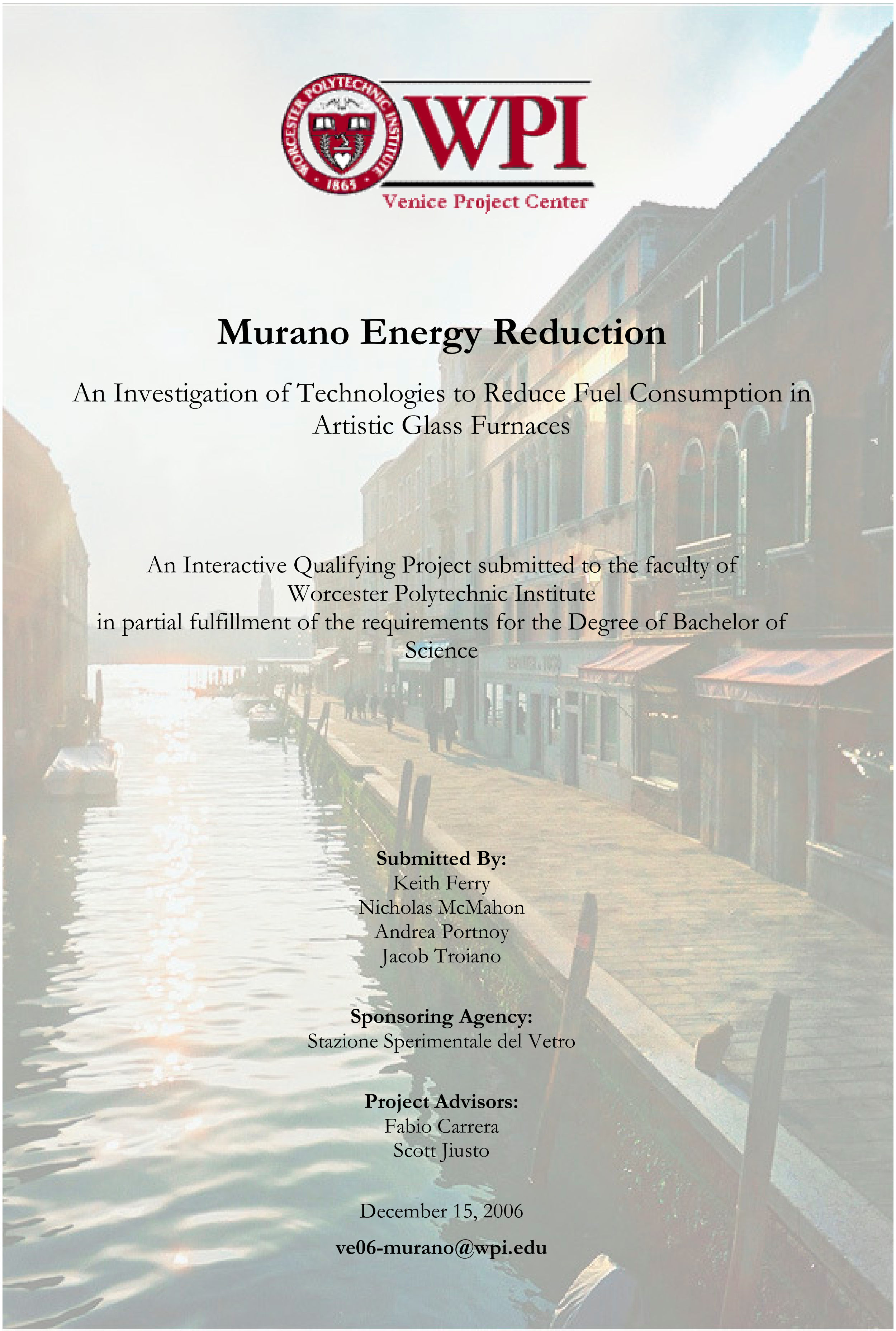

Venice Project Center

Murano Energy Reduction

An Investigation of Technologies to Reduce Fuel Consumption in Artistic Glass Furnaces

An Interactive Qualifying Project submitted to the faculty of
Worcester Polytechnic Institute
in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Our Parents

Abstract

This project, sponsored by the Stazione Sperimentale del Vetro, a research laboratory funded by the glass industry located in Murano, Italy, assessed the technologies available for increasing fuel efficiency in artistic glass furnaces. The project team collected and analyzed data on natural gas consumption and emissions for different technologies and compared it to data from furnaces currently in operation to model the expected savings for each technology. The results show the potential for a 35% increase in efficiency but warrant further studies. The project concludes by recommending a testing procedure to further assess both oxycombustion and recuperative burners.

Executive Summary

The focus of this project was the reduction of energy use for the glass industry of Murano, Italy. Murano has been known for glass manufacturing since the industry moved there from Venice in the late thirteenth century. The traditions and practices used by the glass artisans have remained a carefully guarded secret, and have changed very little since the industry's inception. Although some effort has been made to modernize this process, inefficiencies still exist.

Manufacturing glass is a very heat-intensive process. In order to melt glass, furnaces must reach temperatures up to 1,600 degrees Celsius. Typically, most of this heat is released into the environment, either through the furnace walls or through the exhaust out the flue. Although some efforts have been made by individual factories in Murano to reduce this wasted heat, their success has been limited. Reducing this wasted energy could help the glass artisans reduce the cost of operating their furnaces and lower emissions. The sponsor of this project, *The Stazione Sperimentale del Vetro (SSV)*, is a research laboratory, which investigates improvements that can be made to the glass-manufacturing process. The SSV has been instrumental in helping us to collect and analyze data. The goal of this project was to analyze multiple ways of reducing the furnaces' wasted energy and fuel consumption to determine the most promising technologies for implementation on Murano. To do this we carried out the following objectives:

- Investigation of the current technologies that could be used to increase the efficiency of the glass making process, decrease environmental impacts, and lower overall costs.
- Assessment of the performance, economics, and social acceptability of these new technologies.
- Designation of a testing protocol for the adoption of the most promising efficiency improving technologies.

The artistic glass process involves three major phases: melting, working, and annealing. In the melting phase, large amounts of glass are created by heating raw materials to temperatures up to 1,600 degrees Celsius until they form liquid glass. This phase is the most heat-intensive, and therefore provides the most opportunity for waste heat reduction. In the working phase, the artisans shape the glass, inserting it back into

the furnace intermittently to make sure that it remains in a workable state. This requires keeping the furnace door open throughout the working phase. Most of the waste heat from this phase escapes through the door opening, making it difficult to capture. In the third phase known as annealing, the glass is cooled slowly to ensure that it maintains its shape. This phase uses very little heat. In each of these phases, the heat is produced by the combustion of natural gas.


Figure 1: Murano Furnace

In order to prioritize our research we adapted the slogan of "reduce, recycle and reuse" from the solid waste industry. We examined three different methods of utilizing the waste heat from the melting phase: using it to reduce the amount of natural gas consumed by the furnace, recycling by converting the heat into a useable form such as electricity, or reusing it to heat other buildings. After some initial analysis, we decided to focus primarily on energy reduction technologies. These technologies involved the simplest mechanisms, making them some of the most efficient and inexpensive technologies, as well as the easiest to implement.

Figure 2: Three R's

We examined two different ways of reducing gas consumption, recuperative burners and oxycombustion. Recuperative burners use the heat from the waste gas exiting the furnace to preheat the air entering the furnace. Heating up the incoming air reduces the amount of natural gas required to bring it to the temperature of the air inside the furnace. In an oxycombustion furnace, pure oxygen is mixed with the natural gas entering the furnace, instead of air. This increases the furnace's efficiency by eliminating the inert gases that are present in air, primarily nitrogen. In a traditional furnace using air, these gases contribute nothing to the combustion process, but they still need to be heated up to the temperature inside the furnace. When they leave the furnace, they take heat with them, increasing the amount of natural gas needed to operate the furnace. In addition to these two technologies, we also examined ways that the furnace walls could be changed to increase their insulation properties. Such a reduction effort could be combined with either a recuperative burner or oxycombustion.

We decided to analyze these two technologies based on three factors: their performance, their cost, and the glass artisans' reactions to them. For performance, we examined data on gas consumption and emissions, obtained from tests of the furnaces in operation. From this data, we determined the operating cost of each setup. Finally, we spoke with glass artisans about their opinions of the proposed changes with each technology.

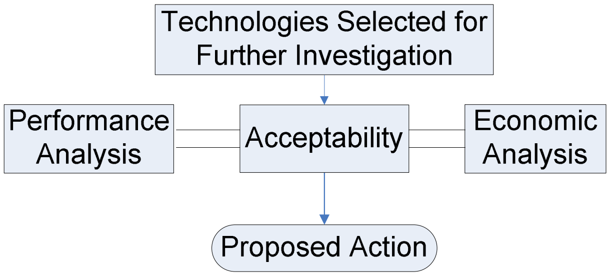

Figure 3: Methodology Flowchart

The first step in analyzing these two technologies and comparing them with furnaces currently in use on Murano was to gather operating data on furnaces running each technology. The SSV carried out a study on oxycombustion in 1994. Oxycombustion burners were installed on several furnaces on Murano, which were then run for one week, while data was collected on gas consumption and emissions. To obtain data for a recuperative burner, the group worked with Charlie Correll of Conway, Massachusetts. Correll is a glass blower who has been researching furnace design, including insulation and recuperative burners, for twenty-five years. He currently designs, operates and sells high efficiency furnaces and recuperative burners for artistic glass blowing. Correll was able to provide data on gas consumption for one of his furnaces, but lacked the equipment to measure emissions. However, this data was approximated from the gas consumption data. The SSV provided data on gas consumption and emissions for a typical Murano furnace from tests conducted in the Ferro glass factory on Murano.

Based on this data, and information about the prices of natural gas and oxygen, we developed an operating cost model for producing glass in each of the three setups. The model for Correll’s technology was combined with data on equipment costs and expected maintenance to determine a payback period. We were unable to do this with the oxycombustion model, due to a lack of data.

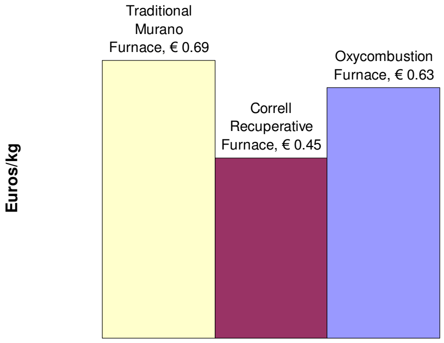

Figure 4: Operating Cost Comparison

Our final analysis of the technologies showed that the Correll technology would offer the most savings, with a 35% reduction in melting furnace operating costs. Although oxycombustion would reduce natural gas consumption more than the Correll technology, it also requires the purchase of oxygen. This brings the cost savings from oxycombustion down to only 10.8%. Considering emissions oxycombustion shows the greatest improvement but the emissions that are output to produce the oxygen must be taken into account as well. The Correll furnace emissions are currently theoretical because Correll lacks the necessary equipment to perform the tests. These results are not conclusive, and so further testing is recommended. The Correll data was collected in his Massachusetts shop, so it cannot be accurately compared to the traditional furnace data collected on Murano, due to uncontrolled variables.

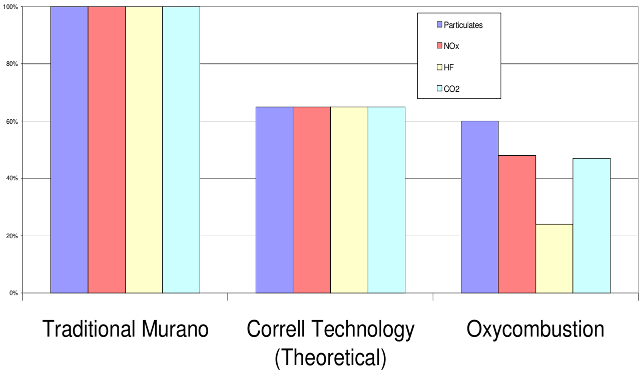

Figure 5: Emissions Reductions

We recommend that Correll be brought to Murano to build one of his recuperative furnaces in a Murano factory, to be tested side by side with a traditional furnace so that controlled data may be collected. Long term testing of a Correll furnace as well as long term testing of oxycombustion is necessary before any wide scale implementation can take place. We spoke with two different glass factories the Zanetti Glass Company and Ferro Glass Company. Both of them were enthusiastic about trying new technologies. Ferro already uses recuperators on four of their seven melting furnaces and is interested in trying Correll's technology. Zanetti is eager to change their furnace operation over to oxycombustion. Although we cannot assume that all factory owners on Murano are as enthusiastic about these new technologies, the reactions show that there is enthusiasm for efficiency improvements. Murano holds great opportunity for change, and its influential nature will surely help that change spread throughout the world.

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1 Introduction

Technological advances simplify daily life and provide us with the comforts and amenities that modern society now takes for granted, but they come at a price. Turning on a light bulb, running the dishwasher and watching television all consume energy. In 2003, the world consumed 2.69 trillion cubic meters of natural gas,[1] and the Energy Information Agency of the United States predicts that there will be a 22% increase in the world's consumption of natural gas by 2010.[2] Since gas and electricity are becoming more expensive, alternative energies and more efficient technologies are being sought as a means of alleviating rising costs.[3] Additionally, fears of global warming due to CO_2 emissions are sparking a new interest in conservation and a reduced dependence on fossil fuels.[4] While significant gains have been made in the quest to lower fuel usage there are still many areas where improvement is needed. Increasing the efficiencies of industrial processes through the reduction and reclamation of waste energy is an effective way to safeguard the environment and offset higher prices. Glass manufacturing is just one example of an industry that has started to realize significant gains in efficiency through new technologies such as burner redesign, insulation techniques and waste heat reclamation.[5]

The artistic glass furnaces of Murano, Italy, present a unique situation. Murano, a small island to the north of Venice, is known worldwide for its artistic glass creations. With over fifty glass factories and upwards of two hundred furnaces, 45 million cubic meters of natural gas are burned annually.[6] These glass furnaces are spread out across the island, interspersed with residential buildings and other commercial shops. The artistic glass furnaces are not large enough to take advantage of industrial efficiency methods. However, there are a number of ways in which their fuel consumption can be reduced.

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[1] USA Department of Energy. Energy Information Administration. 2006 [cited 10/9 2006]. Available from http://www.eia.doe.gov/.

[2] USA Department of Energy.

[3] USA Department of Energy.

[4] Picariello, Steven R., et al. 2001. *Cogeneration -- feasibility study for the artistic glass companies of Murano, Italy.*

[5] Somasundaram, Sriram, Steve Parker, Meredydd Evans and Daryl Brown. 1999. Industrial Energy Efficiency Opportunities in Ukraine. *Proceedings of Renewable and Advanced Energy Systems for the 21st Century.*

[6] Picariello et al. 2001.

We have researched technologies that reduce waste heat and natural gas consumption to provide an accurate picture of the possible solutions for artistic glass furnaces. The motto, adopted by the solid waste field, of "reduce, recycle, and reuse" has been adopted to provided a strategy for narrowing down the most appropriate technologies for Murano. Oxycombustion burners, recuperative furnaces and energy redistribution technologies are promising techniques for *reducing* fuel consumption. We have therefore collected data measuring the performance and costs of these technologies in order to determine the next steps that should be taken to implement them on Murano.

Through this project we have expanded upon existing research compiled by our sponsor, the Stazione Sperimentale del Vetro. We have analyzed applicable technologies with regard to performance, cost and acceptability. Finally we have developed a recommendation for the next steps that Murano should take for implementing these technologies, reducing their environmental impact and securing their name, not only as the world leader in artistic glass but as a model for fuel efficiency and innovation as well.

2 Background

In order to better understand the workings of Murano and the glass industry, it is important to have adequate background knowledge of the history of the island and practices that go into creating quality glass products. Furthermore looking at a broad spectrum of potential solutions to waste energy reduction with an open mind ensures that no solution is ruled out. This chapter begins with an introduction to the island of Murano, including its history, population and unique geographical location. The background chapter then continues with the details of the artistic glass factories and their manufacturing processes, transitioning into energy consumption. After the discussion of Murano's energy usage, the available technological solutions for waste heat and fuel reduction as well as methods for recapture and redistribution of waste heat for Murano are discussed. Finally, the chapter concludes with an introduction of the groups involved in this project, and their backgrounds and roles are explained.

2.1 History of Murano Glass

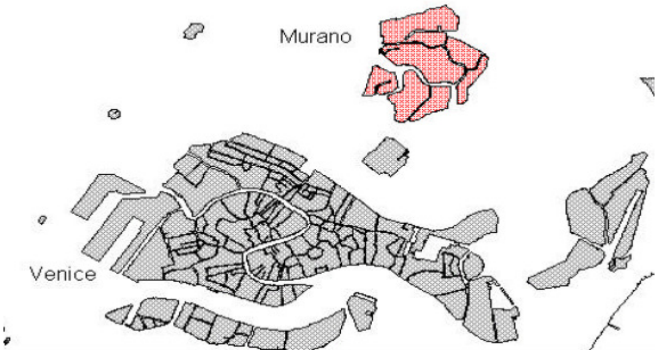

Figure 6: Murano, Italy

The island of Murano is located 1,500 m north of Venice and is home to approximately 4,500 inhabitants. Similar to Venice in many ways, Murano is divided by a network of canals into five islands (Navagero, San Donato, Del Convento, San Pietro, and San Stefano) and two sacche, reclaimed landfills, (Sacca Serenella and Sacca San Mattia). Walking bridges allow ground travel among the islands which contain historical sites, residential homes, shops and the world renowned glass factories.[7]

Founded between the 5th and 7th centuries, the island of Murano was officially declared the 'Glassmaker's Paradise' by the *Maggior Consiglio*[8] (Venetian government) in 1291 and has since been home to Venice's artistic glass manufacturing industry.

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[7] Picariello et al. 2001.

[8] Cottreau, Nicholas J., et al. 2000. *Monitoring pollution on Murano.*

Originally located in Venice, the glass industry was moved to the island of Murano due to the fire hazard its furnaces posed to the wooden buildings of Venice. The dignified glass manufacturing tradition brought such esteem and fortune to Murano that the Republic forbade the glassblowers to leave Venetian territories and share their knowledge. However, the trade secrets eventually spread throughout Europe and others began developing their own interpretations of Venetian glass. The once prestigious glass industry of Murano began to dwindle in the early 19th century, and it was not until the 1860's that the lost traditions were reintroduced by Antonio Salviati. Today, Murano has regained its international status in the artistic glass industry making it a significant sector of the Venetian tourist economy.

2.2 Manufacturing Process

The glass manufacturing process involves multiple phases, each important to the end product. The glass, comprised of 70% sand and 30% silica, is melted into a liquid state at approximately 1,700 °C, which then passes from liquid to solid at approximately 500 °C. The temperature control varies from factory to factory. Some companies rely on modern electric control systems that offer the ability to carefully monitor the temperature as well as fuel injection and air intake. On the other hand, more traditional factories opt to manually control all aspects of the furnace based on experience. Regardless of the method of control, the traditional Murano furnace burner consists of a combination of air and methane as shown to the right. The air is mixed with the methane in an angled, circular motion to produce the most efficient flame.

