Post-Consumer Container Glass Remelting Process Assessment

RECYCLING TECHNOLOGY ASSISTANCE PARTNERSHIP
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Post-Consumer Container Glass Remelting Process Assessment

FINAL REPORT

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1.0 BACKGROUND

The cast and pressed glass product manufacturing industry has been identified by the Clean Washington Center as a potential high-value market for recycled glass. Recycled glass generally requires less energy to process and costs less than batch materials typically used in glassmaking shops. In addition, test trials have shown that, in many cases, by carefully controlling batch formulas and melting procedures, recycled content products can be manufactured with physical and aesthetic qualities similar to those of products made with virgin materials.

1.1 Economic Considerations

From a cost standpoint, recycled glass may appear to be an attractive feedstock for hot shop operations. However, some glass artists believe that these savings may be small compared to the risks associated with using recycled glass. This is because the raw material cost usually represents only a small fraction of the final price of the product. Glass art objects may sell for anywhere from $10 to $200 per pound of glass. By comparison, the primary supplier of premixed batch to the Northwest art glass community sells glass pellets for about $0.35 per pound. Thus the savings in raw materials alone are insignificant in high end applications, especially hand blown products. Recycled glass may be most promising as a substitute feedstock in production casting or pressing operations, where the material represents a larger percentage of the final price.

In addition, crystal clear products require a clarity of glass that can never be obtained with post-consumer bottle glass. Colored or iridescent products, however, can be manufactured using post-consumer glass without diminishing the aesthetic integrity of the piece. The ultimate viability of recycled glass as a feedstock is product driven.

Topics covered in this protocol include:

- Sourcing
- Cullet Preparation
- Batch Chemical Additions
- Melting

- Color Compatibility Tests
- Annealing
- Data From Three Pilot Studies

1.2 How to Use this Protocol

This protocol can be used as a tool for establishing effective and repeatable methods for incorporating post-consumer glass into the melting practices of small glassmaking studios. Reliable, economically efficient, and energy-saving practices in sourcing, processing, and melting recycled post-consumer glass are specified to assure predictable good quality glass. The information contained in this protocol should help interested shops make the appropriate conversions to successfully use recycled glass to replace some, or all, virgin feedstock (raw batch chemicals) or post-industrial cullet, with post-consumer recycled glass cullet.

Recommendations contained in this protocol apply only to recycled soda-lime bottle glass. In general, viscosity requirements of the high-rate production processing press and blow machines used worldwide in the container industry dictate that the chemical composition of container glasses more or less conform to universal standards. Mixing a variety of container glasses for re-melting does not pose any insurmountable barriers to achieving a homogeneous end product, provided that there is no major contamination by inorganic materials or glasses of radically different compositions.

Because glass products vary widely from one studio to the next, the processes described herein take into account various end product requirements.

1.3 Freehand Glass Forming Processes

Glass has been utilized as a decorative and functional material for nearly four thousand years. Almost all of the studio glass shops in Washington State manufacture glass by the traditional hand-forming method. In this method, molten glass is gathered on the end of hollow stainless steel blowpipes or solid steel rods. Cup-shaped wet wooden blocks, steel marveling tables, specialized hand tools, and the breath of the craftsperson are then used to shape molten glass into a variety of products.

1.4 Glass Casting Processes

Glass studio-scale shops which produce cast glass products generally use mild steel ladles to scoop small amounts of molten glass from the furnace. The ladle is then used to pour the fluid glass into an open mold cavity in sand, carbon block or metal.

2.0 Getting Started Using Post-Consumer Recycled Glass

Obtaining a quality glass for blowing or casting from post-consumer bottle glass hinges on four major processes: sourcing, cullet preparation, addition of batch chemicals, and melting. In order to obtain a glass with good working characteristics and very little striae (cords), it is important that the guidelines described herein be followed.

2.1 Sourcing

Connecting with a reliable source of post-consumer recycled glass is the first critical step. First and foremost, the cullet must be clean (i.e. free of dirt, rocks, metals, other glasses like Pyrex7 or automobile head lamps, and ceramics). Unfortunately, coffee mugs, glass cookware and broken dishes are commonly found in many recycling bins. Forging partnerships with community recycling centers, local restaurants, company cafeterias, large scale container plants (such as the Foster Ball Glass Container Corporation in Seattle, WA, or Owens Brockway in Portland, OR) or similar heavy users of glass containers can be an important step in obtaining a clean and consistent recycled glass feedstock.

Drop box sites are one of the easiest places to start. If a clean clear feedstock is desired, it will be necessary to verify that proper quality control measures are implemented at the material's source. Good drop box sites are usually maintained by on-site personnel who have high standards for sorting and contaminant removal.

A good relationship with drop box site staff will allow you to educate them about your shop's own special needs. Presenting samples of ceramic stones and cords in the glass is an effective way to convince suppliers that even small amounts of contamination can cause big problems for the small studio glassmaker.

