GUIDELINES FOR THE DEVELOPMENT OF PRODUCTS

FROM POST-CONSUMER GLASS

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GUIDELINES FOR THE DEVELOPMENT OF PRODUCTS FROM POST-CONSUMER GLASS

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A Thesis

Submitted to

the Graduate Faculty of

Auburn Univeristy

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Industrial Design

Auburn, Al
August 10, 2009

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Signature of Author

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Date of Graduation

VITA

Laura Frances Whitacre, daughter of Dr. Robert Greer Whitacre and Sandra Powers Whitacre, was born on August 23, 1984 in Hattiesburg Ms. She graduated from Hattiesburg High school with honors in May of 2002. She attended Auburn University for five years earning her undergraduate degree in Industrial Design. During her undergraduate studies she gained exposure to several reputable companies through her collaboration efforts in corporate sponsored studios. Whitacre also participated in a study abroad program her junior year at Shu-Te University in Taiwan. This program introduced her to the art of warm glass and inspired in Whitacre the desire to gain more knowledge in the art of glass making. This desire was exercised in 2007 upon admittance to the graduate program at Auburn University. During her graduate studies Whitacre received recognition by the academic honor society Delta Epsilon Iota in which she is now a member.

THESIS ABSTRACT

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FROM POST-CONSUMER GLASS

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Master of Industrial Design, August 10, 2009
(Bachelor of Industrial Design, Auburn University, 2007)

118 Typed Pages

Directed by Rich Britnell

This thesis examines the process of glass manufacturing as well as the benefits associated with reusing and recycling glass. Glass can be re-melted indefinitely without ever losing clarity, yet single use applications such as beverage containers send glass back into the waste stream within a matter of weeks, increasing its chances of landfill destination. There is a need for alternative applications for post-consumer glass in order to re-establish the potential of this glass as a valuable material. The majority of post-consumer glass is re-melted into beverage containers. The process requires an extreme amount of energy; in contrast, the resulting product is of low perceived value: packaging. An alternative to packaging for post-consumer glass is to implement techniques used by

glass artisans to create a line of higher value end products. Processes such as cutting bottles will transform post-consumer glass into usable long lived products such as drinking glasses or vases. Furthermore, this idea invites the possibility of creating a product line with unique characteristics that would be otherwise lost in the re-melting process. In addition, warm glass techniques such as fusing and slumping can be applied to post-consumer glass to form unique sculptures and other valuable art. The purpose of this thesis, therefore, is to evaluate the potential of post-consumer glass beyond the use of disposable packaging.

AKNOWLEDGMENTS

The author would like to thank her family and friends for their love, support and encouragement over the past two years. She would like to thank her committee chair professor, Rich Britnell, for exceptional guidance throughout this entire process. Thank you for believing in me, expecting only the best from me, and enabling me to grow as a person and as a designer. Thank you to committee member Tin Man Lau for providing the opportunity to study abroad at Shu-Te University in Taiwan. The experience introduced me to a new way of thinking and inspired my initial concept for this thesis. Thank you to committee member Lu Tsailu, for his insight and assistance in applying design methods to this thesis. Thank you to David Gowan for sharing his expertise and providing his assistance in the shop. Thank you to Jay Shamburger and Frank Key for their help and support at Auburn City Fest. Thank you to Chad Baily, for always being available and willing to help in a time crunch. Thank you to my peers in the Graduate program for providing an exceptional work environment and continuous support during these challenging and exciting two years.

Style Manual or Journal used:	APA Fifth Edition Manual
Computer software used:	Microsoft Office Word 2007
	Adobe Illustrator CS2
	Adobe Photoshop CS2

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1. INTRODUCTION TO THE PROBLEM

1.1 Problem statement

Ninety percent of recycled glass is used to make new containers intended for single use. The containers serve as a means of packaging. Once the contents inside the container are consumed, it is up to the consumer where the material will ultimately end up. According to the Environmental Protection Agency, “about 28 billion bottles and jars are thrown away every year” (Facts on Recycling, ln 3). This is the result of consumers who do not recognize the potential value of glass, due to the main purpose of the material: beverage containers. Recycling glass is inconvenient, and often consumers do not know where a recycling facility is located; therefore, these valuable containers end up in the waste stream. The glass that is recycled must be transported to a manufacturing plant, requiring additional energy output. Furthermore, the resulting product appears thousands of miles from where it was used. There is an opportunity to mine post-consumer glass from the local waste stream and create valuable end products rather than disposable packaging.

1.2 Need for study

“The use of energy by the sand and glass sector is the biggest environmental concern related to manufacturing; it is among the highest of all the sectors and a significant factor in industry’s production in greenhouse gas” (Graedel, 2005, pg 278).

According to Western Michigan University's Fun Recycling facts, "the use of recycled glass to make new glass cuts related air pollution by up to 20%" (Glass section, para 1). Glass is a flexible material with various applications; it can be re-melted an infinite number of times without any degradation of its physical properties. The value of our recycling efforts is to recover and reuse resources that we have extracted from the environment at their highest and best value. "Of the total glass recycled, approximately 63% is clear glass that is used for re-melting containers" (IMP, para 3). This single-use application means that glass is likely to be returned to the waste stream within just a few weeks. There are many low-value uses for mixed recycled cullet, such as aggregate material in concrete and glassphault. "In some areas where there is overabundance of low grade glass material, it is used to cover over the rubbish in the landfill instead of sand" (Connecticut metal industries, 2007, para 5). There is a need to examine the uses of this valuable material and explore opportunities for new applications of post-consumer glass that yield high-value end products. Furthering applications for the reuse of waste glass is necessary because this reduces the amount of glass going into or on top of our landfills.

1.3 Definition of Terms

Common terms referring to the formation of glass in industry that need clarification are as follows:

Annealing- Cooling a piece of glass slowly to remove stress.

Consistent linear annealing- Cooling slowly drops the temperature through different ranges of annealing.

Crazing- A network of fine cracks inside a surface.

Crucible- A cup-shaped piece of laboratory equipment used to contain chemical compounds when heated to extremely high temperatures.

Cullet- Broken or refuse glass added to new material to facilitate melting in making glass.

Devitrification- A condition in the firing process of fused glass; the surface of the glass develops a whitish scum, crazing, or wrinkling instead of smooth glossy shine because the molecules in the glass change their structure into crystalline solids.

Fire polishing- The technique of returning glass items to the kiln to melt them just enough to give a smooth polished appearance.

Kiln- An oven used for processing a substance by burning firing or drying.

Kiln furniture- Stilts or blocks used to support the kiln shelves for the purpose of stacking the shelves on top of each other.

Kiln Shelf- The surface on which the glass is placed inside the kiln.

Kiln wash- A solvent used to keep glass from sticking to the kiln shelf.

Process temperature- The highest temperature the kiln reaches during the firing.

Pyrometric cone: Used to gauge heat work during the firing of ceramic materials.

Soaking- A technique of holding the kiln temperature steady for a set period of time to ensure all parts of the fired piece reach the same temperature.

Thermal shock- Cracking as a result of rapid temperature change.

1.4 Assumptions

For this research study, secondary sources such as scholarly journals, books, magazines, and the internet will be used. It will be assumed that information collected from these sources is based on fact. It will be understood that the authors of such sources are experts in their respective fields.

Our society has little incentive to recycle and reuse their waste because recycling plants are not local and the end product appears far from the initial recycling spot. It will be assumed that the development of a valuable end product created from locally mined post-consumer glass will provide an incentive for local recycling in the form of donations to the local glass artist. This thesis is intended to promote the re-use of locally mined materials. Post-consumer glass products provide attractive potential for new product applications. Experimentation will be conducted in this thesis to achieve the unique and valuable end result desired by the author. It will be assumed that the experimentation conducted will provide enough information to create guidelines for future glass applications.

1.5 Scope and Limits

This thesis will propose a series of procedures necessary to mine valuable materials from the local waste. This thesis will concentrate on product applications for post-consumer glass products such as wine bottles and beer bottles. This thesis will also provide an understanding of glass forming techniques applicable to post-consumer glass products.

This thesis will not attempt to redesign collection methods to take the place of community recycling programs.

1.6 Anticipated Outcome

It can be expected that this thesis will evaluate current techniques and practices performed by glass artisans with the intention of applying these practices to post-consumer glass. It can be expected that this study will show the potential of post-consumer glass to create high value end products. Product opportunities for post-consumer glass will be uncovered through research and experimentation conducted in this thesis. Experimentation will show that current methods for re-using post-consumer glass are more energy intensive than the final product is beneficial. Techniques used by glass artisans such as cutting, slumping, and fusing yield the possibility of transforming post consumer glass into bowls, trays, cups, jewelry and numerous other glassware products. The effect of this innovation creates a market for waste glass that likely uses less energy than initial bottle manufacturing and yields a more valuable end product. Because the feedstock is locally derived from the waste stream, the utilization of this glass will decrease the money and energy required to transport glass to a centralized re-melting plant. Furthermore, the final result will be a long life end product rather than food or beverage packaging which will likely re-enter the waste stream within weeks of production. This thesis attempts to change society's perspective of waste materials as well as invite the idea of reclaiming glass at its highest potential.

1.7 Literature Review

We live in a world that continues to create waste, an economic system where sellers only value land and commodities relative to their capacity to generate profit.

Advertisers are constantly bombarding consumers with the ideas to discard and replace the goods they already have simply to increase sales. According to the group known as Freegans, “this practice of affluent societies produces an amount of waste so enormous that many people can be fed and supported simply on its trash” (Waste Reclamation, para 1).

The industrial processes also play a major role in the degradation of the global environment (European Commission, 2006). According to the European Commission fact sheet on industrial development, industrial processes cause “climate change, loss of natural resources, air and water pollution and extinction of species” (para 2). As a result, there has been a global movement toward green design in attempt to lessen the environmental impact of manufacturers.

Green product design is a proactive business approach to addressing environmental considerations in the earliest stages of the product development process to minimize negative environmental impacts throughout the product’s life cycle (Business for Social Responsibilty (BSR), para 1). *Reduce, Reuse, Recycle* refers to the EPA’s preferred order of waste disposal. While reusing and recycling material from the waste stream is obviously beneficial to our environment, the EPA emphasizes for us to first reduce our consumption and prevent the generation of waste in the first place.

In Germany, during the beginning of the green movement, laws held manufacturers responsible for the final fate of their packaging. These laws, referred to as take back laws, were a motivation for companies to apply the principles of source reduction.   These regulations successfully stimulated companies' creative mindsets, resulting in the development of imaginative marketing tactics that required much less packaging. As a result, Germany's packaging waste was reduced by 600 million tons during its first two years of operation (BSR, para1).

More than 28 countries, primarily in Europe, have already passed product take back laws. Companies trying to compete within an industry mandated by such laws will probably find their profits reduced if products and packaging are not designed for efficient recovery and reuse or at a minimum, recycling (Recent Developments section, para 2). According to the EPA, extended product responsibility is an emerging principle for a new generation of pollution prevention policies that focus on product systems instead of production facilities (para 3). "Green products may be designed to be more easily upgraded, disassembled, recycled, and reused as well as to use fewer materials and to break down into replaceable modular parts" (BSR, para 1). The ultimate goal is to reduce the amount of material ending up in our waste stream. The principles of green product design can lead us to solving the depletion of the Earth's mineral riches. Furthermore, designing a product with environmental parameters in mind will enable companies to increase profits as a result of reduced material input cost.

1.7.1 Creative re-use

Figure 1: Wine barrel furniture

As stated in the article *Manufacturing for Reuse*, featured in *Fortune Archives*, “94% of the stuff that is pulled out of the Earth enters the waste stream within months” (Bylinsky, pg 2). It is through creative implementation that we are able to see the path to sustainable design using materials from our waste stream. There are countless opportunities to generate income by reusing someone else’s discards. Furthermore, this kind of reuse to create new products consequently extends the life of otherwise trashed items to ultimately create a green product.

For example, Paul Block, owner of Vintage Furniture Manufacturing Company, realized the profitable potential of reusing discards in 1997. After first posing the question “how can one create art without creating waste?” Block found that the answer lies in the exploration of unfamiliar and unexploited materials. Block therefore conducted necessary research, enabling him to develop various reuses for discarded barrels in which he saw a great potential to build furniture (2005, para 3).

As a result, he established the Vintage Furniture Manufacturing Company in Calistoga, CA. Block accepts barrel donations from the community; however, he recognizes that only 30% of the barrels he receives have the characteristics to become furniture. Therefore, Block recycles the other 70% into cooking wood to avoid re-introducing the wine barrels into the waste stream (para 6). Within 3 miles of his shop are 75,000 barrels available every year for his use. Block emphasizes that every barrel he has contact with will be reused or recycled. He estimates that he recycles or reuses 50 to 120 barrels each month (para 9). Figure 1 is one example of a rocking chair Block created from old wine barrels.

Another green entrepreneur and artist, Harvey Keys, established Josswood Designs Company in California. The artist, creates custom furniture with a patina of age using fence board and wood from windows that would otherwise be destined for landfill (Weimer, 2004).

According to the article *Sitting on a Fence* by Sarah Weimer, found on The California Integrated Waste Management Board (CIWMB) website, these products have been publicly recognized and televised (para 3). The La Verne cable channel did a story on Keys' products, and, furthermore, Keys rents his products to film studios for use in movies. It should be understood, as noted in Weimer's article, that Keys does not sell his products to film studios because they would likely dispose of the furniture piece upon completion of the film. Through his company's products, he hopes to broaden the awareness of the idea to reuse materials as well as the importance of purchasing reused items.

Similar to the above entrepreneurs, Canela Valentine of Faze II Recycling uncovered a creative way to generate income from discarded items. She created tough re-usable bags in three sizes from un-torn grain sacks. Valentine's efforts did not stop there. In addition Valentine suggests the grain sack producers should include instructions on the bags explaining proper opening techniques and even where to locate a bin for customers to return the sacks to further promote more of this particular type of reuse (Thompson, 1997, para 4). Valentine's ideas further the possibility for future grain sack reuse and fewer wasted sacks due to proper initial opening of the grain sacks.

1.7.2 Broaden Awareness

Figure 2: Lamp design by Rene Chen

The likelihood of additional applications for creative product reuse will increase by broadening the awareness of such reuse practices.

The *Recycling Market Development Zone program* was implemented in California by the (CIWMB) to encourage practices of reuse. According to their website, "The program combines recycling with economic development to fuel new businesses, expand existing ones, create jobs, and divert waste from the waste stream" (2007, para 1). Not only does the program provide attractive loans and technical assistance, it also provides free product marketing to businesses that use materials from the waste stream to manufacture their products (para 2).

A two-week adventure in up-cycling at Massachusetts Institute of Technology is a great example of broadening awareness. The event, called Junkyard Art held in 2005, gave participants a new perspective on trash. Participants such as Rene Chen, a sophomore in materials science and engineering, were challenged to transform discarded objects into their own new creations (Wright, 2005).

Chen , used scrap glass such as jagged jar bottoms to create an intriguing and beautiful lamp illustrated in Figure 2 (Wright, 2005). "According to the Earthworks Group, about 28 billion bottles and jars are thrown away every year. That's enough to fill both towers of New York's World Trade Center every two weeks" (Newton's Apple, 2006, para 6). Chen's lamp design demonstrates the act of reclaiming a material amongst the trash thrown away and providing an alternative to its landfill destination. As a result of reuse practices, we are capable of saving valuable landfill space and conserving natural resources. Rene Chen's design required no additional energy output to create her lamp. This observation begs the question, what kind of market exists for creatively reclaiming waste glass?

Figure 3: Bowl by Lauren Becker

In addition to bottles and jars, glass can be reclaimed from sources of plate glass such as windows, doors, and shelves. The company Recycled Glass Works, started by the artist Lauren Becker, specializes in products formed from reclaimed window type glass. Every piece is designed from condemned glass such as broken windows. The glass is individually cut and kiln fired over specialized molds. The products Becker creates through this formation process may be utilized as decorative tableware including coasters, plates, and bowls. The bowl in Figure 3 is currently available for sale on the Recycled Glassworks website. As can be seen in the image, Becker incorporates patterns in the formation of her molds to yield a variety of elegant effects on her final products. Becker's desire to create tableware such as large bowls likely determined her utilization of flat waste glass as opposed to post-consumer glass bottles and jars. This may be assumed because of the rounded nature of post-consumer container glass. However, through experimentation represented in the later portion of this thesis, it could be deemed possible to create similar types of products from bottles and jars by utilizing different molds in the melting process.

