873.01587
Name Unknown	1052	2	210.00	30	4080	3500	18518.51852
Artigianato Muranese SNC	11	3	210.00	30	132000	420000	18518.51852
Moretti Franco	83	1	220.00	31.42857143	9000	79200	19400.35273
Name Unknown	1027	3	232.00	33.14285714	51600	216533.3333	20458.55379
Nuova Artigiana Colleoni SNC	89	7	210.00	30	36000	315000	22222.22222
J.W.P. di Cavagnis	61	5	222.40	31.77142857	51000	483166.6667	22417.98942
AVEM Arte Vetreria Muranese SAS	15	5	200.00	28.57142857	34836	278000	24761.90476
Name Unknown	1054	2	210.00	30	10356	115633	29629.62963
Bisazza Vetro SRL	24	8	60.00	8.571428571	15960	26000	31746.03175
Mosaici Donà	84	2	200.00	28.57142857	28800	144000	35273.36861
Name Unknown	1042	4	230.00	32.85714286	120204	215970	36507.93651
Ercole Moretti e fratelli	47	11	217.00	31	144000	578666.6667	45925.92593
Lavorazioni Artistiche di Amadi Fabiano	69	8	215.00	30.71428571	24000	150500	30335.097
Name Unknown	1050	2	200.00	28.57142857	28800	144000	49382.71605
Linea Padovan	72	4	220.00	31.42857143	72000	322666.6667	50440.91711
Cristal Center Factory in Murano SRL	35	2	200.00	28.57142857	38400	240000	52910.05291
Nuova Marco Polo SRL	90	16	210.00	30	400800	1750000	55555.55556
Name Unknown	1032	1	220.00	31.42857143	720	66000	62081.12875
Ongaro Fuga di Fuga G. e C.	92	9	217.00	31	336000	1707066.667	68888.88889
Name Unknown	1045	2	200.00	28.57142857	34800	146666.6667	70546.73721
Pagan Murrine di C. Pagan	94	6	200.00	28.57142857	162000	366666.6667	70546.73721
Name Unknown	1031	2	230.00	32.85714286	60000	184000	81128.7478
Berengo Fine Arts	21	9	225.00	32.14285714	129600	75990	198412.6984
Name Unknown	1053	11	220.00	31.42857143	1080000	1833333.333	349206.3492
Legal Name	factory_code	Number Of Furnaces	days_operation/year	weeks_operation/year	Electricity_KWh/year	CH4/yr(m3)	Melting Pot Contents (kg/yr)

Specific Heat of Waste gas (kcal/m3*K)	Output Temperature (k)	Input Temperature (K)	Energy Contained in Waste Gas (Kcal/yr)	CH4/KG glass	Heat Acquired From CH4 Combustion (Kcal/yr)
0.38	1623	298	4.46E+07	2.7041175	6.76E+07
0.38	1623	298	7.18E+07	1.564525125	1.09E+08
0.38	1623	298	3.69E+08	8.04796875	5.60E+08
0.38	1623	298	2.11E+08	4.385338172	3.20E+08
0.38	1623	298	3.62E+08	5.1507	5.49E+08
0.38	1623	298	4.15E+08	5.7945375	6.30E+08
0.38	1623	298	4.95E+08	5.1507	7.50E+08
0.38	1623	298	4.89E+08	4.26220425	7.41E+08
0.38	1623	298	5.04E+08	4.18494375	7.64E+08
0.38	1623	298	2.73E+09	22.63088813	4.13E+09
0.38	1623	298	7.65E+08	6.11645625	1.16E+09
0.38	1623	298	7.31E+08	5.7945375	1.11E+09
0.38	1623	298	4.62E+08	3.355037213	7.00E+08
0.38	1623	298	6.02E+08	3.49818375	9.13E+08
0.38	1623	298	6.76E+08	3.92740875	1.02E+09
0.38	1623	298	2.22E+09	12.87675	3.36E+09
0.38	1623	298	1.86E+08	1.03014	2.82E+08
0.38	1623	298	3.17E+08	1.6739775	4.80E+08
0.38	1623	298	1.11E+09	4.82878125	1.68E+09
0.38	1623	298	5.10E+09	20.88121622	7.73E+09
0.38	1623	298	1.67E+09	6.720053906	2.54E+09
0.38	1623	298	4.26E+08	1.690073438	6.47E+08
0.38	1623	298	1.76E+09	6.966804628	2.67E+09
0.38	1623	298	1.52E+08	0.590184375	2.31E+08
0.38	1623	298	1.61E+09	6.2237625	2.44E+09
0.38	1623	298	1.94E+07	0.06438375	2.94E+07
0.38	1623	298	2.33E+09	7.72605	3.53E+09
0.38	1623	298	4.39E+08	1.390689	6.65E+08
0.38	1623	298	1.20E+09	3.60549	1.82E+09
0.38	1623	298	1.74E+09	4.82878125	2.65E+09
0.38	1623	298	2.68E+09	7.342006579	4.06E+09
0.38	1623	298	1.54E+09	3.824504808	2.34E+09
0.38	1623	298	6.40E+08	1.329443958	9.71E+08
0.38	1623	298	1.44E+08	0.27899625	2.18E+08
0.38	1623	298	7.98E+08	1.390689	1.21E+09
0.38	1623	298	1.20E+09	2.015211375	1.81E+09
0.38	1623	298	3.20E+09	4.29225	4.86E+09
0.38	1623	298	8.34E+08	1.690073438	1.26E+09
0.38	1623	298	7.98E+08	0.993349286	1.21E+09
0.38	1623	298	1.79E+09	2.179142308	2.71E+09
0.38	1623	298	1.33E+09	1.54521	2.02E+09
0.38	1623	298	9.69E+09	10.730625	1.47E+10
0.38	1623	298	3.66E+08	0.362158594	5.54E+08
0.38	1623	298	9.45E+09	8.441425	1.43E+10
0.38	1623	298	8.12E+08	0.70822125	1.23E+09
0.38	1623	298	2.03E+09	1.770553125	3.08E+09
0.38	1623	298	1.02E+09	0.772605	1.55E+09
0.38	1623	298	4.21E+08	0.130467231	6.38E+08
0.38	1623	298	1.02E+10	1.7884375	1.54E+10
Specific Heat of Waste gas (kcal/m3*K)	Output Temperature (k)	Input Temperature (K)	Energy Contained in Waste Gas (Kcal/yr)	CH4/KG glass	Heat Acquired From CH4 Combustion (Kcal/yr)

Heat Needed to Melt Pot Contents (Kcal)	Total Heat Loss (Kcal/yr)	glass_production_KG	Total Waste Gas (m3/yr)	Flue Efficiency	Total recoverable energy (Kcal)	glass_production_tonne	Heat Loss per furnace (kcal/yr)
2.30E+07	4.46E+07	821.43	8.86E+04	5.50E-01	2.45E+07	0.821428571	4.01E+07
3.71E+07	7.18E+07	2,285.71	1.43E+05	5.50E-01	3.95E+07	2.285714286	3.23E+07
1.91E+08	3.69E+08	2,285.71	7.33E+05	5.50E-01	2.03E+08	2.285714286	1.11E+08
1.09E+08	2.11E+08	2,400.00	4.20E+05	5.50E-01	1.16E+08	2.4	1.90E+08
1.87E+08	3.62E+08	3,503.57	7.19E+05	5.50E-01	1.99E+08	3.503571429	3.26E+08
2.15E+08	4.15E+08	3,571.43	8.25E+05	5.50E-01	2.28E+08	3.571428571	1.87E+08
2.56E+08	4.95E+08	4,785.71	9.83E+05	5.50E-01	2.72E+08	4.785714286	4.45E+08
2.53E+08	4.89E+08	5,714.29	9.71E+05	5.50E-01	2.69E+08	5.714285714	2.20E+08
2.60E+08	5.04E+08	6,000.00	1.00E+06	5.50E-01	2.77E+08	6	2.27E+08
1.41E+09	2.73E+09	6,000.00	5.41E+06	5.50E-01	1.50E+09	6	4.09E+08
3.95E+08	7.65E+08	6,228.57	1.52E+06	5.50E-01	4.21E+08	6.228571429	3.44E+08
3.78E+08	7.31E+08	6,285.71	1.45E+06	5.50E-01	4.02E+08	6.285714286	2.19E+08
2.39E+08	4.62E+08	6,857.14	9.17E+05	5.50E-01	2.54E+08	6.857142857	2.08E+08
3.11E+08	6.02E+08	8,571.43	1.20E+06	5.50E-01	3.31E+08	8.571428571	2.71E+08
3.49E+08	6.76E+08	8,571.43	1.34E+06	5.50E-01	3.72E+08	8.571428571	2.03E+08
1.14E+09	2.22E+09	8,571.43	4.40E+06	5.50E-01	1.22E+09	8.571428571	3.32E+08
9.61E+07	1.86E+08	9,000.00	3.70E+05	5.50E-01	1.02E+08	9	3.35E+07
1.64E+08	3.17E+08	9,428.57	6.29E+05	5.50E-01	1.74E+08	9.428571429	2.85E+08
5.72E+08	1.11E+09	11,428.57	2.20E+06	5.50E-01	6.09E+08	11.42857143	4.98E+08
2.63E+09	5.10E+09	12,157.14	1.01E+07	5.50E-01	2.80E+09	12.15714286	3.82E+08
8.64E+08	1.67E+09	12,400.00	3.32E+06	5.50E-01	9.20E+08	12.4	1.88E+08
2.20E+08	4.26E+08	12,571.43	8.47E+05	5.50E-01	2.35E+08	12.57142857	3.84E+08
9.08E+08	1.76E+09	12,571.43	3.49E+06	5.50E-01	9.67E+08	12.57142857	5.27E+08
7.87E+07	1.52E+08	12,857.14	3.03E+05	5.50E-01	8.38E+07	12.85714286	1.37E+08
8.30E+08	1.61E+09	12,857.14	3.19E+06	5.50E-01	8.83E+08	12.85714286	3.61E+08
1.00E+07	1.94E+07	15,000.00	3.85E+04	5.50E-01	1.07E+07	15	8.72E+06
1.20E+09	2.33E+09	15,000.00	4.62E+06	5.50E-01	1.28E+09	15	6.98E+08
2.27E+08	4.39E+08	15,714.29	8.71E+05	5.50E-01	2.41E+08	15.71428571	3.95E+08
6.20E+08	1.20E+09	16,571.43	2.38E+06	5.50E-01	6.60E+08	16.57142857	3.60E+08
9.01E+08	1.74E+09	18,000.00	3.47E+06	5.50E-01	9.60E+08	18	2.24E+08
1.38E+09	2.68E+09	18,158.57	5.31E+06	5.50E-01	1.47E+09	18.15857143	4.82E+08
7.95E+08	1.54E+09	20,057.14	3.06E+06	5.50E-01	8.47E+08	20.05714286	2.77E+08
3.31E+08	6.40E+08	24,000.00	1.27E+06	5.50E-01	3.52E+08	24	2.88E+08
7.44E+07	1.44E+08	25,714.29	2.86E+05	5.50E-01	7.92E+07	25.71428571	1.62E+07
4.12E+08	7.98E+08	28,571.43	1.58E+06	5.50E-01	4.39E+08	28.57142857	3.59E+08
6.18E+08	1.20E+09	29,571.43	2.38E+06	5.50E-01	6.58E+08	29.57142857	2.69E+08
1.66E+09	3.20E+09	37,200.00	6.37E+06	5.50E-01	1.76E+09	37.2	2.62E+08
4.31E+08	8.34E+08	24,571.43	1.66E+06	5.50E-01	4.58E+08	24.57142857	9.38E+07
4.12E+08	7.98E+08	40,000.00	1.58E+06	5.50E-01	4.39E+08	40	3.59E+08
9.23E+08	1.79E+09	40,857.14	3.55E+06	5.50E-01	9.83E+08	40.85714286	4.02E+08
6.87E+08	1.33E+09	42,857.14	2.64E+06	5.50E-01	7.31E+08	42.85714286	5.98E+08
5.01E+09	9.69E+09	45,000.00	1.93E+07	5.50E-01	5.33E+09	45	5.45E+08
1.89E+08	3.66E+08	50,285.71	7.26E+05	5.50E-01	2.01E+08	50.28571429	3.29E+08
4.88E+09	9.45E+09	55,800.00	1.88E+07	5.50E-01	5.20E+09	55.8	9.45E+08
4.20E+08	8.12E+08	57,142.86	1.61E+06	5.50E-01	4.47E+08	57.14285714	3.66E+08
1.05E+09	2.03E+09	57,142.86	4.03E+06	5.50E-01	1.12E+09	57.14285714	3.05E+08
5.27E+08	1.02E+09	65,714.29	2.02E+06	5.50E-01	5.60E+08	65.71428571	4.59E+08
2.17E+08	4.21E+08	160,714.29	8.36E+05	5.50E-01	2.31E+08	160.7142857	4.21E+07
5.25E+09	1.02E+10	282,857.14	2.02E+07	5.50E-01	5.58E+09	282.8571429	8.31E+08
Heat Needed to Melt Pot Contents (Kcal)	Total Heat Loss (Kcal)	glass_production_KG	Total Waste Gas (m3/yr)	Flue Efficiency	Total recoverable energy (Kcal)	glass_production_tonne	Heat Loss per furnace (kcal/yr)