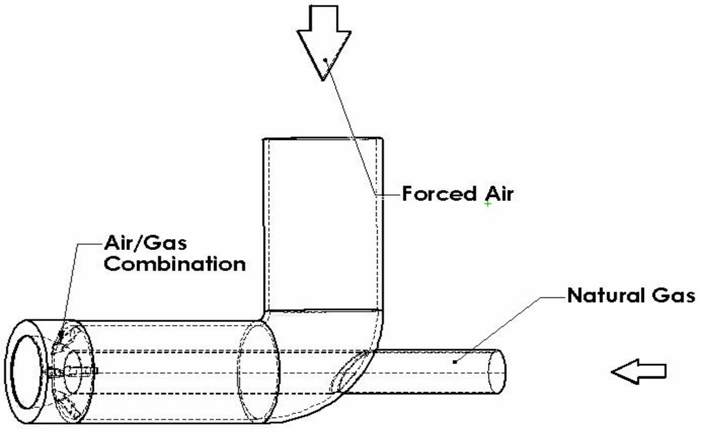

Figure 7: Murano Burner Operation

Figure 8: Traditional Murano Furnace with Front Wall Removed for Servicing

The majority of furnaces used on Murano are slow-baking and of medium (500kg) capacity. The furnaces perform fusion, a discontinuous cycle lasting eight hours a day, five days a week from 5 p.m. until 1 a.m. Following the end of the fusion process, the temperature is lowered to allow for the shaping of the glass. At approximately 7:00 a.m. when the glass cools, the glass masters begin the shaping process. This process uses a different furnace known as a Glory Hole to keep the glass in a workable state. The number and type of furnaces varies among factories; some have four and others have ten depending on the company. Finally when the finished shape has been created it is annealed. At this stage, the glass is put through a very slow cooling process during which the structure of the glass is strengthened. Typically, the glass manufacturers work two hundred days of the year making new glass two to three times per week, pausing for a prolonged time during the winter and summer for holidays and to perform maintenance on the furnaces. Many factories prefer to build and maintain the furnaces on their own. Typically during the maintenance period, the front walls of the furnaces are taken down (see Figure 8) and the insides are cleaned of the excess glass and particles after which the wall is then rebuilt.

2.3 Factory and Furnace Structure

The average glass factory on Murano has four melting furnaces. These are either of the daytank or crucible variety. A daytank is used for large batches of glass, typically over 500kg. The glass is melted in the bottom of the furnace, directly against the refractory brick. Because the glass is in contact with the furnace, unwanted debris may get into the melted batch. This is not desirable and thus when quality is of the utmost importance, a crucible furnace will be used. A crucible furnace holds one or more crucibles in which the glass is melted. The crucible is made from a castable ceramic which is more durable than the refractory brick and so does not pollute the glass

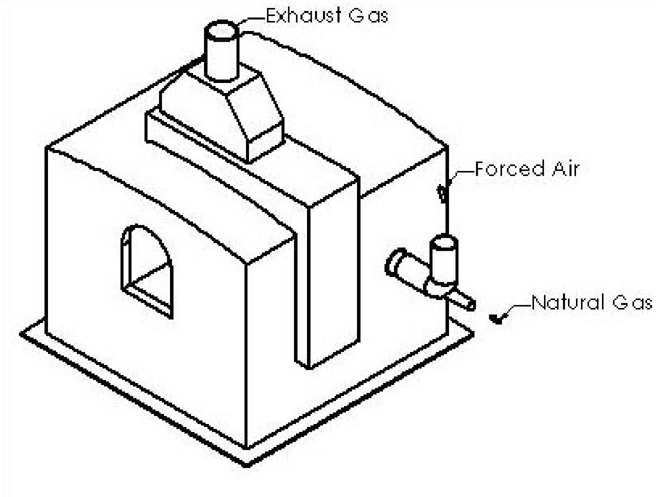

Figure 9: Traditional Murano Furnace and Burner

with unwanted fragments. The crucible furnace is used for melts of lower volume, around 100kg or less. Using multiple crucibles allows for different compositions and colors of glass to be melted at the same time.

2.4 Energy Consumption and Emissions of Murano Furnaces

The fuel consumption of the Murano factories is very important to this project as it is what we are seeking to reduce. The following section deals with background knowledge of the fuel usage and resulting emissions of the Murano furnaces.

2.4.1 Current Fuel Consumption of Factories and Costs

Creating glass is an energy intensive process; a typical glass factory on Murano will spend 8,000€ per month on natural gas.[9] The fuel consumption can be broken down further. The melting process consumes 60% of energy, the working process 30% and the annealing phase uses the remaining 10%. While the individual glassmaker is more concerned about his final product, the factory owner must take into account operating costs, 15% of which is natural gas charges, creating incentive to keep fuel charges to a minimum.

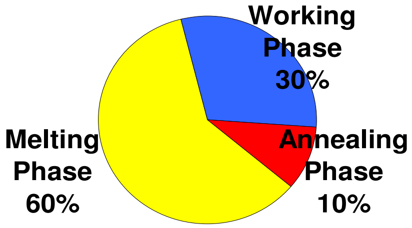

Figure 10: Energy Usage in Glass Making

2.4.2 Emissions of Furnaces

As with any industry, the emissions of the glass manufacturers of Murano are a major concern, especially since the manufacturing process often involves fusing often toxic materials together at extreme temperatures. Though the amount of pollutants released is small in comparison to many large industrial areas, the type of pollutants emitted from the metals used to color artistic glass pose a serious environmental hazard.[10]

Historically the furnaces of Murano were fired with fuel oil. The emissions from these burners were toxic and caused degradation to the monuments and statues on Venice. Because of this it was mandated by the city of Venice in the 1970's that the furnaces be fired by natural gas which has cleaner emissions. A special price was negotiated with the gas companies to offset the increased cost of using natural gas

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[9] Picariello, Steven R., et al.

[10] Cottreau, Nicholas J., et al.

instead of fuel oil. In some cases, this was as much as 40% off of the normal price for consumers.[11] The natural gas cut down on the emissions of the furnaces, and in 2002 particulate filters were added to the exhaust systems to further reduce emissions.

The mixture of the various materials involved in glass manufacturing results in the release of numerous toxins into the atmosphere. The extreme heat of the combustion process is responsible for the discharge of dangerous gases such as carbon dioxide and poisonous oxides such as carbon monoxide and nitrogen oxide. Also emitted from the mixture during combustion are additives including boron, chlorine, fluorine, lead nitrates, and sulfates. To add to the threat of these toxins, when combined with water, nitrates, sulfates, and chlorine create acids are destructive to architecture and unhealthy for wildlife and humans. This poses a serious environmental hazard considering the geographic location of Murano exposes the lagoon and surrounding islands to these toxins.

In addition to these pollutants, perhaps the most dangerous emissions of glass manufacturing are a result of the addition of color. Since the materials required to add color to glass are primarily heavy metals, the toxins released from their combustion have major effects on living organisms. These toxins typically enter the respiratory or ingestion systems of humans and animals and most notably attack organs. Table 1 shows common pollutants produced in the glass making process. Although the major focus of this project is the analysis and reduction of fuel use, the emissions output is also a concern since fuel usage is proportional to the amount of emissions created from burning the fuel.

Pollutant	**Cause**
Particulate Matter	Evaporation Process
Nitrogen Oxides	Combustion process/nitrate mixture
Gaseous Fluoride	Raw materials to fluidize/refine/de-luster glass
Arsenic Compounds	Raw materials to refine glass
Other Metals (chromium, cobalt, nickel, lead, copper, tin)	Coloring glass
Antimony Compounds	Replacement of arsenic compounds
Cadmium Compounds	Coloring glass

Table 1: Glass Pollutants

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[11] Picariello, Steven R., et al.

2.5 Energy Reduction Technologies

The following section is devoted to providing background on the different technologies that could be used to reduce natural gas consumption and reuse waste heat in glass furnaces.

A lens that has proven useful when planning energy efficiency improvements is one that allows a look at the big picture with regard to the phrase "reduce, recycle and reuse." This is borrowed from the solid waste field and is easily recognizable by anyone brought up in the 1990's. The three R's break down the process of recycling solid waste, but they are also very applicable to the field of energy efficiency and so we have used them to rate the technologies identified in this section.

Figure 11: Reduce Recyle Reuse

The following is a description of the three R's as related to solid waste. Reduce means the reduction of waste at the source. This includes increasing the lifespan of a product by using longer lasting materials, using less packaging on a product, or the redesign of a product so that fewer materials are used. Reduction is the most preferred method of waste management because it prevents the generation of waste. Reuse of an item can take several forms. It may mean donating your used goods to charity or finding a new use for discarded items. Recycling is the reprocessing of materials that have no further use into valuable resources.

The application of this methodology to energy is relatively straightforward. Reduction requires us to examine the process in which the energy is used and to look for places in which it can be altered for less consumption. This may mean driving less, turning down the thermostat, or closing the windows and putting on a sweater when it is cold. Reuse of energy involves taking energy that would otherwise be wasted, usually in the form of heat, and reusing it. This can be accomplished through heat exchangers that transfer heat from one medium to another for transport. Exhaust from an industrial process can be reused to heat a building in this way. Recycling energy is more complicated and involves converting the form of the wasted energy, such as converting heat to electricity with a heat engine or vice versa with a resistive heater. Because of the energy losses to entropy, excessive cost and complexity of infrastructure, this method is least preferred.

This thought process when researching possible solutions for improving efficiency in the glass making provided us with a hierarchy, that was used to rate any changes that could be made to the furnaces of Murano. First of all, it is important to examine the process to look for any simple changes that could be made to reduce energy consumption. Secondly, there may be simple solutions, such as adding insulation, that would reduce heat losses and ultimately gas consumption. Recycling and reusing techniques for energy were also examined in depth.

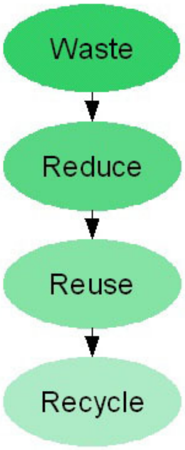

Figure 12: Three R Hierarchy

The technologies that are most directly applicable to the artistic glass furnaces are recuperative and oxycombustion burners. Cogeneration technologies that use heat engines to convert heat into electricity as well as district heating methods were also explored as possible ways to recycle waste heat.

2.5.1 Insulation

Figure 13: Traditional Murano Furnace with Front Wall Removed for Servicing

There are two ways in which the heat leaves a furnace; it can escape through the flue and through the walls. Adequate insulation is paramount to holding heat in the furnace and distributing it to the glass load. A traditional Murano furnace is constructed of a layer of hardbrick followed by a layer of softbrick with a layer of ceramic fiber in between. A glass artist, Charles Correll, based in Massachusetts at Correll Glass Studios, has made improvements in the area of insulation to glass furnaces. By using the following structure; 3000° F hardbrick liner, consisting of splits mortared and stacked on edge, backed by a two inch layer of 3000° F castable refractory, Correll has created furnaces with superior insulating qualities. Through his insulating techniques and the addition of a recuperative burner Correll estimates that he has lowered his fuel consumption by 40%.

It may seem obvious that increasing the insulation of a furnace is a prudent move to reduce fuel consumption but there are a number of reasons why these steps have not been taken. Until recently the glass factories were able to buy natural gas at a price 40% lower than the general public. Because of this, fuel savings through insulation were thought to be negligible since gas could be purchased so cheaply. In 2004 the European

Union ruled that it was unfair for the Murano factories to receive such a discount. As a result, the factories now must deal with the full charge for fuel; this change is providing incentive to switch to more fuel efficient practices one of which may be increasing insulation. Another reason for keeping furnace construction simple is the need to service the furnaces. The high temperatures and caustic environment inside of a furnace lead to the breakdown of the refractory materials that make up the inner walls of the furnace. Each furnace must be taken apart and rebuilt twice a year. The more complicated and exotic the materials used to make the furnace are, the more time consuming and expensive the rebuilding of the furnace will be.

2.5.2 Recuperative Burners

Reduce

Redesign of natural gas burners has allowed for great advances in fuel efficiency. A recuperative burner uses exhaust gases from the furnace to preheat the incoming air on its way to the furnace.[12] This means that the burner does not have to heat the air inside the furnace as much before it combusts, reducing fuel consumption. The recuperative burner is commonly used in artistic furnaces similar to those found in Murano.[13] Currently approximately 50% of glass furnaces on Murano use recuperators. Correll Glass Studios has been using recuperative burners in their furnaces for over eighteen years and reports gains in fuel efficiency of up to 40%.

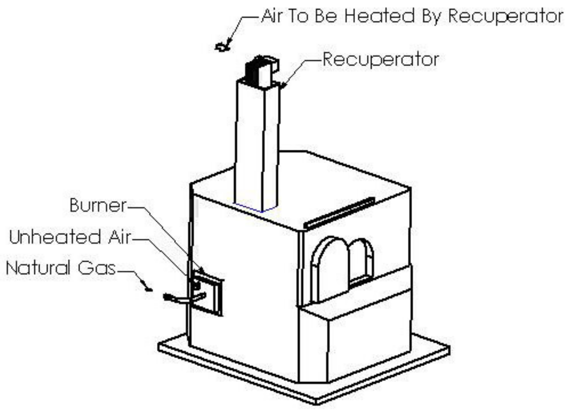

Figure 14: Recuperated Furnace

Currently, approximately 50% of glass furnaces on Murano use recuperators. These recuperators are made of either stainless steel or a cast alloy. These materials are chosen for their durability and heat transfer properties. While they get the job done, they are not efficient at preheating the incoming air because they must be placed far from the heat source so that the materials are not destroyed by the intense temperatures. Other materials, such as silicon carbide, are more durable in high heat environments but less

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[12] Sturgill, and Dennis T. 1985. *Cogeneration from glass furnace waste heat recovery*. Vol. 4,528,012.

[13] Correll, Charles M. Recuperation and Insulation in Glassmaking: An Overview. 2006 [cited 10/12 2006]. Available from http://www.correllglassstudio.com/recuppater.htm.

proficient at heat transfer than steel alloys. Correll Glass Studios has developed a recuperative heat exchanger that is made of both silicon carbide and stainless steel. This design allows the recuperator to be placed closer to the heat source capturing more heat and distributing it to the incoming air. The result is preheated air at a temperature of 815°C as opposed to the 250°C that Murano furnaces currently obtain using the single material recuperators. Correll style recuperators have not been used on Murano before and are a relatively new concept in the artistic glass making field. There are companies on Murano that are interested in trying a Correll style furnace in their factories to determine for themselves the fuel savings of this method. Testing of a Correll recuperative burner on Murano is discussed in 5.

2.5.3 Oxycombustion

Reduce

Current glass furnace burners run on natural gas and air. The air is fed to the burner via a blower so that more oxygen is present and the flame will burn at a higher temperature. Oxycombustion replaces the air feed with one of pure oxygen. This allows the flame to burn at a much higher temperature since the nitrogen that is present in air has been removed.[14] Higher temperatures allow for more efficient burns and better diffusion of the heat through the furnace. Oxycombustion has been tested on the island of Murano in artistic glass furnaces. The data recorded showed a fuel savings of approximately 50% with emissions being reduced up to 70%.[15] The added cost of buying the oxygen however will cut into any net savings as is discussed in the Results and Analysis section 4. While oxycombustion looks promising it is complicated and will require significant changes to the island's modus operandi.

Figure 15: Oxycombustion Burner

Testing of oxycombustion technology began in 1996 in the Sacca Serenella district of Murano. A large push to carry out this testing came from the SAPIO Spa Company, an Italian subsidiary of the American business, Airproducts. SAPIO Spa proposed to the glass industry of Murano that, should they adopt oxycombustion

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[14] Stazione Sperimentale del Vetro. Environmental Improvement Resulting from Oxycombustion Technology. in Integaire [database online]. 2005 [cited October 22 2006]. Available from http://www.integaire.org/database-new/examples/uploaded/view_example.php?id=413&c=&m=0.

[15] Stazione Sperimentale del Vetro.

burners, SAPIO Spa would install an oxygen pipeline from Porto Marghera, Italy to Murano. Oxygen produced in Porto Marghera would then be distributed to the furnaces on Murano. Since this testing was carried out, no significant actions have been taken to move forward with a conversion to oxycombustion. However, the district of Sacca Serenella, which is still under development, has begun to install underground infrastructure for oxygen pipelines. The findings from the 1996 oxycombustion testing will be reported in the Results and Analysis Section 4 of this paper.

Despite the potential benefits, there are reasons why oxycombustion has not been adopted, first and foremost is the cost. For hundreds of years the factories of Murano have relied on air, which is free, as a means to oxidize their fuel. The thought of paying for the oxidizer (oxygen) is preposterous to many factory owners. The first few companies that switch over will also see additional hardware costs due to new equipment and thus no one wants to be first. Additionally, lifespan testing on oxycombustion furnaces has not been carried out and it remains to be seen whether the intense oxygen enriched flames will break down the furnace at a faster rate. With these factors in mind, selected companies on Sacca Serenella will be carrying out prolonged testing of oxycombustion to determine its long term costs and benefits. Despite the positive outlook for oxycombustion, the politics and bureaucracy associated with major changes such as this are causing the process to move slowly.

2.5.4 Cogeneration

Recycle

Cogeneration is a method of creating electricity from heat using a heat engine. In 2001 a study was carried out by Worcester Polytechnic Institute to determine whether it was feasible to use a cogeneration system on the glass furnaces of Murano. The findings showed that in order to have an acceptable payback period it would be necessary to use generators working at a higher efficiency than was possible at the time.[16] This project has revisited the topic of cogeneration as a means of recycling waste energy.

There are two types of cogeneration systems: the topping cycle and the bottoming cycle. The topping cycle uses fuel to drive a turbine connected to a generator to produce electricity. Excess heat created during the electricity generation process is reclaimed and used for heating purposes. Steam and gas turbines are commonly used

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[16] Picariello, Steven R., et al. 2001. *Cogeneration -- feasibility study for the artistic glass companies of Murano, Italy.*

with the topping cycle.[17] Alternatively, the bottoming cycle is a system that is coupled to a high temperature exhaust stream, usually that of an industrial process. Typical bottoming cycles rely on steam turbines, organic Rankine-cycle turbines, gas turbines, and the Stirling cycle.[18] The nature of glass making dictates that a bottoming cycle be used since the heat must be generated for the furnace before electricity generation can take place. Traditional cogeneration is carried out on a large scale at an industrial factory or power plant, but recent developments in technology have greatly reduced the size requirements and money needed for cogeneration. This has led to the creation of a new industry known as micro-cogeneration.

Micro-cogeneration is being targeted at domestic use for replacement of oil and gas fired furnaces. The concept is that one unit can be used to heat a home as well as supply it with electricity. While micro-cogeneration is rare, most units use the Stirling cycle and produce electricity in the 1-15kW range.[19] These systems are generally compact and require little maintenance since they are intended for the average homeowner. The use of the Stirling cycle in these units increases their efficiency by as much as 90% over traditional heat engines.[20] However, due to their relatively recent introduction to the market, their reliance on a dedicated natural gas fuel burner, and their prohibitive cost (at least $10,000) these units are not widespread. The energy outputs are currently too low to make them practical for use in electricity generation in energy intensive processes. Off-the-shelf systems are currently set up to run in a topping cycle making them impractical for recapturing existing heat sources without significantly modified components.

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[17] Hu, S. D. 1985. *Cogeneration.* Reston, Va.: Reston Pub. Co.

[18] Hu, S. D..

[19] Dentice d'Accadia, M., M. Sasso, S. Sibilio, and L. Vanoli. 2003/7. Micro-combined heat and power in residential and light commercial applications. *Applied Thermal Engineering* 23, no. 10:1247-1259.

[20] Microgen. Microgen- Technical Specifications. in Microgen [database online]. 2006 [cited 9/15 2006]. Available from http://www.microgen.com/pdfs/technical_specification.pdf.