A busy local restaurant or cafeteria can provide a large stable supply of glass containers from a single beverage brand. A labeled receptacle to collect the glass containers makes it easy for cafeteria staff or patrons to supply your shop with clean single-source cullet.

2.2 Cullet Preparation

Preparing the cullet for melting consists of cleaning the cullet, removing any remaining debris, and crushing it to an appropriate size, if necessary.

In all circumstances, it is a worthwhile practice to pour the glass out onto a screen or flat surface in order to wash it and search for contaminants prior to using it in a melt. If any debris or dirt is present, it will need to be removed. Some paper in the batch is acceptable. Excessive amounts of paper (i.e. other than the remaining bottle labels) should be removed, however, as the ash generated during the melt can cause contamination problems.

When it is possible to obtain all recycled glass from the same large scale container plant, processing to like-sized particles is not critically important. The same is usually true when using similar types of containers. What is more likely is that recycled glass is obtained from a variety of sources. In this case, it is best to crush the glass to a like size, ideally less than 1/4 inch, to insure uniform melting.

It is recommended that, whenever possible, the glass be crushed to between 1/16 and 3/4 inches, especially if large quantities of chemicals are to be added to the batch. The amount of crushing necessary to prepare recycled glass depends to some extent on the product being made. In small scale hand blowing and casting shops, however, it is usually best to crush the glass to a size that allows it to melt with the addition of the oxidizers, fluxes, and fining agents described in the next section and listed in the attached appendices. These chemicals do not combine well with cullet larger than 3/4 inch, which generally take longer to melt and can result in bubbles, chunks of chemicals, striae, or cords in the final product. In addition, forcing air bubbles up through the bottom of the tank or pot using a compressed air line hooked up to a blowpipe may help.

For mold blown and cast glass objects, which require little or no fluxing, less size reduction may be acceptable, especially if color compatibility is not important (see *Color Compatibility Testing*, below). Some container crushing is still recommended, though, to minimize the violent impacts against the furnace side walls due to the thermal shock explosions occurring at the moment the cullet is charged into the furnace. These large particle explosions are particularly detrimental to free standing pots or crucibles.

Regardless of the application, it is important to sift or wash the smallest powder-sized particles (called *"fines")* out of the feedstock. Grains under 1/16 inch tend to trap small air bubbles in the batch, and make the batch more difficult to melt, increasing the need for fluxing and fining agents (usually noxious or toxic chemicals). Very fine glass powder also increases the residency time for floating out bubbles from the melt. Water washing the crushed glass on a common #16 mesh window screen easily solves this problem. The water also helps to reduce dusting when handling the cullet.

Currently there are no operating commercial suppliers crushing glass to the specifications or cleanliness needed by small glassmaking shops in Washington State, although the newly forming Trivitro Corporation (Seattle) (206) 301-0181 is expected to begin to market beneficiated post-industrial and post-consumer feedstocks sometime this year. Alternatively, bench scale glass crushers that can produce finely and uniformly ground cullet are available from several companies. Prices for these crushers start at $5,000. A bottle breaker can be purchased for less than $2,000, although this type of equipment cannot produce the finely ground glass that studios generally require.

Further information on small-scale glass to fines processors may be obtained by contacting the following manufacturers.[1]

[1] This is not intended to be a complete list of manufacturers. Others can be found in the Thomas Register.

- SMC Manufacturing, Vancouver, B.C.
  Contact: Geoff Brown, 604-266-0422

- Andela Tool & Machine, Richfield Springs, NY
  Cindy Andela, 315-858-0055

- Glass Aggregate Manufacturing & Engineering (G.A.M.E.), Faribault, MN
  Don Cook, 507-334-6437

- Glass Recycling Inc., Marrietta, GA
  Don Lucas, 404-516-0816

2.3 Batch Chemical Additions

It is a common practice in large glass factories to add glass cullet to raw batch materials in order to promote rapid melting of the batch, and thus save on energy costs. Large container manufacturing plants often purchase post-consumer recycled glass from curbside collection companies in order to reintroduce this glass into their melts.[2] The fact that most bottle glasses are of similar composition makes the practice of adding post-consumer glass to standard batch melts possible, and highly effective, for small studios as well.

However, glass for the high production container industry is formulated to set up quickly and hold its shape when mechanically blown into molds. Glass melts for freehand blown objects and certain complicated fabricated products, on the other hand, need a long working range. Multiple re-heatings during the freehand process further drive off the dissolved gases and the volatile alkalis in the glass, raising the viscosity and shortening the working range.

Casting Applications. Additional chemicals are added to recycled glass for three primary reasons:

[2] Opinions vary as to what the maximum useful quantity should be, but the usual proportions are from 15% to 50% by weight of cullet in the industrial furnace feedstock. Appendix B gives the formula which Owens-Brockway Container Company7, Portland, OR considers to be representative of their clear cullet pile of post-consumer glass. Owens-Brockway then adjusts their other chemical additions to put dissolved gases and alkali volatiles back into the glass as the cullet melts.