Heat out Flue (Kcal/yr)	Cogeneration Efficiency	Energy Obtained from Cogeneration Application (kcal/yr)	KWh / furnace / year	KWh Total /year
2.21E+07	3.00E-01	6.62E+06	7.67E+03	7.67E+03
1.78E+07	3.00E-01	5.33E+06	6.17E+03	1.23E+04
6.09E+07	3.00E-01	1.83E+07	2.12E+04	6.35E+04
1.05E+08	3.00E-01	3.14E+07	3.63E+04	3.63E+04
1.79E+08	3.00E-01	5.38E+07	6.23E+04	6.23E+04
1.03E+08	3.00E-01	3.08E+07	3.57E+04	7.14E+04
2.45E+08	3.00E-01	7.35E+07	8.51E+04	8.51E+04
1.21E+08	3.00E-01	3.63E+07	4.20E+04	8.41E+04
1.25E+08	3.00E-01	3.74E+07	4.33E+04	8.67E+04
2.25E+08	3.00E-01	6.75E+07	7.81E+04	4.69E+05
1.89E+08	3.00E-01	5.68E+07	6.58E+04	1.32E+05
1.21E+08	3.00E-01	3.62E+07	4.19E+04	1.26E+05
1.14E+08	3.00E-01	3.43E+07	3.97E+04	7.94E+04
1.49E+08	3.00E-01	4.47E+07	5.18E+04	1.04E+05
1.11E+08	3.00E-01	3.34E+07	3.87E+04	1.16E+05
1.83E+08	3.00E-01	5.48E+07	6.35E+04	3.81E+05
1.84E+07	3.00E-01	5.53E+06	6.40E+03	3.20E+04
1.57E+08	3.00E-01	4.70E+07	5.45E+04	5.45E+04
2.74E+08	3.00E-01	8.22E+07	9.53E+04	1.91E+05
2.10E+08	3.00E-01	6.31E+07	7.30E+04	8.76E+05
1.03E+08	3.00E-01	3.10E+07	3.60E+04	2.88E+05
2.11E+08	3.00E-01	6.33E+07	7.34E+04	7.34E+04
2.90E+08	3.00E-01	8.70E+07	1.01E+05	3.02E+05
7.54E+07	3.00E-01	2.26E+07	2.62E+04	2.62E+04
1.99E+08	3.00E-01	5.96E+07	6.91E+04	2.76E+05
4.80E+06	3.00E-01	1.44E+06	1.67E+03	3.33E+03
3.84E+08	3.00E-01	1.15E+08	1.33E+05	4.00E+05
2.17E+08	3.00E-01	6.51E+07	7.54E+04	7.54E+04
1.98E+08	3.00E-01	5.94E+07	6.88E+04	2.06E+05
1.23E+08	3.00E-01	3.70E+07	4.29E+04	3.00E+05
2.65E+08	3.00E-01	7.95E+07	9.21E+04	4.60E+05
1.52E+08	3.00E-01	4.57E+07	5.30E+04	2.65E+05
1.59E+08	3.00E-01	4.76E+07	5.51E+04	1.10E+05
8.91E+06	3.00E-01	2.67E+06	3.10E+03	2.48E+04
1.97E+08	3.00E-01	5.92E+07	6.86E+04	1.37E+05
1.48E+08	3.00E-01	4.44E+07	5.14E+04	2.06E+05
1.44E+08	3.00E-01	4.33E+07	5.01E+04	5.51E+05
5.16E+07	3.00E-01	1.55E+07	1.79E+04	1.43E+05
1.97E+08	3.00E-01	5.92E+07	6.86E+04	1.37E+05
2.21E+08	3.00E-01	6.63E+07	7.68E+04	3.07E+05
3.29E+08	3.00E-01	9.87E+07	1.14E+05	2.29E+05
3.00E+08	3.00E-01	9.00E+07	1.04E+05	1.67E+06
1.81E+08	3.00E-01	5.43E+07	6.29E+04	6.29E+04
5.20E+08	3.00E-01	1.56E+08	1.81E+05	1.63E+06
2.01E+08	3.00E-01	6.03E+07	6.99E+04	1.40E+05
1.68E+08	3.00E-01	5.03E+07	5.82E+04	3.49E+05
2.52E+08	3.00E-01	7.57E+07	8.76E+04	1.75E+05
2.31E+07	3.00E-01	6.94E+06	8.04E+03	7.24E+04
4.57E+08	3.00E-01	1.37E+08	1.59E+05	1.75E+06
Heat out Flue (Kcal/yr)	Cogeneration Efficiency	Energy Obtained from Cogeneration Application (kcal/yr)	KWh / furnace / year	KWh Total /year

D.2 50 Factory HE Model Calc (Conditional Formatting)

Factory Name	Code	CH4/KG glass	KWh Total /yr	Glass Production (metric ton)	Glass Production (kg)	CH4/yr(m3)	Number Of Furnaces
Name Unknown	1052	0.1	3.33E+03	15	15,000.00	3500	2
Berengo Fine Arts	21	0.1	7.24E+04	160.7142857	160,714.29	75990	9
Bisazza Vetro SRL	24	0.3	2.48E+04	25.71428571	25,714.29	26000	8
Name Unknown	1032	0.4	6.29E+04	50.28571429	50,285.71	66000	1
Name Unknown	1014	0.6	2.62E+04	12.85714286	12,857.14	27500	1
Name Unknown	1045	0.7	1.40E+05	57.14285714	57,142.86	146666.6667	2
Name Unknown	1031	0.8	1.75E+05	65.71428571	65,714.29	184000	2
Name Unknown	1050	1.0	1.37E+05	40	40,000.00	144000	2
Premiata Glass	97	1.0	3.20E+04	9	9,000.00	33600	5
Name Unknown	1054	1.3	1.10E+05	24	24,000.00	115633	2
Mosaici Donà	84	1.4	1.37E+05	28.57142857	28,571.43	144000	2
Moretti Franco	83	1.4	7.54E+04	15.71428571	15,714.29	79200	1
Cristal Center Factory in Murano SRL	35	1.5	2.29E+05	42.85714286	42,857.14	240000	2
Name Unknown	1044	1.6	1.23E+04	2.285714286	2,285.71	12960	2
Name Unknown	1043	1.7	5.45E+04	9.428571429	9,428.57	57200	1
Name Unknown	1033	1.7	7.34E+04	12.57142857	12,571.43	77000	1
Lavorazioni Artistiche di Amadi Fabiano	69	1.7	1.43E+05	24.57142857	24,571.43	150500	8
Pagan Murrine di C. Pagan	94	1.8	3.49E+05	57.14285714	57,142.86	366666.6667	6
Name Unknown	1053	1.8	1.75E+06	282.8571429	282,857.14	1833333.333	11
Name Unknown	1042	2.0	2.06E+05	29.57142857	29,571.43	215970	4
Linea Padovan	72	2.2	3.07E+05	40.85714286	40,857.14	322666.6667	4
Mazzuccato di M. Daniele SRL	79	2.7	7.67E+03	0.821428571	821.43	8050	1
Tagliapietra Dino	117	3.4	7.94E+04	6.857142857	6,857.14	83376	2
Artigianto Artistico Veneziano	12	3.5	1.04E+05	8.571428571	8,571.43	108666.6667	2
Name Unknown	1027	3.6	2.06E+05	16.57142857	16,571.43	216533.3333	3
AVEM Arte Vetreria Muranese SAS	15	3.8	2.65E+05	20.05714286	20,057.14	278000	5
Vetreria Artistica Archimede Seguso	**122**	**3.8**	**4.89E+05**	**37.02**	**37,020.00**	**513168**	**4**
Guarnieri Vetr. A.	59	3.9	1.16E+05	8.571428571	8,571.43	122000	3
A.V. Mazzega SRL	2	4.2	8.67E+04	6	6,000.00	91000	2
Name Unknown	1006	4.3	8.41E+04	5.714285714	5,714.29	88266.66667	2
Ercole Moretti e fratelli	47	4.3	5.51E+05	37.2	37,200.00	578666.6667	11
Name Unknown	1036	4.4	3.63E+04	2.4	2,400.00	38143	1
Name Unknown	1029	4.8	1.91E+05	11.42857143	11,428.57	200000	2
Nuova Artigiana Colleoni SNC	89	4.8	3.00E+05	18	18,000.00	315000	7
Fratelli Barbini di Barbini Cesare	55	5.2	6.23E+04	3.503571429	3,503.57	65400	1
Nuova PIM Cristalleria SAS	91	5.2	8.51E+04	4.785714286	4,785.71	89333.33333	1
Donà Guido	40	5.8	7.14E+04	3.571428571	3,571.43	75000	2
L'Artistica Muranese di Badioli M. e. C.	62	5.8	1.26E+05	6.285714286	6,285.71	132000	3
D'este Bruno	36	6.1	1.32E+05	6.228571429	6,228.57	138066.6667	2
La Murrina SRL	66	6.2	2.76E+05	12.85714286	12,857.14	290000	4
Linea Mazzuccato	71	6.7	2.88E+05	12.4	12,400.00	301991.6667	8
Gambaro e Poggi SNC	57	7.0	3.02E+05	12.57142857	12,571.43	317408.6667	3
J.W.P. di Cavagnis	61	7.3	4.60E+05	18.15857143	18,158.57	483166.6667	5
Artigianato Muranese SNC	11	7.7	4.00E+05	15	15,000.00	420000	3
Barovier e Toso	20	8.0	6.35E+04	2.285714286	2,285.71	66666.66667	3
Ongaro Fuga di Fuga G. e C.	92	8.4	1.63E+06	55.8	55,800.00	1707066.667	9
Nuova Marco Polo SRL	90	10.7	1.67E+06	45	45,000.00	1750000	16
Name Unknown	1055	12.9	3.81E+05	8.571428571	8,571.43	400000	6
Name Unknown	158	20.9	8.76E+05	12.15714286	12,157.14	920000	12
Vetreria Artistica Schiavon	133	22.6	4.69E+05	6	6,000.00	492100	6
Factory Name	Code	CH4/KG glass	KWh Total /yr	Glass Production (metric ton)	Glass Production (kg)	CH4/yr(m3)	Number Of Furnaces

Days of Operation / yr	Weeks of Operation / yr	Electricity (KWh/yr)	Melting Pot Contents (kg/yr)	Specific Heat of Waste gas (kcal/m3*K)	Output Temperature (k)	Input Temperature (K)
210.00	30	4080	18518.51852	0.38	1623	298
225.00	32.14285714	129600	198412.6984			
60.00	8.571428571	15960	31746.03175			
220.00	31.42857143	720	62081.12875			
150.00	21.42857143	3000	15873.01587			
200.00	28.57142857	34800	70546.73721			
230.00	32.85714286	60000	81128.7478			
200.00	28.57142857	28800	49382.71605			
210.00	30	27600	11111.11111			
210.00	30	10356	29629.62963			
200.00	28.57142857	28800	35273.36861			
220.00	31.42857143	9000	19400.35273			
200.00	28.57142857	38400	52910.05291			
160.00	22.85714286	1056	2821.869489			
220.00	31.42857143	5160	11640.21164			
220.00	31.42857143	13200	15520.28219			
215.00	30.71428571	24000	30335.097			
200.00	28.57142857	162000	70546.73721			
220.00	31.42857143	1080000	349206.3492			
230.00	32.85714286	120204	36507.93651			
220.00	31.42857143	72000	50440.91711			
230.00	32.85714286	1560	1014.109347			
240.00	34.28571429	122736	8465.608466			
200.00	28.57142857	12960	10582.01058			
232.00	33.14285714	51600	20458.55379			
200.00	28.57142857	34836	24761.90476			
320.00	**45.7**	**113859**	**45703.7037**			
200.00	28.57142857	14400	10582.01058			
210.00	30	6000	7407.407407			
200.00	28.57142857	157620	7054.673721			
217.00	31	144000	45925.92593			
210.00	30	6696	2962.962963			
200.00	28.57142857	11940	14109.34744			
210.00	30	36000	22222.22222			
218.00	31.14285714	12000	4325.396825			
335.00	47.85714286	35520	5908.289242			
250.00	35.71428571	35400	4409.171076			
246.67	35.23809524	5652	7760.141093			
218.00	31.14285714	12000	7689.594356			
300.00	42.85714286	36000	15873.01587			
217.00	31	50388	15308.64198			
220.00	31.42857143	115488	15520.28219			
222.40	31.77142857	51000	22417.98942			
210.00	30	132000	18518.51852			
200.00	28.57142857	9600	2821.869489			
217.00	31	336000	68888.88889			
210.00	30	400800	55555.55556			
200.00	28.57142857	168696	10582.01058			
230.00	32.85714286	84000	15008.81834			
210.00	30	182400	7407.407407			
Days of Operation / yr	Weeks of Operation / yr	Electricity (KWh/yr)	Melting Pot Contents (kg/yr)	Specific Heat of Waste gas (kcal/m3*K)	Output Temperature (k)	Input Temperature (K)