2.5.4.1 Stirling Engine

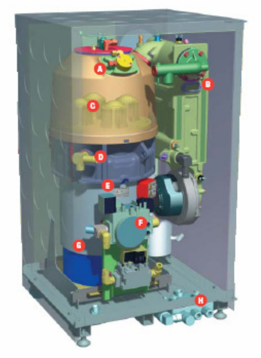

Figure 16: Whispergen Micro-Cogeneration Unit

The Stirling cycle was invented in 1816 by Robert Stirling as a replacement for the steam engine that would often disastrously explode.[21] The Stirling engine relies on a temperature differential to drive its pistons. One piston must be hot while the other is at a lower temperature. This form of energy input is known as external combustion. Because the heat is produced outside of the engine itself it can potentially be run on almost any fuel. The efficiencies of the Stirling cycle (up to 40%) and its ability to run on any heat source make it one of the most lucrative sources for power generation from waste heat. The technology, as applied to power generation, is still in its infancy and units are not commercially available for applications such as waste heat power generation on the scale of artistic glass furnaces.

2.5.4.2 Steam Cycle

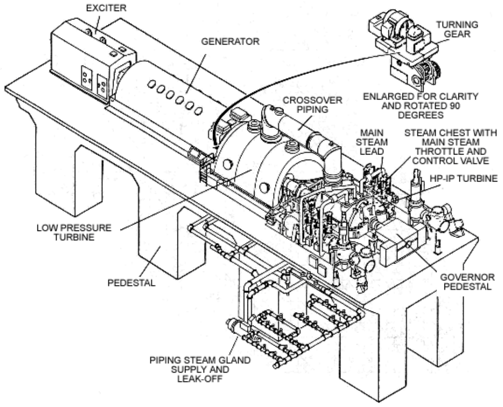

Figure 17: A Typical Power Station Steam Generator and Equipment

One alternative to the Stirling cycle for cogeneration is the use of steam to drive a turbine. Steam turbine technology is generally used in large scale operations such as power plants. The process works by creating steam, which drives a turbine. The turbine is coupled with a generator that produces electricity. The steam is then condensed back into a liquid and the cycle restarts.[22] While large steam turbines can have efficiencies of 40-45%, smaller modular steam systems only reach 30-35% efficiency.[23] Steam power systems are the most prevalent of all the technologies available and thus most easily obtained. However, their many parts and

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[21] Encyclopedia Brittanica. Energy Conversion. in Encyclopedia Brittanica [database online]. 2006 [cited 9/15 2006]. Available from http://search.eb.com/eb/article-45928.

[22] Energy Manager Training. Steam Turbine. 2004 [cited 9/15 2006]. Available from http://www.energymanagertraining.com/power_plants/steam_turbine.htm.

[23] Consumer Energy Council of America. Steam Engines. in Consumer Energy Council of America [database online]. 2003 [cited 9/15 2006]. Available from http://www.deforum.org/steam-engines.htm.

mechanical nature inherently mean that they must be serviced and maintained by qualified professionals. New developments in physics and photonics have created a new technology that can extract energy from heat using no moving parts, thus creating a highly efficient electrical generation system known as thermophotovoltaics.

2.5.4.3 Thermophotovoltaics

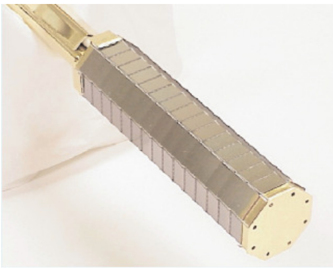
Figure 18: A TPV module manufactured by JX Crystal

Thermophotovoltaics (TPV) is an emerging field that has great potential for energy recapture. TPV cells are very similar to the more common solar photovoltaic cells with one exception. While solar PV cells derive their energy from light, TPV cells rely on heat.[24] This feature allows them to generate significant amounts of electricity just from being placed near a heat source. Due to the newness of this technology, current commercially available options only produce 1.5kW and thus are not yet practical for large applications. If the TPV cells were further developed and available at lower costs they would be very promising for the artistic glass industry as they could simply be placed in the furnace with very few changes required and extract electricity. Rather than create electricity from heat it is sometime useful to redistribute this excess heat using heat exchangers and distribution networks.

2.5.5 District Heating

Reuse


Figure 19: Masnedø CHP Power Station in Denmark

A method of redistributing waste heat in a useful form known as district heating has also been explored. The concept as related to Murano would extract heat from glass furnaces and distribute it to other buildings. The country of Denmark stands out as a leader in the field of district heating providing for over 50% of its space heating needs through the process. Their extensive system is fueled by waste

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[24] Fraas, Lewis. Thermo PV. 2006 [cited 9/15 2006]. Available from http://www.jxcrystals.com/ThermoPV.htm.

incineration, biomass, oil, natural gas, and waste heat generated by industry.[25] In order to take advantage of district heating it is necessary to have a centralized location where heat is generated as well as a network of insulated pipes to supply the individual users with heat in the form of steam or hot water. Individual buildings must also have compliant heating systems to interface with the district supply. One problem with district heating is making use of the heat that is generated during times of low demand. Combined heat and power systems provide some solution to this problem by using heat-powered generators to convert extra heat into electricity. District heating on Murano would require a significant infrastructure change to the island to install the distribution network. Additionally the heat losses involved with transferring the heat over long distances would be an inefficient use of the heat produced in the furnaces. It would be much more practical to reduce waste heat at the site rather than try to distribute it throughout the island.

2.6 Groups Involved

The following is a description of the groups involved in this project. Their respective backgrounds and interests are summarized for overview.

2.6.1 Stazione Sperimentale del Vetro

The Stazione Sperimentale del Vetro (SSV) is the sponsor of this project. It is a research lab located in Murano, Italy that is dedicated to the research and development of glass technology and manufacturing methods. The SSV is funded through the glass industry and works mostly for large industrial manufacturers. However the SSV's proximity to the world class artisans of Murano make it only natural that the SSV work for the development of the craft of artistic glass blowing. The WPI team has worked closely with Dr. Bianca Maria Scalet, who was the liaison between the two organizations. Assisting with additional support in the field of engineering were Alberto Deste and Dr. Roberto Dall'Igna of the SSV.

Figure 20: Stazione Sperimentale del Vetro, Murano, Italy

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[25] Manczyk, Henry, and Michael D. Leach. Combined Heat and Power Generation and District Heating in Denmark: History, Goals, and Technology.

2.6.2 Correll Glass Studios

Figure 21: Goblet made by Correll

Correll Glass studios, owned by Charles Correll and based out of Conway Massachusetts is a one man operation specializing in glass hotshop equipment and artistic glass creations. Correll began glass blowing in 1971 at the Jamestown Glasshouse of 1608. Correll has made a name for himself in American glass circles with his skilled craftsmanship and technological advances in furnace and burner design. Correll's philosophy is to question the traditional methods in favor of more fuel efficient and practical designs in order to save on gas consumption and lower emissions from furnaces. His long career of working with glass has also made him adept at knowing the aesthetic qualities that an experienced artisan will require of their furnace. Correll worked with the WPI team to determine whether his recuperative burners were appropriate for use in the glass factories of Murano as well providing furnace insulation data and analysis.

2.7 Summary

There are parties interested in lowering the fuel consumption of the Murano glass industry on both the factory side as well as the research and technology side. As is evident from the aforementioned technologies, there are a number of ways in which the efficiencies of the glass furnaces of Murano could be improved. The glass industry of Murano has a rich history full of tradition that has allowed the island to take its place as the world leader in artistic glass creation. Becoming a model for fuel efficiency and conscious environmentalism and following the reduce, reuse and recycle motto will make them a model for all industries.

3 Methodology

The goal of this project was to create a plan for the reduction of waste heat and natural gas consumption in glass furnaces on the island of Murano, Italy. The team researched existing technologies and carried out tests for the purpose of determining an appropriate technology for reducing Murano's fuel usage.

In order to fulfill this task the group carried out the following objectives:

- Investigation of the current technologies that could be used to increase the efficiency of the glass making process, decrease environmental impacts, and lower overall costs.
- Assessment of the performance, economics, and social acceptability of these new technologies.
- Designation of a testing protocol for the adoption of the most promising efficiency improving technologies.

Using mathematical modeling and real world tests on existing furnaces the fuel consumption, emissions, and associated costs of the selected technologies have been analyzed. The procedure for this is outlined in this section and the results are reported in section 4. The following flowchart illustrates the source, type of data and what the data was ultimately used for.

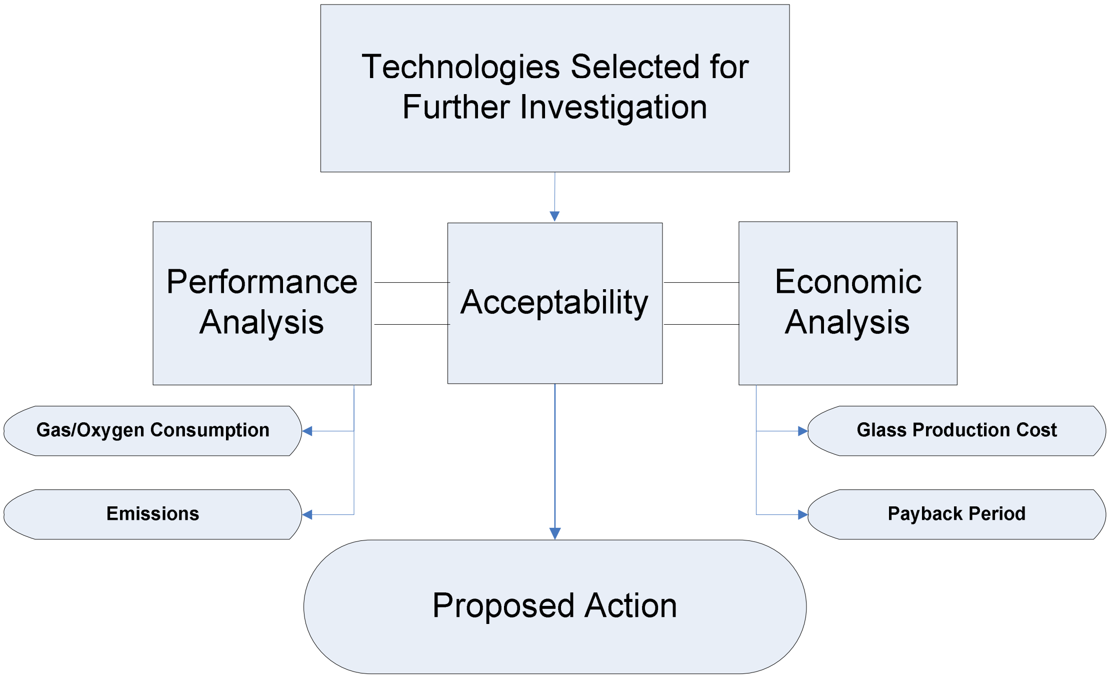

Figure 22: Methodology Flowchart

3.1 Investigation of Energy Reduction Technologies

Technologies Selected for Further Investigation

There are a number of different energy reduction technologies that we identified in the background of this paper. While all of these technologies have potential to reduce energy consumption in furnaces they all work on varying principles and are at different stages in development and commercialization. In order to determine the most appropriate technologies we divided those identified in background research into the categories: recuperative burners, oxycombustion burners, cogeneration technologies, and district heating. We then looked at each category with regards to commercial availability, magnitude of change required for implementation, and where the technology fell on the Reduce, Reuse and Recycle hierarchy.

Cogeneration technologies including Stirling, steam and thermophotovoltaics are neither technically viable nor commercially available as options to small scale artistic glass furnaces like those found on Murano. Likewise, it was decided that implementing a district heating infrastructure overlooked the more basic problem of reducing fuel usage altogether.

After applying these filters and talking with our sponsor we made the decision to pursue analysis of recuperative furnaces and oxycombustion burners. The Correll style recuperator had not been used on Murano before, nor had it been investigated previously. The SSV and Correll were both interested in the application of these recuperators to Murano. With this in mind we decided to gather data that would allow us to make a comparison between Correll's recuperative furnace and a traditional Murano Furnace. Because many people on Murano were excited about oxycombustion we also decided to investigate it in comparison with recuperators and the traditional furnaces of Murano.

Our data collection focused on the performance, economics and acceptability of a traditional furnace, a recuperative furnace and an oxycombustion furnace. The rest of this chapter will explain the tests and techniques that we used for data collection on these furnaces and the analysis that was then performed. Table 2 outlines the tests that were able to be performed on each furnace and a description follows.

	Test					Data		Analysis		
Furnace	**Fuel Consumption**	**Emissions**	**Performed By**	**Location**	**Date of Testing**	**Hardware Costs**	**Operating Costs**	**Operating Costs**	**Hardware Payback**	**Insulation**
Traditional Murano	√	√	SSPV	Murano Italy	Nov-06	√	√	√	√	√
Correll Recuperative	√	N/A	Correll	MA, USA	Nov-06	√	√	√	√	√
Oxycombustion	√	√	SSPV	Murano Italy	1994	N/A	√	√	N/A	√

Table 2: Testing Overview

3.1.1 Traditional Murano Furnace Investigation

The performance testing and cost analysis on the new technologies that we performed needed a baseline for comparison. To do this we collected performance and cost data on a traditional furnace that is currently in use on Murano. This furnace was a 200kg daytank at the Ferro Glass Company. The fuel consumption and emissions data was collected by the SSV in November 2006, during our stay in Venice.

3.1.2 Recuperative Furnace Investigation

In order to properly run comparative tests on a Correll recuperative furnace and a traditional Murano furnace it would be necessary to perform quantitative measurements on the furnaces side by side with exactly the same operating conditions. Unfortunately we were not able to have a Correll furnace on Murano for testing. The data collected for this furnace was done in the Correll Glass Studio shop in Massachusetts in November 2006 and carried out by Charles Correll, the inventor and manufacturer of the furnace. His tests were carried out with our guidance although we were not able to be there. The data collected included: fuel consumption and furnace wall insulation thicknesses. Correll was not able to obtain emissions data because he does not have access to the proper testing equipment. For this reason we made mathematical estimates of the emissions from his furnace as is discussed in the results section. Additionally Correll provided us with cost estimates and building schedules for his equipment for cost analysis and implementation purposes.

3.1.3 Oxycombustion Burner Investigation

Oxycombustion was tested on Murano by the SSV in 1994. A furnace was modified to use an oxycombustion burner and test batches of glass were melted. The fuel consumption, oxygen consumption and emissions of this furnace were measured by the SSV with the oxycombustion burner in place as well as a traditional burner in place. This information was compiled by the SSV in a report. We used this report to obtain information for performance and cost analysis on oxycombustion technology.

3.2 Assessing Feasibility of Selected Technologies

Once we selected the most promising technologies from background research we had to collect data and produce analysis to assess the feasibility of using the selected technologies in the glass furnaces of Murano. In order to assess the feasibility of the technologies we quantified the performance, economics, and social acceptability of furnaces using each of the selected technologies.

3.2.1 Insulation Techniques Investigation

Heat loss occurs in three areas in a furnace through the flue, the door and through the walls. Proper insulation keeps heat from leaving through the furnace walls and thus reduces fuel consumption. Correll has developed a simple way of comparing furnace insulation by calculating equivalent inches of firebrick (E.I.F.). Firebrick is a commonly used construction material for furnaces, and thus while it does not have particularly good insulation properties; it provides a good baseline for comparative analysis. The value of firebrick shall be defined as 1; all other materials' insulation properties will be defined as equivalent inches of firebrick. Table 3 shows the equivalent inches of firebrick for common furnace building materials. Once the E.I.F. has been determined for each material and the individual sections of the wall are summed, a comparison can be made between two or more furnaces. Our analysis of insulation was between a traditional furnace and a Correll recuperative furnace. When oxycombustion testing was performed it was done on a

Material	E.I.F.
Heavy Firebrick	1.00
Heavy Castable	1.00
3000° Insulating Castable	2.92
2500° Insulating Castable	2.92
2200° Insulating Castable	4.80
2000° Softbrick	4.30
2600° Softbrick	3.70
2800° Softbrick	3.15
1900° Block Insulation	12.00

Table 3: Equivalent Inches of Firebrick for Common Furnace Building Materials

traditionally built furnace and so the insulation properties were equivalent to a traditional Murano furnace.

3.2.2 Natural Gas Consumption Testing

The performance of a furnace was defined by us to mean the consumption of natural gas per kilogram of glass produced and the concentration of emissions from the furnace.

To determine natural gas consumption on a furnace a means of measuring the gas flow is necessary. In all testing areas a standard flow meter was used by the tester to quantify how much gas flowed into the burner and thus was combusted. During the test the furnace was used to melt a batch of glass and hold the glass at temperature for a period of eight hours. The flow meter was checked hourly and the consumption recorded for the duration of test. This procedure was followed for all fuel consumption tests described in this report.

3.2.3 Emissions Testing

To determine the make up of emissions an array of probes is typically employed to test for specific elements and their concentrations. Additionally a membrane filter is used to collect particulate. The membrane filter is then weighed to determine mass and the particulate matter collected is broken down in a lab to find its composition.

The aforementioned technique is available to the SSV and was used to determine emissions of the traditional Murano furnace as well as the oxycombustion furnace. The elements tested for were particulate matter, nitrous oxide, and hydrofluoric acid. This testing was not able to be carried out on the Correll furnace because Correll's shop does not have the necessary equipment. We have calculated CO_2 emissions for all furnaces by analyzing the amount of natural gas burned using the assumption that $1m^3$ of natural gas contains $1.4*10^{-2}$ metric tons of CO_2 as found on the Energy Information Agency's website.

3.2.4 Economics of Furnaces Assessment

In order to assess the economic aspects of the different technologies tested we looked at two major aspects of furnaces using each technology: fuel cost to produce one kilogram of glass and hardware costs.

Quantifying the consumption of natural gas per kilogram of glass produced gave us the necessary data to calculate fuel cost per kilogram of glass (*€/kg*). We determined this using standard fuel rates for glass factories on Murano and the natural gas consumption data. We used the results of this to make a quantitative comparison between a traditional Murano furnace, a Correll recuperative furnace and an oxycombustion furnace. The comparison takes into account the fuel consumption and the cost savings of each technology.

In order to determine the hardware costs of technologies we asked Murano factories to supply us with costs for the initial investments of their traditional furnaces. We compared this hardware costs obtained from Correll on the recuperative furnace and analyzed the potential savings that a recuperative furnace could provide over a traditional furnace. The initial investment divided by the yearly savings gives a basic payback period in years for each technology. Hardware costs were not available for oxycombustion burners and so this analysis was only done for a Correll recuperative furnace in comparison with a traditional Murano furnace.

3.2.5 Acceptability of Selected Technologies Assessment

Glass has been made on Murano for over seven hundred years. This has led to long traditions that are as much a part of the glass making process as the sand and silica that make up the glass. Any change to the glass making process must be done carefully so as not to negatively change the way in which the artists work. When investigating the different energy reduction technologies we sought to obtain the opinion of the artisans that had worked with or heard of each technology. We also paid particular attention to the opinions and thoughts of the factory owners regarding fuel prices, new technologies, and glass quality.

3.3 Designing Testing Protocol for Selected Technologies

During the course of this project there were a number of elements that we identified as needing further testing and analysis. To facilitate this in future studies we have determined the steps that need to be taken to collect this data and make educated decisions about the implementation of selected technologies.

3.3.1 Testing Procedure for Selected Technology

It was outside the scope and timeframe of this project for us to determine the ultimate solution to fuel reduction on Murano. We have decided to take our findings from this analysis and propose a testing procedure for the next step in determining how to lower the fuel consumption of Murano. When drafting this proposal we had to pay attention to all the data that we were missing and all the assumptions that we made and take note of areas that needed improvement. There will never be a final solution, only continuing improvements. The goal of our proposed testing procedure is to aid in determining whether or not the selected technology is suitable for implementation.

4 Results and Analysis

In this section we report on the results of our furnace testing. We have collected data on the performance, cost and acceptability of: a traditional furnace, a recuperative furnace, and an oxycombustion furnace. Conclusions of this data are discussed in Section 5.