1.7.3 Recycling Related Manufacturing:

Recycling is a continual process of collection, processing, transportation, manufacture, retail and consumption. The most important and often the most neglected part of the chain is recycling-related manufacturing (IMP, para 1). The symbol for recycling is shown with three chasing arrows, the third arrow is critical to the success of recycling process. Without a strong market for recycled materials, there is no incentive to collect recyclables and manufacture recycled content products. Therefore, it is imperative to explore a material's highest potential to ensure its success as a second life product.

Michigan Tech's Institute of Materials Processing branch (IMP) asserts that recycling related-manufacturing offers a community local economic development potential. They state "manufacturers of recycled materials hold a majority of the economic pay off of the entire recycling process. Adding to the jobs and revenue that recycling, collection, and processing bring to an area, manufacturers of recycled products provide high-skill industrial jobs and sizeable sales revenue to a community" (IMP, para 2). A scrap-based manufacturing firm tends to be a small firm that would likely need to locate nearby sources of feedstock. A possible outcome of these type firms in a community would be to revitalize that community's industrial sector while at the same time diminishing the local waste stream through buying locally derived feed-stock.

Therefore, this thesis will concentrate on the second life potential for post-consumer glass in a local community.

1.7.4 Problems with glass recycling:

A disappointing ten to twelve percent of the glass used in the United States is recycled (Newton's Apple, para 6). Light bulbs, cookware, and window panes are made by incorporating ceramics with the glass so they are not considered recyclable because doing so would introduce impurities into the container recycling process. Regardless, it is the bottles and jars we throw away that make up most of our trash. Increasing the ways to reuse glass waste also increases the demand for glass recycling, which results in waste reduction.

The previously mentioned entrepreneurs reiterate that reusing items can be a great way to generate income as well as help the environment. Furthermore, material reuse is an opportunity to set an example for creativity in manufacturing and design. Of the materials being recycled today, glass has been referred to as one of the most difficult to reuse (IMP, para 3). One of the major problems in the past with glass recycling has been the separation of clear and colored glass. There have been few applications for mixed waste glass. "Of the total glass recycled, approximately 63% is clear glass that is used for re-melting to produce more containers" (IMP, para 3, ln 4). This single use application means the glass will likely to be returned to the waste stream within just a few weeks. In addition, shipping glass to a centralized recycling center is costly.

The tile manufacturing industry offers a promising high value alternative for local glass recycling efforts, by extending the life of the waste glass and creating a product that can be used multiple times. This process consequently removes the item from the waste stream indefinitely. According to the EPA, recycling is estimated to create nearly five times as many jobs as land filling. One study reported that 103,000 jobs in the northeast region of the United States are attributed to recycling (Jobs through recycling, para 3). There are three stages to recycling: collecting recyclable materials, manufacturing recycled content products, and selling those products. Market development means fostering businesses that manufacture and market recycled content products, strengthening consumer demand for those products.

1.7.5 Current Glass Applications

There have been few takers for refuse glass not presorted by color. Due to predictions of higher amounts of waste glass collection in the U.S., engineers at the Institute of Materials Processing of Michigan Tech University began working on applications for the reuse of waste glass. Michigan Tech engineers found that when waste glass is used as an additive in clay, it lowers the processing temperature, which, as a result, lowers the costs for producing tiles and bricks. The glass chemically bonds with the clay to make the product stronger. Also, finely ground glass readily replaces the calcium carbonate filler in plastic. After the ground glass was mixed with a ceramic, it was inexpensively processed to form finished parts that do not require machining (IMP, para 1-5). According to the Michigan Tech engineers, “glass is a natural resource that can be mined from the waste stream and become a valuable commodity to those that recover it" (IMP, para 4).

1.7.6 Energy Use

According to Graedel's book *Greening the Industrial Facility*, "the use of energy by the sand and glass sector is the biggest environmental concern related to manufacturing; it is among the highest of all the sectors and a significant factor in industry's production in greenhouse gas" (2005, pg 278, para 4). The melting process is the most energy intensive and costly part of glass production. Sand is the only ingredient used more than recycled glass in container production. The cost savings of using recycled glass for manufacturers is in the use of energy. This is because cullet from soda-lime glass melts at a lower temperature than mixing and melting of raw materials. Therefore, when recycled glass is added to the mixture, manufacturers can save on energy needed to melt the glass for production. According to the Ohio Department of Natural Resources, "manufacturing glass from recycled materials saves 68 % energy and half the water normally required in the manufacturing process" (n.d., para 11). Glass container manufacturers have a steady supply of quality cullet to make glass containers.

Figure 4: Icestone mosaic countertop

Consequently, industries are developing new uses for glass that produce less strain on our environment. According to Tucker's article featured in *In Business Magazine,* "Ice Stone surfaces [represented in Figure 4] are keeping tons of glass out of landfills and transforming it into high-end countertops and vanities using an emission free and chemical free process" (2006, para1).

Ice Stone is a mosaic mixture of 75% recycled glass, 17 to 18% white Portland cement, pigment and proprietary ingredients. During the manufacturing process, the glass is mixed with cement and poured into molds, which are then vibrated and finally put into curing chambers. When they are cured, the finished slabs are polished on an Italian stone-polishing machine, resulting in a surface that looks like modern-day terrazzo, the faux marble flooring (para 8).

According to the Ice Stone website, 85% of mined natural stone is imported from other countries. Furthermore, natural stone is often mined under dangerous working conditions, and it requires a significant amount of fossil fuel to transport the natural stone to the U.S. Therefore, Ice Stone surfaces are marketed as a sustainable alternative to minded natural stone such as granite and marble. In addition, the manufacturing process is considered environmentally friendly. However, the recycled glass used in Ice Stone must be very clean in order to adhere strongly and tightly to cement; therefore, the glass is already presorted by color and size of the pieces. Glass pieces accompanied with bits of debris are rejected for use in this process (para 8-9).

1.7.7 Cost Efficiency

Reuse or recycling of waste is an attractive option if it is cost effective. In the U.S., recycling of many materials has not yet become a cost effective alternative. However, as landfill and disposal costs increase, recycling and reuse will become more important.

The Isle of Lewis in Scotland was previously dumping its glass in landfills because the cost of shipping the glass to the mainland for recycling was about double the market price of the waste material. However, with disposal costs increasing, sending glass to a landfill no longer had its advantages. As a result, the Lewis glass recycling plant was created in April 2004. The plant, owned and operated by the Western Isle Council, accepts glass bottles and jars of all kinds with labels and metal foil still attached. The new plant produces aggregate and re-melt material as well as various higher value products for other uses. This is possible because the plant uses two basic processes: a glass breaking and grinding system as well as a classifying system that separates the glass into desired sizes, which overcomes the previously stated issues with recycling. Senior recycling officer David Macleod states "the classifier is the key element because it allows the plant to make relatively valuable products for local market" (Kason Technical Library, para 3). The main interest of the plant initially was to avoid sending material to a landfill. Nonetheless, the solution of implementing the Lewis plant provides the opportunity to make saleable products. MacLeod states “if we were a commercial organization this would definitely have to potential to be a profitable process” (para 6).

Recycling glass is beneficial to the environment in several ways. “Glass produced from recycled glass instead of raw materials reduces related air pollution by 20% and related water pollution by 50%. Throwaway bottles consume three times as much energy as reusable, returnable containers. And, recycling glass reduces the space in landfills that would otherwise be taken up by used bottles and jars” (Newton’s Apple, 2006, para 5). Utilizing the markets for the recycled glass is necessary to create an incentive to recover this valuable material and further the possibilities of future applications. As the Isle of Lewis demonstrated, with proper collection and strategic methods for the use of post consumer glass, it is possible to create valuable second life products locally.

1.7.8 Creative Manufacturing

In his article “The Odd Couple,” from the American Ceramic Society Bulletin, the executive director of the Glass Manufacturing Industry Council, Michael Greenman, recognizes the persistent efforts in the U.K. to introduce creativity in manufacturing and business. According to his article, the U.K. appears to be seeking a position of leadership in post-industrial manufacturing, whereas the link between manufacturing and creativity is an unknown concept in Washington (Greenman, para 11).

According to Greenman, methods developed by glass artists to produce new visual effects have been studied and adopted by glass scientists, resulting in a beneficial collaboration which yields creative solutions for glass applications. For example, “the ancient process for making complex patterns in glass known as millefiori was adapted in the last century to create optical fibers. Opalized glass, blown from phosphorus-calcium silica, glass has evolved into bioactive glass for human bone replacements” (2007, para 3).

It is evident that opportunities for further collaboration between art and science exist, but it is up to farsighted organizations to pursue these ideas. With the practice of creative implementation, we are able to see the path to sustainable design through the use of materials in our waste stream. It is necessary to understand the uses and problems associated with post-consumer glass to further its potential as a valuable second life product.

Harvard Keys, who makes furniture from wine barrels, hand-selects his material for each project, and what he could not use was returned to the recycle chain. His method can be applied to post-consumer glass products by hand-selecting bottles and additional materials intended for reuse. The idea invites the possibility of a creating product line with unique characteristics that would be otherwise lost in the mass production recycling process.

Post-consumer glass collected by local efforts and transformed into second life products lends the possibility of accumulated scrap glass. This scrap glass should be considered saved glass. In other words, it is glass that has been intercepted from its destination in our waste stream and is in need of being properly returned to the recycling chain for the possibility of its reuse. Furthermore, the unique product created from hand selected glass bottles and jars yields less additional energy while contributing to the environmental benefits related to recycling.

In addition, increasing innovations in glass melting operations are upcoming and will further the possibilities of more efficient processes yielding less negative environmental impacts, therefore opening the possibility of kiln forming glass in an environmentally friendly manner. For example, the microwave kiln can offer high accuracy and short firing times, which directly relate to the reduction of energy consumption and increased productivity. Furthermore, according to Takasago Industry Company, new technology has yielded a kiln product that has no exhaust gas and is considered environmentally friendly (2007).

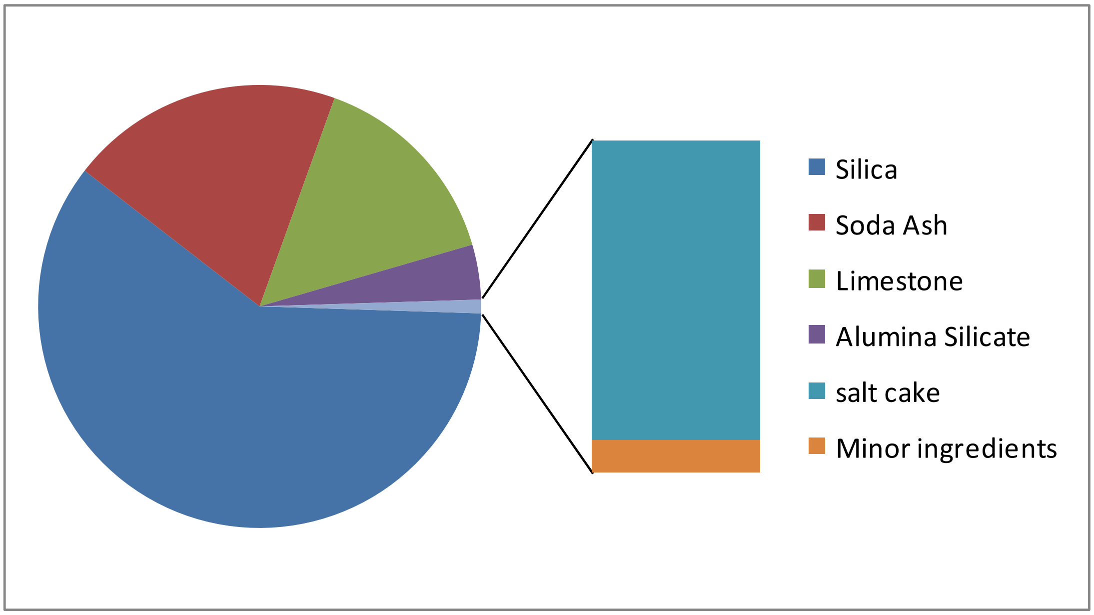
In conclusion, post-consumer glass is a prime candidate for recycling and reuse because it never loses clarity or durability. Due to its chemical make-up, glass can be re-melted indefinitely. The process of softening glass up to its melting temperature, also referred to as warm glass work, allows for various product opportunities with the use of diverse mold designs. This thesis will explore the potential of post-consumer glass through brainstorming and experimentation. As a result, this thesis will provide local opportunities for the reuse and recycling [re-melting] of post-consumer glass. A possible result is an increase in local glass recycling efforts and interest, and a reduction of post consumer glass in the waste stream.

1.7.9 Properties of Glass

According to the article "Explore Glass Chemical Composition", glass by definition is an amorphous solid material made by fusing silica with a basic oxide. Glass is considered amorphous because it is neither a solid nor a liquid; it exists in a glassy state. The categorizing of these materials by chemical composition is necessary because mixing these glass components in the recycling process alters the behavior and compatibility of glass. These categories are lead glass, borosilicate glass, and soda-lime glass. Lead glass has a high percentage of lead oxide resulting in a relatively soft surface. The soft surface is suited for decorating processes such as grinding, cutting, and engraving. The second category, borosilicate glass, demonstrates greater resistance to thermal changes and chemical corrosion. Any silicate glass having at least 5% of boric oxide in its composition is considered borosilicate. Borosilicate glass is suitable for use in industrial chemical process plants, in laboratories, for ampoules and vials in the pharmaceutical industry and in bulbs for high powered lamps, and borosilicate glass is also used in the home for heat-resistant cooking products such as the Pyrex brand. (Glass On web, S,R,L 2007). The third category, soda-lime glass, is the most common commercial glass and also the least expensive. It accounts for 90% of total production and is used for bottles, jars, everyday drinking glasses and window glass.

As Table 1, demonstrates soda-lime glass usually contains 60 to 75% silica, 12 to 18% soda, and 5 to 12% lime (Glass On web, S,R,L 2007). Soda-lime glass is not resistant to high temperatures, sudden thermal changes or corrosive chemicals. Soda-lime glass, due to its chemical properties, can be re-melted an infinite number of times without degradation of its physical properties.

Table 1: Properties of Soda Lime Glass



Soda-lime glass is the central focus of my research. Recycled glass containers are primary feedstock for the glass manufacturers; 90% of containers are used to make new non-refillable, single use containers (Glass On Web, S,R,L 2007).

The container glass can be made in different colors with the addition of minor ingredients such as iron sulfide, which gives glass an amber color. The pie chart illustrates these color agents as minor ingredients. Colored glass containers are important for some manufacturers like the brewery industry, which utilizes the amber glass to protect the contents against ultraviolet light damage.

1.7.10 Bottle Manufacturing

At a bottling manufacturing plant, glass is heated up to 2,,800 degrees Fahrenheit, at which state the glass appears to have the consistency of honey. The resulting liquid, or molten glass, is molded and blown into container shapes using a specially designed production machine such as the one shown in Figure 5. The molten glass is then cooled in a specialized annealing oven that toughens the container against breakage.

Figure 5: Bottle production equipment

Furnace inefficiency and heat loss actually triple the amount of energy used in manufacturing glass (Sandia Corporation, 2004, para 1). Glass manufacturers believe it is the right time for developing and applying new approaches to monitoring and control of glass production and the design of melting furnaces (Sandia Corporation, para 4). In addition to these concerns, the glass manufacturers should begin to consider different applications for glass forming. Methods that demand less energy in the formation of post-consumer glass products as well as a more efficient furnace design will considerably reduce the cost of glass product manufacturing.

Statistics imply that the use of 100% recycled glass in production would save the highest possible amount of energy in applications for re-melting. This scenario is not currently plausible for the application of bottling manufacturers; there are over 40 billion containers produced each year. Because of the high production volume of containers, manufacturers do not have the cullet supply to use 100% recycled glass. On average, glass containers manufactured in the U.S. contain almost one-third recycled glass. By comparison, 90 to 95% of glass in recycled in Europe is recycled, leaving the U.S. far behind in our green efforts. In addition, the mass production cycle implemented in the U.S. of re-melting bottles requires an excessive amount of energy and results in major environmental effects, yielding a low valued packaging product. “The manufacturing of non-refillable, one-way glass containers is an energy intensive process that depletes our mineral resources, pollutes air and water resources, and generates millions of tons of post-consumer waste each year” (Sandia Corporation, para 3). In contrast, it is plausible to create a sustainable second life products from the post consumer materials our society considers waste.

1.7.11 Environmental effects

Two types of air emission are generated in the production of glass according to the *Pollution Prevention and Abatement Handbook.* These emissions are from the combustion of fuel for operating the glass melting furnaces and fine particulates from the vaporization and re-crystallization of materials in the melt. Sulfur oxides (SO), nitrogen oxides (NO), and particulates which can contain heavy metals such as arsenic and lead make up the main emissions produced from glass manufacturing (World Bank Group, 1998). “Container pressing and blowing operations produce a periodic mist when the hot gob comes into contact with the release agent used on molds.” (pg 320, ln 49-52) Today with temperatures reaching record highs, we are familiar with the effects of greenhouse gases. Glass production is a major contributor of these greenhouse gasses. The environmental costs far surpass the benefits of the product we create: a non-refillable container that will likely enter the waste stream and occupy valuable landfill space.