Energy Contained in Waste Gas (Kcal/yr)	Heat Acquired From CH4 Combustion (Kcal/yr)	Heat Needed to Melt Pot Contents (Kcal)	Total Heat Loss (Kcal/yr)	Total Waste Gas (m3/yr)	Flue Efficiency
1.94E+07	2.94E+07	1.00E+07	1.94E+07	3.85E+04	55%
4.21E+08	6.38E+08	2.17E+08	4.21E+08	8.36E+05	55%
1.44E+08	2.18E+08	7.44E+07	1.44E+08	2.86E+05	55%
3.66E+08	5.54E+08	1.89E+08	3.66E+08	7.26E+05	55%
1.52E+08	2.31E+08	7.87E+07	1.52E+08	3.03E+05	55%
8.12E+08	1.23E+09	4.20E+08	8.12E+08	1.61E+06	55%
1.02E+09	1.55E+09	5.27E+08	1.02E+09	2.02E+06	55%
7.98E+08	1.21E+09	4.12E+08	7.98E+08	1.58E+06	55%
1.86E+08	2.82E+08	9.61E+07	1.86E+08	3.70E+05	55%
6.40E+08	9.71E+08	3.31E+08	6.40E+08	1.27E+06	55%
7.98E+08	1.21E+09	4.12E+08	7.98E+08	1.58E+06	55%
4.39E+08	6.65E+08	2.27E+08	4.39E+08	8.71E+05	55%
1.33E+09	2.02E+09	6.87E+08	1.33E+09	2.64E+06	55%
7.18E+07	1.09E+08	3.71E+07	7.18E+07	1.43E+05	55%
3.17E+08	4.80E+08	1.64E+08	3.17E+08	6.29E+05	55%
4.26E+08	6.47E+08	2.20E+08	4.26E+08	8.47E+05	55%
8.34E+08	1.26E+09	4.31E+08	8.34E+08	1.66E+06	55%
2.03E+09	3.08E+09	1.05E+09	2.03E+09	4.03E+06	55%
1.02E+10	1.54E+10	5.25E+09	1.02E+10	2.02E+07	55%
1.20E+09	1.81E+09	6.18E+08	1.20E+09	2.38E+06	55%
1.79E+09	2.71E+09	9.23E+08	1.79E+09	3.55E+06	55%
4.46E+07	6.76E+07	2.30E+07	4.46E+07	8.86E+04	55%
4.62E+08	7.00E+08	2.39E+08	4.62E+08	9.17E+05	55%
6.02E+08	9.13E+08	3.11E+08	6.02E+08	1.20E+06	55%
1.20E+09	1.82E+09	6.20E+08	1.20E+09	2.38E+06	55%
1.54E+09	2.34E+09	7.95E+08	1.54E+09	3.06E+06	55%
2.84E+09	**4.31E+09**	**1.47E+09**	**2.84E+09**	**5.64E+06**	**55%**
6.76E+08	1.02E+09	3.49E+08	6.76E+08	1.34E+06	55%
5.04E+08	7.64E+08	2.60E+08	5.04E+08	1.00E+06	55%
4.89E+08	7.41E+08	2.53E+08	4.89E+08	9.71E+05	55%
3.20E+09	4.86E+09	1.66E+09	3.20E+09	6.37E+06	55%
2.11E+08	3.20E+08	1.09E+08	2.11E+08	4.20E+05	55%
1.11E+09	1.68E+09	5.72E+08	1.11E+09	2.20E+06	55%
1.74E+09	2.65E+09	9.01E+08	1.74E+09	3.47E+06	55%
3.62E+08	5.49E+08	1.87E+08	3.62E+08	7.19E+05	55%
4.95E+08	7.50E+08	2.56E+08	4.95E+08	9.83E+05	55%
4.15E+08	6.30E+08	2.15E+08	4.15E+08	8.25E+05	55%
7.31E+08	1.11E+09	3.78E+08	7.31E+08	1.45E+06	55%
7.65E+08	1.16E+09	3.95E+08	7.65E+08	1.52E+06	55%
1.61E+09	2.44E+09	8.30E+08	1.61E+09	3.19E+06	55%
1.67E+09	2.54E+09	8.64E+08	1.67E+09	3.32E+06	55%
1.76E+09	2.67E+09	9.08E+08	1.76E+09	3.49E+06	55%
2.68E+09	4.06E+09	1.38E+09	2.68E+09	5.31E+06	55%
2.33E+09	3.53E+09	1.20E+09	2.33E+09	4.62E+06	55%
3.69E+08	5.60E+08	1.91E+08	3.69E+08	7.33E+05	55%
9.45E+09	1.43E+10	4.88E+09	9.45E+09	1.88E+07	55%
9.69E+09	1.47E+10	5.01E+09	9.69E+09	1.93E+07	55%
2.22E+09	3.36E+09	1.14E+09	2.22E+09	4.40E+06	55%
5.10E+09	7.73E+09	2.63E+09	5.10E+09	1.01E+07	55%
2.73E+09	4.13E+09	1.41E+09	2.73E+09	5.41E+06	55%
Energy Contained in Waste Gas (Kcal/yr)	Heat Acquired From CH4 Combustion (Kcal/yr)	Heat Needed to Melt Pot Contents (Kcal)	Total Heat Loss (Kcal/yr)	Total Waste Gas (m3/yr)	Flue Efficiency

Total recoverable energy (Kcal)	Heat Loss / furnace (kcal/yr)	Heat out Flue (Kcal/yr)	Cogeneration Efficiency	Energy Obtained from Cogeneration Application (kcal/yr)	KWh / furnace / yr
1.07E+07	8.72E+06	4.80E+06	30%	1.44E+06	1.67E+03
2.31E+08	4.21E+07	2.31E+07	30%	6.94E+06	8.04E+03
7.92E+07	1.62E+07	8.91E+06	30%	2.67E+06	3.10E+03
2.01E+08	3.29E+08	1.81E+08	30%	5.43E+07	6.29E+04
8.38E+07	1.37E+08	7.54E+07	30%	2.26E+07	2.62E+04
4.47E+08	3.66E+08	2.01E+08	30%	6.03E+07	6.99E+04
5.60E+08	4.59E+08	2.52E+08	30%	7.57E+07	8.76E+04
4.39E+08	3.59E+08	1.97E+08	30%	5.92E+07	6.86E+04
1.02E+08	3.35E+07	1.84E+07	30%	5.53E+06	6.40E+03
3.52E+08	2.88E+08	1.59E+08	30%	4.76E+07	5.51E+04
4.39E+08	3.59E+08	1.97E+08	30%	5.92E+07	6.86E+04
2.41E+08	3.95E+08	2.17E+08	30%	6.51E+07	7.54E+04
7.31E+08	5.98E+08	3.29E+08	30%	9.87E+07	1.14E+05
3.95E+07	3.23E+07	1.78E+07	30%	5.33E+06	6.17E+03
1.74E+08	2.85E+08	1.57E+08	30%	4.70E+07	5.45E+04
2.35E+08	3.84E+08	2.11E+08	30%	6.33E+07	7.34E+04
4.58E+08	9.38E+07	5.16E+07	30%	1.55E+07	1.79E+04
1.12E+09	3.05E+08	1.68E+08	30%	5.03E+07	5.82E+04
5.58E+09	8.31E+08	4.57E+08	30%	1.37E+08	1.59E+05
6.58E+08	2.69E+08	1.48E+08	30%	4.44E+07	5.14E+04
9.83E+08	4.02E+08	2.21E+08	30%	6.63E+07	7.68E+04
2.45E+07	4.01E+07	2.21E+07	30%	6.62E+06	7.67E+03
2.54E+08	2.08E+08	1.14E+08	30%	3.43E+07	3.97E+04
3.31E+08	2.71E+08	1.49E+08	30%	4.47E+07	5.18E+04
6.60E+08	3.60E+08	1.98E+08	30%	5.94E+07	6.88E+04
8.47E+08	2.77E+08	1.52E+08	30%	4.57E+07	5.30E+04
1.56E+09	**6.39E+08**	**3.52E+08**	**30%**	**1.06E+08**	**1.22E+05**
3.72E+08	2.03E+08	1.11E+08	30%	3.34E+07	3.87E+04
2.77E+08	2.27E+08	1.25E+08	30%	3.74E+07	4.33E+04
2.69E+08	2.20E+08	1.21E+08	30%	3.63E+07	4.20E+04
1.76E+09	2.62E+08	1.44E+08	30%	4.33E+07	5.01E+04
1.16E+08	1.90E+08	1.05E+08	30%	3.14E+07	3.63E+04
6.09E+08	4.98E+08	2.74E+08	30%	8.22E+07	9.53E+04
9.60E+08	2.24E+08	1.23E+08	30%	3.70E+07	4.29E+04
1.99E+08	3.26E+08	1.79E+08	30%	5.38E+07	6.23E+04
2.72E+08	4.45E+08	2.45E+08	30%	7.35E+07	8.51E+04
2.28E+08	1.87E+08	1.03E+08	30%	3.08E+07	3.57E+04
4.02E+08	2.19E+08	1.21E+08	30%	3.62E+07	4.19E+04
4.21E+08	3.44E+08	1.89E+08	30%	5.68E+07	6.58E+04
8.83E+08	3.61E+08	1.99E+08	30%	5.96E+07	6.91E+04
9.20E+08	1.88E+08	1.03E+08	30%	3.10E+07	3.60E+04
9.67E+08	5.27E+08	2.90E+08	30%	8.70E+07	1.01E+05
1.47E+09	4.82E+08	2.65E+08	30%	7.95E+07	9.21E+04
1.28E+09	6.98E+08	3.84E+08	30%	1.15E+08	1.33E+05
2.03E+08	1.11E+08	6.09E+07	30%	1.83E+07	2.12E+04
5.20E+09	9.45E+08	5.20E+08	30%	1.56E+08	1.81E+05
5.33E+09	5.45E+08	3.00E+08	30%	9.00E+07	1.04E+05
1.22E+09	3.32E+08	1.83E+08	30%	5.48E+07	6.35E+04
2.80E+09	3.82E+08	2.10E+08	30%	6.31E+07	7.30E+04
1.50E+09	4.09E+08	2.25E+08	30%	6.75E+07	7.81E+04
Total recoverable energy (Kcal)	Heat Loss / furnace (kcal/yr)	Heat out Flue (Kcal/yr)	Cogeneration Efficiency	Energy Obtained from Cogeneration Application (kcal/yr)	KWh / furnace / yr

D.3 27 Non-Deviated Factories

Factory Name	Code	CH4/KG glass	KWh Total /yr	Glass Production (metric ton)	Glass Production (kg)	CH4/yr(m3)	Number Of Furnaces	Days of Operation / yr
Mazzuccato di M. Daniele SRL	79	2.7041175	7.67E+03	0.821428571	821.43	8050	1	230.00
Barovier e Toso	20	8.04796875	6.35E+04	2.285714286	2,285.71	66666.66667	3	200.00
Name Unknown	1036	4.385338172	3.63E+04	2.4	2,400.00	38143	1	210.00
Fratelli Barbini di Barbini Cesare	55	5.1507	6.23E+04	3.503571429	3,503.57	65400	1	218.00
Donà Guido	40	5.7945375	7.14E+04	3.571428571	3,571.43	75000	2	250.00
Nuova PIM Cristalleria SAS	91	5.1507	8.51E+04	4.785714286	4,785.71	89333.33333	1	335.00
Name Unknown	1006	4.26220425	8.41E+04	5.714285714	5,714.29	88266.66667	2	200.00
A.V. Mazzega SRL	2	4.18494375	8.67E+04	6	6,000.00	91000	2	210.00
D'este Bruno	36	6.11645625	1.32E+05	6.228571429	6,228.57	138066.6667	2	218.00
L'Artistica Muranese di Badioli M. e. C.	62	5.7945375	1.26E+05	6.285714286	6,285.71	132000	3	246.67
Tagliapietra Dino	117	3.355037213	7.94E+04	6.857142857	6,857.14	83376	2	240.00
Artigianto Artistico Veneziano	12	3.49818375	1.04E+05	8.571428571	8,571.43	108666.6667	2	200.00
Guarnieri Vetr. A.	59	3.92740875	1.16E+05	8.571428571	8,571.43	122000	3	200.00
Name Unknown	1029	4.82878125	1.91E+05	11.42857143	11,428.57	200000	2	200.00
Linea Mazzuccato	71	6.720053906	2.88E+05	12.4	12,400.00	301991.6667	8	217.00
Gambaro e Poggi SNC	57	6.966804628	3.02E+05	12.57142857	12,571.43	317408.6667	3	220.00
La Murrina SRL	66	6.2237625	2.76E+05	12.85714286	12,857.14	290000	4	300.00
Artigianato Muranese SNC	11	7.72605	4.00E+05	15	15,000.00	420000	3	210.00
Name Unknown	1027	3.60549	2.06E+05	16.57142857	16,571.43	216533.3333	3	232.00
Nuova Artigiana Colleoni SNC	89	4.82878125	3.00E+05	18	18,000.00	315000	7	210.00
J.W.P. di Cavagnis	61	7.342006579	4.60E+05	18.15857143	18,158.57	483166.6667	5	222.40
AVEM Arte Vetreria Muranese SAS	15	3.824504808	2.65E+05	20.05714286	20,057.14	278000	5	200.00
Name Unknown	1042	2.015211375	2.06E+05	29.57142857	29,571.43	215970	4	230.00
Vetreria Artistica Archimede Seguso	**122**	**3.824922461**	**4.89E+05**	**37.02**	**37,020.00**	**513168**	**4**	**320.00**
Ercole Moretti e fratelli	47	4.29225	5.51E+05	37.2	37,200.00	578666.6667	11	217.00
Linea Padovan	72	2.179142308	3.07E+05	40.85714286	40,857.14	322666.6667	4	220.00
Ongaro Fuga di Fuga G. e C.	92	8.441425	1.63E+06	55.8	55,800.00	1707066.667	9	217.00