4.1 Feasibility of Selected Technologies

After we determined that we would be focusing on recuperative furnaces and oxycombustion burners we needed to quantify the performance, economics and acceptability of these furnaces. Tests were run on the recuperative furnace by Correll in Massachusetts and the traditional furnace in Murano by the SSV. Data that was collected during the oxycombustion testing of 1994 was examined by us.

4.1.1 Insulation Analysis Results

Using the procedure as defined in section 3.2.1 Insulation Techniques Investigation, the following results were obtained (see Table 4). A furnace using Correll's construction methods has insulation properties 2.5 times as effective as one constructed in the traditional manner on Murano. This is in spite of the fact that the walls are physically 8cm thinner than those on a traditional furnace. The use of materials such as vermiculite and insulating castable considerably add to the insulation properties of this

Traditional Murano Furnace

Layer	Material	Thickness (cm)	E.I.F.	Product
1	Alumina Hardbrick	22.0	1.0	22.0
2	2600º Softbrick	11.0	3.7	40.7
3	2400º Ceramic Fiber	2.5	12.0	30.0
Total		**35.5**	**16.7**	**92.7**

Correll Furnace

Layer	Material	Thickness (cm)	E.I.F.	Product
1	Heavy Firebrick	5.1	1.0	5.1
2	3000º Insulating Castable	5.1	2.9	14.8
3	1600º Vermiculite Castable	17.7	12.0	212.5
Total		**27.8**	**15.9**	**232.4**

Summary

	Furnace	Actual Thickness (cm	E.I.F	Relation
	Traditional Murano Furnace	35.5	92.7	0.40
	Correll Furnace	27.8	232.4	2.51

Table 4: Insulation Analysis Summary

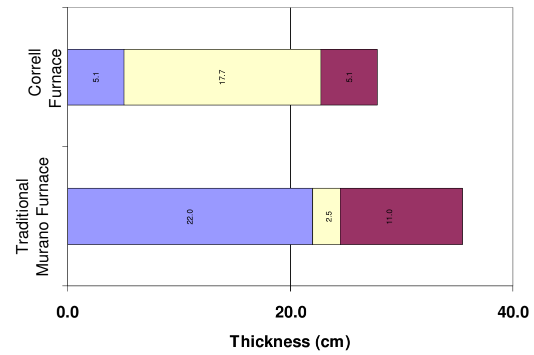

Figure 23: Insulation Thicknesses

furnace. Figure 23 illustrates the different materials and their thicknesses used in the two different furnace construction techniques. In the big picture this factor of 2.5 is not as large as it may appears. This is because the majority of the heat loss happens through the furnace flue and the door since there is no resistance to convection in this area. Increased insulation does allow the input flame more time to heat the glass load before the heat is lost through the walls. A recuperator can be used to recover heat that would otherwise be lost through the flue.

In order to determine whether Correll's furnace designs are appropriate for Murano it will be necessary for one of his furnaces to be tested in a Murano factory. The lifespan of his materials under the duty-cycle of a production factory will need to be determined.

4.1.2 Natural Gas Consumption Results

Using the procedure described in section 3.2.2 we produced the summary shown in Table 5. This table compares the fuel consumption of the traditional furnace with a Correll furnace and an oxycombustion furnace. The results show that a Correll furnace achieves a 35% reduction in fuel usage over a traditional furnace while an oxycombustion burner is able to reduce fuel consumption by 45%. The oxycombustion reduction does not take into account the amount of oxygen that must now be supplied to the burner.

Technology	CH4 Comsumption	O2 Consumption
	m^3/kg	m^3/kg
Traditional Murano	2.12	0
Correll Technology	1.37	0
Oxycombustion	1.15	2.46

Table 5: Gas Consumption Summary

4.1.3 Emissions Results

The calculations that we performed on CO_2 emissions is summarized in Table 6. CO_2 is directly related to fuel consumption and so this is theoretical data. The measured emissions for particulate matter, hydrofluoric acid, and nitrous oxide are summarized in Table 7.

Technology	CO2 Metric Tons/kg (glass)
Traditional Murano Furnace	3.02E-02
Correll	1.95E-02
Oxycombustion	1.62E-02

Table 6: CO2 Emissions Summary

		Emissions g/h		
Phase	Pollutant	CH4/Air	Correll (Theoretical)	Oxycombustion
1	Polveri	13.00	4.55	7.90
	NOx	600.00	210.00	290.00
	HF	4.65	1.63	1.13
2	Polveri	25.00	8.75	10.00
	NOx	890.00	311.50	300.00
	HF	3.04	1.06	1.69
3	Polveri	28.00	9.80	16.00
	NOx	790.00	276.50	300.00
	HF	3.95	1.38	0.50
4	Polveri	63.00	22.05	33.00
	NOx	160.00	56.00	63.00
	HF	2.48	0.87	0.57

Table 7: Emissions Summary

In the comparison of emissions there are a number of variables that are unknown and make it hard for us to create an accurate picture of recuperators and oxycombustion. In summary we expect recuperative furnaces with a 35% fuel efficiency increase to have at least a 35% decrease in emissions. Oxycombustion lowers emissions by an average of 41%. However the missing piece here is that it takes energy to produce the oxygen gas. Thus the net decrease in emissions needs to take into account the emissions of the fuel that is consumed to make the oxygen. We have been told that the potential source of oxygen for Murano is a by product of a larger operation in which nitrogen gas is created. This means that the production of oxygen, as a by product, does not have any direct fuel use associated with it, making it a clean source. We were not able to find the numbers on

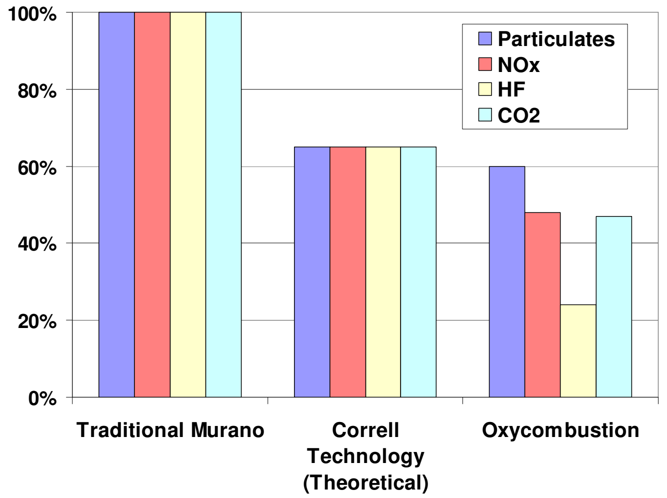

Figure 24: Emissions Comparison

this though and so the best we can do is mention that the emissions of oxycombustion should take this into account. Figure 24 shows the emissions as a percent reduction of a traditional furnace (oxycombustion does not include production emissions).

4.1.4 Economics of Technologies

This section will start by breaking down the operating and hardware costs by furnace and then bring them together for comparison at the end.

The fuel usage that we found during testing of a traditional Murano furnace was 2.1 m^3/kg of glass produced. At the standard rate for gas usage on Murano of 0.33€/m^3 this works out to be 0.69€/kg.

A traditional style pot furnace as built by a Murano factory costs 10,000€. These furnaces are typically serviced once a month at a cost of 150€. The lifespan before a complete rebuild is needed is four years.

The fuel consumption tests of a Correll recuperative furnace show a 35% reduction in fuel usage so a 35% reduction in operating costs is also expected. We have determined that glass can be produced with a Correll furnace at a cost of 0.45 €/kg see Figure 26 and Figure 28. Using the average production of glass per furnace per year on Murano of 10,000kg we have found a 2,400€/yr savings over the traditional furnace. Furthermore the cost of a 100kg Correll pot furnace was determined to be 11,500€ including the recuperator and control system. Because we do not know how well a Correll furnace will hold up to the duty cycle the furnaces are put through on Murano we have estimated the service period and costs to be the same as a traditional furnace. This means that the payback period subtracting the cost of a new traditional furnace is 3.13 years.

We have created a graph to show the varying payback period in years for a Correll recuperative furnace with varying efficiency improvements over traditional furnaces in Figure 25. This is useful because the actual efficiency improvements have not been quantified and thus should the actual results prove to be different then our findings the analysis can be redone.

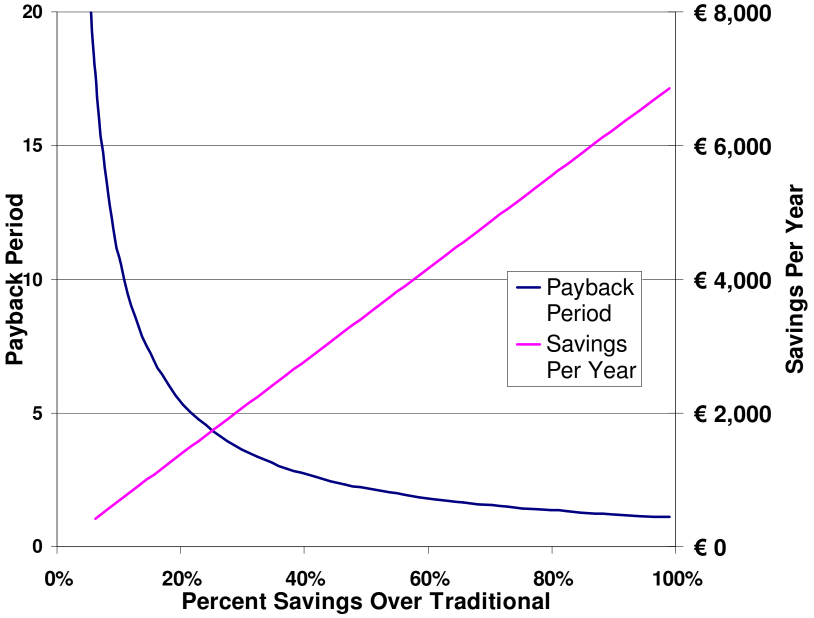

Figure 25: Payback Period of Correll Furnace

Oxycombustion provides natural gas consumption reductions of 45%. This does not translate into cost savings of equal value though. Oxygen is not free and its usage must be factored into the cost. Using current fuel and oxygen prices provided by the SSV we have determined that oxycombustion burners cost 0.63€/kg of glass produced. This is only a 10.8% reduction in cost over the traditional furnace operating cost of 0.69€/kg. This number differs from that of the original cost savings estimate done by the SSV of 20%. The procedure that the SSV used to determine its numbers was not available and thus we can only suggest that the findings be reviewed. One possible explanation is variable fuel costs; the price of natural gas has risen significantly since 1994 when the original analysis was conducted.

Detailed hardware costs were not able to be obtained for oxycombustion burners. We did find out that in order to convert a factory to oxycombustion the first step is to replace the burners. As the furnaces deteriorate and need to be rebuilt they will be constructed in a new style that makes more efficient use of the oxygen enriched flame. We were not able to obtain the necessary information to determine a payback period for oxycombustion. Future testing will help to quantify a payback period and other associated costs.

In order to look at the technologies side by side we have prepared Figure 26 to illustrate the operating costs of each furnace. The operating cost was used as the unit of comparison since oxycombustion consumes a gas other than natural gas in the melt cycle. This chart does not take into account hardware costs since we were not able to determine this for oxycombustion. The chart illustrates that, should Correll's furnace improve fuel consumption by 35% over traditional furnaces, it will be cheaper to convert furnaces to this style rather than switch to oxycombustion. Figure 27 shows the operating costs of oxycombustion versus the operating costs of a Correll furnace with varying efficiency improvements. We can see that the Correll furnace only needs to maintain an efficiency increase of 16% to maintain its competitiveness with oxycombustion.

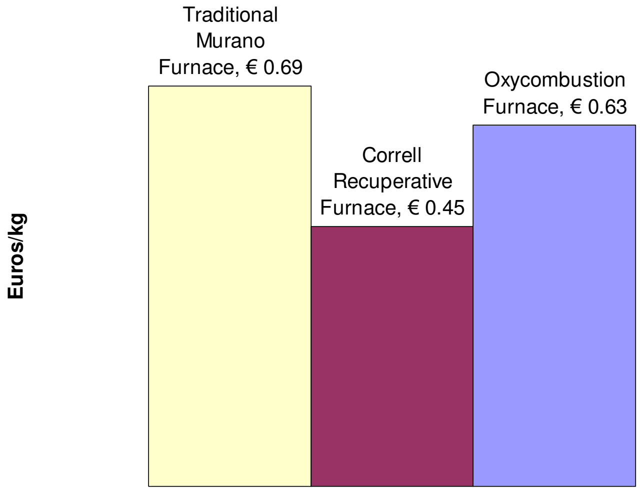

Figure 26: Operating Costs per kg of Glass by Furnace

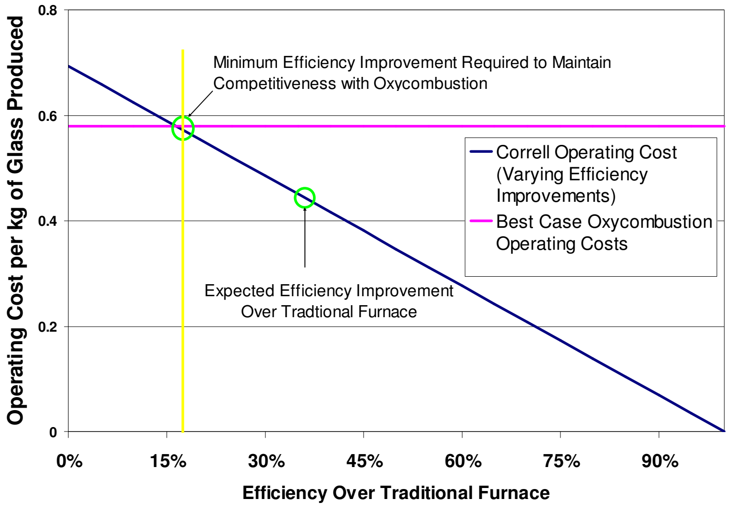

Figure 27: Operating Cost Comparison, Varying Efficiency Improvements

4.1.5 Acceptability of Furnace Changes

One realization that became apparent as the team explored the factories of Murano and talked with the factory owners was that while the melting furnace is an essential element, its details are not all that important. The furnace has two roles, to melt the glass and to keep it melted long enough for the artisan to work and transform the glass into a piece of artwork. As long as the furnace can adequately accomplish this the artisan will not have any qualms about how it is done.

Having the aid of the SSV and our advisor Fabio Carrera was essential in getting into the glass factories because they will not open their doors to just anyone. The secrecy that dates back to the 13th century when Venice forbid the glassmakers to leave the island for fear of losing their edge in the world glass market is still alive to some extent. When the team tried to obtain the composition of firebrick from a local supplier they were informed it was trade secret as was the price of the brick itself. This is not to say that there are not open minded people on Murano. Farnea Mariangelo of the Zanetti Glass Company eagerly awaits the adoption of oxycombustion technology so that he can lower his fuel bill; likewise, the owner of the Ferro Glass Company has expressed interest in obtaining and trying a Correll furnace in his factory.

This is a time of opportunity on the island of Murano. World fuel prices are rising, Murano glass factories recently lost their natural gas discount price and there are exciting methods for lowering fuel consumption on the table. The next steps will be key to the reduction of natural gas use in artistic applications, not just on Murano but across the globe. Murano is known around the world for its amazing glass artisans. Should a change to reduce fuel use take place it would set an example not only for artisans but industry as well, to be more conscious and to make positive changes in their processes to be more energy efficient.

5 Conclusions and Recommendations

The findings of our project have shown that there is ample opportunity to improve the fuel efficiency of Murano. However, our testing should only regarded as preliminary since it was by no means perfect. This section summarizes the potential savings of the technologies that we investigated to all of Murano and then makes a proposal to do follow-up studies on both oxycombustion and recuperators to ensure that the data is accurate and an educated decision can be made as to the future of glass furnaces on Murano.

5.1 Theoretical Application of Technologies to Murano

It is our hope that in the near future Murano will adopt an energy saving technology to reduce its fuel consumption. Whether or not this change involves recuperative furnaces, oxycombustion or something completely different will work itself out in the upcoming testing. For the purpose of estimation we have applied the savings that we have calculated for recuperative furnaces and oxycombustion to the entire island of Murano (Table 8).

The savings have only been applied to the melting furnaces on Murano, which account for 60% of the total fuel consumption on the island. Should the recuperative furnaces hold up to their claims Murano stands to save upwards of 3 million Euro per year over traditional furnaces, while oxycombustion shows a savings of 1.6 million Euros per year. In terms of CO_2 reducing fuel consumption by 35% through recuperative furnaces is the equivalent of preventing 150,000 metric tons of CO_2 from entering the atmosphere each year and up to 320,000 metric tons of CO_2 with oxycombustion. Either way this is a significant savings for the island.

Natural Gas Consumption (m3) per year	45,000,000.00
€/m3 Natural Gas	€ 0.33
Cost per year	€ 14,850,000
Melting Furnaces on Murano	60%
Cost per year of Melting furnaces	€ 8,910,000
Recuperative Furnace Savings	35%
Savings of Recuperative Furnace on Murano per year	€ 3,118,500
Oxycombustion Burner Savings	11%
Savings of Oxycombustion on Murano per year	€ 1,603,800

Table 8: Theoretical Savings Applied to Murano

5.2 Further Testing of Recuperators

Correll himself has stated that a recuperator is not a silver bullet in reducing fuel consumption. There are many variables including insulation techniques and operating practices that vary by the furnace and artisan. These variables affect the fuel consumption with different weights but nevertheless change the results.

One option that we explored was to bring just a recuperator to Murano to install on a furnace and carry out testing in this manner. It was determined by Correll though that while this would work, it would not accurately portray the benefits of his whole system since he could not account for the insulation of the furnace on which it was to be installed. Additionally, the furnace planned for this test was not comparable in size to the furnace that the recuperator was meant for.

Using recuperators and altering insulation both hold potential for reducing fuel consumption on Murano. Changing Murano's furnaces to take advantage of these improvements is in many ways simpler than converting to oxycombustion, since there is no change to the infrastructure of Murano (running an oxygen pipeline) as required by oxycombustion.

The one certainty that we found in all of the testing was that a Correll recuperative furnace needs to be tested on Murano, side by side with a traditional furnace so that efficiency improvements can be measured accurately. To do this we recommend that Charles Correll be brought to Murano to build his furnace. The furnace recommended by Correll should be a 100kg Pot Furnace. We have identified a 100kg pot Furnace at the Zanetti factory that could be used for direct comparison studies.

The procedure for conducting this study should be carried out with the following guidelines:

- Melt a batch of glass in the traditional pot furnace
    - Measure the weight of the batch
    - Record the composition of the batch
- Record the gas flow through the furnace using a flow meter
- Measure the emissions from the furnace
- Record the amount of time that the furnace was run for

- Melt a batch of glass in the Correll recuperative pot furnace

    - Ensure that weight and composition of this batch are identical to that of the batch melted in the traditional pot furnace
- Record the gas flow through the furnace using a flow meter
- Measure the emissions from the furnace
- Record the amount of time that the was run for
- Ask the artisans that work this furnace their opinions on the furnace and the glass that it produces

- Determine the operating consumption of the furnace in m^3 of natural gas consumed per *kg* of glass melted
- Determine the emissions of the furnace
- In a long term test determine the service period of the Correll recuperative furnace

It is our hope that with this new data a more definitive model can be made for the efficiency improvements of a Correll recuperative furnace over a traditional Murano furnace. If the results are favorable word will spread through Murano and Correll's technology will work its way into the factories of the island and around the world. We have authored a proposal that can be found in Section 7.10. It has been presented to the SSV and is awaiting approval. The proposal outlines the potential benefits of the new Correll furnaces, associated costs and a timeframe for carrying out a test on Murano.