1.7.12 Collection

Container cullet is available from the community in two major sources: buyback centers and curbside programs. The remaining cullet is recovered at drop-off centers and community service programs. The results achieved from each collection strategy are often commingled. Curbside collection of glass may result in a mixture of colored glass and even different types of glass. After the glass is collected, it might then be sorted by color or other characteristics at a materials recovery facility. Large contaminants are removed by hand whenever possible.

Curbside collection requires less work on the part of residents, however, the contamination levels can be greater. This is due to the breakage of materials in transport. Drop-off centers often require the glass to be separated into different receptacles according to color. To increase recycling participation, in some areas collection centers accept all recyclable items in one receptacle. The city of Auburn, AL, employs this type of recycling facility in the parking lot of the on-campus apartments. The recyclables collected must be sorted at a later time. This method is not ideal for the collection of glass because of contamination issues.

After the glass is collected, contaminants are removed to a materials recovery facility. The glass is then crushed and goes through a series of refinements. Magnets and air currents are used to remove remaining contaminants. Sophisticated sorting equipment uses lasers to further remove small contaminants and sort the cullet into batches by color.

1.7.13 Contamination

Although all glass is made of silica and soda, the type and quantity vary with different types of glass. Container glass, previously referred to as soda-lime glass, has distinct redundant formulation from the other glass types. If window glass, crystal or laboratory glass is put in for recycling, it will cause quality problems in manufacturing due to different melting points and chemical incompatibility. Therefore, only container glass can be used to make new containers. Nonetheless, each container made from glass has a slightly different composition resulting in differing coefficients of expansion (COE). For this reason, at a bottle manufacturing plant, batch additions must be added to the cullet supply. Theses batch additions include sand and other ingredients to equalize the COE temperature. The additions, however, increase the necessary temperature needed to melt the cullet. The application of kiln forming that uses locally collected post-consumer glass invites the possibility of creating high valued end products requiring less energy to create more bottles.

Incompatibility also refers to the glass color. Mixing different colors of cullet might create a bigger problem than just off-spec colors. If green or clear glass is melted with brown (amber) glass, the different chemical compositions may release a gas. The gas creates bubbles which alter the appearance of the glass and may weaken the glass walls, leading to breakage.

The problem is not that there is not enough glass to recycle; it is that there is not enough "quality" supply. “The success of curbside glass recycling programs has resulted in more post-consumer glass than municipalities can use; there is also post-industrial glass waste available. Therefore, this excess glass is in need of further development for alternate products” (Dubrille, para 2). Use of this glass is beneficial because it reduces landfill space occupied by glass, reduces the need for recycled glass storage and supports the economic viability of recycling programs. However, if the glass is contaminated, the uses for it are somewhat limited and low value. Therefore an efficient collection strategy is in needed to ensure quality glass supply for local recycling efforts.

Mixed waste glass applications are increasing; however, many of the applications are low value. For example, the mixed glass can be finely ground and replace sand as aggregate material in concrete and glassphault. According to the article “Glass Recycling” found on the Connecticut Metal Industry website, “In some areas where there is overabundance of low grade glass material it is used to cover over the rubbish in the landfill instead of sand” (Glass Recycling, para 5). Also, as previously mentioned, the tile industry has given this glass a second life in the form of counter tops and attractive flooring. Attempting to locally collect post-consumer glass requires the knowledge of alternate uses for scrap glass that might be accumulated. However, the accumulation of scrap glass will be less than that of a centralized recycling plant.

1.7.14 Perceived Value

Figure 6: Bottles intermingled in trash

Consumers likely throw away their beverage containers due to a low perceived value of the material. From the consumer perspective, the bottle's sole purpose is a means of beverage packaging; therefore, it is discarded after the beverage consumption takes place. The consumer's perceived value of glass seemingly decreased with the decline of refillable bottles. Before the debut of the disposable steel can in 1938, all fountain soft drinks and draught beer was sold in refillable glass bottles. According to the Container Recycling Institute, after only 10 years these steel one way containers comprised 11% of beer market share; refillable bottles had dropped to 86%. In 1960, 47% of beer was sold in one-way containers and 6% of soft drinks were sold in one-way bottles and cans. Today, less than 1% of packaged soft drink volume is sold in refillable bottles (Decline of Reusable Beverage Bottles, 2006, para 1-2). Because the containers are no longer refillable, consumers mistakenly perceive the item as trash. This consumer perception heavily increases the probability that the glass will enter the waste stream.

Deposits on beverage containers were used for many decades by industry to ensure the return of their refillable bottles. Therefore, bottle bills assigned glass containers a previously higher perceived value. The use of glass as a packaging material in the absence of bottle bills implies to consumers that container glass has little second use value. However, this glass has infinite potential to become a lucrative product. Any glass product that is currently made from raw materials could be made from recycled glass. Creating a product from post-consumer glass is an attempt to change the consumers' perceived value of glass used for packaging purposes.

Mining glass from the waste stream is important especially in rural communities because they often find it overly difficult to market their glass to glass processors. Furthermore, the cost of shipping the glass often outweighs the benefits of recycling. It is imperative, therefore, to explore non-container alternatives for recycling post-consumer glass in these small communities. The opportunity exists to create sustainable products from post-consumer glass containers. Furthermore, by creating a recycled content product that is locally manufactured, the residents of the town will likely be prone to donate feedstock in attempt to support their community efforts of a greener society. In addition, the residents are likely to take pride in the sustainable end product created and further contribute through the purchase of these products.

For example, you are likely to throw away a beverage bottle after a single use without thinking twice, but would you throw away your drinking glass after using it only one time? Creating a product such as a drinking glass from post-consumer glass attempts to change consumer's perception of the material. Consumers will be less likely to toss the bottle in the trash if they had access to a local manufacturer cleverly utilizing the material to make products that they will likely purchase in the near future. The opportunity also exists to spread awareness on the benefits of reusing waste materials rather than shipping them off, which is costly. The incentive for recycling in this situation is to revitalize the local industrial sector.

1.7.15 Wine Bottles

Considering the potential problems with incompatible glass types and contamination, an efficient way to utilize glass from the waste stream might be to focus on one type and color of glass. Therefore, it may be determined if color matching reveals plausible compatibility of containers.

A "wine boom" in Japan has caused the volume of empty wine bottles to increase sharply (Japan Echo Inco, para 4). Japan, as a result, experienced an accumulation of green wine bottles in its waste stream. Bottling collection companies faced many difficulties in disposing of the green bottles; therefore, it is not rare to see lots piled high with mountains of green bottles in Japan.

The greatest obstacle to recycling wine bottles in a centralized facility is their color. The materials used to give bottles a green color contain metallic elements such as manganese. If the bottles are converted into cullet and melted their color cannot be removed. Clear and brown bottles are widely used and therefore are easy to recycle.

Bottle collection companies are facing great difficulty in finding ways to dispose of green wine bottles throughout Japan (para 5).

Similarly, in the U.S., green glass is also particularly hard to market to bottling manufacturers. Hourihan of the Municipal Utilities Authority states that “there is more glass imported into the country than consumed in any furnace because basically we don’t bottle as much liquid into green bottles as we are importing it” (GIE Media, para 11) American beer manufacturers prefer brown or clear glass because green bottles are associated with imported beer (para 12). Red wine, however, which is rapidly gaining popularity, nearly always comes in green bottles because this color of glass affords it the best protection against the harmful effects of light and other factors.

U.S. wine consumption has been steadily climbing since 1991. The increase occurred after the CBS "60 Minutes" French Paradox broadcast and hundreds of other news media reported on the favorable health effects of moderate wine consumption. Also the popularity of the hit movie "Sideways" continued to lift the public's interest in wine, particularly in Pinot Noir from California. With the increase of red wine consumption and observing Japan’s struggles, we can assume that this will result in the increase of green glass wine bottles in our waste stream to be recovered. In effort to discourage the disposal of these valuable bottles, a market is needed to utilize the excess green glass.

The price for colored glass is lower than any other cullet as most glass bottle manufacturers will not accept colored glass (SWRC, 2003). The energy used for shipping glass is intensive. Locally mining green glass from the waste stream in the form of wine bottles will eliminate the excessive energy output of transporting a material with seemingly low value. Due to the difficulty associated with recycling green bottles, they are an attractive candidate for this thesis. Green bottles lend the possibility of having the same properties, yet they are unique in shape, yielding high potential for creative applications.

Examining the use of creative applications such as the techniques used by glass artists is an attempt to lower the amount of glass that is re-melted. Fewer re-melt applications will save an abundance of energy and prevent excessive greenhouse gas emissions.

Figure 7: Recycled Goblet

1.7.16 Products from Wine bottles

The idea of reclaiming bottle glass is gradually increasing in popularity. The Green Glass Company refers to themselves as the pioneers of the reclaimed glassware industry. According to their website, the company's origins date back to South Africa in 1992. Today, their products can be found in retail stores across the world as well as ordered directly from their website. The company's innovative process of transforming an entire wine bottle into a wine glass without producing any waste glass separates their products from all other recycled glass companies. The final result of this process is illustrated in Figure 7. The unique process is patent protected.

The Green Glass Company designs include tableware including cups, glasses, unique vases, candle holders, and even coat racks. These products sell for around $33 to $75 a piece. The affordable price tag invites anyone to incorporate green into their dining space. The unique Green Glass Company wine goblets were even featured on the Today Show on February 29, 2008.

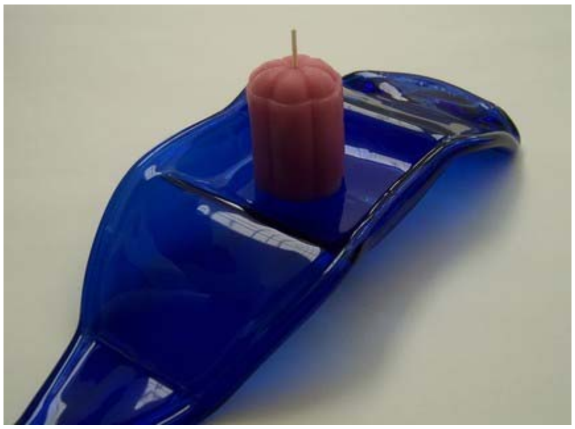
The Green Glass Company creates their unique products from specific types and shapes of bottles. The company is supplied these bottles from customer donations as well as through partnerships with wineries, restaurants, and bars that accumulate the bottle types they need. The Green Glass company actively seeks further partnerships that could deliver consistent bottle supply.

Another unique and popular tableware product is the flattened bottle platter created from post-consumer bottle glass. Olive Barn's Bottle platters were mentioned on the Rachael Ray TV show May 28, 2007. The bottle platter is intended as a versatile addition to the home and kitchen; therefore, each piece is packaged with a helpful booklet illustrating the many possible uses. Each platter takes over 8 hours to create. The bottle is placed directly onto the kiln shelf inside a kiln and slowly heated up to around 1400 degrees F. This process flattens the bottle. Once the bottle has reached the desired shape, it must go through the annealing process to prevent cracking. A wire placed onto the glass before it is melted acts as a hook once the tray has been formed. The hook can be used to attach a spreading knife to the cheese tray or to hang the platter on the wall for decoration. The basic bottle platter sells on Olive Barn's website for as low as $18. The more elegant platters, such as the deluxe label flat wine bottle platters, sell for $36 on the website. Many variations of this product have emerged, and the prices vary depending on the process required to create the product.

Figure 8: Gold mica dish

By placing the bottle in a mold inside the kiln rather than directly on the kiln shelf, the bottle can take on a more curved shape, extending its use as a dish for dipping sauce or salsa. The purpose of a mold is to control the shape of the bottle during the melting process and the final result is a bowl like dip rather than a flattened surface. The dish in Figure 8 was formed by placing gold mica into a recycled tall clear wine bottle and placing the bottle into a mold inside a glass production kiln. This product result is more delicate than other bottle platters because of the addition of gold mica; therefore, it absolutely must be washed by hand. This product is listed online at Etsy.com. However the item is listed as sold out and there is no further information listing the item's price.

Figure 9: Candle Bridge available on Etsy



The use of a mold in forming whole bottles yields the possibility of creating a variety of products for this thesis. The end result possibilities are limited only by the imagination of the artist. Figure 9 illustrates what happens when an artist forms a wine bottle over a candle bridge mold inside a kiln. This product, marketed as a candle holder, sells on Etsy.com for $10.95 plus shipping and handling. Additional uses for reclaimed bottles are constantly emerging as 'green' becomes a plausible addition to home décor. David Guilfoose, a reclaimed-glass designer, is responsible for the creation of the Green Wine Bottle series, a collection of functional sculptures made from reclaimed wine bottles. His degree in Advanced Psychology and interest in art made from found objects is what he claims inspired his unique collection. It is with the word 'green' that Guilfoose proclaims he celebrates ecological conservation as well as psychological inspiration towards balance and health (para 2). Each hand crafted piece is intended to inspire creative efforts towards living a greener life. The products created by Guilfoose include unique lamps, bells, candlesticks, and vases.

Figure 10: Bells by David Guilfoose

Figure 10 illustrates his creative transformation of bottles into bells. Featured on his website, these bells were created by removing the bottom portion of the wine bottles and integrating found materials.

Harvest Restaurant is recognized on the Green partners section of Guilfoose's website for supplying post-consumer bottles used to create his products. Though the detailed process of collecting and preserving the wine bottles is not described on the website, there seems to be a plausible explanation. Collecting the bottles intact from a partnership would require the responsible party to collect the bottles in a cardboard wine box for safe keeping. The wine box is equipped with cardboard separators to create compartments for the bottles and protect them during transport. These boxes are the same as those used for shipping wine to be sold at bars or restaurants and would be readily available for storing bottles. Incorporating various materials yields more flexible product applications. For example, one-of-a-kind pieces at Leelanau Garden Furniture in Michigan are created by hand bending and welding stainless steel and incorporating kiln-cast glass wine bottles as the glass table top surface.

Figure 11: Bistro Set from Leelanau Garden Furniture

The end result of this process is garden furniture. Figure 11 is a Bistro set from this company. The supply of wine bottles for this furniture comes from local wineries, therefore enticing many locals to purchase this green product from their own community. In addition, the products are available for ordering online.

It is evident an overall understanding of the tools and machines used in the cutting and melting process of glass is required for further product evaluation. The next chapter is a discussion of the glass forming techniques to be considered for experimentation in this thesis. The design process for a product line using post-consumer glass can be developed after the processes for forming and shaping the glass have been determined.

2. PROCESSES FOR POST CONSUMER GLASS

2.1 Introduction to Cold Working Glass

In reference to glass art techniques, there are cold shop techniques and hot shop techniques. Cold working glass in this thesis will refer to methods of working with glass in its frozen state. Processes such as cutting, drilling, grinding, and sanding will be addressed in this section. The most basic glass forming technique that can be applied to using post-consumer glass bottles is cutting. There are various methods that can be applied to glass bottle cutting. Each, however, will yield a slightly different result. For example, when searching for ways to cut a glass bottle you may discover methods using a hot wire or burning string. These techniques tend to leave burn marks on the glass which cannot be removed. Therefore this thesis will exclude such experimentation as the burning string.

It is not a new idea to cut a glass bottle; artists have been transforming cut bottles into drinking glasses for years. Therefore, it is the methods chosen by previous artists that will prove beneficial to this thesis. Wine bottles are ideal for experimentation because they are thick and therefore likely to stand up to the vibrations of a power saw, whereas other bottles (beer bottles in particular) are very thin and more likely to break. After cutting glass, grinding techniques are performed to remove additional material and even out the edges. Grinding is done using several basic tools: flat wheel grinders, belt grinders, and buffing wheels. Rotary or oscillating laps may be used in some cases as well as vertical grinding wheels. The most important notion to understand is that all processes for cold working glass must be preformed wet.

The purpose of using water is to remove the glass fragments and to keep the glass cool so that it does not crack from stress due to local heating. Tools for cold working glass incorporate industrial diamonds due to the hardness of the material.