Weeks of Operation / yr	Electricity (KWh/yr)	Melting Pot Contents (kg/yr)	Specific Heat of Waste gas (kcal/m3*K)	Output Temperature (k)	Input Temperature (K)
32.85714286	1560	1014.109347	0.38	1623	298
28.57142857	9600	2821.869489	0.38	1623	298
30	6696	2962.962963	0.38	1623	298
31.14285714	12000	4325.396825	0.38	1623	298
35.71428571	35400	4409.171076	0.38	1623	298
47.85714286	35520	5908.289242	0.38	1623	298
28.57142857	157620	7054.673721	0.38	1623	298
30	6000	7407.407407	0.38	1623	298
31.14285714	12000	7689.594356	0.38	1623	298
35.23809524	5652	7760.141093	0.38	1623	298
34.28571429	122736	8465.608466	0.38	1623	298
28.57142857	12960	10582.01058	0.38	1623	298
28.57142857	14400	10582.01058	0.38	1623	298
28.57142857	11940	14109.34744	0.38	1623	298
31	50388	15308.64198	0.38	1623	298
31.42857143	115488	15520.28219	0.38	1623	298
42.85714286	36000	15873.01587	0.38	1623	298
30	132000	18518.51852	0.38	1623	298
33.14285714	51600	20458.55379	0.38	1623	298
30	36000	22222.22222	0.38	1623	298
31.77142857	51000	22417.98942	0.38	1623	298
28.57142857	34836	24761.90476	0.38	1623	298
32.85714286	120204	36507.93651	0.38	1623	298
45.7	**113859**	**45703.7037**	**0.38**	**1623**	**298**
31	144000	45925.92593	0.38	1623	298
31.42857143	72000	50440.91711	0.38	1623	298
31	336000	68888.88889	0.38	1623	298

Energy Contained in Waste Gas (Kcal/yr)	Heat Acquired From CH4 Combustion (Kcal/yr)	Heat Needed to Melt Pot Contents (Kcal)	Total Heat Loss (Kcal/yr)	Total Waste Gas (m3/yr)	Flue Efficiency
4.46E+07	6.76E+07	2.30E+07	4.46E+07	8.86E+04	5.50E-01
3.69E+08	5.60E+08	1.91E+08	3.69E+08	7.33E+05	5.50E-01
2.11E+08	3.20E+08	1.09E+08	2.11E+08	4.20E+05	5.50E-01
3.62E+08	5.49E+08	1.87E+08	3.62E+08	7.19E+05	5.50E-01
4.15E+08	6.30E+08	2.15E+08	4.15E+08	8.25E+05	5.50E-01
4.95E+08	7.50E+08	2.56E+08	4.95E+08	9.83E+05	5.50E-01
4.89E+08	7.41E+08	2.53E+08	4.89E+08	9.71E+05	5.50E-01
5.04E+08	7.64E+08	2.60E+08	5.04E+08	1.00E+06	5.50E-01
7.65E+08	1.16E+09	3.95E+08	7.65E+08	1.52E+06	5.50E-01
7.31E+08	1.11E+09	3.78E+08	7.31E+08	1.45E+06	5.50E-01
4.62E+08	7.00E+08	2.39E+08	4.62E+08	9.17E+05	5.50E-01
6.02E+08	9.13E+08	3.11E+08	6.02E+08	1.20E+06	5.50E-01
6.76E+08	1.02E+09	3.49E+08	6.76E+08	1.34E+06	5.50E-01
1.11E+09	1.68E+09	5.72E+08	1.11E+09	2.20E+06	5.50E-01
1.67E+09	2.54E+09	8.64E+08	1.67E+09	3.32E+06	5.50E-01
1.76E+09	2.67E+09	9.08E+08	1.76E+09	3.49E+06	5.50E-01
1.61E+09	2.44E+09	8.30E+08	1.61E+09	3.19E+06	5.50E-01
2.33E+09	3.53E+09	1.20E+09	2.33E+09	4.62E+06	5.50E-01
1.20E+09	1.82E+09	6.20E+08	1.20E+09	2.38E+06	5.50E-01
1.74E+09	2.65E+09	9.01E+08	1.74E+09	3.47E+06	5.50E-01
2.68E+09	4.06E+09	1.38E+09	2.68E+09	5.31E+06	5.50E-01
1.54E+09	2.34E+09	7.95E+08	1.54E+09	3.06E+06	5.50E-01
1.20E+09	1.81E+09	6.18E+08	1.20E+09	2.38E+06	5.50E-01
2.84E+09	**4.31E+09**	**1.47E+09**	**2.84E+09**	**5.64E+06**	**5.50E-01**
3.20E+09	4.86E+09	1.66E+09	3.20E+09	6.37E+06	5.50E-01
1.79E+09	2.71E+09	9.23E+08	1.79E+09	3.55E+06	5.50E-01
9.45E+09	1.43E+10	4.88E+09	9.45E+09	1.88E+07	5.50E-01

Total recoverable energy (Kcal)	Heat Loss / furnace (kcal/yr)	Heat out Flue (Kcal/yr)	Cogeneration Efficiency	Energy Obtained from Cogeneration Application (kcal/yr)	KWh / furnace / yr
2.45E+07	4.01E+07	2.21E+07	3.00E-01	6.62E+06	7.67E+03
2.03E+08	1.11E+08	6.09E+07	3.00E-01	1.83E+07	2.12E+04
1.16E+08	1.90E+08	1.05E+08	3.00E-01	3.14E+07	3.63E+04
1.99E+08	3.26E+08	1.79E+08	3.00E-01	5.38E+07	6.23E+04
2.28E+08	1.87E+08	1.03E+08	3.00E-01	3.08E+07	3.57E+04
2.72E+08	4.45E+08	2.45E+08	3.00E-01	7.35E+07	8.51E+04
2.69E+08	2.20E+08	1.21E+08	3.00E-01	3.63E+07	4.20E+04
2.77E+08	2.27E+08	1.25E+08	3.00E-01	3.74E+07	4.33E+04
4.21E+08	3.44E+08	1.89E+08	3.00E-01	5.68E+07	6.58E+04
4.02E+08	2.19E+08	1.21E+08	3.00E-01	3.62E+07	4.19E+04
2.54E+08	2.08E+08	1.14E+08	3.00E-01	3.43E+07	3.97E+04
3.31E+08	2.71E+08	1.49E+08	3.00E-01	4.47E+07	5.18E+04
3.72E+08	2.03E+08	1.11E+08	3.00E-01	3.34E+07	3.87E+04
6.09E+08	4.98E+08	2.74E+08	3.00E-01	8.22E+07	9.53E+04
9.20E+08	1.88E+08	1.03E+08	3.00E-01	3.10E+07	3.60E+04
9.67E+08	5.27E+08	2.90E+08	3.00E-01	8.70E+07	1.01E+05
8.83E+08	3.61E+08	1.99E+08	3.00E-01	5.96E+07	6.91E+04
1.28E+09	6.98E+08	3.84E+08	3.00E-01	1.15E+08	1.33E+05
6.60E+08	3.60E+08	1.98E+08	3.00E-01	5.94E+07	6.88E+04
9.60E+08	2.24E+08	1.23E+08	3.00E-01	3.70E+07	4.29E+04
1.47E+09	4.82E+08	2.65E+08	3.00E-01	7.95E+07	9.21E+04
8.47E+08	2.77E+08	1.52E+08	3.00E-01	4.57E+07	5.30E+04
6.58E+08	2.69E+08	1.48E+08	3.00E-01	4.44E+07	5.14E+04
1.56E+09	**6.39E+08**	**3.52E+08**	**3.00E-01**	**1.06E+08**	**1.22E+05**
1.76E+09	2.62E+08	1.44E+08	3.00E-01	4.33E+07	5.01E+04
9.83E+08	4.02E+08	2.21E+08	3.00E-01	6.63E+07	7.68E+04
5.20E+09	9.45E+08	5.20E+08	3.00E-01	1.56E+08	1.81E+05

D.4 kWh Temp (Temperature affect on kWh for Non-Deviating Factories)

Factory Name	Code	CH4/KG glass	Glass Production (metric ton)		1350 C	1150 C	950 C	750 C
Name Unknown	1052	0.1	15.000	KWH Total/ year	3.33E+03	2.83E+03	2.33E+03	1.82E+03
Mazzuccato di M. Daniele SRL	79	2.7	0.821		7.67E+03	6.51E+03	5.35E+03	4.20E+03
Name Unknown	1044	1.6	2.286		1.23E+04	1.05E+04	8.62E+03	6.76E+03
Bisazza Vetro SRL	24	0.3	25.714		2.48E+04	2.10E+04	1.73E+04	1.36E+04
Name Unknown	1014	0.6	12.857		2.62E+04	2.22E+04	1.83E+04	1.43E+04
Premiata Glass	97	1.0	9.000		3.20E+04	2.72E+04	2.23E+04	1.75E+04
Name Unknown	1036	4.4	2.400		3.63E+04	3.09E+04	2.54E+04	1.99E+04
Name Unknown	1043	1.7	9.429		5.45E+04	4.63E+04	3.80E+04	2.98E+04
Fratelli Barbini di Barbini Cesare	55	5.2	3.504		6.23E+04	5.29E+04	4.35E+04	3.41E+04
Name Unknown	1032	0.4	50.286		6.29E+04	5.34E+04	4.39E+04	3.44E+04
Barovier e Toso	20	8.0	2.286		6.35E+04	5.39E+04	4.43E+04	3.47E+04
Donà Guido	40	5.8	3.571		7.14E+04	6.07E+04	4.99E+04	3.91E+04
Berengo Fine Arts	21	0.1	160.714		7.24E+04	6.15E+04	5.05E+04	3.96E+04
Name Unknown	1033	1.7	12.571		7.34E+04	6.23E+04	5.12E+04	4.01E+04
Moretti Franco	83	1.4	15.714		7.54E+04	6.41E+04	5.27E+04	4.13E+04
Tagliapietra Dino	117	3.4	6.857		7.94E+04	6.74E+04	5.54E+04	4.35E+04
Name Unknown	1006	4.3	5.714		8.41E+04	7.14E+04	5.87E+04	4.60E+04
Nuova PIM Cristalleria SAS	91	5.2	4.786		8.51E+04	7.23E+04	5.94E+04	4.66E+04
A.V. Mazzega SRL	2	4.2	6.000		8.67E+04	7.36E+04	6.05E+04	4.74E+04
Artigianto Artistico Veneziano	12	3.5	8.571		1.04E+05	8.79E+04	7.23E+04	5.66E+04
Name Unknown	1054	1.3	24.000		1.10E+05	9.35E+04	7.69E+04	6.03E+04
Guarnieri Vetr. A.	59	3.9	8.571		1.16E+05	9.87E+04	8.11E+04	6.36E+04
L'Artistica Muranese di Badioli M. e. C.	62	5.8	6.286		1.26E+05	1.07E+05	8.78E+04	6.88E+04
D'este Bruno	36	6.1	6.229		1.32E+05	1.12E+05	9.18E+04	7.20E+04
Name Unknown	1050	1.0	40.000		1.37E+05	1.16E+05	9.58E+04	7.51E+04
Mosaici Donà	84	1.4	28.571		1.37E+05	1.16E+05	9.58E+04	7.51E+04
Name Unknown	1045	0.7	57.143		1.40E+05	1.19E+05	9.75E+04	7.64E+04
Lavorazioni Artistiche di Amadi Fabiano	69	1.7	24.571		1.43E+05	1.22E+05	1.00E+05	7.84E+04
Name Unknown	1031	0.8	65.714		1.75E+05	1.49E+05	1.22E+05	9.59E+04
Name Unknown	1029	4.8	11.429		1.91E+05	1.62E+05	1.33E+05	1.04E+05
Name Unknown	1042	2.0	29.571		2.06E+05	1.75E+05	1.44E+05	1.13E+05
Name Unknown	1027	3.6	16.571		2.06E+05	1.75E+05	1.44E+05	1.13E+05
Cristal Center Factory in Murano SRL	35	1.5	42.857		2.29E+05	1.94E+05	1.60E+05	1.25E+05
AVEM Arte Vetreria Muranese SAS	15	3.8	20.057		2.65E+05	2.25E+05	1.85E+05	1.45E+05
La Murrina SRL	66	6.2	12.857		2.76E+05	2.35E+05	1.93E+05	1.51E+05
Linea Mazzuccato	71	6.7	12.400		2.88E+05	2.44E+05	2.01E+05	1.57E+05
Nuova Artigiana Colleoni SNC	89	4.8	18.000		3.00E+05	2.55E+05	2.09E+05	1.64E+05
Gambaro e Poggi SNC	57	7.0	12.571		3.02E+05	2.57E+05	2.11E+05	1.65E+05
Linea Padovan	72	2.2	40.857		3.07E+05	2.61E+05	2.15E+05	1.68E+05
Pagan Murrine di C. Pagan	94	1.8	57.143		3.49E+05	2.97E+05	2.44E+05	1.91E+05
Name Unknown	1055	12.9	8.571		3.81E+05	3.24E+05	2.66E+05	2.08E+05
Artigianato Muranese SNC	11	7.7	15.000		4.00E+05	3.40E+05	2.79E+05	2.19E+05
J.W.P. di Cavagnis	61	7.3	18.159		4.60E+05	3.91E+05	3.21E+05	2.52E+05
Vetreria Artistica Schiavon	133	22.6	6.000		4.69E+05	3.98E+05	3.27E+05	2.57E+05
Vetreria Artistica Archimede Seguso	**122**	**3.8**	**37.020**		**4.89E+05**	**4.15E+05**	**3.41E+05**	**2.67E+05**
Ercole Moretti e fratelli	47	4.3	37.200		5.51E+05	4.68E+05	3.85E+05	3.02E+05
Name Unknown	158	20.9	12.157		8.76E+05	7.44E+05	6.12E+05	4.80E+05
Ongaro Fuga di Fuga G. e C.	92	8.4	55.800		1.63E+06	1.38E+06	1.14E+06	8.90E+05
Nuova Marco Polo SRL	90	10.7	45.000		1.67E+06	1.42E+06	1.16E+06	9.12E+05
Name Unknown	1053	1.8	282.857		1.75E+06	1.48E+06	1.22E+06	9.56E+05
Factory Name	Code	CH4/KG glass	Glass Production (metric ton)		1350 C	1150 C	950 C	750 C
Mazzuccato di M. Daniele SRL	79	2.7	0.821	KWH Total/ year	7.67E+03	6.51E+03	5.35E+03	4.20E+03

