

# Closing the loop

## Design for Recovery Guidelines: **Glass Packaging**

glass



## Design for Recovery Guidelines: Glass Packaging

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When considering ways to enhance the sustainability of packaging, a primary goal must be to make wise use of material resources that are recoverable at the end of their useful life in industrial or biological cycles. To make this happen, it is critical to connect packaging design and manufacture with the available end-of-life recovery systems, creating a “closed loop” material system. Often, however, in the United States, the two ends of the packaging supply chain—the packaging designers and the recyclers—do not communicate effectively with each other: packaging which is not recyclable is created, material resources are lost to landfills, and closed-loop systems are not realized.

Often in the development of new packaging, little attention is paid to its practical recyclability, given the limitations of the current recovery systems. As a result, new packaging is released into the marketplace without an effective infrastructure for its collection and recovery, forcing recyclers to respond as best they can in an ad hoc manner. The *Design for Recovery Guidelines: Glass Packaging* (the Guidelines) will provide information that is necessary to assess the potential recyclability of new types of packaging before they are released into the marketplace.

One of the barriers to effective communication along the packaging supply chain is the lack of informational resources that explain how design decisions affect recyclability. This document is an effort to fill this gap. The Association of Postconsumer Plastic Recyclers (APR) has done an excellent job providing its *Design for Recyclability Guidelines* for plastic bottles, explaining which plastic bottles, including their attachments, inks, coatings, and colorants, are compatible with today’s various recycling technologies. This document extends this type of technical guidance to glass packaging so that package designers have the information they need to design glass packaging that behaves optimally in the recycling process.

The primary purpose of this document is to explain the effects of different physical aspects of glass packaging on the practical recyclability of that packaging in the current recycling system. To add context to this guidance, this document also provides an overview of glass manufacturing and conversion processes and the glass packaging collection, sorting, and reprocessing operations. A brief discussion is given regarding their relationships with the overall process in which glass packaging is recycled.



Glass has a long history of use as a packaging material that dates back over 3,000 years (GPI, 2010a) and glass currently accounts for 13.1% of all packaging in the U.S. by weight (U.S. EPA, 2009). Its benefits as a packaging material include transparency, chemical inertness, durability, and its ability to be formed into artistic shapes. There are many types of glass, each defined by their specific chemical makeup, but soda-lime glass is the most common type used in packaging applications. It is equivalently referred to as “container glass.” Soda-lime glass consists mainly of silica with appreciable amounts of sodium oxide and lime, as well as small amounts of alumina and other metal oxides.

Glass containers may be made in a wide array of shapes and sizes that are well suited to package a variety of products. Beverage bottles account for over three quarters of the glass containers produced, with the majority of glass beverage bottles being produced for alcoholic beverages. Bottles for beer and other flavored alcoholic beverages account for 64% of all glass packaging production, while wine bottles account for 5%, liquor bottles account for 4%, and other beverages account for an additional 9% (Cattaneo, 2009). Food containers, such as jars for sauces and bottles for dressings and condiments, account for 17% of glass packaging production, and the remaining 1% is accounted for by an assortment of other products, including pharmaceuticals and cosmetics (Cattaneo, 2009). Glass containers are produced in a range of sizes, from small vials and jars that hold less than one ounce to large four-liter jugs. In 2008, the U.S. manufactured over 34 billion glass containers (U.S. Census Bureau, 2009).

Along with shape and size, color is an important characteristic of glass containers. The vast majority of glass containers are constructed from clear, brown, or green glass. In general, clear glass is used most frequently, followed by brown and then green. Other colors, such as blue and purple, are sometimes used, but in relation to clear, brown, and green glass, their occurrence is almost negligible. In addition to aesthetics and brand identity, glass color is somewhat functional. Products that are affected by light, such as pharmaceuticals and beer, are usually packaged in brown containers because brown glass transmits the least amount of light. Foods are usually packaged in clear containers to enable an unobstructed view of the contents. Most wines are packaged in green bottles, although the choice of color is primarily dictated by tradition and the associated consumer perception (Soroka, 2002).

### Did You Know?

73% of glass bottles produced contain alcoholic beverages, such as beer, wine, and liquor.

Recovered soda-lime glass of all colors and container types is usually an ingredient in the production of new soda-lime glass. The information provided in the Guidelines is intended to cover the treatments and components most commonly used on a wide variety of glass containers. Glass packaging is manufactured to meet performance, health and safety, and market requirements. The Guidelines recognize the importance of those requirements and acknowledge that they are necessary to the safe delivery and/or marketability of the product and that there may be no viable alternatives. However, the main focus of the Guidelines is to make suggestions that will maximize the recyclability of glass packaging.

Finally, some barriers to the increased recyclability of glass packaging may be attributed to design aspects of the package, while others may be attributed to issues unrelated to design, such as consumer behavior, collection and sorting processes, and recycling program infrastructure in communities across the United States. For glass packaging, the greatest barriers to recycling may be the geographic variation of markets for recovered glass, the inability of most sorting equipment to distinguish between soda-lime glass and other glass types, and the loss of cullet quality due to container breakage in the collection and sorting processes. However, the Guidelines are limited to a discussion of how the design of glass packaging affects its potential recovery, not the comprehensive issues surrounding successful recovery of glass packaging.

Primary research for the Guidelines included interviews of stakeholders from various portions of the glass recycling process. Interviews were conducted with glass producers, brand owners, operators of recycling programs, industry associations, and governmental organizations. In addition, a broad literature search was performed to find recent developments in glass recycling.

Glass may be infinitely recycled with essentially no loss of quality. Because of this, it is a valuable commodity in high demand by the glass container manufacturing industry. However, there is a very large amount of soda-lime glass that is not recycled into new containers. In 2009, almost 10 million tons of glass packaging was used in the U.S., representing 4% of all municipal solid waste by weight. Of this amount, only 3 million tons (31% of glass containers, 1.2% of all municipal solid waste) were collected (U.S. EPA, 2011). Using the estimate that 80% of collected glass is used to make new glass containers (GPI, 2010b), it follows that only 24.8% of the glass containers used in 2008 were recycled to create new glass containers. States that have container deposit legislation commonly exceed this national average for glass container collection. For example, in 2009, California collected 80% of all glass beverage containers that were sold (CalRecycle, 2010a).

Along with constraints imposed by collection practices and geography, certain decisions made in the packaging design process may have impacts on the recyclability of glass containers. Closures, labels, and decorations often end up as contaminants in the glass recycling system where they may ultimately lower the value of an entire load of glass and prevent it from being used in the production of new containers. When contaminants do persist into the glassmaking process, they often result in the production of defective containers or damage to the expensive glassmaking equipment. Well-designed containers can result in more recovered glass being available to make new glass containers in an economically and environmentally preferable system.

Because the ways in which design decisions affect recyclability of glass are often not obvious, this guidance describes the most common effects and offers alternatives when possible, although recycling-compatible alternatives may not exist for some of the commonly-used problematic components. Ideally, this guidance will inform decisions that lead to the creation of glass containers that are truly optimal for the recycling process—containers that can be remade again and again in a “closed loop” system.

### Did You Know?

Like steel and aluminum, glass is an infinitely recyclable material with no loss of quality.

## Internal and External Treatments

### EXTERNAL COATINGS

#### What is it?

Over 95% of glass containers manufactured in the U.S. receive two exterior coatings during the glassmaking process (American Glass Research, 2005). The first coating, termed the “hot end” coating, is applied before annealing, right after the container is formed. This coating is usually a thin layer of tin oxide, commonly applied in the form of stannic chloride (tin tetrachloride) or an organic compound such as butyltin trichloride. The second coating, termed the “cold end” coating, is applied after annealing is completed, and consists of a lubricant such as oleic acid or polyethylene wax (Snyder, 1990).

#### Why is it used?

The hot end coating acts as a chelate that enhances bonding between the glass container and the cold end coating. The cold end coating reduces the friction on the containers as they rub against each other, and provides general protection against surface scratches over each container’s lifespan. Such protection is critical for the mechanical integrity of glass containers, as even small surface scratches provide points from which failure-inducing fractures may form (Snyder, 1990).