5.3 Oxycombustion Analysis

When the oxycombustion testing was carried out the oxygen was supplied to the burner from a tank. A system like this has a limited capacity of oxygen and needs to be constantly refilled. This is not a practical way of operating the Murano furnaces due to their high production volume. In order to make oxycombustion practical, a pipeline would need to be run from the oxygen producing plant on the mainland. This would provide the furnaces with a constant source of oxygen. The associated costs of running this pipeline and converting

Oxygen Pipeline Construction	€4 million
Local Distribution Network	€4 million
Adaptation of Existing Furnaces	€2 million

Table 9: Oxycombustion Infrastructure Costs as Estimated by SSV

Murano to oxycombustion have been estimated at 8 million euros by the SSV.[26] Sapio, the Italian company that would provide the oxygen to Murano has stated that should ten factories convert to oxycombustion then they will pay for the pipeline to be installed. Before any company will commit to changing over their furnaces to oxycombustion it is necessary to be absolutely sure that this change will be to their benefit. For this reason extended tests will be carried out in the future on the district of Sacca Serenella. The main objectives of this testing will be to determine the lifespan of the oxycombustion burner and the furnace on which it is installed to determine the long term costs of running an oxycombustion furnace, and to further identify the quality of the glass produced using these furnaces.

This testing was scheduled to begin in the winter of 2005. It has not yet been started though due to political and economic hold-ups. Five companies will convert their entire factory to run on oxycombustion burners. The oxygen will be supplied from a central tank that will be refilled by boat weekly. The initial change will require that the current burners be replaced with oxycombustion burners. This will work in the short-term but as the furnaces are serviced and rebuilt modifications will be made to adjust the materials and size of the combustion chamber to make more efficient use of the oxygen enriched flame. This testing has been on the table for a number of years now and so we have no influence over the way in which it will be carried out or when it will begin. It is our opinion that the oxycombustion testing continues as planned.

5.4 Project Conclusion

The research and testing of different burner technologies during this project has shown that there is ample opportunity to increase the efficiency of the glass making process on Murano. Insulation, recuperation, and oxycombustion are all examples of changes that could revolutionize the energy impact of artistic glass. Unfortunately, the time span and scope of this project did not allow for the thorough, rigorous testing that is necessary to bring an ultimate conclusion to the question of the most appropriate improvements for Murano furnaces.

The testing process for oxycombustion began twelve years ago and is just now going into the long-term testing phase. This is being facilitated by the SSV and the city of Venice and is scheduled to begin in 2007. With the help of the SSV it is the recommendation of the WPI team that Charles Correll be brought to Murano to build a

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[26] Stazione Sperimentale del Vetro.

recuperative furnace in a glass factory. This will allow testing similar to the oxycombustion testing to begin on his methods. These experiments will allow the glass factories to try his furnaces first hand and determine the relative fuel savings experientially. This will also let them assess the lifespan and durability of his design.

Correll is very dedicated to his mission of reducing fuel and environmental impacts of glass making and has stated his interest in coming to Murano to build his recuperative furnace for testing. A proposal has been authored and presented to the SSV by the WPI team outlining the costs and benefits of this testing.

The island of Murano has a stunning history of producing the best artistic glass in the world. Their traditions date back hundreds of years and their artisans are revered worldwide for their skill and ingenuity. The downfall to these traditions could be the ever mounting costs and high emissions due to the large amounts of fuel used to fire the furnaces that allow the artisans to make their creations. We have identified technologies that have the possibility to let Murano be known for another asset, their attention to efficiency and fuel consumption in an energy conscious society. Recuperators have the potential to lower the fuel usage of Murano by as much as 40% while oxycombustion may be able to provide savings of up to 50%. Neither of these technologies are a catchall solution to the consumption of fuel on Murano though and they will both need to undergo further testing before they can be deemed ready for wide scale implementation.

We have collected initial data to support the claims of recuperator makers such as Correll Glass Studios. Additionally we have reviewed previous tests of oxycombustion burners. We believe that both of these technologies can make an impact on the fuel consumption of Murano, however additional tests need to be performed before a final decision can be made. Issues that need to be addressed include the following: long term durability, long term costs, actual fuel savings on Murano and artisan opinion of the new technologies. There is a plan in motion to test oxycombustion burners for these qualities. To make sure that recuperative furnaces are tested similarly we have presented a plan for the construction and testing of a recuperative furnace on Murano as built by Correll Glass Studios.

We anticipate that any immediate changes to the Murano processes will be the implementation of one or both of these technologies. Once the reduction phase of the process is carried out it may be beneficial to look at the numerous other technologies identified in the background section of this report. Reducing, recycling and reusing the waste energy across Murano will further move the island to the forefront of energy efficiency affecting the way in which industry and artisans view their impact on the environment and society not only on Murano but across the world.

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7 Appendices

7.1 Appendix A: Annotated Bibliography

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Glass Furnace Waste Heat Recovery

Korobitsyn, Mikhail. "Industrial Applications of the Air Bottoming Cycle." Energy Conversion and Management 43, Issues.9-12 (2002): 1311-22.

The air bottoming cycle is a thermodynamic cycle that has been applied to the glass industry with positive results. It was found the ABC will convert waste heat to electricity at 26% efficiency and that the glass companies that adopt this technology would realize a 3-4 year payback.

Somasundaram, Sriram, Steve Parker, Meredydd Evans and Daryl Brown. (1999). "Industrial Energy Efficiency Opportunities in Ukraine." *Proceedings of Renewable and Advanced Energy Systems for the 21st Century*, April 11-15, 1999. Maui, Hawaii: American Society of Mechanical Engineers.

This article is a case study done on the Gostomel glass manufacturing plant in the Ukraine. It was proposed that the plant undergo energy efficiency renovations which included the addition of heat recovery boilers for use with their glass furnaces. In this study it was found that such measures would result in natural gas savings of 1,884,282 m3/yearr and a cost reduction of 156,395 US dollars/year.

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This is an IQP which was done in E-Term of 2001. The team conducted a feasibility study to determine whether or not it would be practical to install a form of cogeneration technology in glass furnaces on the island of Murano, Italy.

Black, Joshua C., Brian Cavanna and Nicholas J. Cottreau. Monitoring Pollution on Murano: An Analysis of the Artistic Glass Industry of Murano, Italy
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This Interactive Qualifying Project that researched the pollution aspects of the Murano glass factories. It provides helpful background information and provided a template to following during the project.

Patent 4,528012 Cogeneration from Glass Furnace Waste Heat Recovery
<http://www.pat2pdf.org/patents/pat4528012.pdf>

This patent outlines a device for generating electricity from waste heat in a glass furnace. The proposed device uses an air compressor to drive the exhaust gasses through a turbine, connected to a generator. After running through the turbine, the air, which still retains some of its heat, is sent back to the furnace, increasing its efficiency.

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Goldstein, L., J. Mortensen, and D. Trickett. Grid-Connected Renewable-Electric Policies in the European Union. Vol. NREL/TP-620-26247. United States: 1999.

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and incentives that various countries are giving to businesses that are installing these technologies.

International Energy Agency. Energy Policies of IEA Countries - Italy 2003 Review. Paris, France: Organization of Economic Co-Operation and Development, 2003. <http://www.iea.org/textbase/nppdf/free/2000/italy2003.pdf#search=%22energy%20resale%20policies%20in%20italy%22>.

This report specifies the energy policies and usage of various sources of energy specifically to Italy. Furthermore, this source breaks down Italy to display the energy usage in Venice.

Energy Research and Development: Global Trends in Policy and Investment. Italy National Energy Policy/Overview. http://energytrends.pnl.gov/italy/it004.htm (September 10, 2006)

This source has a good general overview of laws passed concerning energy consumption and emission standards. Includes helpful graphs and chart data.

Murano

Goodson, Deanna Couras. Murano Island.
http://www.lifeinitaly.com/tourism/veneto/murano-island.asp

This site provided useful background information of the history of Murano as well as modern island information such as population.

Encyclopedia Britannica. Murano <http://www.britannica.com/bcom/eb/article/6/0,5716,55686+1+54321,00.html?query=murano>

This site provided geographical as well as historical information about Murano.

Integaire. Programme agreements tools to reduce pollutant emissions from industrial sites in municipal Venice

<http://www.integaire.org/database-new/examples/uploaded/view_example.php?c=&m= 0&id=446> (September 21, 2006)

Informative site describing the details of the manufacturing process for factories in Murano.

7.2 Appendix B: Gas Consumption Data

Filename: "Results Comparison_Murano-B06.xls"

Sheets: Gas, Gas Chart

Gas Consumption Data

Technology	Glass Produced	Gas Consumption		Oxygen Consumption
	Kg/day	m^3/day	m^3/kg Glass	m^3/day
Tradition Murano Furnace				
Test 1	190	399	2.1	0
Test 2	190	407	2.14	0
Correll Technology				
Test 1	190	260	1.37	0
Oxycombustion				
Test 1	183	226	1.23	2.64
Test 2	193	206	1.07	2.28

Table 10: Gas Consumption by Furnace

Gas Consumption Summary

Technology	Glass Produced	Gas Comsumption	Oxygen Consumption
	Kg/day	m^3/kg	m^3/kg
Traditional Murano	190	2.12	0
Correll Technology	190	1.37	0
Oxycombustion	188	1.15	2.46

Table 11: Gas Consumption Summary

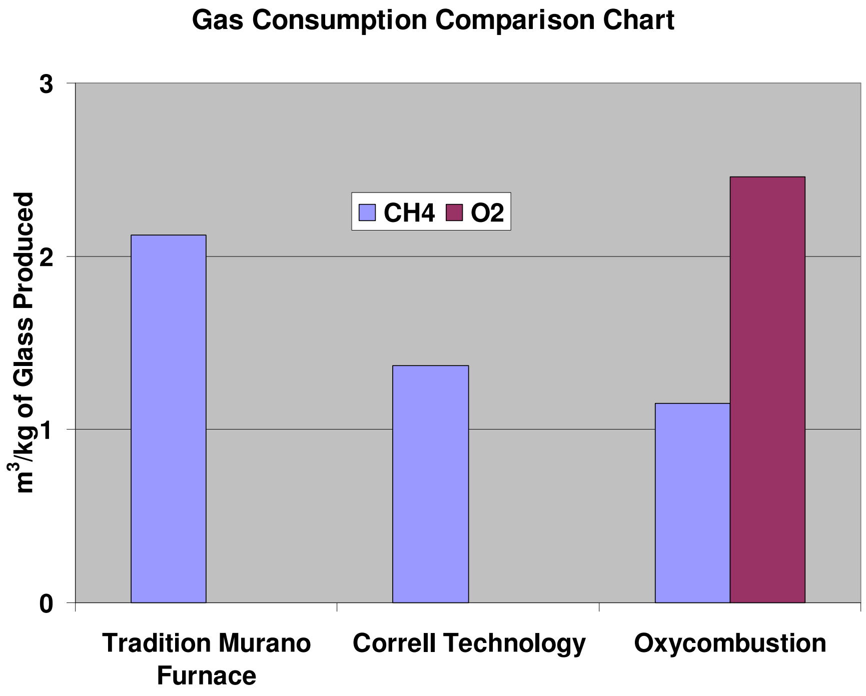


Figure 28: Gas Consumption Comparison Chart

7.3 Appendix C: Emissions Data

Filename: “Results Comparison_Murano-B06.xls”

Sheets: Emissions, CO$_2$ Emissions, Emissions Chart

Emissions of Technologies				
		Emissions		
		g/h		
Phase	Pollutant	Methane/Air	Correll (Theoretical)	Oxycombustion
1	Polveri	13	4.55	7.9
	NOx	600	210.00	290
	HF	4.65	1.63	1.13
2	Polveri	25	8.75	10
	NOx	890	311.50	300
	HF	3.04	1.06	1.69
3	Polveri	28	9.80	16
	NOx	790	276.50	300
	HF	3.95	1.38	0.5
4	Polveri	63	22.05	33
	NOx	160	56.00	63
	HF	2.48	0.87	0.57

Table 12: Emissions by Technology in Grams per Hour

Emissions Percentage Comparison				
		Emissions Change from Methane/Air		
		g/h		
Phase	Pollutant	Methane/Air	Correll (Theoretical)	Oxycombustion
1	Polveri	100%	65%	60%
	NOx	100%	65%	48.00%
	HF	100%	65%	24.00%
	C0$_2$	100%	65%	47%
2	Polveri	100%	65%	40%
	NOx	100%	65%	33.00%
	HF	100%	65%	55.00%
	C0$_2$	100%	65%	47%
3	Polveri	100%	65%	57.00%
	NOx	100%	65%	37.00%
	HF	100%	65%	12.00%
	C0$_2$	100%	65%	47%
4	Polveri	100%	65%	52.00%
	NOx	100%	65%	39.00%
	HF	100%	65%	23.00%
	C0$_2$	100%	65%	47%

Table 13: Emissions Percentage Comparison by Technology

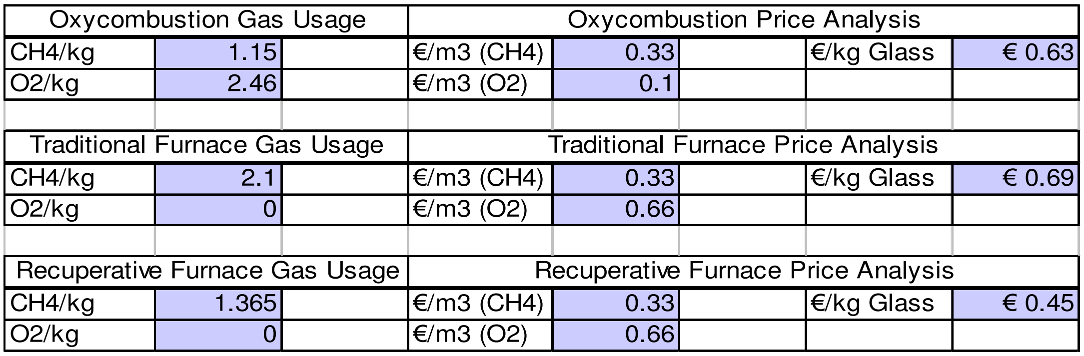
7.4 Appendix D: Cost Analysis

Filename: "Operating Cost Analysis_Murano-B06.xls"

"Payback Analysis_Murano-B06.xls"

Sheets: Euro per kg Cost

Correll Furnace Cost Data



Oxycombustion Gas Usage			Oxycombustion Price Analysis				
CH4/kg	1.15		€/m3 (CH4)	0.33		€/kg Glass	€ 0.63
O2/kg	2.46		€/m3 (O2)	0.1			
Traditional Furnace Gas Usage			Traditional Furnace Price Analysis				
CH4/kg	2.1		€/m3 (CH4)	0.33		€/kg Glass	€ 0.69
O2/kg	0		€/m3 (O2)	0.66			
Recuperative Furnace Gas Usage			Recuperative Furnace Price Analysis				
CH4/kg	1.365		€/m3 (CH4)	0.33		€/kg Glass	€ 0.45
O2/kg	0		€/m3 (O2)	0.66			

Table 14: Gas Consumption and Operating Costs by Furnace

Percent Savings		35%
Gas		
	CH4(m3/kg)	1.371
	O2(m3/kg)	27
	Price(€/kg)	€ 0.45
	Cost per Year (€/yr)	€ 4,524.30
Service	Maintenance Period (x/yr)	2
	Cost/per maintenance	€ 300.00
	Cost per year (€/yr)	€ 600.00
Capital		
	Furnace Cost (€)	€ 11,538.46
	Total (€)	€ 11,538.46
Payback		
	Netsavings/yr	€ 2,405.70
	Payback Period	4.80
	Cost Minus Traditional	€ 7,538.46
	Payback Minus Traditional	3.13

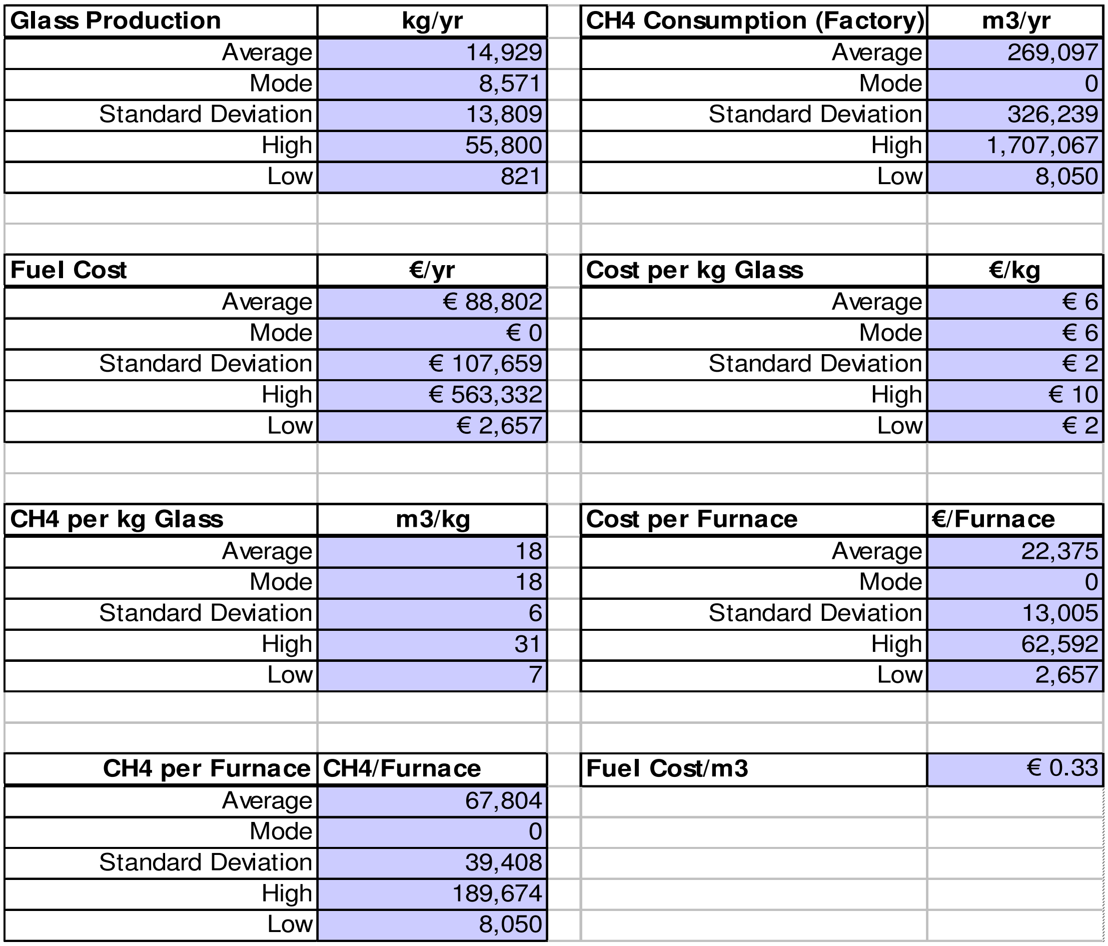
Table 15: Payback Data for Correll Recuperative Furnace

7.5 Appendix E: Factory Data

Filename: "Factory Data_Murano-B06.xls"

Sheets: 2000 Factory Report Data

Statistics Summary



Glass Production	kg/yr
Average	14,929
Mode	8,571
Standard Deviation	13,809
High	55,800
Low	821

CH4 Consumption (Factory)	m3/yr
Average	269,097
Mode	0
Standard Deviation	326,239
High	1,707,067
Low	8,050

Fuel Cost	€/yr
Average	€ 88,802
Mode	€ 0
Standard Deviation	€ 107,659
High	€ 563,332
Low	€ 2,657

Cost per kg Glass	€/kg
Average	€ 6
Mode	€ 6
Standard Deviation	€ 2
High	€ 10
Low	€ 2