(1) to insure **compatibility** with common colorbars,

(2) to increase the **working range** of the remelted glass, and

(3) to facilitate the **melting** and blending of recycled glasses from various sources.

If the remelted glass is intended to be cast or mold blown, trial melts have shown that the batch additions listed below can produce a glass with a relatively quick set time and a linear expansion coefficient (LEC) that matches that of German colorbars. To each 100 pounds of glass, the following chemicals were mixed and added:

2 lbs. soda ash
33 g. borax
175 g. niter
150 g. fluorspar
1/2 lb. lithium carbonate
50 g. antimony oxide
25 g. manganese dioxide

For certain cast products, where color compatibility is not an issue and a longer working range is unnecessary, it may be possible to either cut these amounts in half or eliminate them altogether.

The formula above was developed at Avalon Glass Company (Seattle, WA) using a very clean, clear bottle cullet, crushed to a relatively consistent size (1/16” to 1/4”).[3] It is important to note that there are many variables that influence the physical characteristics of the remelted glass. Different shop conditions and base glasses will result in remelted glasses with different physical characteristics. Each individual studio is encouraged to experiment with this formula, making changes as necessary to arrive at the chemical proportions that will work best with its own individual processes and applications.

Reasons for including the recommended additions are listed in Appendix A - Chemicals for Glass.

Freehand Glass Forming Applications. To obtain the working range required for freehand processes, additional fluxing agents are added to the batch (soda ash being the most common). It is recommended that the total soda ash content remain below 18% (by weight), otherwise the glass will lose its durability and become susceptible to corrosion by moisture. Bottle glass already contains between 13% to 16% soda ash. About 2% is generally expected to volatilize during the melting process. Since bottle glass is formulated to set quickly, additional fluxing agents will probably be required to achieve the desired working characteristics, especially if the glass is to be hand blown. Due to the limited scope of this project and the economic considerations discussed earlier, trials were not performed to arrive at an optimal batch recipe for hand blown products.

Decolorizing Agents. Chemicals are available to decolorize glass by breaking down the sulfur-iron ligands and balancing the chromium ions present in brown and green glasses. A small amount (one tablespoon) of powder blue (a frit made from cobalt blue glass) may be used to modify the green hue of the clear bottle glass. For a more complete technical discussion of decolorization methods, refer to *Color Modification of Post-Consumer Glass Cullet* Clean Washington Center publication #GL-96-4.

2.4 Melting

Soda-lime-silica glass chemistry and hand-forming techniques have been essentially the same for 2,000 years. The primary changes in the glass industries during that time have been improved-efficiency combustion technology and longer-life refractory materials.

Because the quantities of ware produced in small scale glass studios are relatively small, glass is most often melted in ceramic crucibles or small refractory-brick lined day tanks; usually at the highest temperature that the walls, roof, and pot or crucible can endure.

[3] See discussion of trial melt beginning on page 9, conducted at Avalon Glass Company.

At melting temperatures of 2350 to 2600 degrees Fahrenheit, the viscosity of the glass is lowered to a point that allows the bubbles to rise readily through the melt. The raw materials interact chemically during the melting process and thereby alter much of their individual composition. The gases given off in bubbles during the decomposition of some of the raw materials serve a useful purpose by agitating the melt and making it more homogeneous.

At these temperatures, however, the rate at which the furnace is attacked and dissolved by the corrosive elements in the glass is accelerated. At a temperature of 2,600 degrees Fahrenheit, it has been shown that a medium scale glass factory is capable of melting 7 tons of glass in a 13 hour melt cycle.[4] This requires that furnaces be made with AZS (Alumina-Zirconia-Silica) liners and super-duty silica brick crowns. These dense refractories are able to resist dissolution for 15-18 months of continuous operation. The type of feedstock being melted also has an enormous effect on the life of a furnace. Raw batch chemicals and the high heat required to melt the virgin materials are the most harmful (corrosive), while straight cullet and lower temperatures are actually the least damaging. Straight cullet requires about 10% less energy to melt.

Some shops are loath to try recycled glass for fear of contaminating their furnaces. However, the switch to more expensive virgin chemical batch or post-industrial cullet feedstocks, for those products deemed to require it, can be made by flushing the furnace with a small melt.

During the trial melts, the furnace was charged at regular intervals for three hours at about 2350 degrees Fahrenheit. The glass was then allowed to melt at the same temperature for another four hours, and finally left to idle for several hours. The final step of rapid cooling is called squeezing. Squeezing appears to effectively eliminate the large free oxygen and gas bubbles present at higher temperatures. The furnace temperature is then slowly raised back to the working temperature. This melt cycle is capable of producing a very clean glass, free of fines and small bubbles.

[4] This estimate is based on data obtained from Spectrum Glass Company, Woodinville, Washington.