#### Where is it found?

Every type of glass container typically receives both the hot end and cold end coating. Oleic acid is generally not used for the cold end coating on beer bottles because it may negatively affect the flavor of the beer (Snyder, 1990).

#### External Coatings in Recycling

The external coatings that are applied to glass containers are not problematic in the recycling process, and are beneficial in protecting glass containers from premature breakage that would preclude the glass from color sorting. Because these coatings are typically vaporized off the glass in the melting furnace, care should be exercised in choosing an external coating that will result in the lowest amount of emissions (M. Lonsway, personal communication, April 16, 2010).

#### Alternatives

It is not recommended to forgo external coatings, because of the protection they provide. As noted above, there are several different, functionally equivalent compounds that may be used as the cold end coating. For example, if there is concern that oleic acid will negatively affect the flavor of beer, polyethylene wax may instead be used to coat beer bottles.



## INTERNAL TREATMENTS

### What is it?

In addition to exterior treatments and coatings, the interiors of some glass bottles are given a treatment called dealkalization, which eliminates a container's ability to react with its contents. The treatment "dealkalizes" the interior glass surface by forcing the replacement of problematic sodium ions with non-problematic hydrogen or hydronium ions. This process is typically initiated by injecting either a sulfur-based or fluorine-based salt into the glass containers before they enter the annealing lehr. When the lehr is heated, the compound decomposes to create the hydrogen-bearing gases that evict the sodium ions. Once the lehr is subsequently cooled, the evicted sodium ions react with the hydrogen-depleted gases to form salts that can be easily washed away.

### Why is it used?

Soda-lime glass is partially composed of alkaline sodium ions, which have a small tendency to migrate from the interior glass surface into the liquid contents and raise the liquid's pH. Though most liquids contain a natural capacity to withstand changes in pH, some pharmaceuticals and alcoholic spirits have no such resistance, and the introduction of an alkaline substance will cause them to become increasingly alkaline. When the liquid's pH is raised high enough, it becomes caustic and eats away at the glass container, leaving small glass particles suspended in the liquid.

### Where is it found?

Dealkalization is used on bottles that are intended to contain chemically sensitive liquids. It is used on the majority of liquor bottles. It is also used as an alternative to borosilicate glass for pharmaceutical containers.

### Dealkalized Glass in Recycling

Dealkalized glass is not problematic in recycling operations. Although its chemical composition is slightly modified, its impact on the overall chemistry of a melted batch of glass is negligible (P. Ross, personal communication, June 22, 2010).

### Alternatives

For liquor bottles, there is no functionally equivalent alternative that is used. Borosilicate glass is a widely used alternative to dealkalized glass for pharmaceutical packaging. Because borosilicate glass often persists through the sorting process into a soda-lime glass furnace where its high melting temperature causes it to be very problematic, dealkalized glass is the recommended glass type for pharmaceuticals (Soroka, 2002).



## RADIO FREQUENCY IDENTIFICATION (RFID) TAGS

### What is it?

Radio frequency identification tags are occasionally affixed to packaging and used for automatic identification and data collection purposes. Similar in purpose to a bar code used to track inventory, a RFID tag consists of layers of paper, plastic (PET), and adhesive sandwiching a metal foil antenna or conductive ink (aluminum, copper, or silver), and may include a computer chip or battery (O'Connor, 2008; European Commission, 2007; Maltby et al., 2005).

### Why is it used?

RFID tags store information, such as the contents of a pallet or package, destination in a store, or warehouse location. The information on RFID tags is accessed remotely by readers that display the tag information. The tags have also been suggested as a replacement for UPC bar codes that would not only track inventory information, but also inform consumers about how to recycle the package when it is time for disposal (Thomas, 2008). In 2008, the U.S. EPA also suggested that RFID tags could play a role in material recovery at a package or product's end of life by tracking valuable or hazardous materials for collection and recycling (Kowl, 2008).

### Where is it found?

To date, RFID tags remain relatively expensive and are therefore not in wide use. They are primarily used on shipping packaging, such as corrugated containers, pallets, high-value merchandise, and pharmaceuticals. Although some retailers have suggested they will soon attach RFID tags to all products sold, the expense of the tags has limited the expansion of this plan (O'Connor, 2008).

## Did You Know?

RFID tags with metal components are considered a contaminant to the glass recycling process.

### RFID Tags in Recycling

RFID tags will be harmful to the glass production process if they are not effectively sorted out from glass containers. The glassmaking process is highly affected by the presence of metals, which are present in RFID tags as the transmitting antenna and other components. Metal particles can sink to the bottom of a melted batch of glass, where they can cause damage to the expensive furnace lining. Also, some metals act as colorants. When mixed with glass in the furnace, these metals are capable of creating a visible effect on the color of the batch of glass. To compensate for unwanted colorations, additional colorants must be added to create an overall neutral hue. Moreover, small metal particles may not melt in the furnace and can prevent other particles in the batch from melting, ultimately creating defective glass and resulting in rejected containers (GPI, 2010c).

### Alternatives

Currently there are no functionally equivalent alternatives to RFID tags. It is recommended that their use on glass packaging be avoided.

## Lids and Closures

### STEEL

#### What is it?

Steel is commonly used to make jar lids and crown caps. In both applications, the underside of the closure is lined to create an airtight seal between the steel closure and glass container. The lining may be comprised of a single layer of soft plastic or may be a separate component consisting of layered paper, foil, wax, and plastic. Steel lids made for glass food jars usually consist of one piece, though Mason jar lids consist of a flat round piece used in conjunction with a threaded outer band. These jar lids are almost universally constructed to twist off so that they may be resealed, while crown caps used for single-serving beverages are commonly fashioned to twist or pry off and remain detached (Soroka, 2002).

#### Why is it used?

Steel lids and closures are used for their strength, protective barrier properties, and durability. Steel jar lids often feature a tamper-evident “click button” that reveals if a jar has been previously opened.

#### Where is it found?

Steel lids and closures are extremely prevalent in glass packaging. Most glass jars for food products use a steel lid, and nearly every beer bottle uses a steel crown closure. Steel lids are almost always used when a glass container must undergo a pasteurization process.

### Did You Know?

Metals of any type are a problem for glass reprocessing. Metal can damage the furnace lining, give the glass an unwanted color, or cause defects in finished glass containers.

#### Steel Lids and Closures in Recycling

Steel lids and closures are generally easy to separate and remove from glass containers during the sorting process and are often sold as scrap for steel recycling (Eco-Cycle, n.d.). Steel is the only packaging material that is inherently magnetic, making it very uncommon for steel components to pass through a sorting process undetected. This is especially true since glass containers are often processed through an automated sorting line twice: once at a material recovery facility (MRF) and once during glass beneficiation.

Any steel component passing the initial magnetic separator undetected (possible when a lid or closure is still attached to a heavy non-magnetic container) is usually detected and removed when the glass is crushed and subjected to a second round of magnetic separation. Any steel pieces that reach the melting furnace despite magnetic sorting are very problematic in the glassmaking process. In addition to imparting an unwanted greenish-yellow tint to a batch of glass, steel pieces will damage the refractory bricks lining the furnace and cause pieces to come loose. These loose pieces may ultimately end up as an inclusion in a defective glass container, and the expensive refractive lining will require premature repair (J. Cattaneo, personal communication, March 3, 2010; J. Scripter, personal communication, March 15, 2010; B. Clark, personal communication, March 31, 2010; T. Abel & B. Dillamin, personal communication, April 16, 2010).

#### Alternatives

There are many alternatives to using steel lids and closures, including plastic and aluminum screw tops. However, automated sorting techniques are more effective at identifying and removing steel than plastic and aluminum, so it is not recommended to use a plastic or aluminum closure in place of a steel lid or crown closure.