Name Unknown	1036	4.4	2.400		3.63E+04	3.09E+04	2.54E+04	1.99E+04
Fratelli Barbini di Barbini Cesare	55	5.2	3.504		6.23E+04	5.29E+04	4.35E+04	3.41E+04
Barovier e Toso	20	8.0	2.286		6.35E+04	5.39E+04	4.43E+04	3.47E+04
Donà Guido	40	5.8	3.571		7.14E+04	6.07E+04	4.99E+04	3.91E+04
Tagliapietra Dino	117	3.4	6.857		7.94E+04	6.74E+04	5.54E+04	4.35E+04
Name Unknown	1006	4.3	5.714		8.41E+04	7.14E+04	5.87E+04	4.60E+04
Nuova PIM Cristalleria SAS	91	5.2	4.786		8.51E+04	7.23E+04	5.94E+04	4.66E+04
A.V. Mazzega SRL	2	4.2	6.000		8.67E+04	7.36E+04	6.05E+04	4.74E+04
Artigianto Artistico Veneziano	12	3.5	8.571		1.04E+05	8.79E+04	7.23E+04	5.66E+04
Guarnieri Vetr. A.	59	3.9	8.571		1.16E+05	9.87E+04	8.11E+04	6.36E+04
L'Artistica Muranese di Badioli M. e. C.	62	5.8	6.286		1.26E+05	1.07E+05	8.78E+04	6.88E+04
D'este Bruno	36	6.1	6.229		1.32E+05	1.12E+05	9.18E+04	7.20E+04
Name Unknown	1029	4.8	11.429		1.91E+05	1.62E+05	1.33E+05	1.04E+05
Name Unknown	1042	2.0	29.571		2.06E+05	1.75E+05	1.44E+05	1.13E+05
Name Unknown	1027	3.6	16.571		2.06E+05	1.75E+05	1.44E+05	1.13E+05
AVEM Arte Vetreria Muranese SAS	15	3.8	20.057		2.65E+05	2.25E+05	1.85E+05	1.45E+05
La Murrina SRL	66	6.2	12.857		2.76E+05	2.35E+05	1.93E+05	1.51E+05
Linea Mazzuccato	71	6.7	12.400		2.88E+05	2.44E+05	2.01E+05	1.57E+05
Nuova Artigiana Colleoni SNC	89	4.8	18.000		3.00E+05	2.55E+05	2.09E+05	1.64E+05
Gambaro e Poggi SNC	57	7.0	12.571		3.02E+05	2.57E+05	2.11E+05	1.65E+05
Linea Padovan	72	2.2	40.857		3.07E+05	2.61E+05	2.15E+05	1.68E+05
Artigianato Muranese SNC	11	7.7	15.000		4.00E+05	3.40E+05	2.79E+05	2.19E+05
J.W.P. di Cavagnis	61	7.3	18.159		4.60E+05	3.91E+05	3.21E+05	2.52E+05
Vetreria Artistica Archimede Seguso	**122**	**3.8**	**37.020**		**4.89E+05**	**4.15E+05**	**3.41E+05**	**2.67E+05**
Ercole Moretti e fratelli	47	4.3	37.200		5.51E+05	4.68E+05	3.85E+05	3.02E+05
Ongaro Fuga di Fuga G. e C.	92	8.4	55.800		1.63E+06	1.38E+06	1.14E+06	8.90E+05

Appendix E – Extrapolation

Extrapolation

“Extrapolation.xls”

E.1 Extrapolation Data

E.2 Extrapolation Analysis

E.1 Extrapolation Data

Legal Name	factory_code	Number Of Furnaces	Electricity_KWh/year	Total Heat Loss in Kcal/Yr	Total Heat Loss in KWh/Yr
A.V. Mazzega SRL	2	2	6000	504003837	5.86E+05
Artigianato Muranese SNC	11	3	132000	2326171556	2.71E+06
Artigianto Artistico Veneziano	12	2	12960	601850735.8	7.00E+05
AVEM Arte Vetreria Muranese SAS	15	5	34836	1539704030	1.79E+06
Barovier e Toso	20	3	9600	369233580.2	4.29E+05
D'este Bruno	36	2	12000	764682744.7	8.89E+05
Donà Guido	40	2	35400	415387777.8	4.83E+05
Ercole Moretti e fratelli	47	11	144000	3204947477	3.73E+06
Fratelli Barbini di Barbini Cesare	55	1	12000	362218142.2	4.21E+05
Gambaro e Poggi SNC	57	3	115488	1757969076	2.04E+06
Guarnieri Vetr. A.	59	3	14400	675697451.9	7.86E+05
J.W.P. di Cavagnis	61	5	51000	2676020373	3.11E+06
L'Artistica Muranese di Badioli M. e. C.	62	3	5652	731082488.9	8.50E+05
La Murrina SRL	66	4	36000	1606166074	1.87E+06
Linea Mazzuccato	71	8	50388	1672581964	1.95E+06
Linea Padovan	72	4	72000	1787090528	2.08E+06
Mazzuccato di M. Daniele SRL	79	1	1560	44584954.81	5.19E+04
Nuova Artigiana Colleoni SNC	89	7	36000	1744628667	2.03E+06
Nuova PIM Cristalleria SAS	91	1	35520	494772997.5	5.75E+05
Ongaro Fuga di Fuga G. e C.	92	9	336000	9454595056	1.10E+07
Tagliapietra Dino	117	2	122736	461778284.8	5.37E+05
Vetr. Art. Archimede Seguso	122	4	113859	3.57E+08	4.89E+05
Name Unknown	1006	2	157620	488865260.2	5.69E+05
Name Unknown	1027	3	51600	1199270669	1.39E+06
Name Unknown	1029	2	11940	1107700741	1.29E+06
Name Unknown	1036	1	6696	211255146.8	2.46E+05
Name Unknown	1042	4	120204	1196150645	1.39E+06
	Total	97	1.74E+06	3.78E+10	4.40E+07

E.2 Extrapolation Analysis

Overall Efficiency	Electricity KWh/Year	Total Allowable Investment Over 3 Years	Over 5 Years	Over 7 Years	Over 10 Years
6%	2.64E+06	L. 13,722,865,144	L. 22,871,441,907	L. 32,020,018,670	L. 45,742,883,814
8%	3.52E+06	L. 18,297,153,525	L. 30,495,255,876	L. 42,693,358,226	L. 60,990,511,752
10%	4.40E+06	L. 22,871,441,907	L. 38,119,069,845	L. 53,366,697,783	L. 76,238,139,689
12%	5.28E+06	L. 27,445,730,288	L. 45,742,883,814	L. 64,040,037,339	L. 91,485,767,627
14%	6.16E+06	L. 32,020,018,670	L. 53,366,697,783	L. 74,713,376,896	L. 106,733,395,565
16%	7.04E+06	L. 36,594,307,051	L. 60,990,511,752	L. 85,386,716,452	L. 121,981,023,503
18%	7.92E+06	L. 41,168,595,432	L. 68,614,325,721	L. 96,060,056,009	L. 137,228,651,441
20%	8.80E+06	L. 45,742,883,814	L. 76,238,139,689	L. 106,733,395,565	L. 152,476,279,379
22%	9.68E+06	L. 50,317,172,195	L. 83,861,953,658	L. 117,406,735,122	L. 167,723,907,317
24%	1.06E+07	L. 54,891,460,576	L. 91,485,767,627	L. 128,080,074,678	L. 182,971,535,255

green = self sustaining
red = not self sustaining

Minimum Efficiency	6%
Increment	2%
Total Electrical Usage	1.74E+06
Electricity Sale Price	L. 300
Min. Self-sust. Eff.	3.95%
Total factories	27
Factories on Murano	156
Multiplier for extrapolation	5.777777778
Exchange Rate 1€ =	L. 1,936.27

Overall Efficiency	Electricity KWh/Year	Total Allowable Investment Over 3 Years	Over 5 Years	Over 7 Years	Over 10 Years
6%	2.64E+06	€ 7,087,268.38	€ 11,812,113.96	€ 16,536,959.55	€ 23,624,227.93
8%	3.52E+06	€ 9,449,691.17	€ 15,749,485.29	€ 22,049,279.40	€ 31,498,970.57
10%	4.40E+06	€ 11,812,113.96	€ 19,686,856.61	€ 27,561,599.25	€ 39,373,713.22
12%	5.28E+06	€ 14,174,536.76	€ 23,624,227.93	€ 33,073,919.10	€ 47,248,455.86
14%	6.16E+06	€ 16,536,959.55	€ 27,561,599.25	€ 38,586,238.95	€ 55,123,198.50
16%	7.04E+06	€ 18,899,382.34	€ 31,498,970.57	€ 44,098,558.80	€ 62,997,941.15
18%	7.92E+06	€ 21,261,805.14	€ 35,436,341.89	€ 49,610,878.65	€ 70,872,683.79
20%	8.80E+06	€ 23,624,227.93	€ 39,373,713.22	€ 55,123,198.50	€ 78,747,426.43
22%	9.68E+06	€ 25,986,650.72	€ 43,311,084.54	€ 60,635,518.35	€ 86,622,169.08
24%	1.06E+07	€ 28,349,073.52	€ 47,248,455.86	€ 66,147,838.20	€ 94,496,911.72

green = self sustaining
red = not self sustaining

Appendix F – Factory Data Sheets

Factory Data Sheets

“Factory Data.mdb”

3 Fiori SNC # 1

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	3
Glass Production	3.14E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	33,733.33 m^3
Mass of Material Melted per Year	3,880.07 Kg
Natural Gas Usage per Unit of Glass	2.96 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.83E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	9.65E+07 Kcal/Yr
Total Heat Loss	1.87E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	3.71E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.03E+08 Kcal/Yr
Electricity Production	3.57E+04 KWhl/Yr

A.V. Mazzega SRL # 2

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	2
Glass Production	6.00E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	6000 KWh
Yearly Natural Gas Usage	91,000.00 m^3
Mass of Material Melted per Year	7,407.41 Kg
Natural Gas Usage per Unit of Glass	4.18 m^3/Kg
Heat Acquired From Natural Gas Combustion	7.64E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	2.60E+08 Kcal/Yr
Total Heat Loss	5.04E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.00E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.77E+08 Kcal/Yr
Electricity Production	9.63E+04 KWhl/Yr