The crucible in a pot furnace can either be invested in other refractory material or freestanding, and heated with natural gas, propane, or electric elements as energy sources. The most energy efficient furnace for a small shop is the multi-phase electric freestanding pot furnace with solid-state rectifier power controls. The freestanding crucible is also more fragile, however, so care must be taken to use the correct melting procedures, cullet gradations, and batch recipes. An invested furnace is less energy efficient, but can withstand more abuse.

2.5 Color Compatibility Tests

The linear expansion coefficient of the new glass should be tested to evaluate whether it is compatible with German colorbars (if color is to be added). Due to melting temperature variations, each studio should do its own testing. The *pull test* is a quick method of evaluating color compatibility. Equal amounts of color and clear glass from the furnace are placed side by side, heated together, and pulled into a long thin thread. As soon as the thread sets up it is placed on the floor and broken into 12 - 18 inch lengths. The two glasses will bend toward the glass with the higher *linear expansion coefficient* (LEC). If when placed against a straight edge, the curvature displacement in the thread is less than 1/4 inch over one foot of length then the glass is said to 'fit,' and the glasses may be used together. If the curvature displacement is greater than one inch then the glasses will probably break apart at some point in time, even months or years later. This is to be avoided as it can be expensive, not to mention embarrassing.

Although commonly used, keep in mind that this pull test is a quick and dirty non-scientific glass shop practice. The more accepted method for determining LEC compatibility is to blow two thin cylinders, one with the glass color on the outside and the other with the glass color on the inside. Cut narrow rings out of each cylinder and score with a glass cutter and break along the score. If the higher expansion (LEC) is on the outside the ring will pull away from the score, and if on the inside the ring will close. No apparent pulling in either direction should indicate similar LEC's which are "compatible." Since it is necessary to wait until the pieces are annealed to perform this test, most shops do not do it, but this test most closely approximates the real product performance.

2.6 Annealing

After a glass article is formed, it must be annealed to remove the internal stresses that were created during the forming process. This is done by "soaking" the formed glass in an annealing oven at a pre-determined temperature. This temperature depends on both the thickness and geometry of the product. One way to determine the annealing temperature is to pull a rod out of the tank glass, approximately 1/4-inch in diameter and 18 inches in length. One end is then captured between two firebricks and cantilevered out into the oven. The temperature is slowly brought up until the rod begins to bend. (Appendix C provides instructions for finding the annealing temperature.)

For example, Tooley[5] gives recommended annealing schedules for soda lime glasses of various thickness. The annealing temperatures given by Tooley range from 1020 °F for $^{1}/_{4}$" plate glass to 934 °F for $1^{1}/_{4}$" plate glass. The time that the glass must spend at the annealing temperature is highly dependent on the thickness of the glass, ranging from 5.5 minutes for $^{1}/_{4}$" glass, to a little over two hours for $1^{1}/_{4}$" glass. This initial soak is followed by a controlled cooling cycle of a similar duration.

3.0 Data From Three Pilot Studies

The following three trial melts provide tangible evidence that conversion to recycled feedstock is economically beneficial and technically feasible for some shops. The processing and test information for these trial melts were used to develop recommended batch formulas and melting procedures contained in this protocol. Since testing re-melted cullet for compatibility with decorative glass colors is essential to successfully changing feedstocks, some discussion of this subject is also included. The trials are presented here in the order in which they were conducted.

3.1 Olive Glass Company

[5] Tooley, Dr. Fay V. *The Handbook of Glass Manufacture, 3rd Edition, Volume II, Ashlee Publishing, 1984.*

Olive Glass Studios7 (Lopez Island, WA) is a typical example of a rurally located studio dependent on bottled gas fuel (propane) and a clever, low-technology manually-operated system. The local drop box recycling staff was eager to participate in finding high value-added products for their glass. Drop box glass is normally trucked off the island at great expense for beneficiation and use elsewhere (e.g., as construction aggregate).

Sourcing and Cullet Preparation. Special barrels were set aside at the drop box site to collect glass from similar products, in this case juice beverage containers. Two different mixtures of cullet were collected, so that two different trials could be conducted. As it turned out, 95% of the containers in the first mixture were Snapple7 beverage bottles. The assumption was that thin-walled bottles would be very nearly the same formula regardless of the particular industrial factory source. The second mixture was comprised of mixed bottles (not all Snapple7 brand), some with thick walls. The paper labels were patiently removed by hand from the first mixture, while no paper labels were removed from the bottles in the second mixture. Both mixtures were crushed in a barrel with a steel bar just enough to break them down to three-inch to 1/2-inch sized pieces. This cullet was then rinsed off with water.

Melting. The Olive Glass Studio furnace is a 230-pound. invested Laclede-Christy7 crucible that is propane gas side-fired with a Giberson7 burner head from just above the crucible level. The burner port is hand drilled and there is no pyrometer to indicate accurate temperature readings.