### PLASTIC

#### What is it?

Most plastic closures are primarily constructed of high-density polyethylene (HDPE), low-density polyethylene (LDPE), or polypropylene (PP). Though most plastic closures are designed to screw onto a threaded finish at the opening of a glass container, they are not always designed to be unscrewed as the primary means of dispensing the contents; there are numerous designs that incorporate a living hinge to create a “flip top” (Soroka, 2002).

The use of a plastic closure usually necessitates the use of a detachable tamper-evident plastic component. Containers having flip tops or wide screw tops may use a plastic film wrapper to enclose the entire upper portion of the bottle much like a wine bottle capsule. If a small screw top is used, it is common to incorporate a breakable ring that remains around the bottle's neck after the container is initially opened.

#### Why is it used?

Plastic closures are mainly used for their combination of protection, durability, and cost. Plastic is also the only material that is used to create closures with a complex structure such as a top for a disposable pepper grinder.

#### Where is it found?

Plastic closures are commonly used on glass bottles designed for contents that are not intended for single-usage consumption, such as spices, alcoholic spirits, condiments, and dressings. These closures are less commonly used on food jars, such as those designed for nuts and peanut butter.

### Did You Know?

If not removed during sorting, melting plastic pieces can introduce air bubbles into the glass during reprocessing.

#### Plastic Lids and Closures in Recycling

Plastic closures are slightly problematic in glass recycling. Although the sorting and beneficiating processes are fairly effective in removing plastic pieces from the recovered glass, it is common for small pieces to remain intermingled with cullet that it is fed into a melting furnace. The glass furnace temperature is high enough to melt and vaporize plastic. However the plastic tends to create numerous bubbles and foam as it vaporizes, which introduces gas bubbles into the melt that must be removed by adding a fining agent such as sodium sulfate. The combination of vaporizing plastic and increased use of fining agents produces emissions that could otherwise be avoided (P. J. Walters, personal communication, May 21, 2010; J. Cattaneo, personal communication, March 3, 2010).

#### Alternatives

Steel and aluminum closures are commonly used alternatives, and aluminum screw tops provide a functionally equivalent alternative to the common plastic screw top. Although metals are also problematic in the glass furnace, sorting technology is generally more efficient at filtering metallic objects out from a load of cullet.

## CORK

### What is it?

Cork stoppers are cylindrical plugs made from aggregated particles of bark from the cork oak tree. They are compressed and inserted into the upper neck of a bottle, where they expand and create a tight protective seal. Corkscrews are generally needed to remove cork stoppers, although the “mushroom” type cork stoppers used on champagne bottles may be removed by hand. Once removed, a cork stopper may be reinserted to seal a bottle, although it is typically not possible to compress and reinsert a cork stopper back to its original placement.

### Why is it used?

Historically, cork was used for its ability to compress and expand and create a watertight seal. Cork stoppers are mainly used today for their perceived association with quality (Soroka, 2002).

### Where is it found?

Cork stoppers remain the most prevalent closure used on wine and champagne bottles. They are occasionally used as a closure for other beverages, such as premium alcoholic spirits and beers.

### Cork Stoppers in Recycling

Cork stoppers are not problematic in the glass recycling process. Corks are not fragile or readily breakable. They typically remain whole during the glass beneficiation process and are easily removed by screens. Once they are filtered out of the crushed cullet, they may be recycled. Any small bits of cork that reach the glass furnace will be vaporized and will not create defects in the produced glass (B. Clark, personal communication, March 31, 2010).

### Alternatives

There are several alternatives to cork stoppers, including aluminum screw tops, synthetic plastic corks, glass stoppers, and steel crown caps. Although there is debate over the ability of the various types of closures to retain their seal over long periods of time, each type of closure is generally considered to be functionally equivalent.

## ALUMINUM

### What is it?

Aluminum screw tops are threaded, resealable closures commonly used as an alternative to plastic screw tops and cork stoppers. When used as a wine closure, they typically incorporate a “skirt” of thin aluminum foil that extends from the cap down the bottle neck to mimic the appearance of a traditional wine bottle capsule. Because the closure is perforated around the lower extent of the cap, the skirt typically remains on the bottle when it is discarded. Aluminum screw tops used in place of the common plastic screw top typically incorporate a tamper-evident band that detaches from the screw top after the initial opening but remains attached to the bottle when it is discarded (Alcan, 2010).

### Why is it used?

Aluminum screw tops are used for their protective properties, ability to be resealed, and visual appeal. In comparison to the traditional cork stopper, the aluminum screw top is especially advantageous in its ability to be resealed and for its chemical durability over long periods of time. As an alternative to a plastic screw top, aluminum screw tops are generally used for their appearance, providing visual differentiation from comparable products.

### Where is it found?

Aluminum closures are used on wine bottles more often than other glass bottles, although they are sometimes used on bottles for other beverages, such as premium water and alcoholic spirits.

### Aluminum Closures in Recycling

Aluminum closures are problematic in glass recycling if they are not effectively removed from the cullet during sorting and beneficiation. Although the use of an eddy current separator is generally very effective in removing aluminum contaminants, the small tamper-evident rings often remain undetected and enter the glass melting furnace. Once in the furnace, they are capable of damaging the refractory furnace lining. The piece of aluminum and broken pieces of the furnace lining may end up as inclusions in the produced glass containers (B. Clark, personal communication, March 31, 2010; R. Abramowitz, personal communication, March 3, 2010; J. Cattaneo, personal communication, March 3, 2010).

### Alternatives

Aluminum screw tops are generally considered to be alternatives to more commonly used closures, such as the cork stopper and the plastic screw top. For single-serving bottles, steel crown closures may be used instead.

### OTHER CLOSURES

#### What is it?

Other closures include lids and caps made from various combinations of plastics, metals, paper, rubber, wood, cork, glass, and ceramics. One notable specialized closure is the “lightning style” closure, consisting of a plastic or ceramic plug with a rubber gasket that sits atop a bottle, held in place by a wire bail. The wire bail is effectively attached to the bottle by encircling the narrowest part of the bottle neck. When the bottle is discarded, this style of closure commonly remains attached to the bottle.

#### Why is it used?

Uncommon closures are typically used to provide visual differentiation and a luxurious look to the packaging. Many of these closures, such as the lightning style closure, were historically widespread in use and are used today to evoke a sense of authenticity.

#### Where is it found?

Because they are typically more expensive, these uncommon closures are usually used on high-end alcoholic beverages such as beer and alcoholic spirits.

#### Other Closures in Recycling

While most materials are not problematic in glass recycling, some materials, such as metals and ceramics, are very problematic. Most plastic and organic materials will burn off in the hot glass melting furnace, but metal and ceramic pieces do not. Because of this, the lightning style closure is problematic in glass recycling. Since this closure is designed to be affixed to the bottle, the metal and ceramic pieces are often still attached to glass pieces during beneficiation and may enter the glass furnace if they remain undetected (R. Abramowitz, personal communication, March 3, 2010).

#### Alternatives

These closures are generally considered to be alternatives to more common closures such as steel and plastic. In many cases a steel crown cap or a plastic screw top may be used in place of an uncommon closure. Although they offer less visual appeal, the glass recycling process is better accustomed to their detection and removal.



### Labels and Decorations

#### ETCHING

##### What is it?

Etching is the process by which selected portions of a glass container are made slightly opaque, creating a decorative effect. Etching may be done by blasting the container with an abrasive material or by exposing the container's surface to a corrosive substance such as hydrofluoric acid. Both methods create numerous small pits in the container's exterior, roughening its surface and decreasing its ability to transmit light. Because a visibly noticeable contrast is created between etched and non-etched areas, etching may be used to create text and can serve as an alternative to plastic or paper labels (GPI, 2010d).

##### Why is it used?

Etching is used for its visual effect and is primarily a decorative treatment, although it may also be used to create text or depict a logo.

##### Where is it found?

Etching is most commonly used on bottles containing alcoholic spirits, but is occasionally used on bottles for perfumes and other cosmetics. It is common to etch a large portion or the entirety of a container to produce the effect of "frosted" glass.