Antica Murano # 7

Furnace Operating Times

Days of Operation per Year	320
Weeks of Opertaion per Year	45.71

Factory Data

Number of Furnaces	1
Glass Production	1.37E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	6,933.33 m^3
Mass of Material Melted per Year	16,931.22 Kg
Natural Gas Usage per Unit of Glass	0.14 m^3/Kg
Heat Acquired From Natural Gas Combustion	5.82E+07 Kcal/Yr
Heat Needed to Melt Pot Contents	1.98E+07 Kcal/Yr
Total Heat Loss	3.84E+07 Kcal/Yr

Output Values

Total Waste Gas per Year	7.63E+04 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.11E+07 Kcal/Yr
Electricity Production	7.34E+03 KWhl/Yr

Artigianato Muranese SNC # 11

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	3
Glass Production	1.50E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	132000 KWh
Yearly Natural Gas Usage	420,000.00 m^3
Mass of Material Melted per Year	18,518.52 Kg
Natural Gas Usage per Unit of Glass	7.73 m^3/Kg
Heat Acquired From Natural Gas Combustion	3.53E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	1.20E+09 Kcal/Yr
Total Heat Loss	2.33E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	4.62E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.28E+09 Kcal/Yr
Electricity Production	4.45E+05 KWhl/Yr

Artigianto Artistico Veneziano # 12

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	2
Glass Production	8.57E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	12960 KWh
Yearly Natural Gas Usage	108,666.67 m^3
Mass of Material Melted per Year	10,582.01 Kg
Natural Gas Usage per Unit of Glass	3.50 m^3/Kg
Heat Acquired From Natural Gas Combustion	9.13E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	3.11E+08 Kcal/Yr
Total Heat Loss	6.02E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.20E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	3.31E+08 Kcal/Yr
Electricity Production	1.15E+05 KWhl/Yr

AVEM Arte Vetreria Muranese SAS # 15

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	5
Glass Production	2.01E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	34836 KWh
Yearly Natural Gas Usage	278,000.00 m^3
Mass of Material Melted per Year	24,761.90 Kg
Natural Gas Usage per Unit of Glass	3.82 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.34E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	7.95E+08 Kcal/Yr
Total Heat Loss	1.54E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	3.06E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	8.47E+08 Kcal/Yr
Electricity Production	2.94E+05 KWhl/Yr

Ballarin # 18

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	4
Glass Production	2.14E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	18,666.67 m^3
Mass of Material Melted per Year	26,455.03 Kg
Natural Gas Usage per Unit of Glass	0.24 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.57E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	5.34E+07 Kcal/Yr
Total Heat Loss	1.03E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	2.05E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	5.69E+07 Kcal/Yr
Electricity Production	1.98E+04 KWhl/Yr

Barovier e Toso # 20

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	3
Glass Production	2.29E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	9600 KWh
Yearly Natural Gas Usage	66,666.67 m^3
Mass of Material Melted per Year	2,821.87 Kg
Natural Gas Usage per Unit of Glass	8.05 m^3/Kg
Heat Acquired From Natural Gas Combustion	5.60E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	1.91E+08 Kcal/Yr
Total Heat Loss	3.69E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	7.33E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.03E+08 Kcal/Yr
Electricity Production	7.06E+04 KWhl/Yr

Berengo Fine Arts # 21

Furnace Operating Times

Days of Operation per Year	225
Weeks of Opertaion per Year	32.14

Factory Data

Number of Furnaces	9
Glass Production	1.61E+05 Kg/Yr

Energy Values

Yearly Electricity Usage	129600 KWh
Yearly Natural Gas Usage	75,990.00 m^3
Mass of Material Melted per Year	198,412.70 Kg
Natural Gas Usage per Unit of Glass	0.13 m^3/Kg
Heat Acquired From Natural Gas Combustion	6.38E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	2.17E+08 Kcal/Yr
Total Heat Loss	4.21E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	8.36E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.31E+08 Kcal/Yr
Electricity Production	8.04E+04 KWhl/Yr

Bisazza Vetro SRL # 24

Furnace Operating Times

Days of Operation per Year	60
Weeks of Opertaion per Year	8.57

Factory Data

Number of Furnaces	8
Glass Production	2.57E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	15960 KWh
Yearly Natural Gas Usage	26,000.00 m^3
Mass of Material Melted per Year	31,746.03 Kg
Natural Gas Usage per Unit of Glass	0.28 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.18E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	7.44E+07 Kcal/Yr
Total Heat Loss	1.44E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	2.86E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	7.92E+07 Kcal/Yr
Electricity Production	2.75E+04 KWhl/Yr

Cristal Center Factory in Murano SRL # 35

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	2
Glass Production	4.29E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	38400 KWh
Yearly Natural Gas Usage	240,000.00 m^3
Mass of Material Melted per Year	52,910.05 Kg
Natural Gas Usage per Unit of Glass	1.55 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.02E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	6.87E+08 Kcal/Yr
Total Heat Loss	1.33E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	2.64E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	7.31E+08 Kcal/Yr
Electricity Production	2.54E+05 KWhl/Yr

D'este Bruno # 36

Furnace Operating Times

Days of Operation per Year	218
Weeks of Opertaion per Year	31.14

Factory Data

Number of Furnaces	2
Glass Production	6.23E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	12000 KWh
Yearly Natural Gas Usage	138,066.67 m^3
Mass of Material Melted per Year	7,689.59 Kg
Natural Gas Usage per Unit of Glass	6.12 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.16E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	3.95E+08 Kcal/Yr
Total Heat Loss	7.65E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.52E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	4.21E+08 Kcal/Yr
Electricity Production	1.46E+05 KWhl/Yr

Donà Guido # 40

Furnace Operating Times

Days of Operation per Year	250
Weeks of Opertaion per Year	35.71

Factory Data

Number of Furnaces	2
Glass Production	3.57E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	35400 KWh
Yearly Natural Gas Usage	75,000.00 m^3
Mass of Material Melted per Year	4,409.17 Kg
Natural Gas Usage per Unit of Glass	5.79 m^3/Kg
Heat Acquired From Natural Gas Combustion	6.30E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	2.15E+08 Kcal/Yr
Total Heat Loss	4.15E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	8.25E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.28E+08 Kcal/Yr
Electricity Production	7.94E+04 KWhl/Yr

Effedue di Franco Fuga # 43

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	2
Glass Production	1.60E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	200,000.00 m^3
Mass of Material Melted per Year	19,753.09 Kg
Natural Gas Usage per Unit of Glass	3.45 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.68E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	5.72E+08 Kcal/Yr
Total Heat Loss	1.11E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	2.20E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	6.09E+08 Kcal/Yr
Electricity Production	2.12E+05 KWhl/Yr

Eli Vetri d'Arte SNC # 45

Furnace Operating Times

Days of Operation per Year	216
Weeks of Opertaion per Year	30.86

Factory Data

Number of Furnaces	1
Glass Production	3.09E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	158,400.00 m^3
Mass of Material Melted per Year	38,095.24 Kg
Natural Gas Usage per Unit of Glass	1.42 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.33E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	4.53E+08 Kcal/Yr
Total Heat Loss	8.77E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.74E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	4.83E+08 Kcal/Yr
Electricity Production	1.68E+05 KWhl/Yr

Ercole Moretti e fratelli # 47

Furnace Operating Times

Days of Operation per Year	217
Weeks of Opertaion per Year	31.00

Factory Data

Number of Furnaces	11
Glass Production	3.72E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	144000 KWh
Yearly Natural Gas Usage	578,666.67 m^3
Mass of Material Melted per Year	45,925.93 Kg
Natural Gas Usage per Unit of Glass	4.29 m^3/Kg
Heat Acquired From Natural Gas Combustion	4.86E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	1.66E+09 Kcal/Yr
Total Heat Loss	3.20E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	6.37E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.76E+09 Kcal/Yr
Electricity Production	6.12E+05 KWhl/Yr

Ferro Galliano # 51

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	3
Glass Production	1.05E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	160,000.00 m^3
Mass of Material Melted per Year	12,962.96 Kg
Natural Gas Usage per Unit of Glass	4.20 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.34E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	4.58E+08 Kcal/Yr
Total Heat Loss	8.86E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.76E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	4.87E+08 Kcal/Yr
Electricity Production	1.69E+05 KWhl/Yr

Fratelli Barbini di Barbini Cesare # 55

Furnace Operating Times

Days of Operation per Year	218
Weeks of Opertaion per Year	31.14

Factory Data

Number of Furnaces	1
Glass Production	3.50E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	12000 KWh
Yearly Natural Gas Usage	65,400.00 m^3
Mass of Material Melted per Year	4,325.40 Kg
Natural Gas Usage per Unit of Glass	5.15 m^3/Kg
Heat Acquired From Natural Gas Combustion	5.49E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	1.87E+08 Kcal/Yr
Total Heat Loss	3.62E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	7.19E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.99E+08 Kcal/Yr
Electricity Production	6.92E+04 KWhl/Yr

Gambaro e Poggi SNC # 57

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	3
Glass Production	1.26E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	115488 KWh
Yearly Natural Gas Usage	317,408.67 m^3
Mass of Material Melted per Year	15,520.28 Kg
Natural Gas Usage per Unit of Glass	6.97 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.67E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	9.08E+08 Kcal/Yr
Total Heat Loss	1.76E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	3.49E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	9.67E+08 Kcal/Yr
Electricity Production	3.36E+05 KWhl/Yr

Guarnieri Vetr. A. # 59

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	3
Glass Production	8.57E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	14400 KWh
Yearly Natural Gas Usage	122,000.00 m^3
Mass of Material Melted per Year	10,582.01 Kg
Natural Gas Usage per Unit of Glass	3.93 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.02E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	3.49E+08 Kcal/Yr
Total Heat Loss	6.76E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.34E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	3.72E+08 Kcal/Yr
Electricity Production	1.29E+05 KWhl/Yr

Furnace Operating Times

Days of Operation per Year	222.4
Weeks of Opertaion per Year	31.77

Factory Data

Number of Furnaces	5
Glass Production	1.82E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	51000 KWh
Yearly Natural Gas Usage	483,166.67 m^3
Mass of Material Melted per Year	22,417.99 Kg
Natural Gas Usage per Unit of Glass	7.34 m^3/Kg
Heat Acquired From Natural Gas Combustion	4.06E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	1.38E+09 Kcal/Yr
Total Heat Loss	2.68E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	5.31E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.47E+09 Kcal/Yr
Electricity Production	5.11E+05 KWhl/Yr

L'Artistica Muranese di Badioli M. e. C. # 62

Furnace Operating Times

Days of Operation per Year	246.6666667
Weeks of Opertaion per Year	35.24

Factory Data

Number of Furnaces	3
Glass Production	6.29E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	5652 KWh
Yearly Natural Gas Usage	132,000.00 m^3
Mass of Material Melted per Year	7,760.14 Kg
Natural Gas Usage per Unit of Glass	5.79 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.11E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	3.78E+08 Kcal/Yr
Total Heat Loss	7.31E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.45E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	4.02E+08 Kcal/Yr
Electricity Production	1.40E+05 KWhl/Yr

La Murrina SRL # 66

Furnace Operating Times

Days of Operation per Year	300
Weeks of Opertaion per Year	42.86

Factory Data

Number of Furnaces	4
Glass Production	1.29E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	36000 KWh
Yearly Natural Gas Usage	290,000.00 m^3
Mass of Material Melted per Year	15,873.02 Kg
Natural Gas Usage per Unit of Glass	6.22 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.44E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	8.30E+08 Kcal/Yr
Total Heat Loss	1.61E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	3.19E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	8.83E+08 Kcal/Yr
Electricity Production	3.07E+05 KWhl/Yr

Lavorazioni Artistiche di Amadi Fabiano # 69

Furnace Operating Times

Days of Operation per Year	215
Weeks of Opertaion per Year	30.71

Factory Data

Number of Furnaces	8
Glass Production	2.46E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	24000 KWh
Yearly Natural Gas Usage	150,500.00 m^3
Mass of Material Melted per Year	30,335.10 Kg
Natural Gas Usage per Unit of Glass	1.69 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.26E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	4.31E+08 Kcal/Yr
Total Heat Loss	8.34E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.66E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	4.58E+08 Kcal/Yr
Electricity Production	1.59E+05 KWhl/Yr

Linea Mazzuccato # 71

Furnace Operating Times

Days of Operation per Year	217
Weeks of Opertaion per Year	31.00

Factory Data

Number of Furnaces	8
Glass Production	1.24E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	50388 KWh
Yearly Natural Gas Usage	301,991.67 m^3
Mass of Material Melted per Year	15,308.64 Kg
Natural Gas Usage per Unit of Glass	6.72 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.54E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	8.64E+08 Kcal/Yr
Total Heat Loss	1.67E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	3.32E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	9.20E+08 Kcal/Yr
Electricity Production	3.20E+05 KWhl/Yr

Linea Padovan # 72

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	4
Glass Production	4.09E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	72000 KWh
Yearly Natural Gas Usage	322,666.67 m^3
Mass of Material Melted per Year	50,440.92 Kg
Natural Gas Usage per Unit of Glass	2.18 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.71E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	9.23E+08 Kcal/Yr
Total Heat Loss	1.79E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	3.55E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	9.83E+08 Kcal/Yr
Electricity Production	3.42E+05 KWhl/Yr