At Olive Glass, chemicals were mixed in the following proportions:

- 25 pounds Soda Ash
- 7 pounds Borax (penta)
- 2 pounds Sodium Nitrate
- 1 lb. Fluorspar
- 100 g. Antimony Oxide
- 150 g. Manganese Dioxide

One hundred pounds of the cullet were then mixed with six pounds of this chemical mixture. The feedstock mixture was charged into the furnace at a rate of approximately 30-pounds every 40 minutes, for a total charging time of 4 hours. Each charge was allowed to melt down flat before adding the next. After the last charge the glass was left on high fire, approximately 2,200 degrees Fahrenheit, for 4 hours. Batch stones and un-melted conglomerations of chemicals were present in all the periodic samplings dripped onto the steel marver. An additional two hours was added to the high fire cycle. After this extended melting time, the furnace was idled at approximately 1,900 degrees Fahrenheit for eight hours. More samples continued to show poor glass quality and the decision was made to reduce the amount of chemicals in the next test.

The second test used the same handling and charging procedures as the first test, but reduced the ratio of added chemicals to three pounds per 100 pounds of rough crushed cullet. High fire was kept to four hours total and periodic punty gather samples showed the glass to be fairly well melted with very few fines and some large bubbles after only two hours. At the end of the normal high fire, the glass looked very clean and free of large and small bubbles. The glass idled for nine hours before use the following day.

Color compatibility (pull) tests were performed with the glass produced in the second melt and numerous German colorbars (Kuglar7, Reichenbach7, and Zimmerman7). All the transparent German colors tried “fit” the clear glass in this test. The opaques fit with the exception of the red-yellow color being slightly off, as is often typical, due to the decrease in expansion (LEC) caused by the replacement of lead by zinc in cadmium and selenium colors. Zinc-oxide modified glasses are also less forgiving of LEC mismatches than lead-oxide modified glasses.

The normal Olive Glass Studio production items were made in order to compare them with products normally made in the shop. Decorative bead tubing, mold blown vases, beer steins, roundels, Christmas ornaments, and cast boat deck lights were made to test handling characteristics of the glass.

The recycled glass was a little stiffer than the West Virginia pressed-ware post-industrial cullet normally used by Olive Glass Company. But as a result of matching the colorbars, it worked fine for all of the applications listed above. This glass seems ideal for mold blown pieces, castings, and Christmas ornaments, where Olive Glass Studio wants the glass to set up quickly. Complex shapes that have thick and thin wall sections are more difficult with this particular recycled cullet melt. More work needed to be done on optimizing the chemical additions for other various working characteristics.

Two major lessons were learned from this pair of test melts:

(1) the mixed glasses from different initial types of cullet were, for the most part, compatible; and
(2) three pounds of fluxing agents were adequate to gain good melting and working characteristics, while excessive chemical additions and large cullet sizes resulted in a poor quality glass.

3.2 Andiamo Glass Company

This Redmond, Washington based company was chosen as a test site for two reasons. First, Andiamo uses natural gas fuel from a gas utility company and the furnace there has a high-tech combustion system with controllers. Second, there was also an opportunity to use feedstock that was crushed and screened to a uniform size by a nearby suburban community drop-box collection operator.

Sourcing and Cullet Preparation. Glass used for this test was obtained from the Mercer Island Community Recycling Center. Color sorting is faithfully carried out by the participants and a high level of contaminant removal and color separation is maintained by an enthusiastic on-site staff.

The cullet is produced by crushing whole bottles in a small hammermill. The size distribution is achieved by sifting the fine particles through a common window screen. The facility uniformly crushes and then sorts to minus 1/4 inch plus 1/16 inch particle size.

The clear glass used for the test consisted of a variety of domestic food containers and beverage bottles, and some imported beverage bottles. The crushed glass was very clean, though a small number of aluminum neck rings and about a half cup of shredded paper labels per 100 pounds of glass were present.

The crushed cullet was poured onto a galvanized metal table where the aluminum was patiently picked out and a fan was directed over the material to remove some of the paper labels. The paper was not thought to be a problem, although a large amount of metal foil labels could cause problems in the melt. The sheet metal table was wetted first so that when the glass was poured off some fines stuck to the wet metal surface.

Melting. Fluxing and fining chemicals were combined in the following proportions:

- 4 pounds Soda Ash
- 600 g. Borax (Penta)
- 350 g. Niter
- 300 g. Fluorspar
- 1 lb. Lithium Carbonate
- 100 g. Antimony Oxide
- 50 g. Manganese Dioxide
- 0.2 g. Cobalt Carbonate

Three pounds of the above mixture was combined per 100 pounds of cullet by hand using a large flour scoop.