##### Etched Glass in Recycling

Etched glass is not problematic in recycling. Although acid etching may slightly modify the chemical makeup of a glass container, the alteration is very minor, and the effect on an entire batch of glass will be negligible.

##### Alternatives

Etched glass is used for various purposes, but generally it may be considered to be an alternative to paper or plastic labels in providing decoration, information, or both.



## APPLIED LABELING

### What is it?

Applied labeling generally refers to applied ceramic labeling (ACL), a method in which special inks are screen-printed onto the surface of a container and then fused to the glass in the annealing lehr. The inks consist mostly of pieces of powdered glass called “frit,” and accordingly contain all of the constituent materials and colorants of glass. Once this powdered glass-based ink is baked on to the glass surface, it has the appearance of a painted label with a durability that is much greater than that of regular paints.

The inks that are traditionally used in ACL tend to contain high levels of volatile organic chemicals and heavy metals in the colorants. 19 states have enacted legislation that bans the usage of these inks, such as California’s Proposition 65 and similar regulations enacted by the Coalition of Northeastern Governors (The Toxics in Packaging Clearinghouse, 2009).

As a regulation-compliant alternative, the applied labeling process may use non-toxic inks based on organic polymers. This type of applied labeling may be referred to as applied color labeling (which is, confusingly, also referred to as ACL; note that in this document, the abbreviation ACL is used only to refer to applied ceramic labeling) or applied organic labeling. The non-toxic inks offer a wider range of bright colors, but their adhesion is highly affected by the condition of the container’s surface. Unlike the traditional inks that are fused to the glass, these inks are affixed to the container’s surface by numerous individual bonds; accordingly, their adhesion is greatest when the surface is roughly textured to provide more area over which bonds may attach. Because the cold end coating smoothes the container’s surface, it generally must be removed and then reapplied after the ink is applied (Ceramic Industry, 2001).

### Why is it used?

While there is no functional advantage to applied labeling, it is often used as an alternative to paper and plastic labels for its appearance of being painted on the glass surface, thereby providing visual distinction on the shelf.

### Where is it found?

Applied organic labeling is not commonly used, but when it is, it is mostly applied to bottles containing beer or alcoholic spirits. Applied ceramic labeling is almost never used in the U.S. but may still enter the recycling system by way of imported beverage bottles, as many other countries have not banned its usage (J. Cattaneo, personal communication, March 3, 2010).

### Applied Labeling in Recycling

Applied organic labeling is not problematic in the recycling process. As its name implies, applied organic labeling utilizes organic materials, which all vaporize in the hot melting furnace. Although they are not problematic in recycling, these inks transform into gaseous emissions as they vaporize. The colored glass frit used in traditional applied ceramic labeling contains a glass chemistry that is different than the chemistry of the glass container on which it is applied, but its occurrence is so rare and the chemical contribution so small that it makes a minor impact on a batch of melted glass. In large amounts, cullet with applied ceramic labeling is capable of imparting a slight blue tint to a batch of glass (J. Cattaneo, personal communication, March 3, 2010).

### Alternatives

Full body plastic shrink labels are the most commonly used alternative to applied labeling. By using a clear label with small areas of color, a plastic shrink label is capable of providing a similar appearance to applied labeling. Paper labels, pressure sensitive labels, and etching are other common methods of imparting decoration and information.



### PAPER LABELS

#### What is it?

Paper labels are commonly applied to glass containers and consist of a printed piece of paper with an adhesive backing. The label paper is typically treated with a glossy coating and in some instances colored aluminum foil to further enhance its visual appeal. If the contents of a glass container require refrigeration, the label paper may be reinforced with a wet strength additive so that it doesn't disintegrate in the presence of condensation.

Paper labels generally fall into one of two classifications: wraparound labels, which fully encircle a container and can only be applied to a section of a container that does not have complex curvature; and spot labels, which are small and may be applied to almost any portion of a container regardless of its curvature. If a wraparound label is used, it is typically affixed by gluing the label to itself by applying a band of adhesive to the label's overlapping edge. Spot labels require more adhesive and are typically attached by applying a thin layer of glue over most of the backing of the label. Most commonly, either a hot-melt or room temperature label pick-up adhesive derived from casein is used to provide adherence (A. H. Crow, personal communication, June 23, 2010; Soroka, 2002).

#### Why is it used?

Paper labels are used for their cost-effective ability to provide a large area on which text and graphics may be displayed in a wide range of colors.

#### Where is it found?

Paper labels are widely used. Most glass containers used for food products are given a paper label, as are most bottles used for wine, beer, and alcoholic spirits.

### Did You Know?

In general, paper presents no problems to the glass recycling process.

#### Paper Labels in Recycling

Paper labels are generally not problematic in recycling. Usually, when glass containers are crushed, the paper labels detach and are later removed from the glass by a vacuum separator. In some cases, glass pieces may remain attached to the paper label where bands of adhesive were located. If the glass pieces do not weigh the paper label down too much, it will still be picked off by the vacuum separator along with the glass pieces that are attached to it, resulting in a small loss of useable cullet. If the attached glass pieces prevent the vacuum separator from removing the label, then the label may continue through the process and enter the glass melting furnace, where it will burn off. The paper labels that are removed during the beneficiation process may be accumulated and sent off to a paper recycling process, although they must be free of any residual glass shards, which is difficult to achieve (J. Scriptor, personal communication, March 15, 2010; B. Clark, personal communication, March 31, 2010; F. Hottenstein, personal communication, April 1, 2010).

#### Alternatives

To provide visual product differentiation, label options other than the commonly-used paper label are often selected. Other labeling methods include etching, applied labeling, plastic shrink labeling, or pressure sensitive labeling. Paper labels are generally the most economical method of displaying a large amount of graphics and text, although plastic shrink labels may provide more coverage over a container.

### PRESSURE SENSITIVE LABELS

#### What is it?

Pressure sensitive labels are multilayer plastic films with a pressure sensitive adhesive applied to the entirety of the label backing, similar to a sticker. The adhesive is composed of either an acrylic polymer or a blend of rubber and petroleum resin. As their name implies, they are affixed to a container by applying pressure, causing the adhesive to bond to the glass surface (A. H. Crow, personal communication, June 23, 2010; Soroka, 2002).

#### Why is it used?

One of the main advantages of using pressure sensitive labels is that the adhesive is integrated onto the labels, so they do not require a separate supply of adhesive to affix them to containers. Also, the labels are usually bulked in rolls of release-coated paper, which provides an advantage over stacked paper labels by making it easier to keep track of the number of labels used. This is of particular importance in pharmaceutical packaging operations, where extra care must be taken in keeping track of labels (Soroka, 2002).

#### Where is it found?

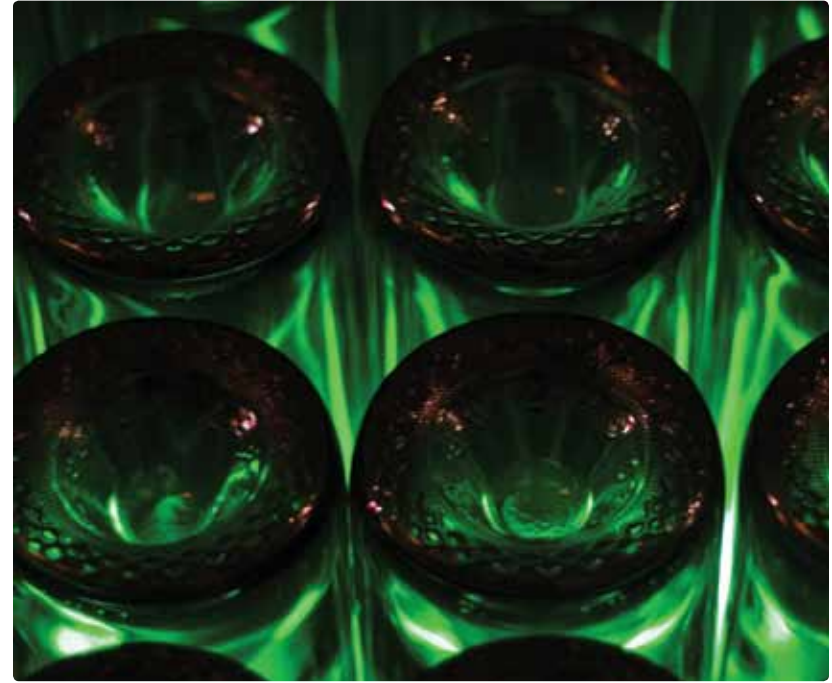
There are no aspects of pressure sensitive labels that prevent them from being used on any type of glass packaging, but they are most commonly used on beer bottles, bottles for premium brand alcoholic spirits, and pharmaceutical containers.