2.2 Industrial Diamonds

According to the *Encyclopedia Britannica,* "a diamond is a mineral composed of pure carbon; it is the hardest naturally occurring substance known. Because of their extreme hardness diamonds have a number of important industrial applications (diamond, ln 1-3)." The dominant industrial use of diamond is in cutting, drilling and abrasives for grinding and polishing. The diamonds used in these industrial applications are not the same as the diamonds sold in a jewelry store. Industrial diamonds are too badly flawed to be of value as gems. According to *Encyclopedia Britannica*, three varieties of industrial diamonds exist: ballas, bort, and carbonado (Industrial diamonds, 2009). The first material, ballas, also called short bort, is extremely hard, and difficult to cut. The next material, bort, is described in the encyclopedia as "a gray to black massive diamond the color of which is caused by inclusions and impurities (ln 11)." Bort is used in diamond drill bits; it is composed of small round stones, averaging 20 to the carat, and called drilling bort. Crushing bort is the lowest grade of diamond, 75% of which comes from Congo. The chief purpose for crushing bort is in manufacturing of grinding wheels.

Carbonado is black opaque diamond with applications including saws for cutting rock and other hard materials, lathes and other types of cutting tools and glass cutters (industrial diamond, 2009). Because of their hardness, diamond based material will be necessary in cold working glass experiments such as cutting glass and finishing the edges.

2.3 Overview: Cold working tools

A wine bottle can be transformed into various products such as drinking glasses, vases or even bracelets by simply using the right tools and properly treating the edges. The most basic tool for cutting glass is a diamond blade glass cutter. This tool is often used by stained glass artists to score flat glass. A glass cutter can be purchased at a local craft store for under $10. It is important to understand that a glass cutter does not cut glass; it scores glass along a line of molecules allowing the glass to break in a preferred place (Glass Fusing Made Easy, 2007-09). It is possible to use this tool to cut wine bottles; however, the resulting cut is determined by a steady hand and good score line. Therefore, when attempting this method, a single score line should be produced without ever lifting the glass cutter. When using a glass cutter to score a bottle, masking tape or a rubber band should be used as a guide as opposed to free handing the score line. After a good score is made, the glass must be tapped to initiate the break. The tapping must be done opposite the score; therefore, using a long rod, one should tap the glass from the inside of the bottle. If the glass will not break, another option is to induce thermal shock. This can be done by quickly changing the temperature of the glass, causing stress in the bottle. The score line is the weakest part of the bottle, and therefore thermal shock will induce the breaking. To induce thermal shock, fill the bottle with the hottest tap water possible. Let it sit for a few seconds to soak up the heat from the water inside, then submerge the bottle into a bucket of ice water. You will hear the bottle crack, confirming that the process is complete. Because this process relies on a good score line, the results are often inconsistent and require a considerable amount of additional grinding and sanding.

Certain industrial power saws have the ability to cut through glass and other hard materials just like a table saw cuts wood. These saws use a diamond blade in order to penetrate the hard material. These saws also incorporate water, which soaks and cools the blade as it cuts. Online glass suppliers and some hobby stores offer specialized saws for cutting art glass; however, these saws are often very expensive. One relatively inexpensive product available that will cut through glass is a wet tile saw. This type of saw is intended for cutting ceramic tile, granite, marble, and other stone products including glass tile and therefore is a desired method of cutting for this thesis. To keep the blade wet while cutting, the saw combines a circular blade with water pump and hose that constantly drenches the cutting area with water; therefore be prepared to get wet as the water will likely spray due to the spinning motion of the blade. A wet tile saw is available at any local hardware store in variable sizes. Lowe's offers a 7" QEP wet tile saw for around $80 including the diamond blade. The 7" wet tile saw doesn't have a large enough blade to cut all the way through the material; therefore, the process of cutting bottles involves rolling the bottle against the blade in order to achieve a complete cut. This method does not require excessive force such as pushing the bottle against the blade. Simply hold the bottle firmly while rolling it in the direction of the blade, and allow the saw to do the work. Once this process is completed, the edge of the diamond blade can be used to grind uneven cuts. Then additional sanding of the edges should be done to ensure a safe product such as a bracelet or drinking glass.

Another option for sawing through a glass bottle is to use a larger tile saw such as the 2HP Professional tile saw as shown in Figure 12.

Figure 12: Cutting with a wet tile saw

This saw incorporates a sliding cutting surface for the material being cut. The larger blade will cut through the entire bottle. The bottle is placed on the sliding surface and pushed through the saw. Consequently, this method enables the user to easily create a clean and even cut as opposed to rolling the bottle into the blade. If desired, a wet tile saw is also useful for cutting bottles vertically into strips. Before doing this, the bottle neck and bottle bottom should be removed. The bottle is then placed vertically on the cutting surface and pushed through the saw. The first cut will yield two beveled bottle halves. The halves can then be cut in half again and into smaller strips. Cutting the bottles into strips enables the use of glass nippers. This is a tool used by stained glass artists to resize and shape pieces of glass. The tool is held in the hand like a pair of pliers and the glass is placed between the two cutting wheels. This tool removes small fragments of glass and can be used to create a variety of shapes such as triangles, rectangles, squares and circles.

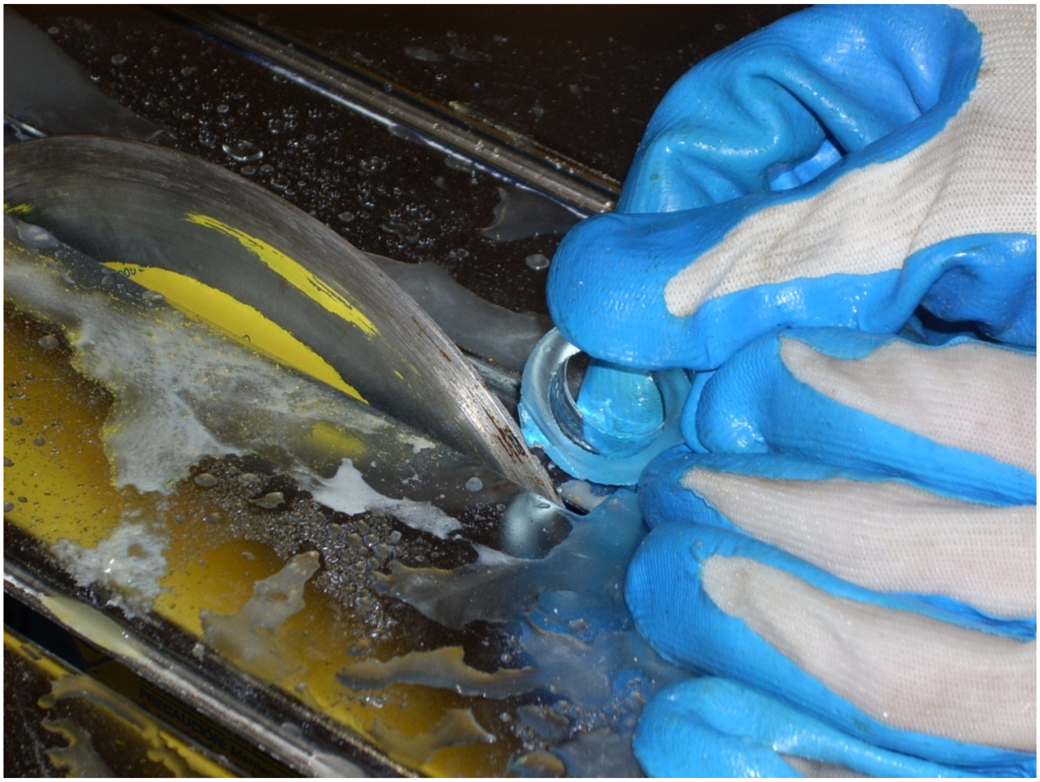
Angled cuts can also be made by using this saw; however, the blade is stationary so the bottle must be placed on an angle to achieve this cut. Holding the bottle in an angled position is difficult; therefore, the addition of a jig is necessary and will enable cuts to be repeated. A jig can be made by simply cutting a block of wood to the desired angle and placed on the sliding surface. Press the bottle against the jig to keep it at a constant angle. Then simply turn on the saw and slide the cutting surface slowly through the blade until it cuts all the way through the bottle.

Figure 13: Cutting angles

After cutting glass, it is important to treat the edges. Edge treatment may be done using a specialized sanding block on the edges, such as the diamond glass sanding block available online in 220 grit for $35.63. Wet or dry sand paper may also be used for edge treatment and is much less expensive, costing less than $1 per sheet. Another option for sanding glass that is less time consuming is to use a belt sander to achieve an even flat edge. Water must be incorporated during the sanding process to avoid localized heating in the glass. Specialized wet belt sanders are available from glass suppliers and specialty tool companies for around $380. If you already have access to a belt sander, glass sanding belts may be purchased for an ordinary sander; however, the glass must be constantly dipped in water.

Sanding should be used to attain even edges, not for the additional removal of material. If the cut glass is uneven and additional material needs to be removed, grinding should take place prior to sanding. This process consists of grinding the edge of the glass until it has the shape and smoothness you desire. Specialty tools such as grinders specifically for glass can be found online through glass suppliers as well as some hobby stores. Glass grinders incorporate water much like the wet tile saw and wet belt sander in order to reduce friction. The use of a glass grinding tool will also speed up the finishing process. As previously stated, any method of cold working glass should incorporate water in order to reduce friction. Grinders for glass use diamond wheels made of sharp, blocky industrial grade diamonds bonded to a metal surface. Hobby Lobby offers a Power Max Grinder for $129.99. Other versions of this saw are also available online and are priced about the same. The purpose of grinding is to remove sharp edges and excess material before sanding to create an attractive and safe end product. It is also possible to use the 7” tile saw for some grinding applications. This is done by holding the glass firmly and using the edge of the blade to remove material as demonstrated in Figure 14.

Figure 14: Grinding the edges



2.4 Introduction to warm glass

Warm glass techniques are those that take place between 1100 and1700 degrees Fahrenheit. These techniques are accomplished using a specialized heating oven called a kiln. For this reason, warm glass techniques are also referred to as kiln forming techniques. A kiln is necessary to increase the temperature of the glass evenly to avoid thermal shock. At extreme temperatures, the glass will become so soft that it can easily free flow and take a new shape or form. Artists sometimes use molds to control the form. Another technique is to allow the glass to melt directly on the kiln shelf. Warm glass techniques addressed in this section are fire polishing, slumping, and fusing. Table 2 illustrates the temperatures for the above techniques.

Table 2: Temperatures for warm glass

Process	Definition	Fahrenheit
Full Fusing	joining 2 or more pieces of glass by heating them as they flow together	1450-1550
Tack Fusing	fusing until the glass just sticks together; each piece retaining its character	1350-1450
Slumping	shaping glass by bending it over/into a mold	1200-1300
Fire Polishing	heating glass just enough to round the edges and give it a shiny appearance	1300-1400
Kiln casting	fusing small pieces of glass (frit) inside a mold	1500-1600

2.4.1 Annealing Range

Glass expands and softens as it is heated up. The outside of the glass actually heats up faster than the inside of the glass; for this reason, the glass needs to be heated at a slow enough rate for the inside temperature to catch up to the outside temperature. On the other hand, as glass cools the inside does not cool off as fast as the outside, which means the inside is still expanding as the outside becomes stiff and begins to contract. This expansion and contraction can result in internally built up stress, eventually causing the glass to break. In order to relieve the stress building up inside the glass, a soak period is implemented into the firing schedule. Soaking refers to holding the temperature steady to allow the inside of the glass to reach the same temperature as the outside. Soaking should be done as the glass enters the point at which it begins to strain, the temperature between 900 and1050 degrees Fahrenheit. Annealing refers to slowly dropping the temperature to relieve stress during the cooling process. Large pieces of glass as well as thick glass will need to be given a longer annealing period. Soaking occurs in the firing process during the initial heating phase as the glass enters the strain point, then again at the process temperature to avoid uneven heating, and finally in the cooling phase to relieve stress.

2.4.2 Fusing:

According to the Glass Fusing Made Easy website, full fuse refers to heating two or more pieces of glass in a kiln until the pieces melt together to form one solid piece of glass. This process usually occurs around 1450 to 1550 Fahrenheit. Tack fusing, on the other hand, is when two or more pieces of glass are heated until the pieces start to melt together. Tack fused pieces look as if they had been glued together. In other words, each piece maintains its original shape and texture. Tack fusing occurs between 1350 and 1450 Fahrenheit (Glass Fusing section, 2007).

Like many other substances, glass expands when it gets hot and contracts when it cools. This change in density, which occurs at the molecular level, can be measured in a laboratory. The rate at which the glass expands is called the Coefficient of Expansion (COE). When working with fuseable art glass it is important that the glasses being fused have the same COE. Therefore, suppliers of such art glass list the COE on the label to avoid accidental mishaps due to incompatible glass. Post-consumer bottle glass has an undetermined COE due to the additions of chemicals at manufacturing plants. Parts of the same bottle can be cut and fused back together, but it is unclear if mixing glass from different bottles will cause the glass to crack due to incompatibility.

If cracking occurs as a result of fusing glass from different bottles, then the glass can be deemed incompatible. According to Brad Walker, author of the book *Warm Glass*, it is also possible to conduct tests to determine glass compatibility. These tests consist of fusing small pieces of glass with an unknown COE to a base glass with a known COE. Once fused, the glass is examined between two strips of polarized film (Walker, 1999-2006). Viewing incompatible glass under polarized film will result in a halo around the edges. The halo indicates stress inside the glass and the tested glass can be deemed incompatible.

2.4.3 Fire Polishing:

Fire polishing is the technique of placing glass items into a kiln and heating it just enough to round the edges, achieving a smooth polished appearance. This technique is often used for rounding the edges of a previously fused glass piece; therefore, the glass tends to be thicker. Because the glass is thicker, it must be heated up at a slower rate. Preparing the piece prior to fire polishing involves grinding the edges to be sure they are even. When doing this, place the finished parts in a container of water to preserve moisture on the edges. If the grit from the grinding action is left to dry out on the edges of the glass, it will be difficult to get rid of. Alcohol may also be used for cleaning the glass prior to firing. After drying the piece, it is placed in the kiln on fiber paper or on a kiln washed shelf for fire polishing (Glass Fusing Made Easy, 2007). Fiber paper or kiln wash is necessary because glass tends to stick to many surfaces when it gets hot. Therefore, kiln shelves can be protected either by applying a primer, or kiln wash, to the top of the shelf or by placing a sheet of specially made fiber paper between the shelf and the glass.

According to the Glass Fusing Made Easy (GFME) website, the temperature necessary for fire polishing typically ranges from 1300 F to 1400 F. At the polishing temperature, glass begins to move and it is possible to distort the edges of the glass if fired too long. Therefore, it is suggested to stay at the polishing temperature for only a short time; between 5 and 20 minutes and only fire polish flat pieces prior to slumping. The firing schedule in Chart 2 is offered on the website Glass Fusing Made Easy. This firing schedule illustrates the suggested rate at which the temperature should increase to avoid internal stress. The process temperature in this schedule reflects that of the technique previously referred to fire polishing.

Table 3: Firing schedule

Starting Temperature	Ending Temperature	Rate in Degrees/hour	Minutes Soaked
0	1000 F	400 F/hr	20
1000 F	1300 F	as fast as possible	5
1300 F	950 F	400 F/hr	60
950 F	100 F	300 F/hr	Turn off the kiln

Notice how the schedule suggests a 20 minute soak when the temperature reaches 1000 degrees in the initial heating phase. Another long soak occurs after the glass has reached the process temperature and the cooling phase begins.

2.4.4 Slumping

Slumping refers to a warm glass technique that involves forming glass into or over a mold. The temperature at which slumping occurs is very close to the temperature of fire polishing: around 1300 degrees. If desired, slumping can occur directly on the kiln shelf; again a special kiln wash or fiber paper is necessary to avoid sticking. Slumping can also be achieved over a form or mold to provide a third dimension. The process of slumping involves gradually heating up the glass based on a firing schedule similar to the one in Table 2. However, slumping would require a longer soak period at the process temperature in order for the glass to take on the shape of a mold.