Mazzuccato di M. Daniele SRL # 79

Furnace Operating Times

Days of Operation per Year	230
Weeks of Opertaion per Year	32.86

Factory Data

Number of Furnaces	1
Glass Production	8.21E+02 Kg/Yr

Energy Values

Yearly Electricity Usage	1560 KWh
Yearly Natural Gas Usage	8,050.00 m^3
Mass of Material Melted per Year	1,014.11 Kg
Natural Gas Usage per Unit of Glass	2.70 m^3/Kg
Heat Acquired From Natural Gas Combustion	6.76E+07 Kcal/Yr
Heat Needed to Melt Pot Contents	2.30E+07 Kcal/Yr
Total Heat Loss	4.46E+07 Kcal/Yr

Output Values

Total Waste Gas per Year	8.86E+04 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.45E+07 Kcal/Yr
Electricity Production	8.52E+03 KWhl/Yr

Mazzuccato International # 80

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	3
Glass Production	1.14E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	240,000.00 m^3
Mass of Material Melted per Year	1,410.93 Kg
Natural Gas Usage per Unit of Glass	57.95 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.02E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	6.87E+08 Kcal/Yr
Total Heat Loss	1.33E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	2.64E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	7.31E+08 Kcal/Yr
Electricity Production	2.54E+05 KWhl/Yr

Moretti Franco # 83

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	1
Glass Production	1.57E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	9000 KWh
Yearly Natural Gas Usage	79,200.00 m^3
Mass of Material Melted per Year	19,400.35 Kg
Natural Gas Usage per Unit of Glass	1.39 m^3/Kg
Heat Acquired From Natural Gas Combustion	6.65E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	2.27E+08 Kcal/Yr
Total Heat Loss	4.39E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	8.71E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.41E+08 Kcal/Yr
Electricity Production	8.38E+04 KWhl/Yr

Mosaici Donà # 84

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	2
Glass Production	2.86E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	28800 KWh
Yearly Natural Gas Usage	144,000.00 m^3
Mass of Material Melted per Year	35,273.37 Kg
Natural Gas Usage per Unit of Glass	1.39 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.21E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	4.12E+08 Kcal/Yr
Total Heat Loss	7.98E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.58E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	4.39E+08 Kcal/Yr
Electricity Production	1.52E+05 KWhl/Yr

Nuova Artigiana Colleoni SNC # 89

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	7
Glass Production	1.80E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	36000 KWh
Yearly Natural Gas Usage	315,000.00 m^3
Mass of Material Melted per Year	22,222.22 Kg
Natural Gas Usage per Unit of Glass	4.83 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.65E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	9.01E+08 Kcal/Yr
Total Heat Loss	1.74E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	3.47E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	9.60E+08 Kcal/Yr
Electricity Production	3.33E+05 KWhl/Yr

Nuova Marco Polo SRL # 90

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	16
Glass Production	4.50E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	400800 KWh
Yearly Natural Gas Usage	1,750,000.00 m^3
Mass of Material Melted per Year	55,555.56 Kg
Natural Gas Usage per Unit of Glass	10.73 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.47E+10 Kcal/Yr
Heat Needed to Melt Pot Contents	5.01E+09 Kcal/Yr
Total Heat Loss	9.69E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	1.93E+07 m^3
Total Recoverable Energy (55% Flue Efficiency)	5.33E+09 Kcal/Yr
Electricity Production	1.85E+06 KWhl/Yr

Nuova PIM Cristalleria SAS # 91

Furnace Operating Times

Days of Operation per Year	335
Weeks of Opertaion per Year	47.86

Factory Data

Number of Furnaces	1
Glass Production	4.79E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	35520 KWh
Yearly Natural Gas Usage	89,333.33 m^3
Mass of Material Melted per Year	5,908.29 Kg
Natural Gas Usage per Unit of Glass	5.15 m^3/Kg
Heat Acquired From Natural Gas Combustion	7.50E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	2.56E+08 Kcal/Yr
Total Heat Loss	4.95E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	9.83E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.72E+08 Kcal/Yr
Electricity Production	9.46E+04 KWhl/Yr

Ongaro Fuga di Fuga G. e C. # 92

Furnace Operating Times

Days of Operation per Year	217
Weeks of Opertaion per Year	31.00

Factory Data

Number of Furnaces	9
Glass Production	5.58E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	336000 KWh
Yearly Natural Gas Usage	1,707,066.67 m^3
Mass of Material Melted per Year	68,888.89 Kg
Natural Gas Usage per Unit of Glass	8.44 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.43E+10 Kcal/Yr
Heat Needed to Melt Pot Contents	4.88E+09 Kcal/Yr
Total Heat Loss	9.45E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	1.88E+07 m^3
Total Recoverable Energy (55% Flue Efficiency)	5.20E+09 Kcal/Yr
Electricity Production	1.81E+06 KWhl/Yr

Pagan Murrine di C. Pagan # 94

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	6
Glass Production	5.71E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	162000 KWh
Yearly Natural Gas Usage	366,666.67 m^3
Mass of Material Melted per Year	70,546.74 Kg
Natural Gas Usage per Unit of Glass	1.77 m^3/Kg
Heat Acquired From Natural Gas Combustion	3.08E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	1.05E+09 Kcal/Yr
Total Heat Loss	2.03E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	4.03E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.12E+09 Kcal/Yr
Electricity Production	3.88E+05 KWhl/Yr

Premiata Glass # 97

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	5
Glass Production	9.00E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	27600 KWh
Yearly Natural Gas Usage	33,600.00 m^3
Mass of Material Melted per Year	11,111.11 Kg
Natural Gas Usage per Unit of Glass	1.03 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.82E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	9.61E+07 Kcal/Yr
Total Heat Loss	1.86E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	3.70E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.02E+08 Kcal/Yr
Electricity Production	3.56E+04 KWhl/Yr

Seguso Gianni # 105

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	1
Glass Production	2.70E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	213,500.00 m^3
Mass of Material Melted per Year	33,333.33 Kg
Natural Gas Usage per Unit of Glass	2.18 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.79E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	6.11E+08 Kcal/Yr
Total Heat Loss	1.18E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	2.35E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	6.50E+08 Kcal/Yr
Electricity Production	2.26E+05 KWhl/Yr

Signoretto Silvano # 112

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	3
Glass Production	Kg/Yr

Energy Values

Yearly Electricity Usage	14400 KWh
Yearly Natural Gas Usage	102,666.67 m^3
Mass of Material Melted per Year	Kg
Natural Gas Usage per Unit of Glass	m^3/Kg
Heat Acquired From Natural Gas Combustion	8.62E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	Kcal/Yr
Total Heat Loss	Kcal/Yr

Output Values

Total Waste Gas per Year	1.13E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	Kcal/Yr
Electricity Production	KWhl/Yr

Tagliapietra Dino # 117

Furnace Operating Times

Days of Operation per Year	240
Weeks of Opertaion per Year	34.29

Factory Data

Number of Furnaces	2
Glass Production	6.86E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	122736 KWh
Yearly Natural Gas Usage	83,376.00 m^3
Mass of Material Melted per Year	8,465.61 Kg
Natural Gas Usage per Unit of Glass	3.36 m^3/Kg
Heat Acquired From Natural Gas Combustion	7.00E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	2.39E+08 Kcal/Yr
Total Heat Loss	4.62E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	9.17E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.54E+08 Kcal/Yr
Electricity Production	8.82E+04 KWhl/Yr

Vetreria Accaeffe # 124

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	33
Glass Production	Kg/Yr

Energy Values

Yearly Electricity Usage	360000 KWh
Yearly Natural Gas Usage	1,804,000.00 m^3
Mass of Material Melted per Year	Kg
Natural Gas Usage per Unit of Glass	m^3/Kg
Heat Acquired From Natural Gas Combustion	1.52E+10 Kcal/Yr
Heat Needed to Melt Pot Contents	Kcal/Yr
Total Heat Loss	Kcal/Yr

Output Values

Total Waste Gas per Year	1.98E+07 m^3
Total Recoverable Energy (55% Flue Efficiency)	Kcal/Yr
Electricity Production	KWhl/Yr

Vetreria Antichi Angeli SAS # 126

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	2
Glass Production	2.29E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	106,666.67 m^3
Mass of Material Melted per Year	28,218.69 Kg
Natural Gas Usage per Unit of Glass	1.29 m^3/Kg
Heat Acquired From Natural Gas Combustion	8.96E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	3.05E+08 Kcal/Yr
Total Heat Loss	5.91E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.17E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	3.25E+08 Kcal/Yr
Electricity Production	1.13E+05 KWhl/Yr

Vetreria Artistica Colleoni SNC # 130

Furnace Operating Times

Days of Operation per Year	0
Weeks of Opertaion per Year	0.00

Factory Data

Number of Furnaces	1
Glass Production	Kg/Yr

Energy Values

Yearly Electricity Usage	38400 KWh
Yearly Natural Gas Usage	m^3
Mass of Material Melted per Year	Kg
Natural Gas Usage per Unit of Glass	m^3/Kg
Heat Acquired From Natural Gas Combustion	Kcal/Yr
Heat Needed to Melt Pot Contents	Kcal/Yr
Total Heat Loss	Kcal/Yr

Output Values

Total Waste Gas per Year	m^3
Total Recoverable Energy (55% Flue Efficiency)	Kcal/Yr
Electricity Production	KWhl/Yr

Vetreria Artistica Schiavon # 133

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	6
Glass Production	6.00E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	182400 KWh
Yearly Natural Gas Usage	492,100.00 m^3
Mass of Material Melted per Year	7,407.41 Kg
Natural Gas Usage per Unit of Glass	22.63 m^3/Kg
Heat Acquired From Natural Gas Combustion	4.13E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	1.41E+09 Kcal/Yr
Total Heat Loss	2.73E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	5.41E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.50E+09 Kcal/Yr
Electricity Production	5.21E+05 KWhl/Yr

Vetreria Studio Rosin SRL # 147

Furnace Operating Times

Days of Operation per Year	230
Weeks of Opertaion per Year	32.86

Factory Data

Number of Furnaces	2
Glass Production	3.29E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	168,666.67 m^3
Mass of Material Melted per Year	40,564.37 Kg
Natural Gas Usage per Unit of Glass	1.42 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.42E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	4.83E+08 Kcal/Yr
Total Heat Loss	9.34E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.86E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	5.14E+08 Kcal/Yr
Electricity Production	1.79E+05 KWhl/Yr

Name Unknown # 158

Furnace Operating Times

Days of Operation per Year	230
Weeks of Opertaion per Year	32.86

Factory Data

Number of Furnaces	12
Glass Production	1.22E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	84000 KWh
Yearly Natural Gas Usage	920,000.00 m^3
Mass of Material Melted per Year	15,008.82 Kg
Natural Gas Usage per Unit of Glass	20.88 m^3/Kg
Heat Acquired From Natural Gas Combustion	7.73E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	2.63E+09 Kcal/Yr
Total Heat Loss	5.10E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	1.01E+07 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.80E+09 Kcal/Yr
Electricity Production	9.74E+05 KWhl/Yr

Name Unknown # 1002

Furnace Operating Times

Days of Operation per Year	180
Weeks of Opertaion per Year	25.71

Factory Data

Number of Furnaces	3
Glass Production	2.06E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	72,000.00 m^3
Mass of Material Melted per Year	25,396.83 Kg
Natural Gas Usage per Unit of Glass	0.97 m^3/Kg
Heat Acquired From Natural Gas Combustion	6.05E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	2.06E+08 Kcal/Yr
Total Heat Loss	3.99E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	7.92E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.19E+08 Kcal/Yr
Electricity Production	7.62E+04 KWhl/Yr

Name Unknown # 1006

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	2
Glass Production	5.71E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	157620 KWh
Yearly Natural Gas Usage	88,266.67 m^3
Mass of Material Melted per Year	7,054.67 Kg
Natural Gas Usage per Unit of Glass	4.26 m^3/Kg
Heat Acquired From Natural Gas Combustion	7.41E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	2.53E+08 Kcal/Yr
Total Heat Loss	4.89E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	9.71E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.69E+08 Kcal/Yr
Electricity Production	9.34E+04 KWhl/Yr

Name Unknown # 1007

Furnace Operating Times

Days of Operation per Year	230
Weeks of Opertaion per Year	32.86

Factory Data

Number of Furnaces	1
Glass Production	3.29E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	59,263.33 m^3
Mass of Material Melted per Year	4,056.44 Kg
Natural Gas Usage per Unit of Glass	4.98 m^3/Kg
Heat Acquired From Natural Gas Combustion	4.98E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	1.70E+08 Kcal/Yr
Total Heat Loss	3.28E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	6.52E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.81E+08 Kcal/Yr
Electricity Production	6.27E+04 KWhl/Yr