#### Pressure Sensitive Labels in Recycling

Pressure sensitive labels are not problematic in glass recycling operations. The labels should be separated and removed from the glass during beneficiation, when the containers are crushed into cullet and vacuumed. However, if the labels reach the glass furnace, they will vaporize because the film, ink, and adhesive are all derived from organic materials.

#### Alternatives

There are numerous alternatives to pressure sensitive labels, including paper labels, full body shrink labels, and applied labeling.



### FULL BODY SHRINK LABELS

#### What is it?

Full body shrink labels made from plastic are used as an alternative to paper labels. These labels are typically constructed from polyvinylchloride (PVC), polypropylene (PP), or polyethylene (PET) and offer an advantage over paper labels in their ability to conform to complex curvature (Soroka, 2010; GPI, 2010d).

#### Why is it used?

Shrink labels are commonly used in instances when full coverage of a container is desired. By applying localized areas of text and graphics to clear shrink labeling, an appearance similar to applied labeling can be achieved. A colored shrink label may be used on a clear glass container to create the appearance of a colored glass container.

#### Where is it found?

Shrink labels are used on a variety of glass containers, including those containing alcoholic spirits, beer, tea, juice, and other beverages.

#### Full Body Shrink Labels in Recycling

Full body shrink labels are generally not problematic in glass recycling. When the glass containers are crushed during beneficiation, the shrink label is usually sufficiently separated from the broken glass pieces and can be removed by a vacuum separator. Because shrink labels are roughly container-shaped, broken pieces of glass may remain inside of the labels and weigh them down, rendering them too heavy to be removed by the vacuum separator. When this happens, labels may prevent glass pieces from being correctly color-sorted by an optical sorting machine. If a plastic shrink label is present in a load of cullet that enters the glass melting furnace, it will vaporize and contribute to unwanted gaseous emissions (B. Clark, personal communication, March 31, 2010; P. J. Walters, personal communication, May 21, 2010; S. Mouw, personal communication, March 11, 2010).

### Did You Know?

During the crushing process, full body shrink labels may trap pieces of broken glass inside, making the label too heavy to be vacuumed off. Labels may also obscure glass pieces from the optical sorting machine.

#### Alternatives

There are several alternatives to full body shrink labels. Depending on the desired appearance of a shrink label, alternative labeling methods, such as applied labeling, may be functionally equivalent. Paper and other plastic labels are widely used alternatives to full body labels, although they do not possess the capability of plastic shrink labels in providing coverage over an entire container. Etching, while limited in color, is the only feasible labeling alternative capable of providing this type of full coverage.

## CAPSULES

### What is it?

Capsules are protective sleeves covering the top of a bottle, and are almost always present on wine bottles and champagne bottles. They are less commonly used as a tamper-evident seal on glass containers with steel lids. Capsules are often perforated so the uppermost section may be readily removed to provide access to the closure while the rest of the capsule remains attached to the bottle. Historically, all capsules were constructed of lead foil, but concerns over lead toxicity resulted in legislation that banned their usage in 1996 (U.S. Code of Federal Regulations, 1996). Modern capsules are typically made from aluminum foil or a heat-shrink plastic such as PVC, polypropylene, or polyethylene.

### Why is it used?

Historically, capsules were used to protect cork stoppers from exposure and deterioration. Today, capsules are used for both their association with the traditional appearance of wine bottles and their properties as a tamper-evident seal.

### Where is it found?

Capsules are often used on wine and champagne bottles and are occasionally used on glass food containers without other tamper-evident features. Capsules are also used on beer bottles to impart a premium appearance. Capsules constructed of lead may still occasionally enter the recycling stream when they are present on old bottles of wine.

### Capsules in Recycling

While plastic capsules are generally not problematic in glass recycling operations, metal capsules are problematic if they enter the glass melting furnace. Like all metal objects, metal capsules are capable of damaging the refractory lining of the furnace and can cause pieces of the furnace lining to break away. Besides damage to the furnace, metal capsules and loose pieces of furnace lining will not melt and may end up as inclusions in glass containers that will be rejected. Lead capsules are particularly problematic because lead is capable of tinting a batch of glass light blue, which necessitates the use of additional colorants to counterbalance the hue. While plastic capsules are not as problematic as metal capsules, they contribute to unwanted emissions as they burn off in the hot melting furnace.

### Alternatives

While capsules provide a useful tamper-evident feature, only a small covering of the bottle opening is necessary for this, and much of a capsule may be omitted. In some instances, other tamper-evident components may be used as an alternative to capsules, such as tamper-evident seals. It is recommended that capsules be constructed from plastic as these capsules are not as problematic as metal capsules.

### WAX

#### What is it?

Wax is occasionally applied as a decoration on glass bottles. It is commonly applied as a small circular “stamp” with an imprinted design, though some glass bottles feature a full capsule made of sealing wax.

#### Why is it used?

Wax is often used to evoke a sense of antiquity by emulating its historical use as a tamper-evident closure or as an identifying symbol. Although wax is occasionally used as a capsule, plastic and metal capsules offer superior functionality in their ease of opening.

#### Where is it found?

Wax is most commonly used on bottles containing premium alcoholic beverages, most often wine and alcoholic spirits. Rarely, wax is used as a decoration on containers for high-end food products.

#### Wax in Recycling

Wax is slightly problematic in the glass recycling operation. While it will burn off and vaporize in the hot glass melting furnace, it complicates optical sorting when it remains attached to pieces of glass from the crushed containers. The opaque characteristic of wax may trigger the optical sorter to remove the pieces of glass with wax attached, resulting in a small loss of usable cullet.

#### Alternatives

As a capsule, wax is a rarely-used alternative to more common materials such as plastic and foil. Small circular pieces of rigid plastic are occasionally used to mimic a decorative wax seal.

### TAMPER-EVIDENT SEALS

#### What is it?

Tamper-evident seals made of paper, foil, plastic, or layered combinations of these materials are commonly applied to glass containers. They are sealed across the opening of a container underneath its closure and must be removed before the contents can be dispensed. Because tamper-evident seals are typically fashioned to completely detach from the container, they are usually discarded separately from the glass container (Soroka, 2002).

#### Why is it used?

Tamper-evident seals are generally used when no tamper-evident feature may be incorporated directly into the closure.

#### Where is it found?

Tamper-evident seals are commonly used on glass food containers with plastic lids, such as peanut butter jars and bottles that contain dressings or condiments.

#### Tamper-evident Seals in Recycling

Although most tamper-evident seals are discarded separately from the container on which they are used, tamper-evident seals remaining attached to containers are not problematic in glass recycling operations. Even though a tamper-evident seal may incorporate a layer of aluminum foil, the small thickness of the metal component will cause it to rapidly oxidize and vaporize in the intense heat of the glass melting furnace.

#### Alternatives

The use of tamper-evident seals may generally be eliminated if a closure with an inherent tamper-evident feature is used. Such closures include steel lids with pressable bubble-tops and aluminum and plastic screw tops with detachable tamper-evident bands. Plastic capsules are occasionally used as an alternative tamper-evident component with closures that are not inherently tamper-evident.