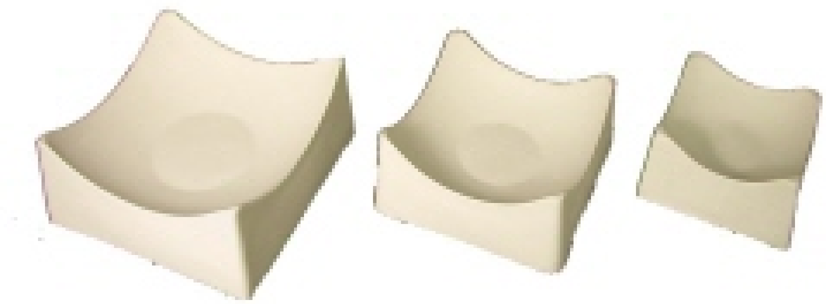
The suppliers of art glass such as Bullseye and Spectrum offer suggested firing schedules for warm glass techniques. The schedules are based on the size of the glass pieces, the thickness, and the COE of the glass being used. Once the glass has reached the process temperature for slumping, the glass must soak at that temperature. According to the GFME website, “longer soaking times cause the glass to flatten out and take on the shape of the mold” (Step 2, ln 1). Cooling the glass is also very important for warm glass techniques. According to GFME, “some people cool off the glass rapidly by opening the lid and allowing the temperature to drop to about 1100 degrees Fahrenheit, while others just turn off the kiln and allow the piece to cool down on its own” (Step 3, ln 2). Cooling the glass rapidly is a technique to help prevent devitrification. The process of opening the kiln lid for a few seconds to achieve rapid cooling is known as flash venting. An annealing soak is still necessary after flash venting to prevent internal stress from building up in the glass

2.5 Introduction to Molds:

The use of a mold allows glass to take on a third dimension. Molds are frequently used for glass slumping and shaping in the kiln as well as glass fusing and casting. They can be made of materials as diverse as stainless steel, pottery clay, and plaster/silica mixtures. Even certain ‘found’ objects will work as molds, for example, an auto hubcap or terra cotta pot. Any material that can withstand the heat of the kiln is acceptable. In a phone conversation with an artist from Blue Skies Glassworks, Michael Tonder, he suggested using a stainless steel bowl covered in kiln wash as a form. However, it should be understood that steel contracts more than glass. Therefore, slumping on the outside of a stainless steel form often works better than slumping on the inside. Slumping different colors of glass over a mold must be done in a two part process. First the glass must be fused together. Then the fused glass is placed over a prepared mold and fired again.

Commercial molds for commonly slumped forms such as bowls and plates are available online from glass supplier stores and ceramic suppliers. The slumping molds in Figure 15 are available at American Glass Supply.com. The smallest size in the figure is a 6” square mold priced at $21, the next size is 8” priced at $32, and the larger mold is 10” priced at $40.

Figure 15: Slumping molds



Molds can also be custom made using different methods and materials. A slumping mold can be formed out of clay and fired in a kiln. In order to create smooth shapes and surfaces, it may be necessary to sand the clay prior to firing. Pottery plaster, which is made of gypsum, is often used for casting molds; however, the plaster alone cannot withstand kiln temperatures. Therefore, a refractory material must be added (Walker, 1999). According to Walker, author of *Contemporary Warm Glass*, the traditional mold material used for kiln casting is 50/50 mixture of plaster and ground silica. Molds can also be made using a ratio of two parts plaster to one part silica (Walker, 1999). Walker states on his website *warmglass.com* that “Despite their usefulness, making plaster/silica molds is not as simple as making other types of molds. Proper mixing requires practice and specific safety procedures must be followed” (Walker, 1999). Commercial mixtures for refractory molds are available through glass and ceramics suppliers. For example, Mold Mix 6 is a refractory preparation that comes with mixing and pouring instructions. However, this material will not hold up through multiple firings. On the other hand, Castalot glass mold material is a fast setting, mold material for glass slumping, fusing or kiln casting applications that may be fired multiple times. According to their website, this material is capable of slumping at least 50 pieces from the same mold (Sunset Grove LLC, 2006). Therefore Castalot mold mix is suitable for producing a large quantity of products from a single, custom designed mold.

2.5.1 Mold Making Process

The process of making a casting mold begins by forming a clay model of the object you desire to create in glass. The clay model should be a form which can be easily removed from the mold. Suitable forms are broad-based and thick-walled with no undercuts. The next step is to create a negative cavity of the clay model; to do this prepare a cardboard box about 1 to 2 inches larger than the model on all sides and affix the model to the bottom of the mold box. The refractory mold material, also called the investment, will then be mixed and added to the mold box. When mixing the investment Walker suggests using a very clean container so as to not contaminate the mixture or cause it to set up more quickly than desired. He also instructs readers to mix the dry ingredients first and then add them gradually to the water (not the water to the dry ingredients).   If the ingredients are measured correctly the investment should “peak” just as the last of the dry ingredients are added to the mixture. Peaking occurs when the mixture sinks slowly and dry investment islands appear in the container. At this point give the mixture a final stir and let it sit undisturbed for five minutes. This process, called “slacking”, helps ensure that the investment particles become saturated with water (Walker, 1999). After allowing the investment to slack, Walker says to slowly pour it into the box that surrounds the clay model. Air bubbles should be removed by tapping the box. After the mixture has air dried, the clay model can be removed, leaving a cavity in the hardened investment. This cavity is the final mold that will be used for kiln forming.

2.5.2 Measuring Glass

Glass frit refers to tiny pieces of glass that fill the cavity of a mold. A simple technique for measuring glass frit is known as the displacement method. This technique is described by David Reekie in his article "Mold Making and Glass Casting Methods," which is published online by Glass Australia- Australian National University School of Art. This method requires water and a container large enough to fit the model. According to Reekie, "when using clay, do this before the model is made or after the clay has been removed from the mold" (pg 4, ln 7). To begin the process, fill the container with water. Next, completely submerge the clay model and mark the water level as a reference. Then remove the model and place glass into the container until the water level reaches the reference mark. Reekie uses large chunks of glass for this method, then weighs them and uses the equivalent weight in smaller particles for the actual cast (2006). Prior to casting the measured glass, a release agent can be added to the mold to facilitate easy removal of the glass after casting.

2.5.3 Lost Wax Casting Technique

Another technique, known as the 'lost wax technique', is used to cast complex shapes. This is a more advanced technique that enables the formation of a hollow core vessel or a sculpture with major undercuts. The lost wax casting method begins by creating an intricate wax model, then investing that model into a mold, and finally melting the wax out of the mold to form a cavity into which a replica can be cast from the desired material.

Lost wax casting of metal is popular because “It permits anything that can be modeled in wax to be faithfully transmuted into metal, and is still used today for certain industrial parts, dental restorations, fine jewelry, and sculpture,” says Andrew Werby, founder of United Artworks and expert on sculptural techniques (Lost Wax Bronze Casting, ln 4). Wax patterns were originally modeled by hand for this method. However, it is now possible to cast wax into molds as well. Synthetic rubbers capture fine detail and even can flex to undercut areas of the model. The use of a rubber mold is critical for the production of wax replicas because the wax model is lost during this process. According to Werby, wax can be cast either solid or hollow; the wax will coat the inside of the mold as it is filled and poured out. This process is repeated to build up the wax to the desired thickness. Once the wax model has been made it is treated much like the clay model in the previous molding processes. The wax is placed in a cardboard box, secured, and then the investment is poured over the model. Once the investment dries, the wax is melted out leaving behind a cavity.

According to glass artist Jamie Mckay of The Striking Art Studio, after removing the wax, glass can be cast into the molded cavity. This is done using a crucible with a hole in the bottom. The crucible is filled with glass frit and suspended over the top of the mold (2006). The amount of glass needed can also be determined by the displacement method. Simply submerge the wax model in the water, mark the level, and then fill the container with glass until the water level reaches the previous mark.   During the high temperature portion of firing, the glass will melt and pour into the molded cavity from the hole in the bottom of the crucible. Once the firing is completed, the plaster model is destroyed to remove the final glass product. For this reason the rubber mold previously mentioned is needed to reproduce the original wax figure and create multiple replicas of the design.

3. PRODUCT DEVELOPMENT

3.1 Bottle Collection

The collection of feedstock in the form of glass bottles should be accumulated through a reliable sourcing partnership. This partnership is necessary to ensure that a quality supply of glass is always available. To establish a partnership, make contacts with local bars and restaurants that serve wine and liquor. Collect only whole bottles from this partnership to avoid commingled feedstock. Clarify with the manager how often the bottles will be picked up. A large workshop is necessary to store the collected glass and to cut and kiln form the glass into products. Establish a location for a workshop prior to the establishment of a sourcing partnership.

For this thesis, a partnership was established with a local restaurant and bar called In Italy. Bottles were accumulated in a wine box and collected at the end of each week in preparation for kiln forming. Bottle preparation involves thoroughly cleaning the inside and outside of the bottle and removing the labels. To clean and remove the labels, place the bottles in warm soapy water. Allow the bottles to soak for ten minutes in order to loosen the glue that attaches the labels. Then, using an abrasive sponge, wipe away the labels. In some cases the label will leave behind a residue of glue. This occurrence is likely due to not soaking the bottles long enough or not soaking them in hot enough water. To remove stubborn residue in this case, a degreasing agent such as Goo-gone works well. Also be sure to remove any foil wrapping or plastic from around the exterior of the bottle.

3.2 Brainstorming

Possibilities for manipulating glass for this thesis have been determined through preliminary research outlined in the previous chapter. Glass bottles can be cut, sanded, smashed, broken into fine particles, and kiln formed. A variety of techniques may be used to generate products for this thesis.

Developing concepts for product opportunities is an essential process for this thesis. This process should begin with basic ideation such as a bubble map. The purpose of the bubble map is to begin brainstorming all possibilities for products. The more possible options accumulated through a bubble map, the better the chance an original product concept can be developed.

Figure 16.1: Brainstorming map

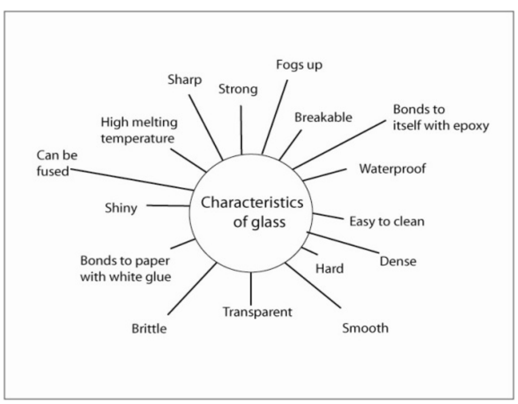
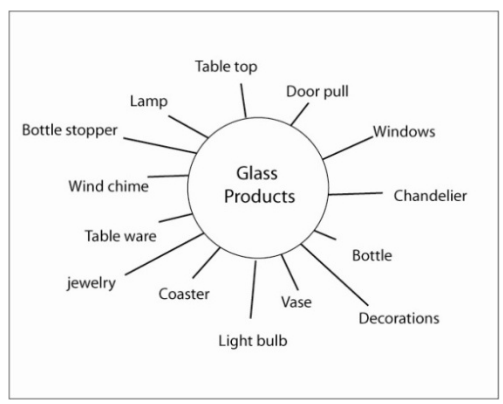


Figure 16.2 Brainstorming map

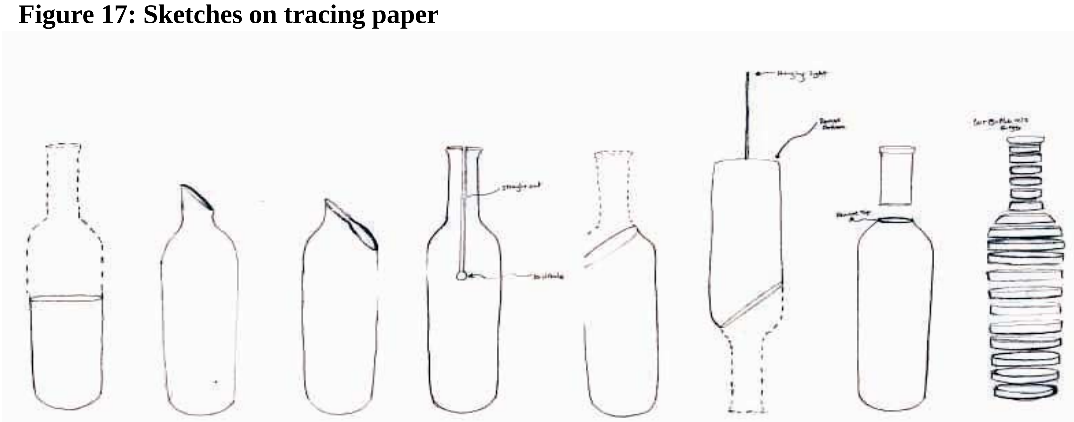


The first brainstorming bubble map in figure 16.1 branches out to identify the characteristics of glass. This process will aid in the development of product possibilities associated with these characteristics. For example, glass is transparent. This characteristic allows for transmission of light. Next, consider all the possible products that come to mind that could be transparent. Another option is to create a bubble map that lists products on the market that are currently made from glass. This map will aid in the accumulation of practical product applications for post-consumer glass. When the bubble map is completed, it will offer a variety of options to consider during the sketching phase of product development.

When developing a product map, write down everything that comes to mind without filtering any ideas. All of the ideas are necessary during this process to create a list from which product ideas can be developed.

The next step in idea generation is to begin drawing. This process is necessary to accumulate various shapes that can be achieved by cutting the bottle in different places. First, take a picture of a wine bottle, print it out and trace it onto a long sheet of tracing paper.

Figure 17: Sketches on tracing paper



It is best to use the tracing paper that comes in a roll as to keep all the idea sketches together. The benefit of keeping sketches in the same place is that new ideas will stem from variations of the first ideas. After the wine bottle has been traced onto the paper, begin drawing lines where a cut could be made. This will help visualize the product possibilities and to assign shapes for the various products developed in the bubble map.

3.3 Using Entire bottle

The collection of post consumer glass obligates the recipient to use the feedstock efficiently without creating glass waste. During the drawing process, take note of the glass that is subtracted from the bottle. For products in this thesis, no glass will be wasted. Each part of the bottle will be strategically cut to yield a specific jewelry design to be kiln formed. Figure 18 illustrates the pendants that will be created from each part of the bottle.

Figure 18: Using the entire bottle

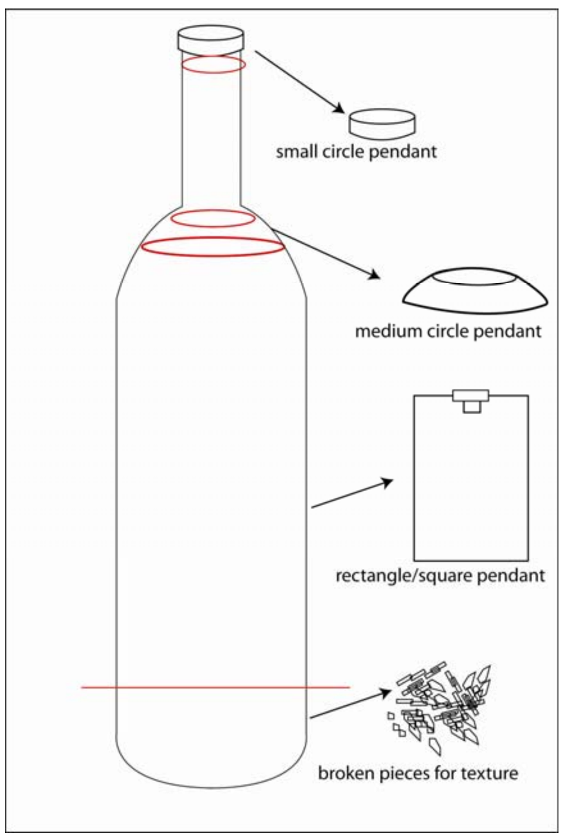
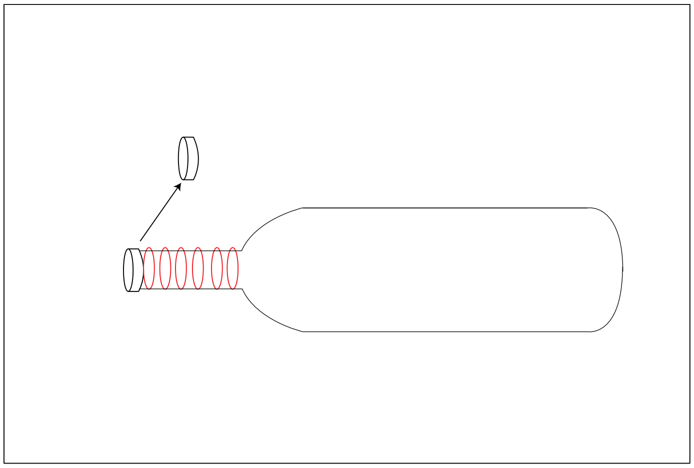
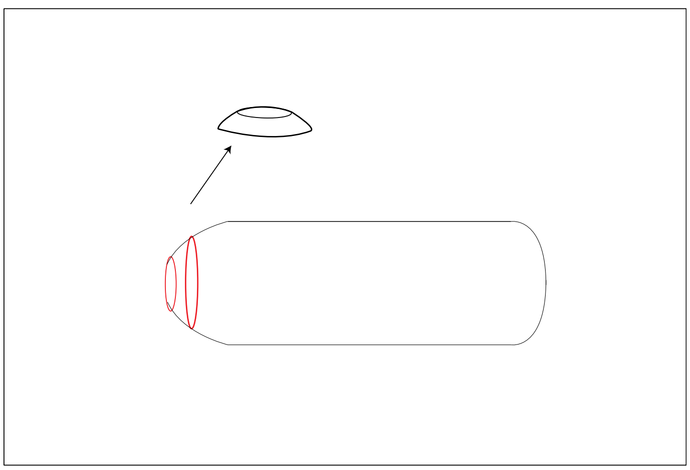


Figure 19: Small circle pendants



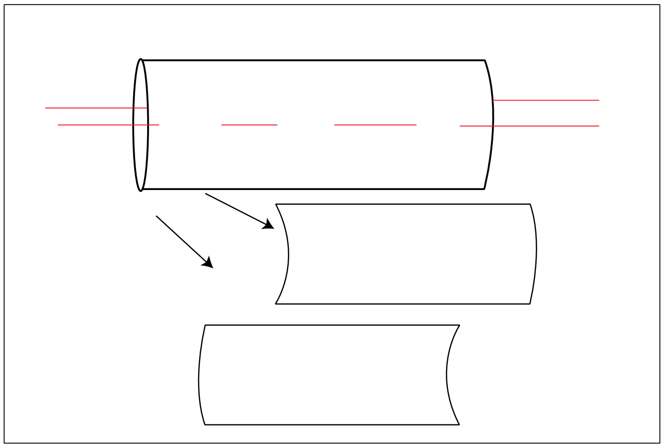
The top portion of the bottle will be cut into rings and used to create small circular pendants for necklaces and earrings. Figure 19 illustrates this process. Start with a whole bottle. Then cut the bottle neck into 1/4 rings until the point at which the bottle widens.