CH4 per kg Glass	m3/kg
Average	18
Mode	18
Standard Deviation	6
High	31
Low	7

Cost per Furnace	€/Furnace
Average	22,375
Mode	0
Standard Deviation	13,005
High	62,592
Low	2,657

CH4 per Furnace	CH4/Furnace
Average	67,804
Mode	0
Standard Deviation	39,408
High	189,674
Low	8,050

Fuel Cost/m3	€ 0.33

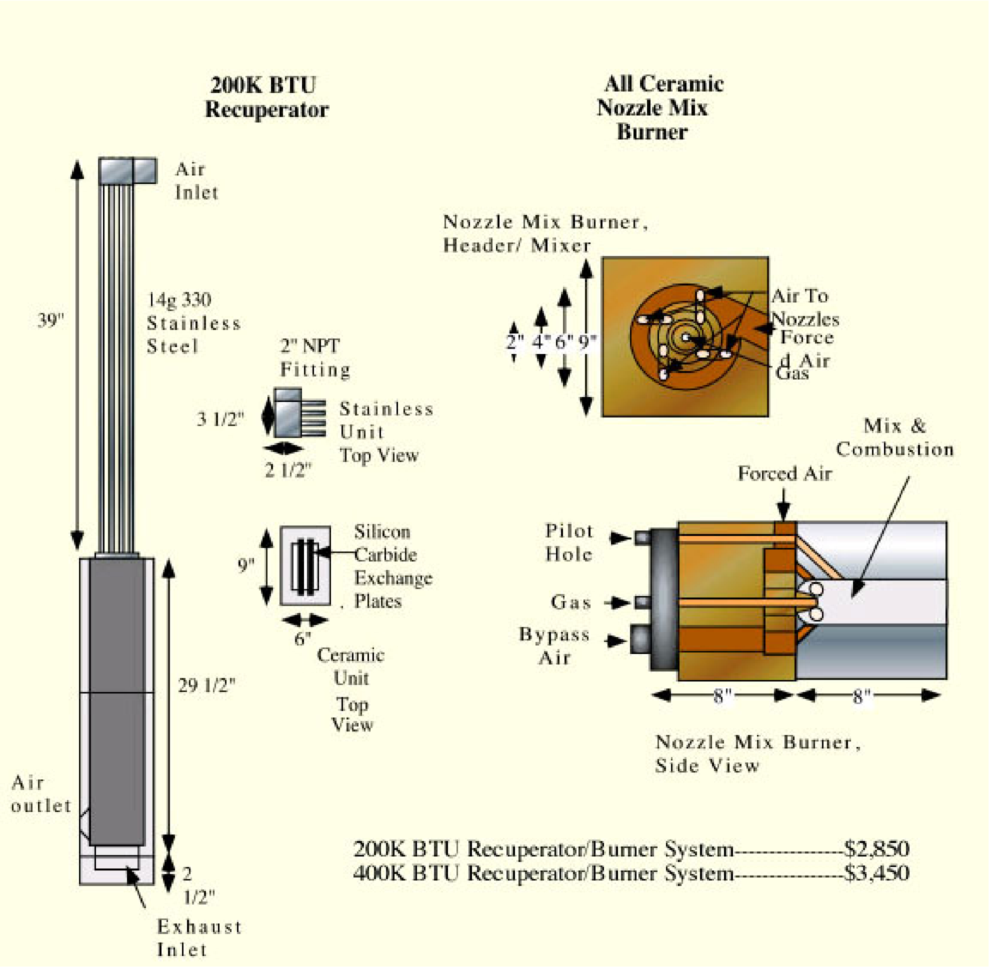
Table 16: Factory Statistics 2000 Census

Factory Name	CH4/KG glass	Glass Production (metric ton)	Glass Production (kg)	CH4/yr(m3)	Number Of Furnaces	Days of Operation / yr	Electricity (KWh/yr)	Melting Pot Contents (kg/yr)	Price of CH4	Cost per kg Glass
Name Unknown	7	30	29,571	215,970	4	230	120,204	36,508	€ 0.33	€ 2.41
Linea Padovan	8	41	40,857	322,667	4	220	72,000	50,441	€ 0.33	€ 2.61
Mazzuccato di M. Daniele SRL	10	1	821	8,050	1	230	1,560	1,014	€ 0.33	€ 3.23
Tagliapietra Dino	12	7	6,857	83,376	2	240	122,736	8,466	€ 0.33	€ 4.01
Artigianto Artistico Veneziano	13	9	8,571	108,667	2	200	12,960	10,582	€ 0.33	€ 4.18
Name Unknown	13	17	16,571	216,533	3	232	51,600	20,459	€ 0.33	€ 4.31
AVEM Arte Vetreria Muranese SAS	14	20	20,057	278,000	5	200	34,836	24,762	€ 0.33	€ 4.57
Vetreria Artistica Archimede Seguso	14	37	37,020	513,168	4	320	113,859	45,704	€ 0.33	€ 4.57
Guarnieri Vetr. A.	14	9	8,571	122,000	3	200	14,400	10,582	€ 0.33	€ 4.70
A.V. Mazzega SRL	15	6	6,000	91,000	2	210	6,000	7,407	€ 0.33	€ 5.01
Name Unknown	15	6	5,714	88,267	2	200	157,620	7,055	€ 0.33	€ 5.10
Ercole Moretti e fratelli	16	37	37,200	578,667	11	217	144,000	45,926	€ 0.33	€ 5.13
Name Unknown	16	2	2,400	38,143	1	210	6,696	2,963	€ 0.33	€ 5.24
Name Unknown	18	11	11,429	200,000	2	200	11,940	14,109	€ 0.33	€ 5.78
Nuova Artigiana Colleoni SNC	18	18	18,000	315,000	7	210	36,000	22,222	€ 0.33	€ 5.78
Fratelli Barbini di Barbini Cesare	19	4	3,504	65,400	1	218	12,000	4,325	€ 0.33	€ 6.16
Nuova PIM Cristalleria SAS	19	5	4,786	89,333	1	335	35,520	5,908	€ 0.33	€ 6.16
Donà Guido	21	4	3,571	75,000	2	250	35,400	4,409	€ 0.33	€ 6.93
L'Artistica Muranese di Badioli M. e. C.	21	6	6,286	132,000	3	247	5,652	7,760	€ 0.33	€ 6.93
D'este Bruno	22	6	6,229	138,067	2	218	12,000	7,690	€ 0.33	€ 7.32
La Murrina SRL	23	13	12,857	290,000	4	300	36,000	15,873	€ 0.33	€ 7.44
Linea Mazzuccato	24	12	12,400	301,992	8	217	50,388	15,309	€ 0.33	€ 8.04
Gambaro e Poggi SNC	25	13	12,571	317,409	3	220	115,488	15,520	€ 0.33	€ 8.33
J.W.P. di Cavagnis	27	18	18,159	483,167	5	222	51,000	22,418	€ 0.33	€ 8.78
Artigianato Muranese SNC	28	15	15,000	420,000	3	210	132,000	18,519	€ 0.33	€ 9.24
Barovier e Toso	29	2	2,286	66,667	3	200	9,600	2,822	€ 0.33	€ 9.63
Ongaro Fuga di Fuga G. e C.	31	56	55,800	1,707,067	9	217	336,000	68,889	€ 0.33	€ 10.10

Table 17: Factory Data 2000 Census

7.6 Appendix F: Correll Glass Studio Literature

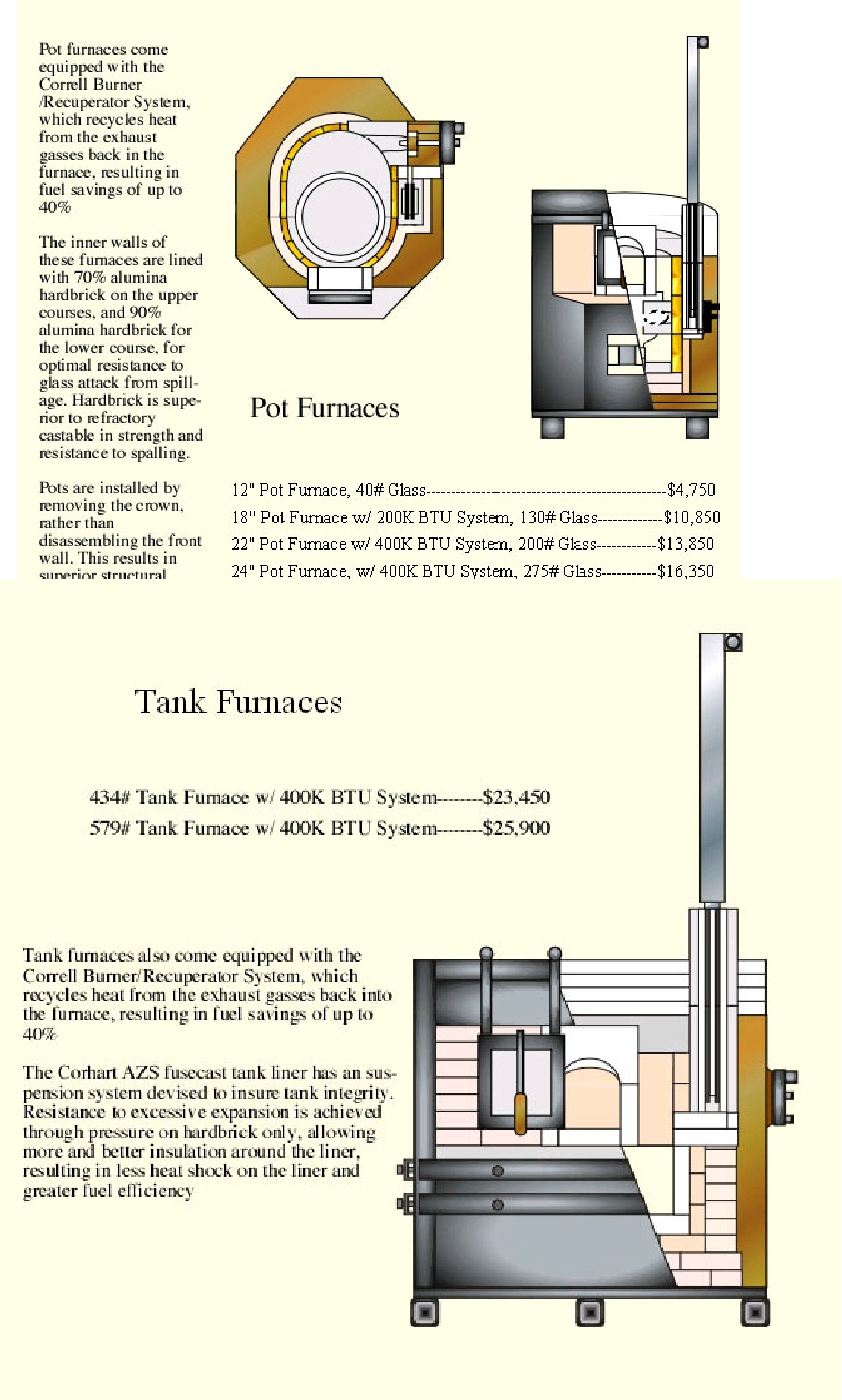
Contact Information:
Correll Glass Studio
66 Hidden Ledge
Conway, MA 01341
Phone: 413-369-4283
Fax: 413-369-4769
Email: ccorrell@comcast.net
Website: http://www.correllglassstudio.com



200K BTU Recuperator/Burner System---------------$2,850
400K BTU Recuperator/Burner System---------------$3,450

Figure 29: Correll Recuperator

Source: http://www.correllglassstudio.com/recupburner.htm



Pot furnaces come equipped with the Correll Burner /Recuperator System, which recycles heat from the exhaust gasses back in the furnace, resulting in fuel savings of up to 40%

The inner walls of these furnaces are lined with 70% alumina hardbrick on the upper courses, and 90% alumina hardbrick for the lower course, for optimal resistance to glass attack from spillage. Hardbrick is superior to refractory castable in strength and resistance to spalling.

Pots are installed by removing the crown, rather than disassembling the front wall. This results in superior structural

Pot Furnaces

12" Pot Furnace, 40# Glass	$4,750
18" Pot Furnace w/ 200K BTU System, 130# Glass	$10,850
22" Pot Furnace w/ 400K BTU System, 200# Glass	$13,850
24" Pot Furnace, w/ 400K BTU System, 275# Glass	$16,350

Tank Furnaces

434# Tank Furnace w/ 400K BTU System	$23,450
579# Tank Furnace w/ 400K BTU System	$25,900

Tank furnaces also come equipped with the Correll Burner/Recuperator System, which recycles heat from the exhaust gasses back into the furnace, resulting in fuel savings of up to 40%

The Corhart AZS fusecast tank liner has an suspension system devised to insure tank integrity. Resistance to excessive expansion is achieved through pressure on hardbrick only, allowing more and better insulation around the liner, resulting in less heat shock on the liner and greater fuel efficiency

Figure 30: Correll Recuperative Furnaces

Source: http://www.correllglassstudio.com/tankfurnaces.htm

7.7 Appendix G: Oxycombustion Report

Environmental Improvement Resulting From Oxycombustion Technology Use in the Glass Industry Located in Sacca Serenella (Murano Island, Venice)

Source: http://www.integaire.org/database-new/examples/uploaded/view_example.php?id=413&c=&m=0

Introduction

One of the main environmental impacts due to this type of manufacturing activity are the emissions of pollutants in the atmosphere.

The production cycle of artistic glass is based on different operational phases; with regard to the environmental impact one of the most important steps is the blending of the vitreous solutions and by the following processing of formed glass.

Fusion of glass is responsible for about the 60% of energy consumption and 90% of solid and gaseous emissions deriving from the whole production cycle.

The aim of the project is the replacement of traditional techniques of glass fusion with techniques that lead to a lesser environmental impact and a lesser consumption of energy.

The furnaces for glass fusion are presently stoked by methane and the combustion is air/methane driven. Since a long time, experimental tests have been underway in order to evaluate the possibility of introducing different fusion techniques that could have relevant benefits also vis-à-vis energy consumption. Among them, the “oxycombustion” technique is one of the most promising.

Oxycombustion use in the glass industries located in Sacca Serenella (Murano Island, Venice) is foreseen as part of an experimental test that aims to reduce the environmental impact of the artistic glass production sector with regard to both, atmospheric emissions (i.e. carbon dioxide) and energy consumption.

The initiative has the support of the City of Venice, Artambiente (Craftsmen Association), SAPIO Spa (Private Company that produces oxygen), Confartigianato di Venezia and is to be enacted by glass craftsmen and the Glass Experimental Station (Laboratory for emissions analyses).

Environmental problems deriving from artistic glass production

Emissions in the atmosphere are caused by the raw materials themselves, the temperatures reached during the fusion phase and the combustion system.

Specifically they are made up of:

- by-products of methane combustion during the production cycle (carbon dioxide, and NO_X due to air oxidisation);
- by-products of the decomposition of the raw materials used to form the vitreous mixture (NO_X due to nitrates decomposition, CO_2 to carbonates);
- by-products of evaporation phenomena and possible re-condensation of volatile substances present into the vitreous mixture (PM, Heavy metals, chlorides and gaseous fluorides).

Oxycombustion replaces traditional methane/air combustion with a methane/oxygen driven combustion. In this way, the calorific value of the fuel increases because the presence of nitrogen, that at high rates in regular air combustion(about 80%), is almost completely removed. The result is a flame with higher temperatures so that a better diffusion of heat to the furnace and to the glass is obtained.

There are five glass industries involved in this experimental oxycombustion test.. They have a similar production cycle and a typology of product.

S APIO Spa is charged with the detailed designs of all structural intervention necessary to run the experimental test both inside and outside the glassworks. Artambiente has to identify the glassworks that will be involved. The City of Venice Administration finances and establishes structural installations necessary for the experimental test as part of its urbanization intervention in Sacca Serenella. Upon the completion of the structural installations, the testing will last at least two years.

It is also expected to make use of the oxygen production potential in Porto Marghera industrial area and to link Murano through an underwater pipeline. Time needed for the pipeline completion is 12-18 months (upon receipt of the requisite authorisation release). To facilitate local distribution an arrival terminal for the pipeline will be built, from where a local distribution network will originate.

Potential energy consumption reduction

A relevant reduction of combustion consumption is due to experimental tests run on furnaces for artistic glass. Their combustion scheme has been modified from the methane/air to methane/oxygen mixture system.

The following table sums up specific consumptions checked during many tests:

	Air / methane	Oxygen / methane
Final consumption (MJ/kg glass)	72,7	38,7[1]
Primary consumption[2] (MJ/kg glass)	72,7	42,2

[1] The value is given as the sum of energy spent for combustion and oxygen production equal to 2,3MJ/Kg of glass (2,1 mc O_2/kg glass; 0,3 kWh/mc O_2)

[2] A conventional factor of 2200 Kcal/KWh has been used.

At the moment in the Murano Island district a methane consumption of 44 million cubic metre has been recorded.

In terms of primary energy, consumption corresponding to the considerable introduction of the oxycombustion technique is reported into the following scheme:

	Air / methane	Oxygen / methane
Primary Consumption (TJ)	1.520	882
Primary Consumption (tep)	36.309	21.076
Saving (%)		-42

Fuels consumption (basically natural gas) for house heating is about 148.000 tep.

Potential reduction of atmospheric emissions

The following scheme sums up the change of CO_2 global emissions corresponding to alternative configurations, both for unit of glass worked and as resulting from a considerable introduction of the oxycombustion technique.

Global CO_2 eq. emissions	Air / methane	Oxygen / methane
Specific (kg/kg glass)	4,9	2,9
Total (kilotons)	102	66

Total reduction of equivalent CO_2 results in about 45.000 tons.

Other benefits

The main benefits derived from oxycombustion, besides the lower energy consumption and the reduction in emissions of greenhouse gases can be summed up in the following points:

1. reduction of nitrogen oxide emissions (lack of nitrogen to oxidize);
2. reduction of solid and gaseous emissions during production cycle (less frequent phenomena of evaporation/re-condensation)
3. reduction of smoke volume to be shifted by fan;
4. reduction of noise emissions (no air compressor is needed).

Inclusive costs

Costs corresponding to production of the distribution system is estimated to be about €10 million. This is broken down as follows:

- €4 million to build the oxygen pipe;
- €4 million to build the network of local distribution;
- €2 million to adapt the fusion furnaces.

Current and new technology working costs are also estimated as follows:

- €8,2 million to buy methane in the current methane/air blend;
- €6,8 million to buy methane and oxygen in the new methane/oxygen blend.

7.8 Appendix H: Recuperation and Insulation – An Overview

Author: Charles Correll

Source: http://www.correllglassstudio.com/recuppaper.htm

Glass is expensive. The major expense involved is the continual and everlasting gas bill. How many of us at one time or another have been confronted with the specter of being shut down because of astronomical fuel costs and rapidly rising fuel prices?

For most small shops and university glass programs it is the largest single expense and the most volatile. In the last ten years we have seen prices multiply by factors ranging from three to ten, depending on demographics.

What can be done about it? Raise the prices? There is a limit to that, and schools do not have the option. Shut down more often? This is counterproductive.

The solution is to find a way to use less fuel while maintaining the quality and quantity of the glass that is produced.

The rapid increase in fuel costs has not been matched by a rise in consciousness in ways to counteract the increase. Furnace building techniques are not generally stressed in schools. The typical response from working shops is to continue to use the furnace designs that have produced dependably in the past. The problem demands a new awareness of and attitude toward the economics of glassmaking. The low esteem in which technical knowledge is held must be reversed. For many it is quiet simply a matter of survival in glass.

The Furnace. This is the heart of any glass operation. First and foremost, the furnace must make quality glass. Secondly, it must be durable.