The Andiamo Studio furnace is heated with natural gas and forced air by a side-mounted Eclipse MVTA burner. It has a 130-pound capacity, round bottom Laclede-Christy invested crucible. The furnace was preheated to 2,300 degrees Fahrenheit and charged with 36 pounds on the first charge, and allowed to melt for 45 minutes. Four more charges were then made with 30 pounds in each charge, 30 minutes apart. The furnace was left on the high fire setting of 2,350 degrees for four hours. The temperature controls were then set at 1,900 degrees and over the next nine hours the glass was left to idle until ready for use the next morning.

Samples of the glass taken two hours into the melt revealed mostly large bubbles, some fines, a little striae, and no batch stones. After four hours there were no cords or large gas bubbles and very few fines. Glass was slightly blue due to the addition of cobalt carbonate. This amount can be reduced to 0.1 gram or replaced with powder blue, a frit made from cobalt blue glass. Pull tests were performed with the German colorbars from Kugler, Zimmerman, and Reichenbach, all of which pulled slightly toward the clear glass. The degree to which the colors in the strands bent toward the clear was very nearly the same as that in subsequent tests with the Spruce Pine Company7 virgin chemical batch feedstock (which the Avalon Glass Company uses regularly). These pull tests indicate that the clear recycled glass cullet should fit the various colorbars, but due to melting temperature variations, each studio should do its own testing.

A variety of pieces were made that were similar to regular production work. Some new pieces were also made in order to test the glass' temperature working range and handling characteristics. The recycled glass was also tested for a new line of products by casting it into prototype sand molds. It worked very well in this application.

The recycled glass stayed hot and more malleable longer than the glass Andiamo was normally melting for production (West Virginia post-industrial art glass at $600 FOB Seattle). Upon re-heating, it seemed difficult to get one area hot for tooling without the whole piece becoming more malleable all at once. The recycled glass set up more quickly but could still be shaped and tooled without making tool marks. For casting, the recycled glass flowed well into complicated forms and easily healed over at the end of the pour.

While it seemed more difficult to work with the recycled glass for thin and complicated shapes that required considerable hand tooling, it was fine for thicker simple shapes. More experience with this glass would probably diminish this problem. The glass would probably be ideal for mold blown work because of its tendency to set-up quickly. This property also proved to be a great benefit when casting into metal and sand molds where it is important that the glass hold its shape and not deform (slump) during transfer into the annealing oven.

Annealing temperature was determined by pulling a rod out of the tank glass to approximately 1/4-inch in diameter and cutting it to 12-inches in length. One end was then captured between two firebricks and cantilevered out into the oven. The temperature was slowly brought up until the rod began to bend. At that point, the temperature was reduced 50 degrees and held at that temperature. (See Appendix C) The annealing schedule was determined to be:

- One hour soak at 920 degrees (see Appendix C - Annealing Temperature)
- 1/2 hour down to 810 degrees
- 1/2 hour down to 710 degrees
- 1/2 hour down to 610 degrees
- then, power-off

Due to their long term experience with glassblowing and significant understanding of glass chemistry, Andiamo Glass Studio was an excellent test site. Indeed, the more experienced glass workers seemed more amenable to trying post-consumer glass as a feedstock, possibly due to their appreciation that all commercial scale container glasses share more similarities than differences.

3.3 Avalon Glass Company

This West Seattle (WA) shop was selected because their glass is melted in an electrically heated freestanding crucible furnace. This furnace might be ideal for melting the minus 1/4-inch to plus 1/16-inch cullet available from the Mercer Island Community Recycling Center.

Melting. The furnace is powered by a silicon-controlled rectifier dimmer switch and eight Glowbar elements manufactured by IR**2** Company7 of New York. It has a 150-pound Lecleod-Christy7 crucible free-standing pot which requires 70-80 amps. on high fire, and 30 amps at idle temperature. An Omega7 controlling pyrometer is used to carefully regulate furnace temperature. Furnace electricity is not metered separately, but the total for monthly electric bills, including annealing ovens and lights, is between $200 and $250. The furnace was designed and constructed by Greg Englesby and Jim Moore of Seattle.

The post-consumer glass used for this test was also sourced from the Mercer Island drop box site. The glass was not screened or washed for this test. Chemical additions were combined in the following proportions:

- 2 pounds Soda Ash
- 33 g. Borax (Penta)
- 175 g. Niter
- 150 g. Fluorspar
- 1/2 lb. Lithium Carbonate
- 50 g. Antimony Oxide
- 25 g. Manganese Dioxide

This mixture was combined with 100 pounds of cullet using a large flour scoop that was also used to charge the furnace.

The furnace was preheated to 2,350 degrees Fahrenheit and charged with six scoops at approximately six pounds per scoop. The first charge was 36 pounds and melted for 60 minutes. The second charge was 30 pounds and allowed to melt for 120 minutes, followed by the third charge of 30 pounds and left on high fire for four hours. The furnace temperature was then reduced to 2,100 degrees for three hours. The furnace temperature is then slowly raised back to the working temperature, in this case 2,150 degrees.