Figure 20: Medium circle pendants



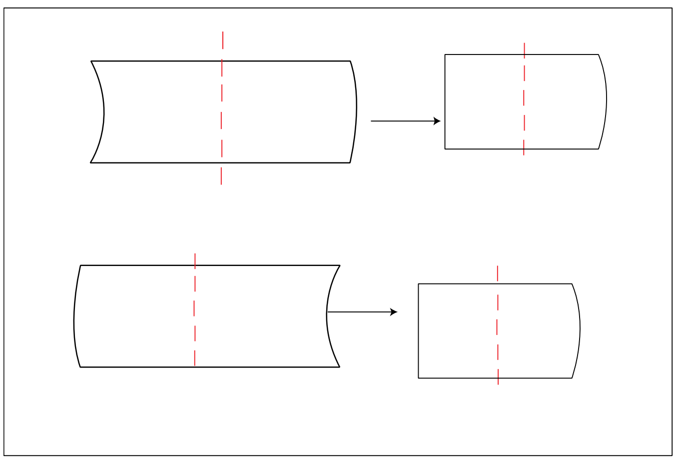
To create medium circular pendants, cut the bottle where the neck widens. The ring will have a beveled appearance when it is freshly cut, but the pendant will flatten out inside the kiln. Each bottle will yield approximately two medium circle pendants. Rings cut from the remaining portion of the will be too large to wear as jewelry. Therefore this portion of the bottle will be cut into vertical strips to make different shaped flat pendants as illustrated in Figure 21.

Figure 21: Cutting vertical strips



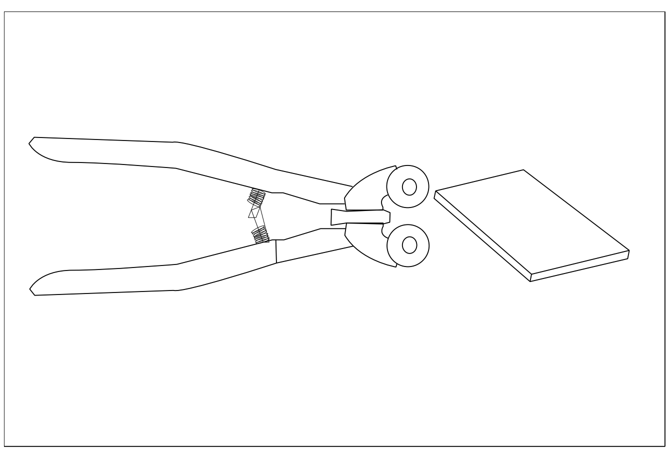
The top portion of the bottle has already been removed for creating small and medium size circle pendants. Now cut off the bottom portion of the bottle. Then cut the bottle in half vertically.

Figure 22: Sizing pieces



Continue cutting the bottle halves down to the approximate size of the pendants desired as shown in Figure 22.

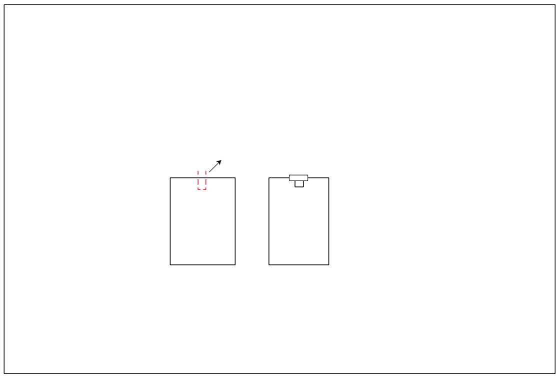
Figure 23: Shaping glass with nippers



Using glass nippers shape the pendant into a triangle, circle, rectangle or square.

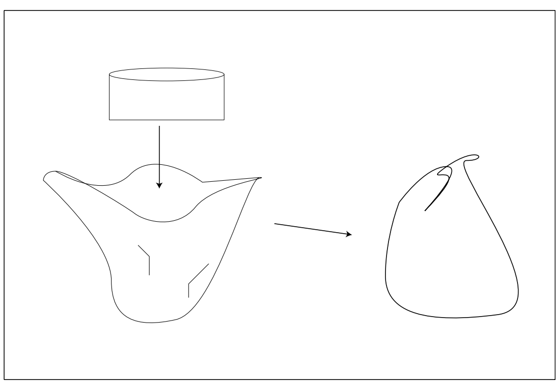
Unlike the circular pendants which have no middle, the shapes accumulated in above processes do not have a way to be hung for jewelry applications. Figure 24 illustrates the process for making a hole to hang these pieces on a chain.

Figure 24: Creating a hole



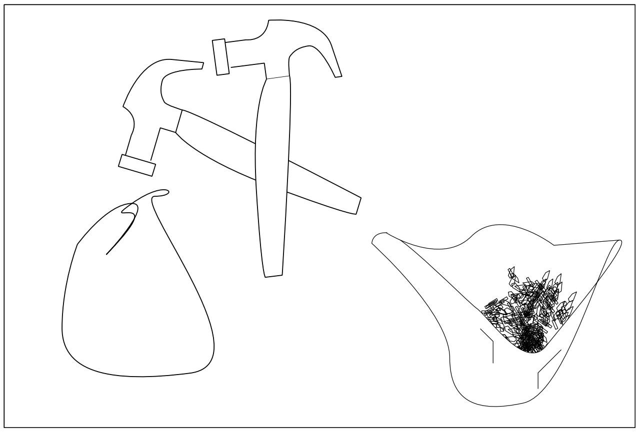
To create a hole, cut partially into the top center portion of the pendant to cut a notch. Then cut a small strip of glass, no more than 1/8” wide. Place this piece over the top portion of the slit and place in the kiln on prepared shelves. The glass will fuse together inside the kiln, creating an elegant pendant for hanging.

Figure 25: Using scrap glass



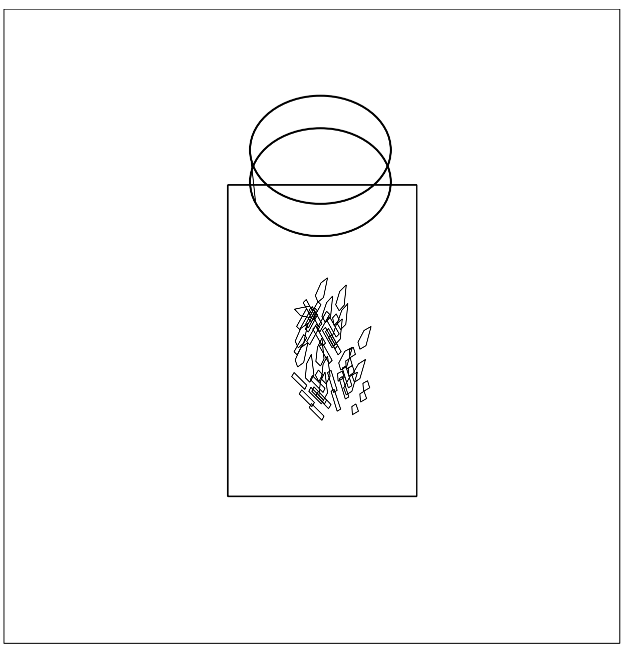
The bottle bottom and any other scrap glass accumulated can be crushed and used to make a textured pendant. To make a textured pendant place the bottle bottom and any excess glass in a plastic bag and close the bag tightly.

Figure 26: Breaking glass into pieces



Then, using a hammer, break the glass into small pieces.

Figure 27: Layered glass



Layer the broken pieces on top of each other or on top of another pendant design. To add sparkle, texture and color, sprinkle the tiny broken pieces onto any design using a spoon.

3.4 Choosing a kiln

There are different types of kilns available for purchase. Some are specifically tailored to fire ceramics, and others are intended for the use of glass. The difference between a glass kiln and a ceramic kiln is the placement of the heating elements. The elements of a ceramic kiln are mounted in the side walls to surround and evenly heat several layers of pottery from the side. The elements of a glass kiln are mounted in the top to ensure even heating of glass. Ceramic kilns also tend to get much hotter than glass kilns due to the higher process temperature needed in ceramics. For the creation of glass products in this thesis, the temperature reached will be no higher than 1400 degrees F. Therefore the use of either type of kiln is acceptable.

Before choosing a kiln there are a few considerations that should be addressed. Kilns are available in manual or automatic. A manual kiln requires the user to manually turn up the kiln heat during the firing cycle using zone switches. The task of using this type of kiln is the necessity of being present during the firing session, which will last several hours. A kiln sitter is a product available to automatically shut off the kiln when the appropriate amount of heat work has been completed. A kiln sitter works using a pyrometric cone. These cones bend when the kiln reaches their processing temperature. When the cones inside a kiln sitter bend, they trigger an arm to release a weighted trigger to turn off the kiln. A common problem due to improper adjustment of the kiln sitter's trigger and claw assembly is consistently over-fired or consistently under fired pieces. Even with the addition of a kiln sitter, it is necessary to be present during the firing process.

An automatic kiln allows a bit more freedom. This type of kiln comes with a specialized controller in which to program your desired firing schedule. These kilns cost more than manual kilns; however, they require less attention because they automatically adjust the kiln temperature according to the firing schedule entered.

Automatic and manual kilns are available in many different sizes. If the kiln you choose is too small, you will be constantly firing. When choosing an appropriate size, make sure that the kiln will be large enough for the quantity of work you intend to produce over a few days and that it will fit the largest piece you intend to fire.

When choosing a kiln there is also the option of a front loading or top loading kiln. The main positive point for top loading kilns is that they tend to be cheaper. However, top loading kilns require stacking and balancing shelves on kiln furniture, which means they are more awkward to pack. Top loading kilns may prove suitable for a hobby ceramicist or as a test kiln, but in the long run the front loading kilns are likely a better investment because they tend to last longer than top loaders and they are easier to load.

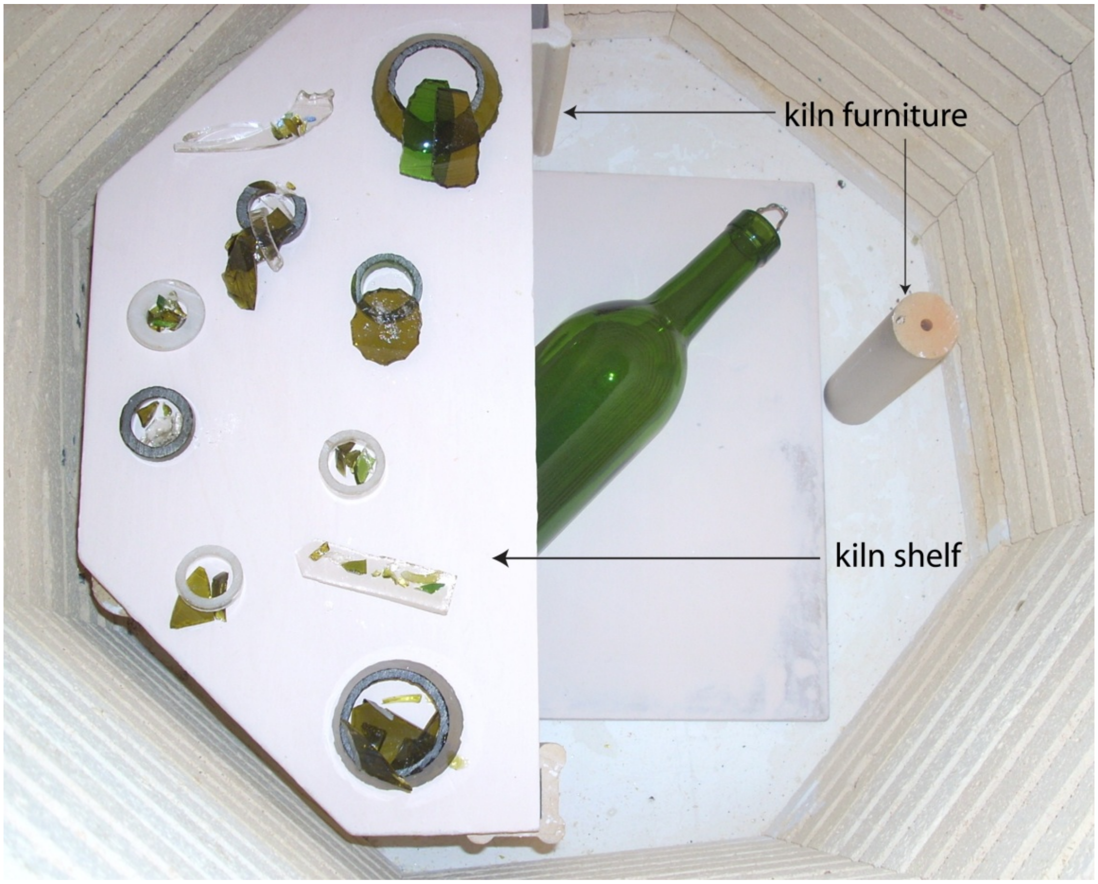
Before installing a kiln in your home or studio, talk to an electrician about your available power supply. While there are some kilns on the market that can be plugged directly into your wall and will work off 120 volts of power, others require an electrician to hardwire the kiln into the wall. Do not attempt to install a kiln without the proper advisement from an electrician.

3.5 Planning for Kiln Forming

Gravity is a natural phenomenon that should be taken into consideration when planning the arrangement of glass in the kiln prior to firing. The cutting of whole bottles results in glass pieces that retain a beveled surface. When placed inside the kiln, these pieces will flatten out and lose many of their original characteristics. The final glass product without the use of a mold is determined by the shape of the base. For example, if you fire a 1” thick ring directly on the kiln shelf, it will flatten out to a ¼” thick ring with a smaller diameter. This is a result of the glass melting to the inside of the ring and reforming on the kiln shelf bottom. Techniques such as layering glass or even forming glass over a mold are options to obtain glass with a third dimension and texture.

The firing process takes several hours and therefore requires special planning in order to maximize the number of products created from each firing. Glass should be designed and arranged accordingly on prepared kiln shelves prior to the firing date. Sketching concepts prior to kiln forming will aid in planning final products. Begin by sketching out the possible shapes that can be cut from accumulated scrap glass. For example, a bottle can be cut into strips, and the strips can be further cut into rectangles, squares, triangles, and even circles. Glass nippers are a handy tool that may be used to shape glass by hand into circles. Once the shapes are cut out, arrange them on the kiln shelves. Keep in mind when designing pieces that a hole may be necessary to hang the glass after firing. It is possible to drill a hole in the glass after firing; however, it is a tedious process and there is a risk of breaking a valuable glass piece. Therefore pre-plan for a way to hang the pieces. Also keep in mind that the shelves stack on top of each other supported by kiln furniture. Glass placed in close proximity to the kiln furniture, such as the whole wine bottle on the kiln floor, will melt and possibly stick to the furniture. Therefore, it is necessary to plan carefully for the placement of glass pieces.