These have been the main considerations for years, and must remain so. Now we must learn to do it less expensively.

What are the essential characteristics of a glass melting furnace? The furnace is basically a box with a burner going in and a flue going out. The purpose of the box is to contain the heat of the combustion gasses long enough to bring the furnace load to a desired temperature. The hot gasses then escape through the flue. The goal should be to maximize the use of the heat generated by the burner. We know how the heat gets into the furnace. How does it get out?

There are only two ways it gets out. The first is by passing through the walls of the furnace to the outside. The second is by leaving with the exhaust gasses through the flue or other openings in the furnace. Let's first consider departure through the walls.

--For years standard design generally has consisted of one course of hard brick for the furnace liner backed up by a course of soft brick and maybe a layer of ceramic fiber. This is sufficient to contain the heat from the burner long enough to heat the furnace load. This and its close variations work to make good glass, but at what cost?

--Consider the nature of insulating materials. Heat passes through a material at a given rate. The slower the rate, the better the insulating quality of that material.

--A good way of looking at the relative qualities of insulating materials is to compare them to the insulating qualities of the standard heavy hardbrick. We can assign an arbitrary value to the insulating value of hardbrick. Call it "one." From this standard, we can denote the values of other materials using multiples of one for "equivalent inches of firebrick" (E.I.F.). Each material has an insulating value that can be expressed in terms of equivalent inches of firebrick. Fortunately there are tables for this. Refer to A.P. Green's, Calculating Heat Transfer Through Refractory Walls.

--The following is an abbreviated table of the approximate insulating values of a number of different materials expressed in equivalent inches of firebrick.

Material	E.I.F.
Heavy Firebrick	1.00
Heavy Castable	1.00
3000° Insulating Castable	2.92
2500° Insulating Castable	2.92
2200° Insulating Castable	4.80
2000° Softbrick	4.30
2600° Softbrick	3.70
2800° Softbrick	3.15
1900° Block Insulation	12.00
1600° Vermiculite Castable	12.00
2400° Ceramic Fiber	12.00

--Let's examine the insulating values of the materials in the "standard" furnace mentioned earlier. Multiply the thickness of each material in inches by its E.I.F. then add the products to obtain the total E.I.F.

Material	Thickness	E.I.F.	Product
One Course Hardbrick	4.5"	1.00	4.50
One Course 2600° Softbrick	4.5"	3.60	16.20
	Total E.I.F.		20.70

--Using the appropriate tables, we find that 20.7 E.I.F. translates to a heat loss of 840 BTU/Hr/Ft2 at 2400° furnace temperature. Let's add one inch of ceramic fiber:

Material	Thickness	E.I.F.	Product
One Course Hardbrick	4.5"	1.00	4.50
One Course 2600° Softbrick	4.5"	3.60	16.20
Ceramic Fiber	1"	12.00	12.00
	Total E.I.F.		32.70

translating to a heat loss of 550 BTU/Hr/Ft2 at 2400°. A one-inch layer of fiber has cut the heat loss through the walls by 34.5%.

--My furnaces were designed considering both the durability of the materials and their insulating values. Start with a 3000° hardbrick liner, consisting of splits mortared and stacked on edge. Back that up with two inches of 3000º insulating Castable. Finish with seven inches of vermiculite castable.

Material	Thickness	E.I.F.	Product
3000º Splits	2”	1.00	2.00
3000º Insulating Castable	2”	2.92	5.84
Vermiculite Castable	7”	12.00	84.00
	Total E.I.F.		91.84

This translates to a heat loss of 200 BTU/Hr/Ft2 at 2400º, a heat loss saving of 76% over the original standard construction. Insulation is cheaper than gas.

Preventing excessive loss of heat through the furnace walls is not the only way insulation saves energy. Most of the energy lost from a furnace leaves via the flue. Two thousands degree gasses leaving at the rate of fifteen feet per second carry fifty percent more heat with them than gasses leaving at ten feet per second. In fact, savings here are much greater than savings through furnace walls. The calculations are rather esoteric, but put four or five inches of fiber around your furnace and watch your gas bill drop.

This brings us to the second way heat exits the furnace: Through the flue.

Consider a furnace set on cruise, holding at 1950º. It is in a state of equilibrium. It is losing heat at exactly the same rate as it is gaining heat. The temperature of the gasses as they enter the flue is 1950º.

Depending on the insulation of the furnace, they are leaving at a faster or slower rate. Much of the heat can be recaptured and fed back into the furnace.

First, let’s looks at the basic characteristics of combustion in a gas burner system. In a pre-mix system gas and air are mixed, usually under pressure, and delivered to a burner where heat is applied to initiate combustion, the breaking of carbon-hydrogen and carbon-carbon bonds and the subsequent creation of carbon-oxygen and hydrogen-oxygen bonds, accompanied by a great release of heat energy. In a word, oxidation takes place.

To be effective, the combustion gasses must enter the furnace at a higher temperature than the interior in order to counteract the heat loss from the furnace. Oxidation of the fuel provides this heat. However, only about twenty percent of the air being mixed with the gas is oxygen. In terms of combustion, the rest of the air is neutral, adding nothing to the reaction. In fact, it is a detriment, since all that air must be heated by the flame before it enters the furnace.

We could get rid of the air and use only oxygen. That would solve the problem, but would increase the cost drastically.

We could pre-heat the air, taking some of the burden off the oxidation reaction. Fortunately, there is a source of free heat to do the trick. All of that heat going out the flue is perfect for the job. All there is to do is capture it and return it to the furnace.

Running the flue gasses back through the burner does no good. There is no oxygen left in them with which to burn the gas. We need to move only the heat from the flue gasses to the incoming combustions air. For this we need a heat exchanger, or recuperator.

Basically, a recuperator is a device that sits in the chimney of the furnace, through which a blower forces the combustion air. The air picks up heat through the walls of the recuperator and delivers it to the burner. The flame then delivers a higher percentage of its heat to the furnace and a lower percentage to the "baggage" air. Since more heat is being delivered per BTU of gas used, we can turn down the burner, thus saving gas.

Hot oxygen increases the efficiency of the oxidation process, releasing more heat to the furnace. Turn down the burner again.

Recuperation is a positive feedback system. The better things work, the better they will work. Consider two furnaces, both with recuperators, one more well insulated than other.

One burner can be set lower than the other because of its additional insulation. Air is traveling more slowly though the recuperator having more time to gain additional heat to return to the furnace. The flue gasses are moving more slowly also, allowing more heat to pass to the combustion air.

More heat is being returned to the furnace. Turn down the burner. The oxygen is hotter, producing more efficient combustion. Turn it down again. Turn down the burner itself, as a result of these conditions, slows down the passage of the air and exhaust, producing even more efficient heat exchange, more heat back to the furnace, and hotter oxygen. Turn down the burner again. This is positive feedback.

It also works in reverse. The less efficient the system is in the first place, the less efficiently it will work. The inefficiencies are compounded.

There are four major criteria to consider in designing and building a recuperator for a glass melting furnace:

•Durability. The material must be able to withstand extremely high temperatures and corrosive chemical attack dependably.
•Heat transfer qualities. The materials used must allow heat to pass through them quickly.
•Surface area. The more surface area exposed to the heat, the more heat passing to the combustion air.
•Burner characteristics. A nozzle mix burner system is required for use with high temperature air.

A material or combination of materials that satisfies the first two criteria is needed. Stainless steel immediately comes to mind. Metal passes heat readily, and there are grades of stainless that are rated at 2000° or more. While this is good, it still will not survive the extreme heat of a melt.

The exhaust gasses must be cooled somewhat before they reach the stainless steel recuperator. This can be accomplished by introducing cool air into the flue from the outside to dilute the exhaust gasses, or by placing the recuperator high in the stack to avoid the temperatures at the mouth of the flue. Both of these methods waste heat.

Other materials can be used that will withstand the heat of the furnace. Silicon carbide has excellent heat transfer qualities, and will withstand high temperatures and chemical attack. However, it needs to be thicker than stainless in order to maintain its structural integrity, thereby losing some of its heat transfer efficiency.

Both materials work well. Let's make them work better.

A primary recuperator using silicon carbide can be placed at the exhaust port. A secondary unit of stainless steel can then be placed on top of the primary unit. The silicon carbide unit will pass heat to the incoming combustion air thus cooling the exhaust enough for the temperature to fall below the service temperature of the stainless unit. Here we have the best of both worlds in one complete unit, the high heat resistance of silicon carbide, and the superior heat transfer qualities of stainless steel, while losing a minimum of exhaust heat.

Recuperative efficiency is directly related to the surface area through which heat can be exchanged. In general, this area should be maximized. The more surface area per volume of gasses, the greater the efficiency of heat exchange.

In reality, there may be some functional limits to these relationships, and to the physical size that can be accommodated. Consider an array of long pipes set in a matrix of given outside dimensions. A large number of small pipes has more combined surface area than a small number of larger pipes, and would theoretically make a better heat exchanger. A limit arises when the pressure drop over the system exceeds the ability of the air pressure source to deliver sufficient combustion air to the burner. The greater the surface area of the unit, the more friction and resistance to air flow.

If the spaces through which the exhaust gasses pass are too small, they can easily be further constricted by deposits of batch material and carbon on the heat exchanger, greatly reducing efficiency. Larger pipes can be used to avoid these problems. The loss in surface area can be made up to a great degree by lengthening the pipes as much as possible, thus increasing the total surface area.

The fourth major criterion to be considered is the burner system. Since the combustion temperature of gas is about 1000°, a pre-mix system should not be used with pre-heated air. There is too great a chance of burn-back and explosion. The gas and the air should not meet until they are actually in the burner throat, effectively inside the furnace. This can be accomplished using a nozzle mix burner. Again, material considerations must be made due to the high heat of the combustion air and the higher flame temperatures associated with it. High temperatures alloys are available. Another solution is to use an all ceramic mixer-burner system to avoid the possible deterioration of the metal alloys.

Through using the procedures outlined above, by paying more attention to my furnace settings, and by keeping my furnaces tight I have cut my gas bill in half without sacrificing anything but a hot, noisy studio. The best thing about it for me is knowing I am again in control. The feelings of desperation concerning the gas bill are gone.