Name Unknown # 1010

Furnace Operating Times

Days of Operation per Year	0
Weeks of Opertaion per Year	0.00

Factory Data

Number of Furnaces	2
Glass Production	Kg/Yr

Energy Values

Yearly Electricity Usage	3624 KWh
Yearly Natural Gas Usage	m^3
Mass of Material Melted per Year	Kg
Natural Gas Usage per Unit of Glass	m^3/Kg
Heat Acquired From Natural Gas Combustion	Kcal/Yr
Heat Needed to Melt Pot Contents	Kcal/Yr
Total Heat Loss	Kcal/Yr

Output Values

Total Waste Gas per Year	m^3
Total Recoverable Energy (55% Flue Efficiency)	Kcal/Yr
Electricity Production	KWhl/Yr

Name Unknown # 1014

Furnace Operating Times

Days of Operation per Year	150
Weeks of Opertaion per Year	21.43

Factory Data

Number of Furnaces	1
Glass Production	1.29E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	3000 KWh
Yearly Natural Gas Usage	27,500.00 m^3
Mass of Material Melted per Year	15,873.02 Kg
Natural Gas Usage per Unit of Glass	0.59 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.31E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	7.87E+07 Kcal/Yr
Total Heat Loss	1.52E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	3.03E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	8.38E+07 Kcal/Yr
Electricity Production	2.91E+04 KWhl/Yr

Name Unknown # 1015

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	4
Glass Production	7.43E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	366,666.67 m^3
Mass of Material Melted per Year	91,710.76 Kg
Natural Gas Usage per Unit of Glass	1.36 m^3/Kg
Heat Acquired From Natural Gas Combustion	3.08E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	1.05E+09 Kcal/Yr
Total Heat Loss	2.03E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	4.03E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.12E+09 Kcal/Yr
Electricity Production	3.88E+05 KWhl/Yr

Name Unknown # 1027

Furnace Operating Times

Days of Operation per Year	232
Weeks of Opertaion per Year	33.14

Factory Data

Number of Furnaces	3
Glass Production	1.66E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	51600 KWh
Yearly Natural Gas Usage	216,533.33 m^3
Mass of Material Melted per Year	20,458.55 Kg
Natural Gas Usage per Unit of Glass	3.61 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.82E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	6.20E+08 Kcal/Yr
Total Heat Loss	1.20E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	2.38E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	6.60E+08 Kcal/Yr
Electricity Production	2.29E+05 KWhl/Yr

Name Unknown # 1028

Furnace Operating Times

Days of Operation per Year	230
Weeks of Opertaion per Year	32.86

Factory Data

Number of Furnaces	3
Glass Production	Kg/Yr

Energy Values

Yearly Electricity Usage	17052 KWh
Yearly Natural Gas Usage	212,175.00 m^3
Mass of Material Melted per Year	Kg
Natural Gas Usage per Unit of Glass	m^3/Kg
Heat Acquired From Natural Gas Combustion	1.78E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	Kcal/Yr
Total Heat Loss	Kcal/Yr

Output Values

Total Waste Gas per Year	2.33E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	Kcal/Yr
Electricity Production	KWhl/Yr

Name Unknown # 1029

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	2
Glass Production	1.14E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	11940 KWh
Yearly Natural Gas Usage	200,000.00 m^3
Mass of Material Melted per Year	14,109.35 Kg
Natural Gas Usage per Unit of Glass	4.83 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.68E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	5.72E+08 Kcal/Yr
Total Heat Loss	1.11E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	2.20E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	6.09E+08 Kcal/Yr
Electricity Production	2.12E+05 KWhl/Yr

Name Unknown # 1031

Furnace Operating Times

Days of Operation per Year	230
Weeks of Opertaion per Year	32.86

Factory Data

Number of Furnaces	2
Glass Production	6.57E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	60000 KWh
Yearly Natural Gas Usage	184,000.00 m^3
Mass of Material Melted per Year	81,128.75 Kg
Natural Gas Usage per Unit of Glass	0.77 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.55E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	5.27E+08 Kcal/Yr
Total Heat Loss	1.02E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	2.02E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	5.60E+08 Kcal/Yr
Electricity Production	1.95E+05 KWhl/Yr

Name Unknown # 1032

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	1
Glass Production	5.03E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	720 KWh
Yearly Natural Gas Usage	66,000.00 m^3
Mass of Material Melted per Year	62,081.13 Kg
Natural Gas Usage per Unit of Glass	0.36 m^3/Kg
Heat Acquired From Natural Gas Combustion	5.54E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	1.89E+08 Kcal/Yr
Total Heat Loss	3.66E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	7.26E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.01E+08 Kcal/Yr
Electricity Production	6.99E+04 KWhl/Yr

Name Unknown # 1033

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	1
Glass Production	1.26E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	13200 KWh
Yearly Natural Gas Usage	77,000.00 m^3
Mass of Material Melted per Year	15,520.28 Kg
Natural Gas Usage per Unit of Glass	1.69 m^3/Kg
Heat Acquired From Natural Gas Combustion	6.47E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	2.20E+08 Kcal/Yr
Total Heat Loss	4.26E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	8.47E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	2.35E+08 Kcal/Yr
Electricity Production	8.15E+04 KWhl/Yr

Name Unknown # 1035

Furnace Operating Times

Days of Operation per Year	230
Weeks of Opertaion per Year	32.86

Factory Data

Number of Furnaces	4
Glass Production	4.93E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	191,666.67 m^3
Mass of Material Melted per Year	60,846.56 Kg
Natural Gas Usage per Unit of Glass	1.07 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.61E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	5.48E+08 Kcal/Yr
Total Heat Loss	1.06E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	2.11E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	5.84E+08 Kcal/Yr
Electricity Production	2.03E+05 KWhl/Yr

Name Unknown # 1036

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	1
Glass Production	2.40E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	6696 KWh
Yearly Natural Gas Usage	38,143.00 m^3
Mass of Material Melted per Year	2,962.96 Kg
Natural Gas Usage per Unit of Glass	4.39 m^3/Kg
Heat Acquired From Natural Gas Combustion	3.20E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	1.09E+08 Kcal/Yr
Total Heat Loss	2.11E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	4.20E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.16E+08 Kcal/Yr
Electricity Production	4.04E+04 KWhl/Yr

Name Unknown # 1042

Furnace Operating Times

Days of Operation per Year	230
Weeks of Opertaion per Year	32.86

Factory Data

Number of Furnaces	4
Glass Production	2.96E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	120204 KWh
Yearly Natural Gas Usage	215,970.00 m^3
Mass of Material Melted per Year	36,507.94 Kg
Natural Gas Usage per Unit of Glass	2.02 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.81E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	6.18E+08 Kcal/Yr
Total Heat Loss	1.20E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	2.38E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	6.58E+08 Kcal/Yr
Electricity Production	2.29E+05 KWhl/Yr

Name Unknown # 1043

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	1
Glass Production	9.43E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	5160 KWh
Yearly Natural Gas Usage	57,200.00 m^3
Mass of Material Melted per Year	11,640.21 Kg
Natural Gas Usage per Unit of Glass	1.67 m^3/Kg
Heat Acquired From Natural Gas Combustion	4.80E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	1.64E+08 Kcal/Yr
Total Heat Loss	3.17E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	6.29E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.74E+08 Kcal/Yr
Electricity Production	6.05E+04 KWhl/Yr

Name Unknown # 1044

Furnace Operating Times

Days of Operation per Year	160
Weeks of Opertaion per Year	22.86

Factory Data

Number of Furnaces	2
Glass Production	2.29E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	1056 KWh
Yearly Natural Gas Usage	12,960.00 m^3
Mass of Material Melted per Year	2,821.87 Kg
Natural Gas Usage per Unit of Glass	1.56 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.09E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	3.71E+07 Kcal/Yr
Total Heat Loss	7.18E+07 Kcal/Yr

Output Values

Total Waste Gas per Year	1.43E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	3.95E+07 Kcal/Yr
Electricity Production	1.37E+04 KWhl/Yr

Name Unknown # 1045

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	2
Glass Production	5.71E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	34800 KWh
Yearly Natural Gas Usage	146,666.67 m^3
Mass of Material Melted per Year	70,546.74 Kg
Natural Gas Usage per Unit of Glass	0.71 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.23E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	4.20E+08 Kcal/Yr
Total Heat Loss	8.12E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.61E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	4.47E+08 Kcal/Yr
Electricity Production	1.55E+05 KWhl/Yr

Name Unknown # 1047

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	1
Glass Production	3.14E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	35,200.00 m^3
Mass of Material Melted per Year	3,880.07 Kg
Natural Gas Usage per Unit of Glass	3.09 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.96E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	1.01E+08 Kcal/Yr
Total Heat Loss	1.95E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	3.87E+05 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.07E+08 Kcal/Yr
Electricity Production	3.73E+04 KWhl/Yr

Name Unknown # 1050

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	2
Glass Production	4.00E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	28800 KWh
Yearly Natural Gas Usage	144,000.00 m^3
Mass of Material Melted per Year	49,382.72 Kg
Natural Gas Usage per Unit of Glass	0.99 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.21E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	4.12E+08 Kcal/Yr
Total Heat Loss	7.98E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.58E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	4.39E+08 Kcal/Yr
Electricity Production	1.52E+05 KWhl/Yr

Name Unknown # 1052

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	2
Glass Production	1.50E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	4080 KWh
Yearly Natural Gas Usage	3,500.00 m^3
Mass of Material Melted per Year	18,518.52 Kg
Natural Gas Usage per Unit of Glass	0.06 m^3/Kg
Heat Acquired From Natural Gas Combustion	2.94E+07 Kcal/Yr
Heat Needed to Melt Pot Contents	1.00E+07 Kcal/Yr
Total Heat Loss	1.94E+07 Kcal/Yr

Output Values

Total Waste Gas per Year	3.85E+04 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.07E+07 Kcal/Yr
Electricity Production	3.70E+03 KWhl/Yr

Name Unknown # 1053

Furnace Operating Times

Days of Operation per Year	220
Weeks of Opertaion per Year	31.43

Factory Data

Number of Furnaces	11
Glass Production	2.83E+05 Kg/Yr

Energy Values

Yearly Electricity Usage	1080000 KWh
Yearly Natural Gas Usage	1,833,333.33 m^3
Mass of Material Melted per Year	349,206.35 Kg
Natural Gas Usage per Unit of Glass	1.79 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.54E+10 Kcal/Yr
Heat Needed to Melt Pot Contents	5.25E+09 Kcal/Yr
Total Heat Loss	1.02E+10 Kcal/Yr

Output Values

Total Waste Gas per Year	2.02E+07 m^3
Total Recoverable Energy (55% Flue Efficiency)	5.58E+09 Kcal/Yr
Electricity Production	1.94E+06 KWhl/Yr

Name Unknown # 1054

Furnace Operating Times

Days of Operation per Year	210
Weeks of Opertaion per Year	30.00

Factory Data

Number of Furnaces	2
Glass Production	2.40E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	10356 KWh
Yearly Natural Gas Usage	115,633.00 m^3
Mass of Material Melted per Year	29,629.63 Kg
Natural Gas Usage per Unit of Glass	1.33 m^3/Kg
Heat Acquired From Natural Gas Combustion	9.71E+08 Kcal/Yr
Heat Needed to Melt Pot Contents	3.31E+08 Kcal/Yr
Total Heat Loss	6.40E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.27E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	3.52E+08 Kcal/Yr
Electricity Production	1.22E+05 KWhl/Yr

Name Unknown **# 1055**

Furnace Operating Times

Days of Operation per Year	200
Weeks of Opertaion per Year	28.57

Factory Data

Number of Furnaces	6
Glass Production	8.57E+03 Kg/Yr

Energy Values

Yearly Electricity Usage	168696 KWh
Yearly Natural Gas Usage	400,000.00 m^3
Mass of Material Melted per Year	10,582.01 Kg
Natural Gas Usage per Unit of Glass	12.88 m^3/Kg
Heat Acquired From Natural Gas Combustion	3.36E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	1.14E+09 Kcal/Yr
Total Heat Loss	2.22E+09 Kcal/Yr

Output Values

Total Waste Gas per Year	4.40E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	1.22E+09 Kcal/Yr
Electricity Production	4.23E+05 KWhl/Yr

Name Unknown # 1056

Furnace Operating Times

Days of Operation per Year	300
Weeks of Opertaion per Year	42.86

Factory Data

Number of Furnaces	2
Glass Production	3.43E+04 Kg/Yr

Energy Values

Yearly Electricity Usage	KWh
Yearly Natural Gas Usage	166,000.00 m^3
Mass of Material Melted per Year	42,328.04 Kg
Natural Gas Usage per Unit of Glass	1.34 m^3/Kg
Heat Acquired From Natural Gas Combustion	1.39E+09 Kcal/Yr
Heat Needed to Melt Pot Contents	4.75E+08 Kcal/Yr
Total Heat Loss	9.19E+08 Kcal/Yr

Output Values

Total Waste Gas per Year	1.83E+06 m^3
Total Recoverable Energy (55% Flue Efficiency)	5.06E+08 Kcal/Yr
Electricity Production	1.76E+05 KWhl/Yr