Figure 28: Top loading ceramic kiln



Designing fused glass pendants or decorations may also be achieved through a process that requires less precise planning. For this process, take a bottle (whole or broken) and place it inside a couple of plastic bags. Then, using a hammer, smash the bottle into manageable pieces. Carefully remove the large pieces and arrange them on the kiln shelf. Then overlap a few medium sized pieces on top of the large glass, trying to fill in the holes. Again, keep in mind that gaps may be necessary for hanging purposes. The last step is to use a spoon to gather all the tiny chips and frit glass and sprinkle them on top to add some sparkle and texture to the finished piece. These pieces can now be fused in a kiln to create a unique final product.

3.6 Getting to know the Kiln

Glass acts differently at varying temperatures, and each kiln is different. Much like using the oven in the kitchen, a kiln requires the user to have certain knowledge. Therefore, getting to know the kiln is important for successful firings. The initial firing experiment will help gain an understanding of the kiln temperatures and how it fires. When loading the kiln, take special consideration of where pieces are placed, as this may give insight to where hot spots may occur. Also, make note of the size and thickness of the glass to determine what size pieces work best according to the firing schedule and keep in mind which glass is mixed from different bottles. Mixed glass can be deemed incompatible if cracking occurs. Placing duplicate pieces in different parts of the kiln, such as rings the same size and rings of varying sizes, also will give insight for the next experiments. The best way to analyze the behavior of glass experiments is to photograph the glass on the shelves before it has been fired and then to photograph the glass on the shelves after it has been fired.

Figure 29.1: Photo before firing

Figure 29.2: Photo after firing

The photographs can be used to compare the nature of the pieces before they were fired and to analyze the final results because, once the glass is removed from the kiln, it may be difficult to recall what the original glass looked like. Information from the first firings will allow you to isolate the cause of failures and increase the chances of a successful firing. Documentation of the entire firing should be carefully recorded in a firing log. A firing log is a journal or notebook in which details about each firing are kept. No one can precisely duplicate the conditions of your kiln or reproduce your experiments because the kiln you are using, the glass you choose and the designs you create are unique to you. A firing log is necessary to keep records of successful firings in order to repeat the good ones and avoid repeating the bad ones. Information in the firing log should include the date, type of firing, type of glass, and details about the schedule of firing. Always include enough information in the firing log to duplicate the firing completely. In addition, record comments about the success or failure of the firing such as what went well and what to avoid next time. Comments should include any cracking in the glass, the nature of the edges, the presence of bubbles, discoloration, and any apparent hot spots in the kiln.

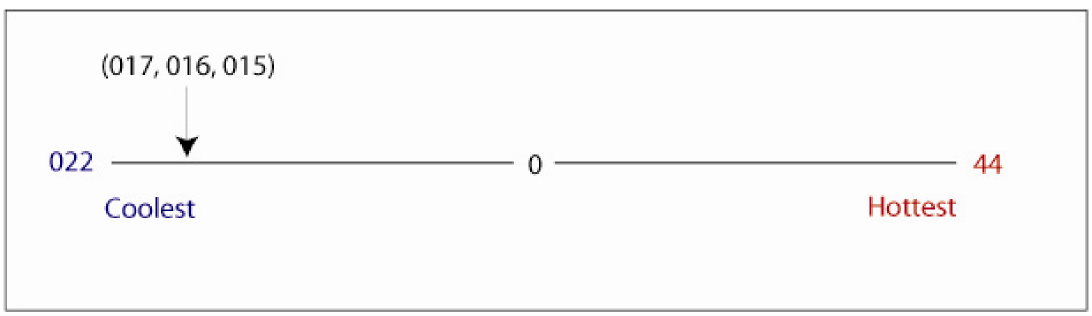
The purpose of experimentation is to extract knowledge from the glass's behavior; therefore, each experiment should be strategically conducted in order to extract the most information.

3.7 Introduction to firing experiments

For this thesis, a top loading manual ceramic kiln was used for experimentation and the creation of final design prototypes. The kiln is designed to hold octagonal shelves supported by ceramic posts called kiln furniture. There are two side heating elements: one located at the top of the kiln and the other located near the bottom. There are two dials on the outside of the kiln that control the elements separately. The dials have three settings: high, medium, and low. The first experiment will serve the purpose of determining the rate at which the temperature rises per hour at each setting as well as how fast the kiln loses heat during the cooling process. A pyrometer will be used periodically throughout the firing to measure the temperature inside a kiln.

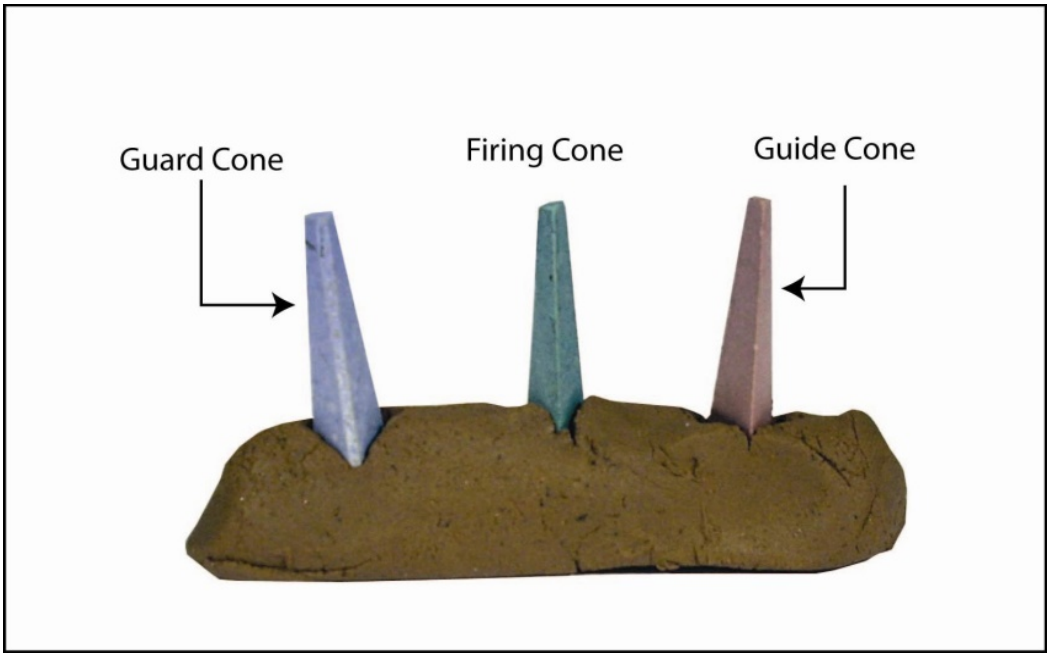
Kilns are not just fired to a temperature; they are also fired to a cone level. A cone is a narrow pyramid shaped piece of clay used to observe the actual heat-work accomplished in a kiln. It is also a unit of measure describing how much heat-work is required for a certain firing process. As shown in Figure 30 cones range from 022, the coolest, through 44, the hottest.

Figure 30: Temperature chart for cones



The numbers represent the temperature at which the cone will bend or deform. The cones are used in groups of three to determine temperature uniformity. The firing cone is the cone that melts at the intended process temperature. The guide cone is one number cooler than the firing cone and the guard cone is one number hotter than the firing cone. The firing cone is placed in between the guide cone and the guard cone; they will melt in order. The cones necessary for fusing and slumping experiments relevant to this thesis are 015, 016, 017.

Figure 31: Temperature cones supported by earth clay



Because of their shape, cones will not balance well in the kiln; therefore, they should be placed inside a bed of earth clay for support, as demonstrated in Figure 31. The cones will not be visible for the first four hours of firing while the kiln is heating up. Much like an oven at home, heating elements begin to glow when they get hot. Once the kiln reaches 1100 degrees F, the elements produce enough light for you to see into the kiln. Cones need to be strategically placed near a peep hole. The guide cone, 017, will begin to deform at 1350 F. This will indicate that the process temperature is approaching. Because the slumping temperature for glass is around 1300 degrees F, you will notice the glass flattening out prior to the deformation of the cones.

Figure 32: Setting up the cones

It is a good idea to place large rings near a peep hole during the initial firing. A whole bottle on its side also works well and allows you to view the slumping process. Watch the glass periodically and keep a record of when the glass ring or bottle begins slumping and how quickly it flattens out. These records are beneficial for later firings.

3.7.1: Experiment 1

During the initial experiment, the kiln was left on low for two hours then turned to up to medium for two hours. The temperature each hour was monitored and recorded in a firing log. According to the documentation of the first firing experiment, the kiln temperature increases 200 degrees per hour at the lowest setting and reaches 400 degrees after 2 hours. During the initial heating phase, organic contaminants are burned off the glass. At the medium setting, the temperature increases at a rate of 500 degrees per hour and reaches 1050 degrees after two hours. This is a critical temperature in the firing process. For best results, it is suggested by many glass artists and professionals to allow the glass to soak at 1100 degrees F to equalize the temperature of the glass. Soaking is difficult in a manual kiln because it requires manually turning temperature knobs and closely watching the temperature using a pyrometer to achieve the proper soak temperature. Furthermore, the lower level of the kiln used for these experiments heats up quicker than the top by 100 degrees F. To compensate for the temperature difference, the control for the lower elements may need to be turned down in order for the top temperature to catch up. It is important to be patient and wait until the temperature at the top and bottom is the same before beginning a soak period.

At the highest setting the temperature of the kiln raises more quickly, and therefore observation is critical. During the first 15 minutes on high, according to the pyrometer, the temperature rose 275 degrees. After 30 minutes on high the temperature reached 1400 degrees F, the intended process temperature for the first experiment. In an attempt to soak the glass at this temperature, the kiln was turned down to the medium setting and the peep holes were plugged up for twenty minutes. The purpose of plugging the peep holes is to ensure that no excess heat escapes from the kiln. After the soaking period, the kiln was turned off until it reached an acceptable annealing temperature.

During the annealing process it is also necessary to soak the glass to ensure even cooling. This was done by turning the kiln on medium thirty minutes and monitoring the temperature with the pyrometer. Though the intention was to equalize the temperature to

1075 degrees F, the medium setting actually increased the temperature back to 1150 degrees F. The kiln was then turned off and allowed to cool naturally. Within 5 minutes after the kiln was turned off, the temperature was back to down to 1075 degrees, indicating that the glass successfully soaked. The kiln was left off and allowed to cool completely before removing the glass**.**

The process temperature reached in the initial firing experiment was 1400 degrees F. Due to the presence of over-fired pieces, it can be determined that the glass soaked too long at the process temperature. Many of the pieces lost their individual characteristics and melted together as a result of over firing. Very few pieces cracked, indicating that the glass was properly annealed. Mixed bottle glass such as the green bottle glass and clear bottle glass successfully fused without cracking.

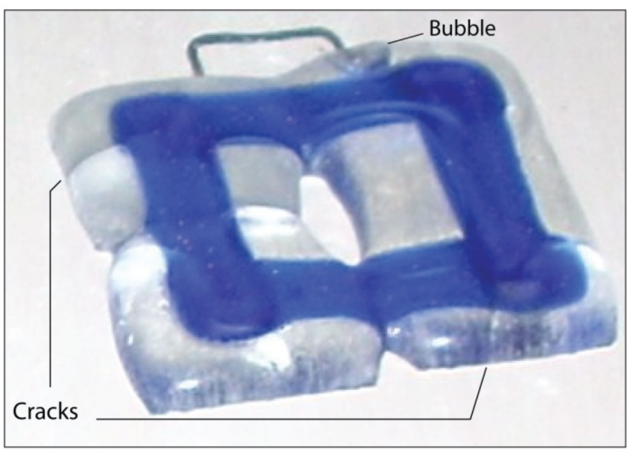


Figure 33: Clear window glass fused with blue bottle glass

The introduction of window glass created a problem when fused with blue bottle glass. There were rounded cracks at the edges of the piece and a bubble where the wire had been placed. The rounded cracks likely occurred during the initial heating of the incompatible glass. This can be assumed due to the presence of rounded edges.

When held up to the light, some of the glass pieces appeared to have tiny bubbles trapped between the layers of glass. This occurrence can be traced back to heating the glass too quickly during the pre-process phase at around 1225 degrees. In the next experiment, it may be beneficial to soak glass at 1100 degrees F before heating up to the process temperature. If done correctly, the soak should eliminate any bubbles in the glass. Bubbles often create an interesting effect in the final product; however, it likely weakens the structure of the glass and therefore bubbles are not a desirable outcome. In the next experiment a lower process temperature will be used in order to maintain some depth and texture to the fired pieces.

3.7.2: Experiment 2

Prior to the second firing experiment, idea sketches were created to illustrate different shapes that could be created by overlapping different pendant shapes.

Figure 34: Concept sketches for glass

The glass was then arranged on prepared kiln shelves according to the idea sketches. Holes were made by partially sawing into the glass pendant and then placing a small piece of glass on top, closing the gap. This ensures that the glass will fuse together in the kiln creating an elegant place to thread a chain.

Figure 35: Concepts arranged in glass

The kiln also contained some pieces that had been previously fired pieces in the kiln again to evaluate their behavior when fired twice. Three levels of glass designs were loaded in the kiln and a whole wine bottle was placed on the kiln floor. Placing a whole bottle near a peep hole provides something to observe during the firing. It will also yield an elegant wall decoration or cheese platter.

The cones were placed in a visible position on the top and bottom shelves to monitor the temperature. The cones will help evaluate if the temperature difference between the top and bottom of the kiln is significant.

The same pre-process schedule was used in this experiment: two hours on low setting and two hours on medium. To eliminate the problems associated with increasing the temperature too rapidly, the glass was allowed to soak at 1100 degrees F before ramping up to the process temperature. This was done by turning the temperature knob to the highest setting while watching a pyrometer. When the temperature on the pyrometer read 1100 degrees F, the kiln was turned off and peep holes were plugged up for 20 minutes. After this soaking process, the temperature was returned to the highest setting and monitored until it reached 1350 degrees F.

As the temperature increases in the highest setting, the cones become visible and are important to watch. As previously mentioned the cones are designed to bend at determined temperatures and are intended to deliver the temperature of an object in the kiln rather than simply the temperature of the air inside. In this firing, the glass was not soaked at the processing temperature. Instead, the cones and pyrometer were closely observed; when the middle cone melted at 1350 F, the kiln was turned off to stop the melting process. Then the kiln was left to cool naturally for thirty minutes. When the temperature reached 1100 degrees F, the annealing soak began. Annealing was done by turning the kiln to the lowest setting for 20 minutes and monitoring the pyrometer to ensure the temperature did not drop below 1000 degrees. Once the annealing phase was completed, the kiln was turned off and allowed to cool naturally to room temperature.

In this experiment, not all of the glass reached a full fuse due to the lower process temperature. The resulting pieces appeared to have more texture and to retain some characteristics of the original source bottle. Often, the problem with tack fusing is that the glass is more delicate due to less surface area attaching the pieces together. When the glass reaches a full fuse, it actually flows into each other, creating a stronger bond. Full fusing is desired in order to create quality pieces that will not break apart.

There was also evidence of uneven heating throughout many of the pieces. Uneven heating is a flaw in the glass and is likely due to the side mounted elements of the kiln. Kilns designed specifically for glass have elements mounted in the top for more even heating. According to the results of this experiment, when using this type of kiln with side mounted elements, a soak period is obviously necessary at the process temperature for even heating. Soaking the glass at the process temperature will allow all parts of a single piece to reach the same temperature. In the first experiment, soaking at the process temperature resulted in more evenly heated pieces such as flat smooth rings. On the other hand, rings in the second experiment appear to be in the process of folding over.

Figure 36.1: Ring from Experiment 1

Figure 36.2: Ring from Experiment 2

Uneven heating creates the appearance of frozen movement within the glass. The result is often an interesting visual effect which produces an array of unique living shapes that cannot be duplicated.

3.7.3: Experiment 3

In preparation for the third firing, pieces from previous firings were analyzed to determine which designs were worthy of duplicating. The pieces that were determined successful were those that had been previously planned through sketches because planned glass that comes out the best.

The firing schedule from the second experiment was repeated up to the process temperature. Consideration of the glass placed on the top shelf determined the next steps. As previously mentioned, glass on the top shelf will heat up more slowly than the pieces on the lower shelves. In attempt to compensate for uneven heating, only the smallest pieces were placed on the top shelf. This decision was made because smaller glass is less sensitive to uneven heating. The process temperature for the third firing reached 1400 degrees F at the bottom and 1350 degrees F at the top. The glass was soaked at the process temperature for only 10 minutes, and then the kiln was allowed to cool naturally to 1050 degrees F. To ensure proper annealing, the glass was soaked at 1050 degrees F for 20 minutes, and then turned the kiln was turned off.