The recycled glass melted faster and “fined out” much more quickly than the Spruce Pine virgin chemical batch formula that Avalon normally uses. Due to the small particle size of the cullet, there were no popping or small explosions as is often seen when using cullet of a much larger size. Preventing this sort of abuse of the furnace’s side walls is critical for lengthening the life of any furnace, particularly a free-standing crucible furnace.

Fining time could probably be reduced for this formula. The chemical agents worked well to stir the various glasses together to obtain one homogeneous glass. There were some cords observed near the bottom of the pot, but these could easily have been a result of residual glass from previous melts.

Pull tests were conducted as described in Appendix C. The threads for both transparent and opaque colors pulled straight, indicating an acceptable fit with the clear glass. The annealing temperature was determined to be 915 degrees Fahrenheit (see Appendix C Annealing Temperature).

The products usually made by Avalon Studio were produced with the post-consumer glass. The recycled content cullet melt lacked the clarity of the Spruce Pine Company glass, but was appropriate for all products where color was introduced. Working characteristics were also different in that the temperature working range was shorter, allowing the glass to set up quickly. This characteristic is desirable, however, for one of the major products made by Avalon - Christmas ornaments. It is likely that hand tool work would be easier given more time to become familiar with the glass’s character.

The ease of melting, the local sourcing, and particularly the cost advantage of $100-$150 per ton (as opposed to $775 per ton for virgin chemical batch or $600 per ton for West Virginia post-industrial glass, both FOB Seattle) makes melting post-consumer feedstock a very attractive opportunity. One of the Avalon associates has recently purchased another building and is planning to expand into a line of cast glass products. The post-consumer glass is well suited in all ways for cast glass production objects.

4.0 CONCLUSIONS

The three trials above constitute an evolution of experimental batch recipes and procedures, the latter of which were the most successful. The best results were attained during the third trial, conducted at Avalon Glass. The melt time was reduced during this trial without compromising the quality of the remelted glass. No popping occurred in the crucible during the melt, and the final product was free of stones and cords.

The working range of the glass produced at Avalon was relatively short, which allowed the glass to set up quickly -- a desirable characteristic for some cast and mold blown products. It is important to note, however, that there are many variables that influence the physical characteristics of remelted glass. Different melt conditions and base glasses will result in remelted glasses with different physical characteristics.

The trials described above have shown that it is possible to produce recycled glass ware with physical and aesthetic qualities similar to those of products made with virgin materials. Depending on the application, the use of recycled glass can also dramatically reduce energy and raw material costs.

Appendix A - *Chemicals for Glass*

Note: **For all chemicals read the MSDS* information carefully!**

Sodium carbonate or soda ash, **Na2 CO3**, is employed to provide alkali to the batch. Soda is a flux which by definition makes the glass melt faster. It also provides a longer working range, decreases the viscosity at all temperatures, increases the thermal expansion, decreases the chemical durability. Experimentally, an addition of 25% of soda ash to silica lowers the melting point from 3110 degrees Fahrenheit to 1460. In practice sodium should not exceed 18% of the batch or the durability may be lowered to a point that the glass is readily attacked by atmospheric water. It is important to keep soda ash in a dry storage space because it readily absorbs moisture and carbon dioxide, changing it to sodium bicarbonate. As a consequence, this additional weight can change the glass formula. More problematic still is that the moisture creates lumps in the soda that may difficult to melt out.

Boric oxide, **B2O3**, is introduced into glass formulas most commonly in the form of sodium tetraborate pentahydrate, Na2B4O7 5H2O, or 5 mole borax. Borax is used in its granular or powdered form and also supplies sodium as Na2O. Borax facilitates melting and fining to such a degree as to lower the melting temperature. It lowers the LEC significantly, shortens the working range, lowers the viscosity, and improves surface quality.

Sodium nitrate, **NaNO3**, also called niter, has the lowest melting point of most of the glassmaking materials. In addition to accelerating the melting of batch, niter is more importantly used as an oxidizing agent. Oxidizing agents work to keep the iron in glass in an oxide state which is yellow-green and easier to mask with decolorizers than the reduced form of iron which is blue-green. Calcium carbonate or lime, **CaCO**, is a powerful flux that reacts with silica at lower temperatures, gives glass stability, reduces the working range, and increases its resistance to chemical attack. If

* Material Safety Data Sheet

present in the glass at greater than 10%, lime may increase the possibility of devitrification (crystallization of glass).

Potassium oxide, **K_2O**, is usually introduced into the batch as potassium nitrate also called potash, K_2CO_3, which like soda, adds alkali. Potassium is a good fining agent and flux, and best when used in conjunction with sodium. Potash glasses are more viscous than soda glasses and colors are brighter, and in some cases even different (e.g. nickel is blue-purple in potash and brown in soda; selenium appears bluish pink in soda and brownish pink in potash).