### Overview of Soda-Lime Glass Production

Glass is produced by heating a mixture of sand, limestone, sodium carbonate, and other feedstocks and then rapidly cooling the mixture. The primary ingredient is silica, which is obtained from sand. When silica is rapidly cooled, it is prevented from forming an ordered crystal structure and a special quality of transparency is created. While glass may be constructed solely from silica, improvements to both the manufacturing process and the quality of the finished glass may be obtained by incorporating additional ingredients termed “fluxes.”

Pure silica has a very high melting temperature of 1,650°C, and a large amount of energy is required to maintain a furnace above this temperature. To lower the required temperature, sodium carbonate (soda ash) is added to the furnace, where heat forces the liberation of carbon dioxide to leave behind sodium oxide (soda) or potassium oxide. Because these compounds have melting temperatures that are considerably lower than that of silica, the inclusion of either compound with silica results in a significantly lower overall melting temperature (Glass Packaging Institute [GPI], 2010e).

While this benefit is advantageous, a glass made solely from this mixture will be susceptible to chemical alterations, most notably dissolution by water. To re-establish chemical durability, calcium oxide is added to stabilize the molecular network. Aluminum oxide (alumina) is also added as a network stabilizer, imparting mechanical durability as well as additional chemical durability. The final composition of soda-lime glass is typically around 72% silica, 13% sodium oxide, 12% calcium oxide, and 2% aluminum oxide (GPI, 2010e).

Virtually all soda-lime glass manufacturers today add pieces of crushed post-consumer glass containers, called cullet, to the melting furnace, as well as broken or rejected glass pieces from within the manufacturing facility. Incorporating cullet both reduces the need for raw materials and further decreases the required furnace temperature, thereby reducing energy consumption and extending furnace life (GreenBlue Institute, 2009). Cullet can account for up to 90% of the raw materials in the production of a batch of container glass (P.J. Walters, personal communication, May 21, 2010). Requirements may vary by state or country. In California, all glass containers must be made using 35% cullet, and Californian glass container manufacturers reported using 47.9% cullet in 2009 (California Public Resources Code Division 12.1; CalRecycle 2010b).

### Did You Know?

For every 10% of cullet used in glass production, the energy needed to manufacture glass is reduced by 2-3%, according to the Glass Packaging Institute.

### Did You Know?

In the packaging industry, clear glass is known as “flint” glass due to its slight grey color.

### The Soda-Lime Glass Production Process

Once all components are added and melted, the molten glass is allowed to flow into a second portion of the furnace, known as the refiner. Here the glass is permitted to cool about 1,000°C to a temperature at which its viscosity is suitable for the forming process. During this period gas bubbles within the liquid glass are eliminated in a process known as “fining.” Most commonly, fining is done by introducing sodium sulfate (salt cake) and carbon, which react to form sodium oxide (soda), sulfur dioxide, and carbon dioxide. Any dissolved gaseous oxygen will combine with the sulfur dioxide to form sulfur trioxide, which dissolves in the glass and does not create any problems (Soroka, 2002; Shelby, 2005).

The color of the glass is created during this portion of the manufacturing process. Initially, all glass is unavoidably tinted greenish yellow by iron oxides that are inherently present in the raw materials. Therefore, to create “colorless” glass, colorants such as selenium and cobalt (which respectively impart red and blue) or magnesium (which imparts purple) are added until the glass is grey and appears colorless. For this reason “colorless” glass is known as flint glass. A multitude of different shades and hues may be created by adding additional colorants; common colorants include iron and sulfur to create amber (brown) glass, chrome to obtain green glass, and cobalt to produce blue glass (GPI, 2010f).

### The Container Forming Process

After the glass attains a satisfactory chemical composition and temperature, it is ready to be formed. Forming begins by forcing the molten glass through a funnel and cutting off small sections of the stream with shearing blades. Each small section, called a gob, contains a precisely calculated amount of glass that will make one container. The individual gobs are sent to a series of molds that will form them into the desired container shape. In the first mold, called the blank mold, the gob is transformed into a hollow, container-like shape called a parison. One of two common processes is used to force the gob to take the shape of the blank mold: the “press and blow” method uses a metal plunger to push the gob into the blank mold, while the “blow and blow” method injects a stream of compressed air. Regardless of which method is used, the parison is then transferred to the second mold, called the blow mold, where compressed air is used to blow the parison into the shape of the finished container (Owens-Illinois, Inc. [O-I], 2010).

During the forming process, the glass container’s exterior loses heat faster than its interior, creating internal stresses that weaken the glass. To eliminate these stresses, the formed glass containers are sent to an annealing oven called a lehr. The containers are then reheated to a consistent temperature around 550°C, and the oven temperature is then slowly lowered so that each container is consistently cooled. The containers are given coatings and treatments during this phase of the manufacturing process, after which they are warehoused and shipped (GPI, 2010d; O-I, 2010).

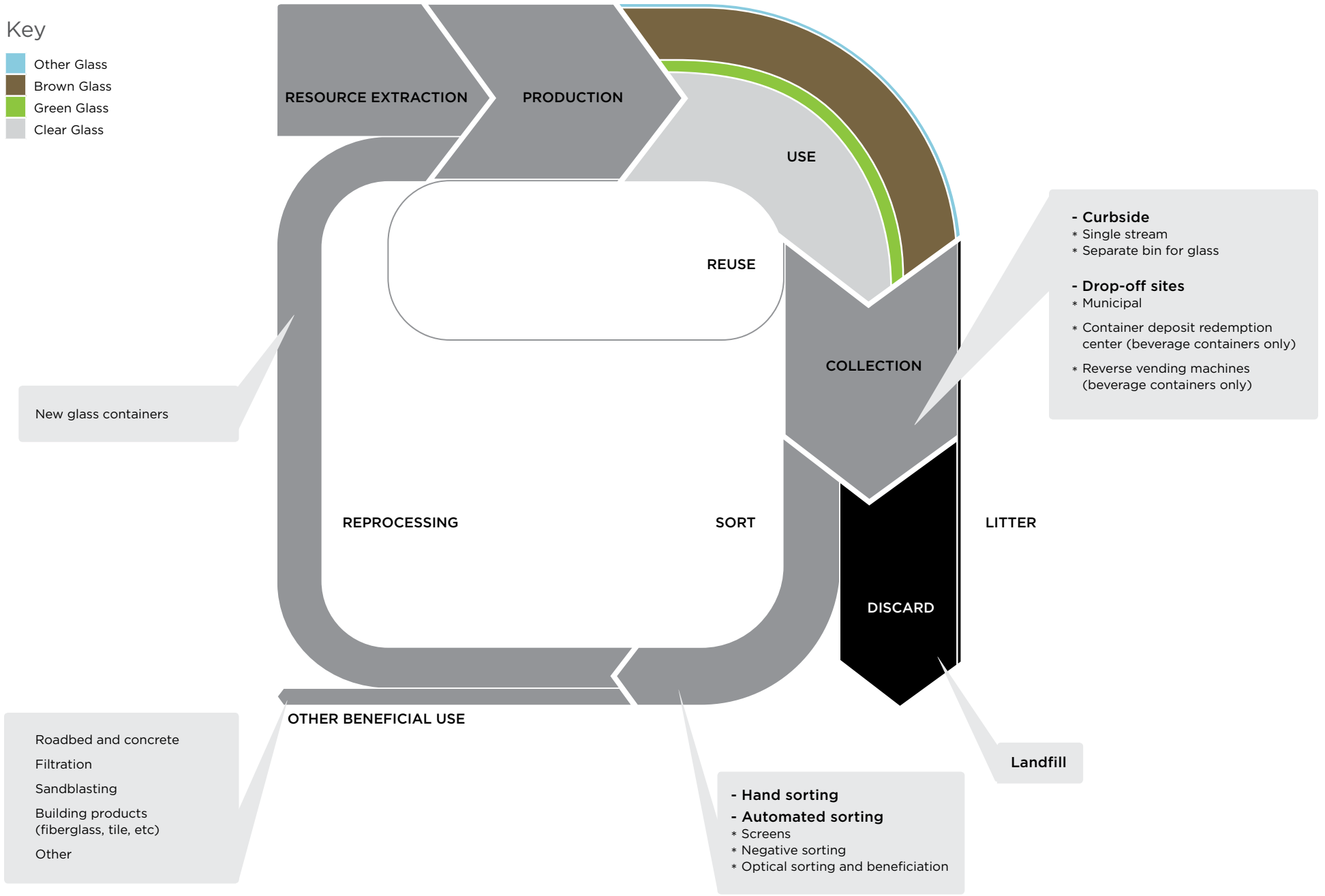
The following sections on the glass recycling process detail the existing and emerging processes that result in a beneficial end-of-life scenario for glass packaging. Reuse of glass packaging represents the highest end-of-life scenario according to the waste hierarchy, but glass packaging is currently only reused on a limited basis in the U.S., mostly by small-scale dairies (though it is a widespread practice in nearby Canada). The closed-loop system of recycling glass packaging by using cullet in the production of new soda-lime glass represents the most beneficial end-of-life scenario for glass packaging in the U.S., but it is not always the most viable end-of-life option due to the geography of reprocessing facilities. Examples of other beneficial end-of-life options for collected glass are given, and the impacts of collection, sorting, and beneficiation on these end-of-life options are discussed.