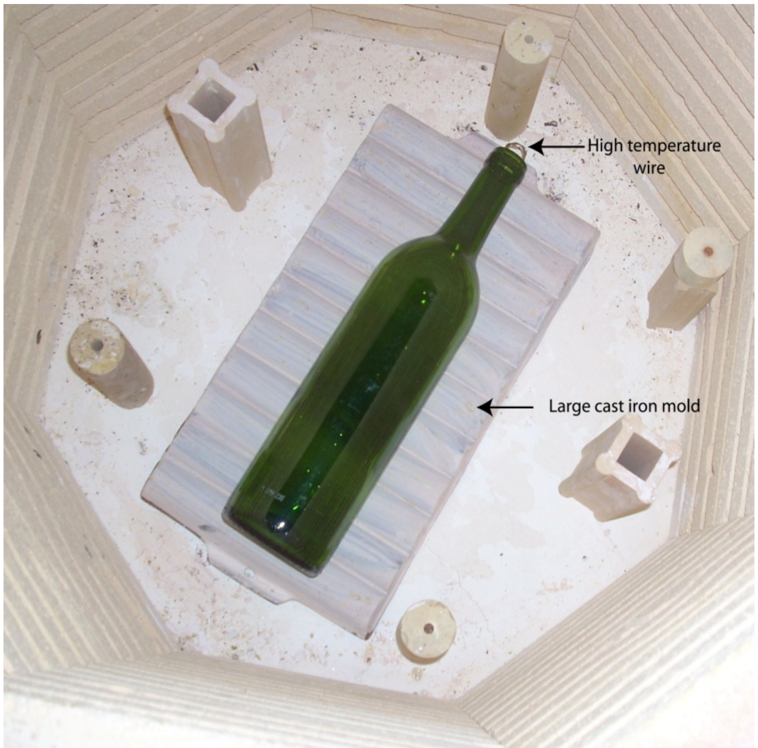
The results of this firing were similar to those of the second experiment. No cracking occurred in glass, indicating a proper annealing schedule; however, some pieces at the top of the kiln did not fully fuse. The reason for this can be traced back to the difference in process temperatures reached at the top and bottom of the kiln.

Another problem encountered in this experiment was that some of the glass achieved a foggy appearance. This result is evidence of devitrification. Devitrification occurs when the glass soaks too long at high temperatures. Blue bottle glass appeared to be the most sensitive to devitrification. In order to prevent this discoloration, the kiln needs to lose heat more quickly. This may be achieved through a process referred to as venting. Venting is done by opening the kiln lid for a few seconds to allow heat to escape. It is critical to monitor the temperature when venting the kiln to make sure it does not drop below the annealing range. Cooling glass too quickly through the annealing range will cause the glass to crack.

3.7.4: Experiment 4

For the fourth firing experiment, the temperature was manually adjusted periodically throughout the firing in attempt to achieve equal heating in the top and bottom of the kiln. This was done by adjusting the top and bottom temperature knobs and monitoring the pyrometer. Two cast iron cooking platters were placed in the kiln as molds. The platters were turned upside down, and covered in kiln wash. The larger platter was placed on the kiln floor as shown in Figure 37. The smaller platter was placed on the next shelf, making room for various other designs. Small glass pieces for jewelry occupied the upper shelves.

Figure 37: Large cast iron platter before firing



A longer soak period at the processing temperature was used to produce evenly fired and generously slumped pieces. Due to this longer soaking period, the glass is in danger of devitrification. In order to prevent this occurrence, the kiln was vented for five seconds after the process soak. The temperature dropped to 1300 degrees F after venting and cooled to the annealing range in 15 minutes. This is half as much cooling time compared to previous firings; therefore, the glass was soaked at the annealing range for thirty minutes before turning the kiln off.

The venting process in this firing improved the clarity of most glass pieces, though the blue glass appeared to lose some clarity. The bottle placed on the large cast iron mold successfully slumped, creating a textured platter for wall art. Prior to the firing, a wire was placed in the mouth of the bottle for hanging purposes. The small cast iron mold was not as successful. The bottle placed on this mold was larger than the small mold itself, which caused a crack to form where the edges of the glass melted onto the kiln shelf. The crack occurred because the cast iron mold retained more heat than the ceramic kiln shelf; as the edges of the bottle melted onto the shelf, they began to cool faster than the rest of the bottle, causing it to break. This firing revealed the necessity of a longer annealing soak when firing over cast iron molds onto the shelf. This longer soak will ensure proper cooling of the glass.

3.7.5: Experiment 5

For the next experiment, shapes were formed out of red earth clay to create a variety of molds for slumping. The clay forms must be fired prior to their use as slumping molds. Therefore, the molds were placed in the kiln along with the other glass designs to be fired. In addition, the large and small cast iron platters were placed in the kiln again. A Coca-Cola bottle was used to slump over the small mold, ensuring that the glass would not melt onto the ceramic shelf. The additional shelf space was then occupied by small circle designs and previously shaped glass pieces. Due to the results of the last firing, the previous firing schedule was repeated.

Figure 38.1 Kiln shelf with fired clay

Figure 38.2 Kiln shelf with fired Coca-Cola bottle

The venting process resulted in clear pieces with vibrant colors. The cast iron molds resulted in generously slumped bottle platters and the fired clay became dry and rigid. The next step for the clay molds will be to cover them will kiln wash and place glass over them for slumping.

3.7.6: Experiment 6

For the last firing experiment, the kiln was filled with the previously fired clay molds, both cast iron platters, and two large riverbed rocks. All of the molds were covered with kiln wash to prevent sticking. The glass pieces were arranged over the molds, and the previous firing schedule was repeated. The additional space on the kiln shelves was occupied by small sanded glass pieces for jewelry.

The glass confined to the clay molds slumped successfully, as expected. The glass that melted beyond the boundary of the molds did, however, crack. The crack occurred where the glass touched the kiln shelf. This occurrence is likely traced back to the annealing process. Additional annealing time should be factored in when glass slumps onto different surfaces. The additional annealing will allow the glass and the surface on which it is resting to remain close to the same temperature.

3.7.7 Conclusion of Firing Experiments

Each firing experiment yielded several usable pieces for the creation of unique and elegant jewelry. The cracked glass from failed experiments was broken into tiny pieces and fired again to create colorful accents in the center of jewelry pendants. Large scrap glass that could not be used was returned to the recycling center to ensure this process did not accumulate additional glass that could be returned to the waste stream.

The incorporation of molds in the kiln forming process offers a variety of textures and shapes that may be created from glass. Found objects that can withstand the high kiln temperatures, such as rocks and cast iron, are useful to create textures in glass. In addition, commercial slumping molds are available online. Using a commercial mold means your time is not consumed by the mold making process; furthermore, a commercial mold will last much longer than most homemade molds.

The use of various molds expands the potential of post-consumer glass, inviting the creation of platters, bowls and sculptures. Many requirements accompany the creation of these larger pieces. A longer firing schedule is needed to accommodate the additional annealing time. Also, a larger kiln is necessary to produce a large enough quantity of products to be sold. The additional height added when using a mold means fewer shelves can be placed in the kiln, and, therefore fewer products will be created with each firing. In contrast, many pieces of jewelry can be made from a single bottle and glass from several bottles can be used each firing. The glass used to create jewelry is no more than two to three inches high, leaving an abundance of room to stack shelves and accumulate a large quantity of saleable products. Furthermore, the small glass pieces are less sensitive to incompatibility due to mixed glass and uneven heating, and require less time for annealing. As a result, the small pieces used to create the jewelry can be designed to incorporate a variety of colors and produce a more consistent outcome even when varying the firing schedule.

3.8 Introduction of the product line

The firing experiments accumulated over 200 pieces of jewelry and 12 cheese platters made from wine bottles. These pieces, as well as several vases cut from wine bottles, became the product line for Treehugger Recycled Glass. The name, Treehugger, meaning environmentalist, was chosen to imply that these products are environmentally friendly. Figure 39 is the visual identity for the brand created by the author.

Figure 39: Treehugger logo

Due to the implications of the brand name, it would be hypocritical to use packaging that is not eco-friendly. For this reason, the packaging for Treehugger was created by cutting used cardboard boxes such as cereal boxes, Coca-Cola boxes, pizza boxes and any other cardboard that might be doomed for the waste basket. The cut boxes were folded over, exposing only the brown color of the card board to give the packaging a unified look.

Once the jewelry is purchased, the recipient will open the package, revealing the print on the inside. This gives the purchaser a subtle reminder that this is an eco-friendly business, and even the packaging gives a waste material a second life.

Figure 40: Treehugger packaging

When creating a new business, a visual identity or logo should be established for future recognition by consumers. The logo should appear on everything associated with selling the products. This includes packaging, business cards, and the company website. It takes time to establish a new business to the public so it is important that the visual identity is consistent with every use.

The importance of a logo is to begin branding products. Branding allows you to separate the identity of your company from other companies selling similar products. A slogan is another technique used to identify a brand. A slogan should describe what the company desires to become known for. Treehugger's slogan is "Transforming Ordinary Bottles into Extraordinary Products!". Once the identity of a brand is established the products can be introduced to the public. Craft shows are a great way to begin brand exposure of such products.

Figure 41: Close up of booth at Auburn City Fest

Treehugger Recycled Glass debuted at the Auburn City Fest on April 25, 2009. Business cards with the Treehugger logo, phone number, and email were available for those who wished to purchase products at a later time. The local community had a very positive reaction to the introduction of Treehugger. Many people were intrigued by the unique product line and made inquiries about how the jewelry was made. Sales from Auburn City Fest totaled over $350. Furthermore, the business cards attracted inquiries even after the Festival was over. Six more customers contacted Treehugger the following week requesting another opportunity to make purchases. Even in the absence of a website, the exposure of only one craft show accumulated $455 for Treehugger, including the money made from post-festival inquiries.

Treehugger will continue participating in craft shows all over the southeast. This continued exposure from future craft shows as well as the addition of a website will enable this business to grow and establish a steady income for future expansion.

4. CONCLUSION OF THE STUDY

4.1 Firing Schedule

Table 4 illustrates the suggested firing schedule for transforming post-consumer bottle glass into pendants for jewelry. The firing schedule was constructed by the author according to information extracted from the previously conducted firing experiments. This schedule is appropriate for the creation of recycled glass jewelry up to 3”x 3” x 3/4” thick. The schedule may also be used as a starting point for further experimentation with larger pieces of post-consumer bottle glass.

Table 4: Final firing schedule

Starting Temperature	Ending Temperature	Rate in Degrees/hour	Minutes Soaked
o	1050	400/hr	20
1050	1400	1000/hr	5
1400	1050	1000/hr	20
1050	800	400/hr	0
trun of f kiln			

Every kiln is different. Record the results of each firing in a firing log for later evaluation. This schedule will successfully produce generously slumped and tack fused pieces such as the jewelry pendants in Figure 43 and several variations. When experimenting with post consumer glass larger than the dimensions 3”x 3” x 3/4'” thick, it will be necessary to alter the firing schedule.

Figure 42: Treehugger Necklace

4.2 Devitrification:

Figure 43: Devitrified pendant

According to the GFME website, devitrification occurs when glass is kept too long in the temperature range just before it becomes molten. Experiments revealed that for post-consumer bottle glass, devitrification will occur if left at 1400 degrees F for too long. At this temperature, a visible fog builds up inside the kiln and leaves a scummy white film on the surface of the glass. To prevent this occurrence, minimize the length of time spent at this temperature range. Flash venting, or opening the kiln for a few seconds to allow heat to escape quickly, is one solution to devitrification. Some glass, such as blue bottle glass, has the tendency to devitrify even at lower temperatures. When using a glass that is more susceptible to devitrification, a devit spray is necessary. A devit spray is applied to the top surface of the item prior to firing. Allow the solution to completely dry before firing.

4.3 Kiln wash problems:

Figure 44: Pendant with kiln wash on back

Kiln wash can sometimes stick to the bottom of the glass. One reason kiln wash will stick to glass is firing on wet kiln shelves or with shelves that have picked up moisture from the air. Also, using shelves that have kiln wash that is beginning to deteriorate can lead to problems. To avoid this occurrence, apply a fresh coat of kiln wash and pre-fire the shelf to around 500 degrees to make sure moisture is out.

Over-firing is another reason kiln wash might stick to a piece. The solution could be as easy as changing the brand of kiln wash or to avoid kiln wash altogether and use fiber paper in its place.

Kiln wash is difficult to remove, and, therefore, prevention is preferable to removal. To remove kiln wash from a glass piece, try soaking it in white vinegar for several days and then scrape the glass with a very fine steel wool. To prevent kiln wash problems, reapply kiln wash frequently. Also, be sure to thoroughly remove old kiln wash by sanding the shelves prior to reapplication. Once a fresh coat of kiln wash has been applied, it may be necessary to pre-fire the shelf to 500 degrees to remove any excess moisture.

4.4 Edges:

Figure 45: Over-fired pendant

The desired result from kiln forming glass is to achieve a smooth, well-rounded edge. If the edges of a fused piece are not generously rounded, then that piece was not fired long enough. Simply soak the glass longer at the process temperature.

In contrast, if the glass piece appears to have needle like projections along the edge such as in Figure 46, then the piece was fired too long. To correct this problem, grind away rough edges and fire the glass again for less time at the process temperature. If it is possible, place the piece near a peep hole and keep an eye on it. Soak the glass at the process temperature until it attains the desired appearance, and then flash vent the kiln to 1100 degrees F to avoid over-firing.

4.5 Cracks in the glass:

Figure 46: Cracked glass

Cracks can occur in glass for many different reasons. To prevent the reoccurrence of cracks it must be determined what caused the crack in the first place. Then adjust the firing schedule to solve the problem. First, analyze the type of crack that appears in the glass. According to Walker, author of *Contemporaray Warm Glass*, curved cracks across the middle of a piece are caused by improper annealing. The cracks often show up as gentle curves that break the pieces into two or three pieces. The crack will curve sharply near the edge of the glass where it exits the piece (2006).

The solution to this problem is to raise the annealing temperature slightly, about 50 degrees, and then to soak longer in the annealing phase. Keep in mind that the purpose of the annealing phase is to relieve stress in the glass and that it is impossible to anneal for too long.

Walker explains that cracks occurring at the point where two different glasses come together indicate incompatibility. These cracks caused from mixing incompatible glass range from very small in size to large cracks that cause the fused pieces to break apart (2006). Even if the crack is barely visible, it is an indication of stress and formation of a weak bond. To solve any incompatibility issues, make notes in your firing log which glasses were mixed together that caused these cracks and avoid mixing those glass types in the future.

Spider web cracks, or small interconnected cracks that extend from a single spot on the bottom side of the glass, occur from the glass sticking to the kiln shelf. According to Walker, these cracks are rarely severe enough to cause the item to split into pieces; however, their appearance can be an eyesore (2006). To prevent the glass from sticking to the kiln shelf, sand the kiln shelf to a smooth finish and reapply a fresh coat of kiln wash.

Pie-shaped cracks with smooth edges that split the piece into several pieces are caused by thermal shock. The smooth rounded edges indicate that the cracks occurred early in the firing cycle, around 400 degrees F. After the piece breaks apart the edges round during later phases of firing, around 1200 degrees F. To avoid the reoccurrence of thermal shock, simply slow down the rate of temperature increase in the initial firing stage. Another solution is to cut very large pieces into smaller ones because smaller glass is less susceptible to thermal shock.

4.6 Conclusion

Billions of glass bottles and jars are thrown away every year with disregard to the potential value of the material. Knowledge is power, and spreading the word about the importance of recycling is imperative. Even more so are the practices of reuse that have not yet become widespread. This thesis is about setting an example for society to step up and recognize the impact we have on our environment. Not only will reuse practices help save our environment, they hold the potential to become very profitable. This thesis presents a process for cutting and transforming bottles into jewelry without wasting any of the material. Furthermore, the lower temperature at which the glass is fired alleviates much of the energy consumption occurring at the hands of bottle manufacturers.

There is enough trash on our earth already and whether we bury it or burn it, the trash is not going away. Our earth will continue to suffer until our actions change.

Often in society, we perceive newer to be better, but if we continue on the path we set we will be burying ourselves in our own waste. With some research and a little creativity, waste can be transformed into something useful, something beautiful, and even something lucrative. The challenge, therefore, is to find ways to put our trash to use.

It takes more than 2 million years for a glass bottle to decompose. This thesis demonstrates a process for creating a valuable product line from post-consumer glass rather than piling it in our landfills. Furthermore, creating a product line from waste materials sets a positive example for society to follow. Without this first step, a change will never be made. Now that the ball is rolling, it is up to society as a whole to recognize what we have done with our resources. It is not just about spreading the word, it is about adopting new practices to save our planet. By using the processes illustrated in this thesis, society can begin putting our waste to use.

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