7.9 Appendix I: Furnace Drawings

Author: Keith Ferry

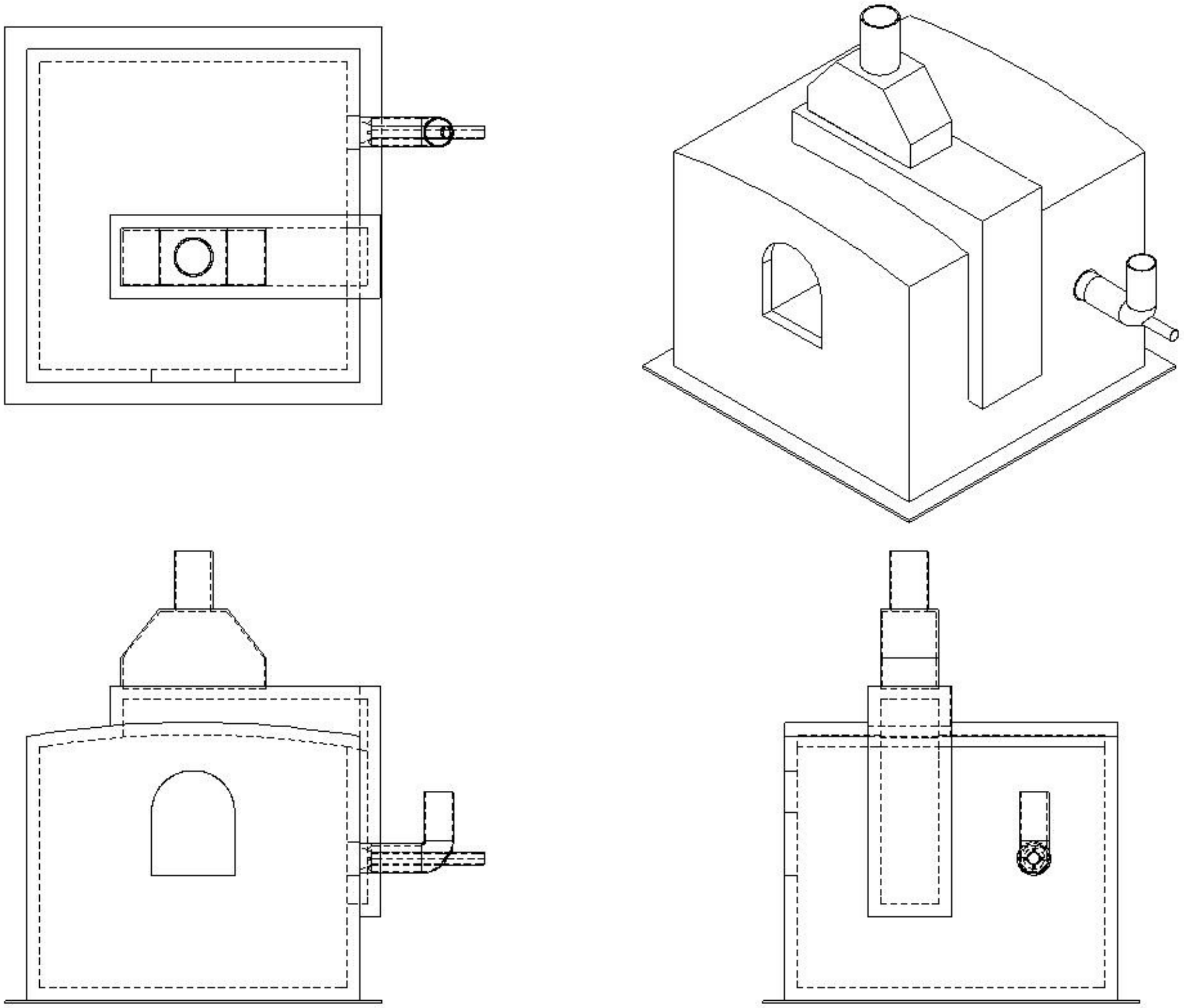


Figure 31: Traditional Murano Furnace

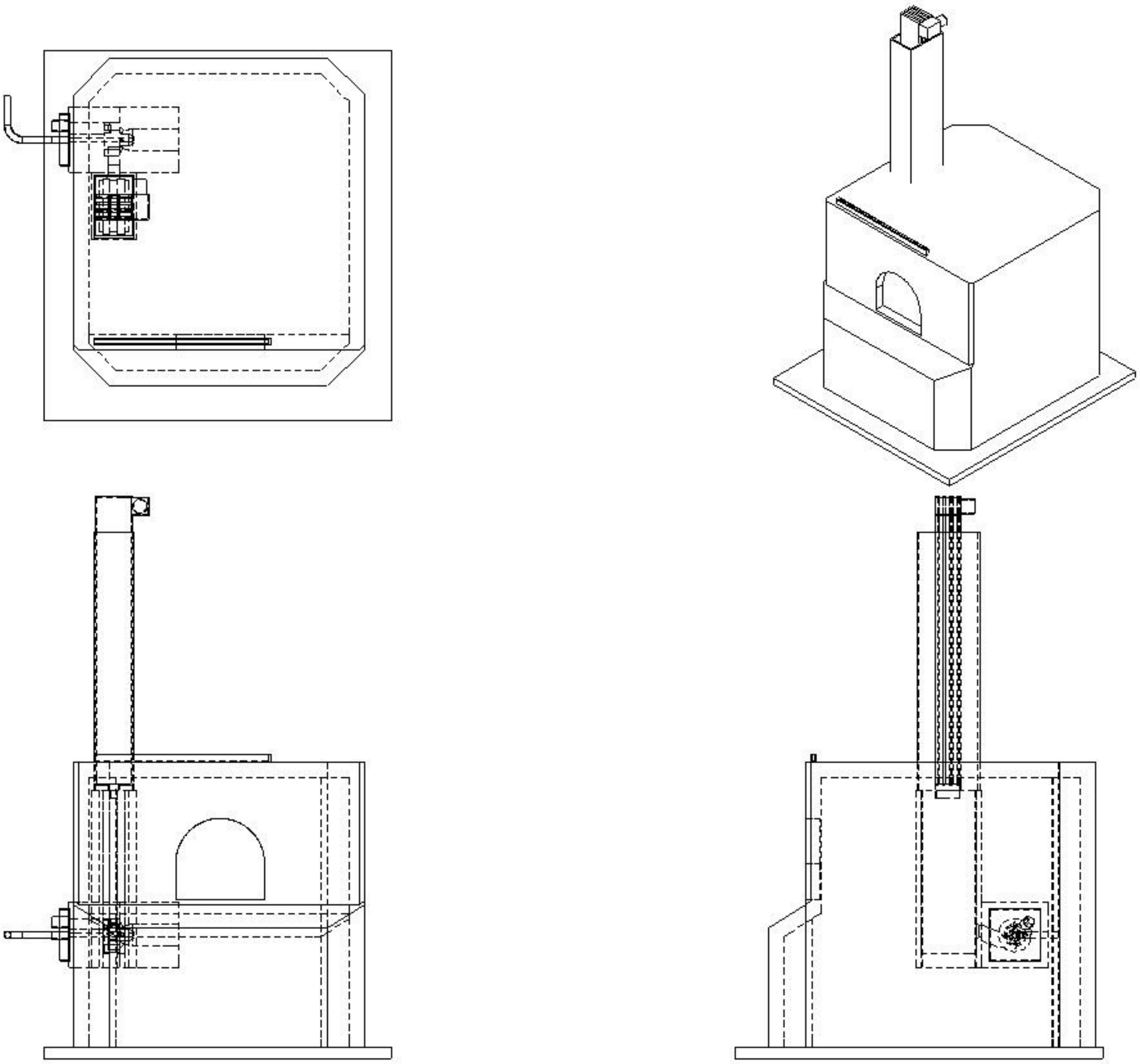


Figure 32: Correll Style Recuperated Pot Furnace

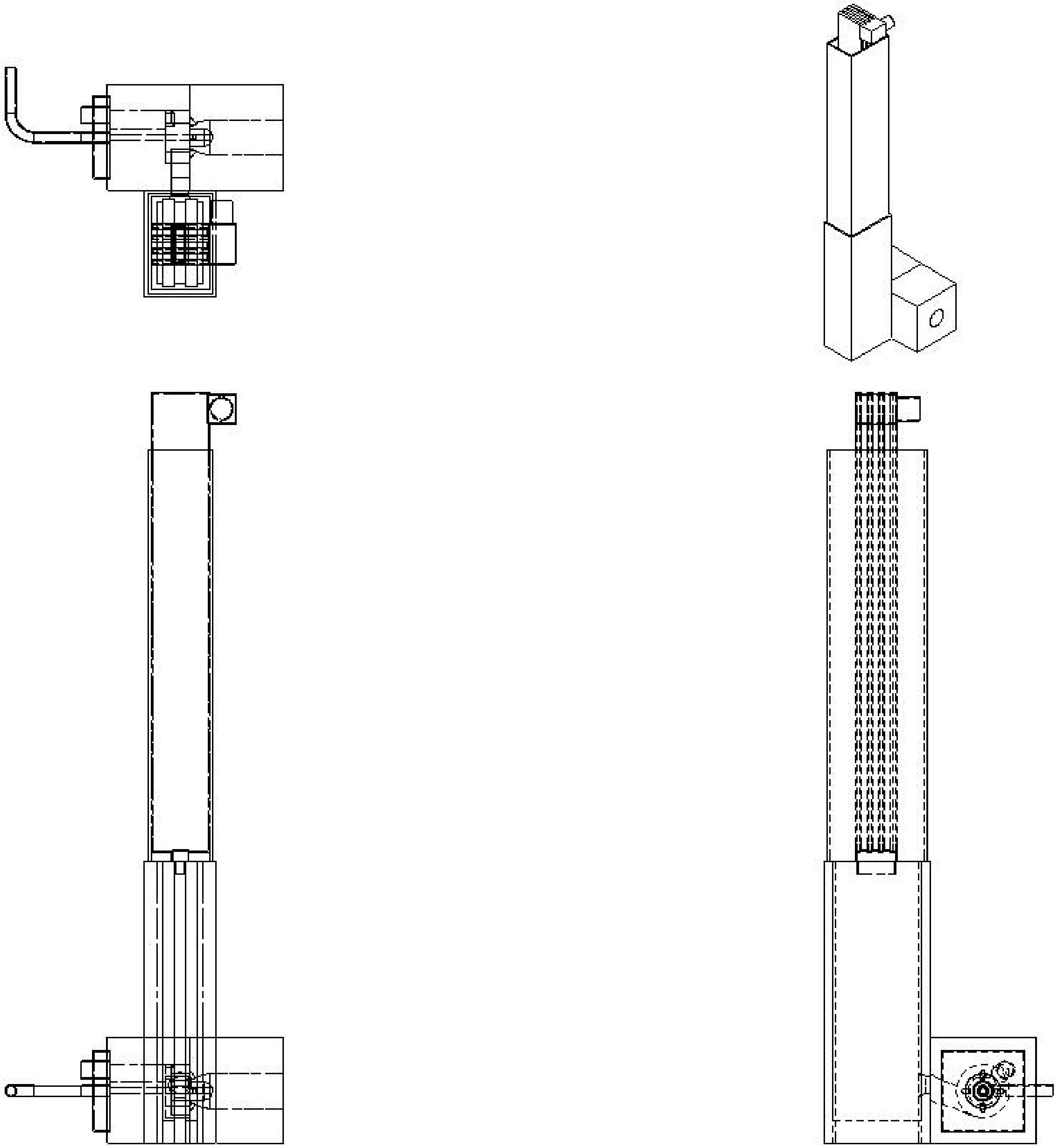


Figure 33: Correll Style Recuperator

7.10 Appendix J: Correll Recuperative Furnace Testing Proposal

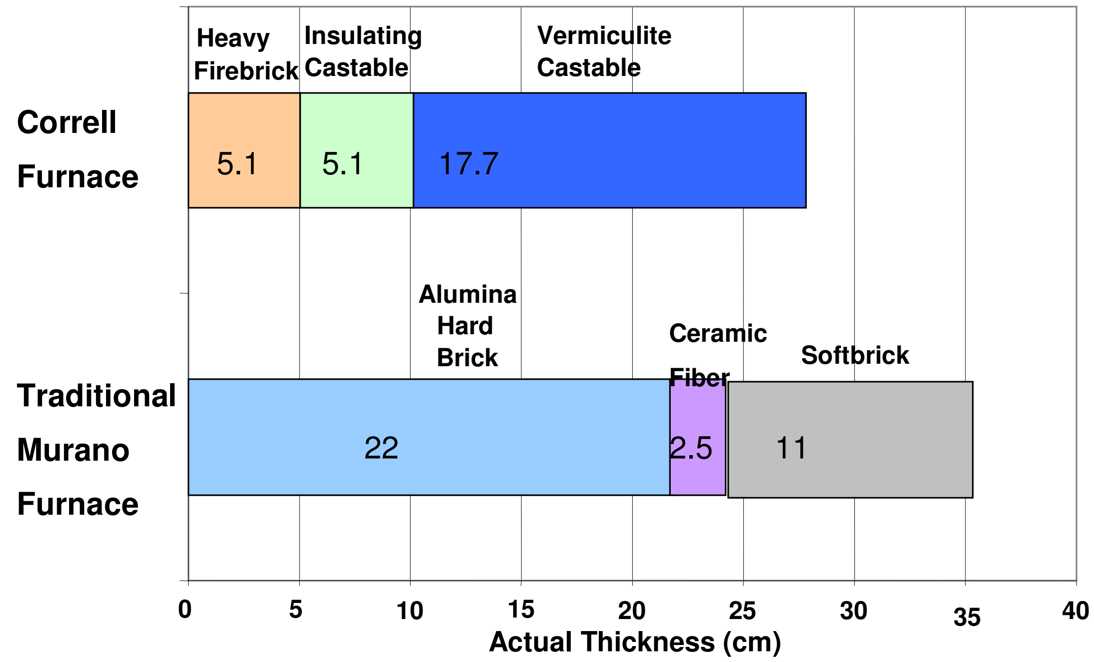
Recuperative Furnace Testing Proposal **December 12, 2006**

Introduction

The past few years have brought about a push for the increase of efficiency in consumption of natural resources. Fossil fuels are becoming scarcer and more expensive. In an effort to alleviate the costs of natural gas and reduce the emissions of glass furnaces on the island of Murano, Italy Worcester Polytechnic Institute (WPI) has assembled a team of students to research different technologies that are capable of doing this. One of the most promising technologies that have been found is a recuperative furnace developed by Charles Correll of Conway, Massachusetts. This proposal is being submitted for the purpose of securing funding to have a Correll recuperative furnace built and tested in Murano. The WPI team is acting as an objective consultant between Murano and Correll. The claims and initial data collected on the Correll furnace have led them to believe that with further testing on Murano, a Correll style furnace will yield significant improvements in fuel consumption.

Recuperative burners use a heat exchanger to extract unused heat from furnace exhaust and distribute it to the air that is being supplied to the burner. In the past recuperators have been used on Murano with mixed results. The heat exchangers were made of either stainless steel or cast alloy. These recuperators were capable of preheating incoming air to a temperature of 250° C. Modest savings were realized but significant gains were not made.

Correll has created a new type of recuperator that relies on a hybrid heat exchanger of silicon carbide and stainless steel. This combination of materials allows the heat exchanger to be placed closer to the furnace while maintaining the integrity of the materials at high temperature. The result is the preheating of incoming air to a temperature of approximately 815° C. This efficiency was previously only capable of being reached on an industrial scale. Correll has developed this burner specifically for use on artistic glass furnaces, which he has been using for over 25 years. In addition to the recuperator Correll has made significant improvements in insulation techniques and furnace design, further increasing the efficiency of the glass melting process. The figure below illustrates the difference in refractory materials between a Correll Furnace and traditional Murano furnace.



Despite the decrease in actual thickness of the insulation, the Correll Furnace provides more efficiency than a traditional Murano furnace. To better understand this concept, Correll has developed a simple way of comparing furnace insulation by calculating equivalent inches of firebrick (E.I.F.). Firebrick is a commonly used construction material for furnaces. The value of firebrick shall be defined as 1; all other materials' insulation properties will be defined as equivalent inches of firebrick. The table to the right shows the equivalent inches of firebrick for common furnace building materials. Once the E.I.F. has been determined for each material and the pieces are summed, a comparison can be made between the furnaces. The table below demonstrates the effectiveness of the insulation used by Correll. Despite being 8 cm thinner, the walls provide 2.5 times the efficiency.

Material	E.I.F.
Heavy Firebrick	1.00
Heavy Castable	1.00
3000° Insulating Castable	2.92
2500° Insulating Castable	2.92
2200° Insulating Castable	4.80
2000° Softbrick	4.30
2600° Softbrick	3.70
2800° Softbrick	3.15
1900° Block Insulation	12.00

Equivalent Inches of Firebrick for Common Furnace Building Materials

Summary				
	Furnace	**Actual Thickness (cm)**	**E.I.F**	**Relation**
	Traditional Murano Furnace	35.5	92.7	0.40
	Correll Furnace	27.8	232.4	2.51

Table 18: Insulation Analysis Summary

Goals

The WPI research team has been working with Correll to determine the feasibility of using his furnace technology on Murano. Past results of these recuperative burners have shown that fuel savings up to 40% are possible. The conclusion of this project is to bring Correll to Murano so that he may build a recuperative furnace to demonstrate his methods to the glass factories of Murano. The furnace will be tested for fuel efficiency improvements, emissions output, lifespan, maintenance, and glass product quality. Additionally the opinions of the craftsman who use the furnace with the burner installed will be recorded to determine if the burner negatively affects their perceived working conditions of the furnace.

Current concerns about this furnace will be addressed by these tests. Silicon Carbide used in other applications is known not to have a significantly long lifespan. The fuel efficiency claims must also be validated before any conclusions can be made as well as confirmation from Murano artisans that the aesthetic performance of the furnace is not altered.

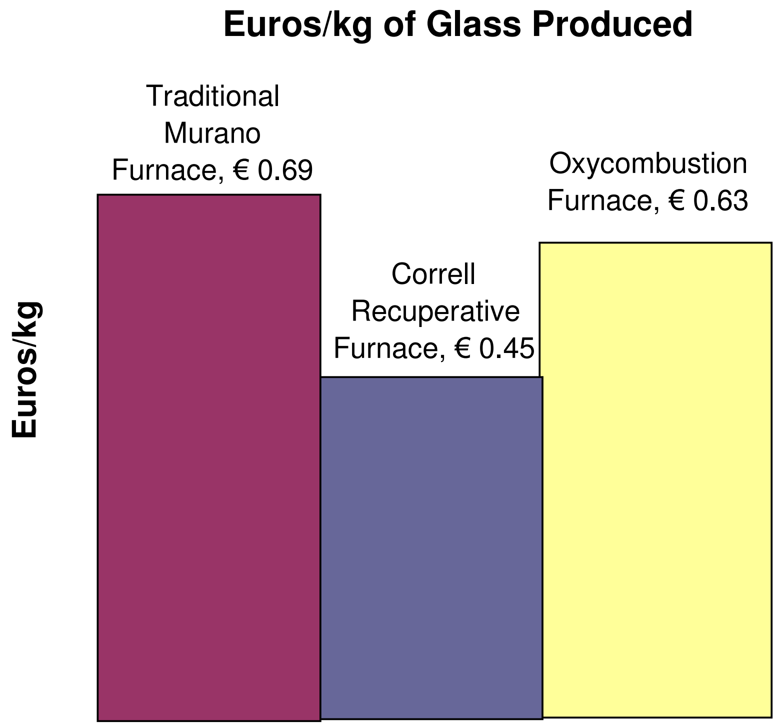
Many factories have expressed their concern for rising fuel costs and the need to conserve energy. Therefore, the team proposes that a Correll furnace be built in a factory willing to participate in the purchasing, construction, and testing. Accordingly, Correll has agreed to travel to Murano and build a furnace equipped with his insulation and recuperator technology. From there, the furnace will be tested by artisans and the Stazione Sperimentale del Vetro for: fuel efficiency, emissions, lifespan, maintenance, and glass quality. Should the furnace prove to be an effective way of reducing fuel consumption, Correll is ecstatic at the opportunity to continue building furnaces for the given factory as well as others across Murano.

Procedure

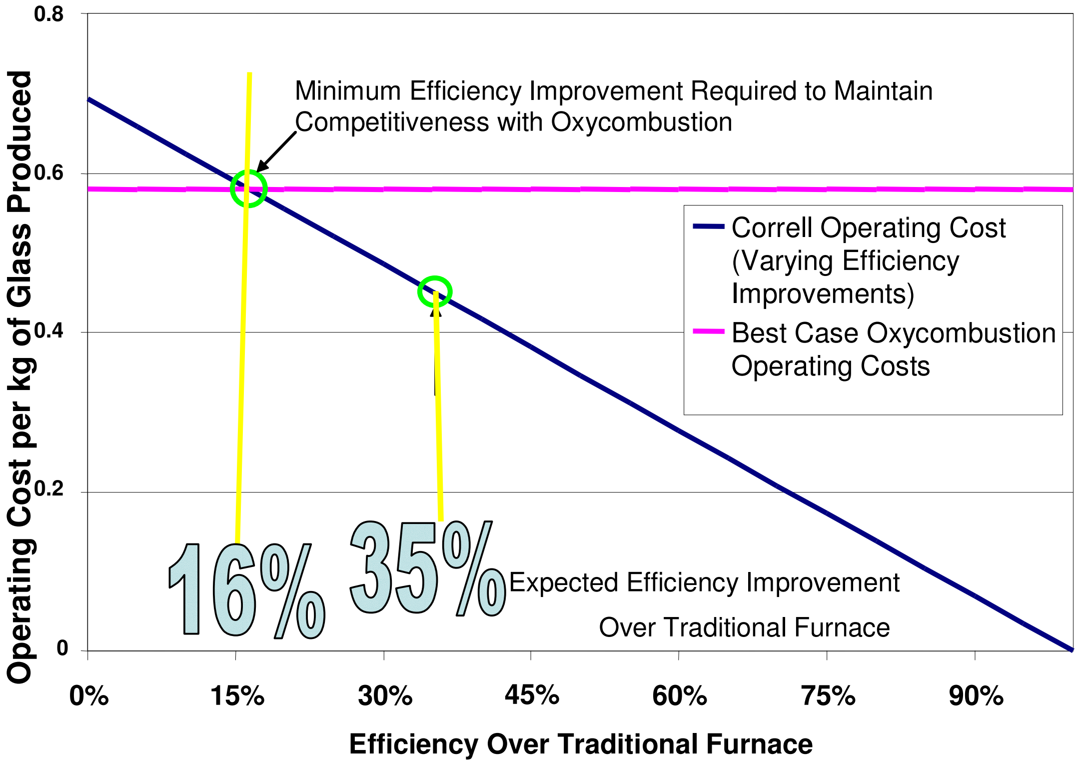
The team has proposed to bring Correll to Murano to build the furnace because of his experience building these furnaces as well as his technical abilities. The build time of the furnace is estimated at 80 hours and a cost of 10,000€, a detailed cost breakdown and timeline for this process are shown at the end of this proposal. Once this furnace has been built, it will be tested by the host factory with the aid of the Stazione to determine its fuel consumption and emissions characteristics.

Conclusion

The WPI team has been working in the Venice region for seven weeks between the dates of October 22nd and December 16th, doing research and collecting data related to this project. A separate in depth report has been created, in addition to this proposal, providing a more in depth analysis of the potential savings of a recuperative furnace as well as the potential savings of oxycombustion burners used in existing furnaces. Not all hardware costs were able to be accounted, however, by using the operating cost of each technology, the team has illustrated below that a Correll furnace offers a cheaper solution rather than oxycombustion.



The team has also concluded that even though the expected effectiveness is 35%, in order to remain competitive with oxycombustion a Correll Furnace only needs to maintain 16% efficiency over a traditional Murano furnace. The chart below shows the operating costs of oxycombustion versus the operating costs of a Correll Furnace with the varying efficiencies.



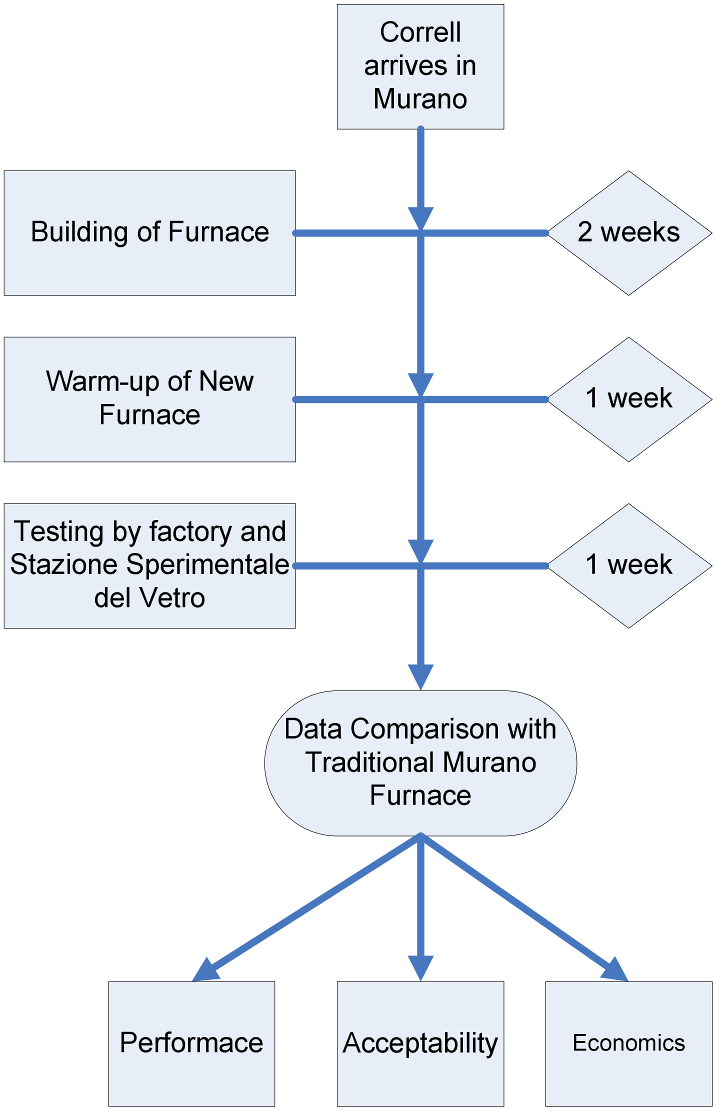
The overall goals of this project have been to reduce the fuel consumption of the glass furnaces of Murano. Long-term testing of oxycombustion burners is scheduled to take place. Based on the team's data collection and conclusions, it is a natural next step to critically examine the potential of recuperative furnaces as well.

Cost Breakdown

Quantity	Item Description	Source	Cost per $	Ext $	Euro
175	Arch Brick, #2	A.P. Green Products	$5.25	$918.75	€ 669.77
	9" x 4 1/2" x 2 1/2"	A.P. Green Products			
40	Hard Brick Straights	A.P. Green Products	$5.25	$210.00	€ 153.09
	9" x 4 1/2' x 2 1/2"	A.P. Green Products			
1	Box 1900° Block Insulation	A.P. Green Products	$119.00	$119.00	€ 86.75
8	Bags 3000° Refractory Castable	A.P. Green Products	$49.00	$392.00	€ 285.77
4	Bags 3000° Insulation Castable	A.P. Green Products	$57.00	$228.00	€ 166.21
4	Sheets 1/8" Steel plate	A.P. Green Products	$125.00	$500.00	€ 364.50
40	Ft. 3" Channel Iron	A.P. Green Products	$4.50	$180.00	€ 131.22
20	Ft. 2"x 2"x 3/16" Angle Iron	A.P. Green Products	$3.00	$60.00	€ 43.74
1	Other Steel	A.P. Green Products	$50.00	$50.00	€ 36.45
1	Correll Burner Recuperator System	Correll	$3,550.00	$3,550.00	€ 2,587.95
1	Control System	Correll	$2,172.56	$2,172.56	€ 1,583.80
1	Flame Safety System	Correll	$917.98	$917.98	€ 669.21
1	Air/Gas Safety System	Correll	$288.64	$288.64	€ 210.42
				Total	**€ 6,988.87**
Traveling Cost	Round Trip Plane Ticket	n/a	1	U.S. Air	€ 800.00
	Transportation to Murano	n/a	2 weeks	ACTV	€ 18.00
	Accommodations	n/a	2 weeks		€ 1,200.00
				Total	**€ 2,018.00**
Labor Cost	Furnace/Recuperator/Control System Bui	n/a	2 weeks	Correll	€ 5,103.00
				Total	**€ 14,109.87**

Table 19: Costs of Transporting Correll and Furnace Materials

Timeline of Testing Correll Technology in Murano



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Bianca	Scalet	Stazione Sperimentale Del Vetro	Project Sponsor	-	-	+001 (39) 041 273-7019	-	-
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Nick	McMahon	WPI	Project Student	-	-	-	-	+1 (207) 975-3655
Andrea	Portnoy	WPI	Project Student	-	-	-	-	-
Jacob	Troiano	WPI	Project Student	-	-	-	-	-
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Table 20: Contact Information List