Key

- Other Glass
- Brown Glass
- Green Glass
- Clear Glass



This graphic is drawn based on data from U.S. EPA's *Municipal Solid Waste in the United States: Facts and Figures 2007* report (U.S. EPA, 2008).

### Overview of the Recycling Process: Collection, Sorting, Beneficiation, and Beneficial Uses of Collected Glass

#### COLLECTION

In the U.S., glass container collection is managed under residential and commercial recycling programs and by container deposit legislation in some states. Recycling programs typically employ drop-off sites, a curbside collection system, or both. In states with container deposit legislation, consumers may return eligible glass beverage containers at designated redemption centers for a small refund.

Residential recycling programs are each managed differently and collection practices vary by locality. Curbside collection is predominantly used in municipalities where the population density is high enough for the operation of a truck fleet to be efficient and cost-effective, and so is not often used in loosely populated areas. The manner in which curbside collection is operated also varies regionally; some systems operate as “single stream” recycling and use one bin for all recyclables, while other programs employ a “dual stream” program with two bins for different types of recyclables. Dual stream programs may use a separate bin for glass containers and operate a separate collection in order to minimize glass breakage and cross-contamination. Occasionally, recycling programs will prohibit the collection of glass containers altogether if they deem the loss of quality from cross-contamination is too great (Kinsella & Gertman, 2007; S. Jackson, personal communication, March 11, 2010).

Municipalities may also use one or more drop-off sites, which usually include glass collection. Drop-off sites provide access to recycling in areas where curbside collection is not available and also provide an opportunity to recycle loads that are too large for curbside collection. Some drop-off sites also serve to collect recyclables excluded in curbside collection programs. Many drop-off sites have separate receptacles for each color of glass (clear, brown, and green), which provides the benefit of eliminating the need for post-collection color sorting while also minimizing glass contamination of other materials.

In states with container deposit legislation, consumers have the option of returning their glass beverage containers at a designated redemption center. To incentivize consumers to return their beverage containers, the legislation requires a small deposit fee to be levied upon each beverage container at the time of purchase. The deposit is redeemed when the beverage container is returned. The amount of the deposit varies by state, but generally in the United States most glass beverage containers may be redeemed for five cents each. The types of accepted containers vary by state, as well; for example, many programs do not include bottles from non-carbonated beverages, such as wine. Because the redeemed glass containers may be sold without ever being commingled with other materials, container deposit legislation is generally effective in outputting glass with low amounts of contaminants (CalRecycle, 2009; P. Slote, personal communication, May 18, 2010).

Although container deposit legislation is designed to encourage consumers to return their beverage containers to the redemption centers, residents may alternatively use curbside collection systems and drop-off sites. Under some container deposit legislation, the operators of a curbside collection program may redeem the deposit on each beverage container they collect. Container deposit legislation does not eliminate the issue of glass contamination in other materials since some glass containers are inevitably collected through curbside systems. However, container deposit legislation is generally effective in minimizing cross-contamination because of the large amount of glass containers that are likely to be collected at redemption centers (CalRecycle, 2009).

Commercial collection systems may be operated as a single or dual stream system similar to residential collection, or they may be designed to cater to specific types of recyclable waste that are generated by a business. Bars and restaurants may be given a large receptacle dedicated solely to glass containers as part of their collection system. Operating a commercial recycling program in this manner is another effective way of producing glass with low amounts of contamination. Participation in commercial recycling programs is voluntary in most areas; however, in an effort to enhance recycling rates some states and municipalities have enacted mandatory participation in recycling programs for certain types of businesses. For example, in North Carolina, establishments that hold permits for selling alcoholic beverages are prohibited from disposing their beverage containers, and they are required to separate their recyclable bottles and cans for collection (North Carolina, 2005). In Australia, restaurants and bars have been pilot testing an in-house glass collection system called a “BottleCycler.” This machine crushes glass bottles on site to a consistent size for recycling and to maximize collection space behind the bar. The machine also serves to keep broken glass from contaminating other materials (National Packaging Covenant, 2008).

Due to the fragile nature of glass, the type of collection system employed has a large impact on the quality of the recovered glass. To be used as a feedstock in the production of new glass containers, recovered glass must be sufficiently free of small shards and contaminants, which is difficult to maintain in a single stream collection system. According to Morawski (2009), only 40% of glass recovered in single stream collection systems retains this necessary level of quality, while the other 60% is landfilled or sold for lower-value uses, such as aggregate for road base. The same study showed that in a dual stream system in which glass is kept separated from other recyclables, 90% of the recovered glass is high quality, while the remaining 10% is sold for lower-value uses; in container deposit systems, 98% of the recovered glass is high quality, while the remaining 2% is sold for lower-value uses (Morawski, 2009). Furthermore, single stream collection systems often result in small shards of broken glass becoming embedded in paper products or trapped in plastic and metal containers, contaminating those materials and lowering their value as well (Cascadia Consulting Group, 2006; S. Jackson, personal communication, March 11, 2010).

### Did You Know?

Due to its breakability, glass can contaminate paper, plastic, and metal scrap in single stream collection. Keeping glass separated from other packaging materials results in better quality glass scrap and less contamination of the other material streams.

### SORTING

After collection, glass generally undergoes one or more sorting processes before it is sold for reprocessing. If glass containers are mixed with other recyclables, the containers must first be sorted from the other materials. Glass that is collected in a color-separated system (i.e. some drop-off centers) may not require any sorting. The degree to which sorting is required usually depends on the intended use of the recovered glass. Glass destined to be used in the production of new containers or fiberglass must be free of all contaminants and sufficiently color-sorted. Glass sold for other beneficial uses usually does not need to be color-sorted, and tolerances for contaminants may be far less stringent (Reindl, 2003; B. Clark, personal communication, March 31, 2010).

Glass that is collected in a commingled recycling system generally goes to a material recovery facility (MRF), where the various materials are separated from one another using automated sorting technology. In small MRF operations, hand sorting may be the predominant method of sorting, whereas larger MRF operations tend to rely on automated sorting equipment. MRFs using automated sorting equipment use mostly “positive” sort methods wherein one distinguishing characteristic of each material type is exploited to remove every object of that material type. Paper products are distinguished with a piece of equipment that filters flat objects from container-shaped objects, steel objects are picked off by exploiting their inherent magnetism, and the electrical conductivity of aluminum recyclables is used to identify and remove them from the mixed stream. After these phases of the sorting process, the remaining material is mostly glass containers, plastic recyclables, and non-recyclable contaminants. The comparatively lightweight plastic recyclables may then be separated out by feeding the mixed materials into an air classifier, which blows a stream of air upwards at the materials and forces the lighter materials away. A “negative” sort assumes all the remaining material is glass (P. Walters, personal communication, May 21, 2010).

### Did You Know?

Glass may be sorted from other materials by weight using gravity and color-sorted using optical sorting technology.