Antimony oxide, **Sb_2O_3**, is similar to arsenious oxide and is used for the same purpose - to assist in the elimination of bubbles from the molten glass and to control the color of iron. Like arsenic, it is also very poisonous, and because the pentoxide decomposes more easily, is in some cases a more effective fining agent. It is the fining agent of choice because it works at lower temperatures and is used in conjunction with niter for maximum oxidizing effect. The oxidizing of iron - moving it from ferrous to the ferric state (i.e. making it yellow-green instead of blue-green) - is probably the most effective way to decolorize post-consumer glass. Antimony erases the inconsistent and difficult to control manganese. Selenium is now the preferred agent for decolorizing.

Lithium carbonate, **Li_2CO_3**, is a very active flux for silica , accelerates melting and fining, and is very effective in getting everything into solution.[*]

Fluorspar, or calcium fluoride, **CaF_2**, provides beneficial fluxing action and makes the glass less viscous, which allows more stirring and bubble action.

Manganese dioxide, **MnO_2**, was used as the only decolorizer in clear glass for hundreds of years, long before the chemistry was understood. Iron is always present as an impurity in raw materials for glass, and as a result of abrasion during beneficiation and transportation. Manganese is employed as an oxidizer to hold iron in the ferric state and as a physical decolorizer that absorbs light very nearly complementary to that of iron, especially in conjunction with a trace of cobalt oxide. It is, however, inconsistent and difficult to control and rarely used in industry any longer.

Antimony virtually erases its effect, giving the glass a gray color and making selenium the element most commonly used as a decolorant.

Cobalt oxide, **CoO**, is an extremely powerful coloring agent in glass, as little as one part in 500,000 will yield a tint of blue and one part in 5,000 is sufficiently intense for most ware. Because it is so strong, the oxide is used as a decolorant in some dilute form, such as **powder blue**, where it exists as a frit of glass containing between 4% and 6% cobalt depending on the supplier.

Selenium oxide, **SeO**, is the preferred decolorant for container glasses. The pink color of selenium partially complements the green color of iron and is an effective decolorizer when the oxidizers arsenic or antimony are present. Iron is thereby held to the yellow end of the spectrum and the glass is further physically decolorized at that point by the addition of a trace of cobalt.

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* According to Kerry Longaker, the production manager for the Glass Eye, with lithium added to the melt, "you can rule the world."

Appendix B - *Cullet Formula*

A large commercial glass container manufacturer cites the following percentages as the compositions of their large stockpiles of post-consumer cullet feedstocks for their furnaces.*

Oxides	**percent**
SiO_2	72.3
Al_2O_3	2.0
Fe_2O_3	0.1
CaO	10.4
MgO	0.6
BaO	0.05
NaO	13.3
	sum = 98.75

other oxides are not used in their calculations.

* Reference: phone report on 2-7-96

Appendix C - *Fritz's Annealing Temperature Test*

HOW TO DETERMINE THE CORRECT ANNEALING TEMPERATURE ("AT") OF YOUR GLASS;

IN **YOUR** OVEN; IN **YOUR** STUDIO

Remember, each oven may have a different temperature for ideal annealing!!!

{{ Do not use anyone else's annealing point numbers for your ovens! }}

My definition of the correct AT is: "that temperature which, in one (1) hour, does not bend a 1/4 inch rod, @ 18-inches long, standing diagonally (approx. 45 degrees) against the floor and wall of the oven being tested; but at that same temperature, does bend the same rod in four (4) hours."

You can run this test WHILE you are loading an oven; I periodically run a test while making my thick blown glass pieces. The canes can be out of the way, near the wall. If you want to test a new setting, remember to put in a **new cane** AFTER the oven is stabilized on the **new setting** ! Also one can substitute for the rod a strip of sheet glass 1/8" by 1/2" by @ 15" long.)

1. To start the testing first pull some straight rods & cut them approx. 18" long. Stabilize the oven in question at a temperature you believe will anneal your glass. Put the **cold** rod into the **hot**, stabilized oven!! The starting temperature doesn't matter, just give it a number. You can use 980 degrees Fahrenheit if you wish. Remember to be sure the temperature is stable at the suspected annealing temperature b e f o r e you put the test in the oven.

2. The best annealing temperature will result in the cane (or strip) remaining straight after one (1) hour, but bending after four (4) hours (at that same temperature!)

3. If the cane is bent in one hour or less, then the temperature too hot !! So lower the annealing temperature set point @ 10 degrees or more) and stabilize at the new temperature before you put in a new cane.

4. If the cane is still straight after four hours, your suspected annealing temperature set point is too low (you are too cold!) So raise the set point about 25 degrees or more. Then **after** the oven temperature is stable, put in a new cane and start a new test.

5. Eventually you can "zero" in on the correct temperature as you continue to test both higher and lower set points. Very thin glass can probably be annealed at a lower "a.t." setting if a long soak time is required (which might otherwise slump the thin units).

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