Because glass is inert and shaped like many other recyclable containers, there is no readily available automated sorting technology capable of filtering glass containers from other materials in the mixed stream using a “positive” sort. Some MRFs purposely use equipment to break glass as a first step, running the incoming materials over conveyor belts with openings through which the glass can fall to conveyor belts below. Doing this early in the sorting process minimizes contamination and worker hazard, especially when using manual labor to sort other materials (Kinsella & Gertman, 2007; Lund, 2001).

Most non-recyclable contaminants are removed by using hand-sorting to remove large objects and screens to remove small objects. Because screens are used to indiscriminately filter out any small object, pieces of broken glass may be removed from the recycling stream and thrown out with assorted non-recyclable contaminants. However, many small contaminants, including glass pieces, may continue through the screening process by traveling atop other recyclables or traveling inside of containers. Inevitably, glass will contain contaminants, and other materials will be contaminated by glass (Morawski, 2009; S. Jackson, personal communication March 11, 2010).

### BENEFICIATION

If glass is to be used as cullet for the production of new glass containers or fiberglass, it must be crushed into pieces of a relatively uniform size, cleaned of as many contaminants as possible, and sufficiently color sorted. This process, known as glass beneficiation, is usually done by a glass beneficiator after the glass is sorted from other materials at a MRF. The first step in the process is usually crushing the glass containers if they are not already broken. This may be done by any one of several methods, including accelerating or allowing the containers to free fall towards a hard surface. Crushing the glass generally separates the glass pieces from any non-glass packaging components such as labels and closures (B. Clark, personal communication, March 31, 2010).

Screens may be used to separate the small glass pieces from the larger, less fragile contaminants that do not break, such as cork stoppers. The crushed glass may then be sent through automated sorting equipment similar to that used at a MRF, such as a magnetic separator to remove steel lids and an eddy current separator to remove aluminum pieces. Running the cullet through an air vacuum is typically done to remove labels and other lightweight non-glass contaminants (F. Hottenstein, personal communication, April 1 & May 27, 2010; B. Clark, personal communication, March 31, 2010).

Cullet used to create new glass containers must be sufficiently color-sorted. The degree to which it must be sorted depends on the color of glass that it will be used to create. In general, it is more resource-intensive to remove color than to add color, and there are also considerations that must be made regarding the chemistry of each color of glass. Specific requirements may be established by a direct agreement between the buyer and seller, or both parties may agree to use specifications established by the American Society for Testing and Materials (ASTM) or, less commonly, the Institute of Scrap Recyclers Industries, Inc. (ISRI) (ASTM, 2006; ISRI, 2009).

### Did You Know?

Clear glass is the most valuable color of glass scrap because it is more difficult to remove color from glass than to add it.

The most stringent specifications imposed by these standards apply to flint cullet, which is consequently the most valuable type of cullet. Both ASTM and ISRI standards call for flint cullet to contain no more than 5% non-flint cullet. While it is acceptable for that 5% to consist entirely of amber cullet, the load cannot consist of more than 1% green cullet or more than half a percent of colors other than amber and green. Standards imposed on loads of amber and green cullet are less stringent. Both ASTM and ISRI standards allow amber cullet to contain up to 10% of other colors. Green cullet may consist of up to 30% other colors by ISRI specifications and up to 50% other colors by ASTM standards (ASTM, 2006; ISRI, 2009).

Although the visual appearance of glass used in fiberglass is not important, the iron used to colorize amber glass can negatively affect the furnace efficiency and the quality of the manufactured fiberglass. To avoid any negative effects, the amount of amber cullet in a load of cullet destined for fiberglass production must be limited by color sorting. ASTM has created standards for three different grades of cullet suitable for fiberglass manufacturing. The lowest grade may contain up to 50% amber cullet, but the highest grade must not contain more than 25% amber cullet (ASTM, 2010). ASTM recommends that the lowest grade should not be used to account for more than 5% of a batch of fiberglass, while the highest grade may be safely used to make up 15% or more of a batch of fiberglass.

Optical sorting technology is often used to sort glass by color and to remove additional contaminants. As glass travels on a conveyor belt, it moves through a light beam, and a measurement of the light spectrum passing through each piece is taken. If no light is transmitted through the piece, it is identified as being a contaminant and a powerful air jet or a mechanical finger pushes the piece out of the processing line. This is effective in removing opaque contaminants such as porcelain, mirror glass, ceramics, and rocks. Otherwise, the equipment measures the intensity of the red, green, and blue components of the transmitted light to determine the color of each piece of cullet and sorts them accordingly. Some equipment is designed only to distinguish between clear and colored cullet, while some equipment is designed to separate the cullet into three distinct color groupings: clear, brown, and green. Other colors of glass, such as blue glass, are often sorted by this equipment into the brown cullet. If no color sorting occurs and mixed color cullet is purchased, a plant may still be able to analyze the incoming cullet's color mix in order to correct the final color of the glass by using dilution with virgin glass or by additional colorants (T. Abel, personal communication, September 10, 2009; Kinsella & Gertman, 2007; F. Hottenstein, personal communication, March 1, 2010).

Although most contaminants may be removed by exploiting their defining physical characteristics with automated sorting technology, there are inevitably some contaminants that will pass through the sorting process and end up mixed with loads of processed cullet. Of particular importance are pieces of glass that are not soda-lime glass, such as the borosilicate glass used in cookware or labware. While optical sorting technology is able to distinguish different colors and transparencies, most machines are not capable of distinguishing between different types of glass, and pieces of glass other than soda-lime glass will pass through undetected. Because the chemical composition of these other types of glass is significantly different than soda-lime glass, their presence is problematic in the melting furnace (Eco-Cycle, n.d.; J. Cattaneo, personal communication, March 3, 2010; and J. Scriptor, personal communication, March 15, 2010).

Recently, sorting machines have been developed that use X-rays instead of visible light. The X-rays are sensitive to the chemical composition of glass types, giving these machines the capability to identify different types of glass including lead-bearing glass (commonly referred to as crystal), barium-bearing glass (commonly used in vacuum tubes), and borosilicate glass (commonly used in cookware and laboratory glassware). Although these machines are able to produce very high quality cullet, their considerable cost has prevented their widespread adoption (TITech, 2010; S+S, 2008; F. Hottenstein, personal communication, April 1, 2010).



### OTHER BENEFICIAL USES OF COLLECTED GLASS

It's estimated that 80% of recovered glass is used as a feedstock to produce new glass containers, while 20% of recovered glass is used for other purposes (GPI, 2010b). Aside from glass container production, fiberglass production represents another high-value beneficial use for collected glass containers. In California, all fiberglass must be made using 30% cullet, and Californian fiberglass manufacturers reported using 45.33% cullet in 2009 (California Public Resources Code Division 12.9; CalRecycle 2010b).

Several factors influence the destination of recovered glass, such as the distance to end markets for glass cullet and the available sorting technology (Reindl, 2003; Skumatz & Freeman, 2007; P. J. Walters, personal communication, May 21, 2010).

Geography plays an important role in determining the type of beneficial use for recovered glass. Because loads of crushed glass are heavy, it is expensive to transport them over long distances, and so the local market will dictate which, if any, colors of glass may be sold. For example, most domestic producers of green glass are located in the western U.S. in order to supply the wine industry with green bottles. However, a large amount of the wine is consumed in the eastern U.S., where the green cullet must then be sold. In places where there is no market for green cullet, it is often deliberately mixed in with loads of flint cullet and amber cullet up to the maximum allowable levels as the only method for providing a useful outlet for otherwise unwanted cullet.

Different types of sorting and beneficiation technology may also determine the destination of recovered glass. Some beneficiating facilities operate using a two-color sorter, and therefore are only able to produce and sell flint cullet and a mixed colored cullet, called "gramber" due to its predominant mix of amber and green cullet (F. Hottenstein, personal communication, April 1, 2010; Bill Clark, personal communication, March 31, 2010; P. J. Walters, personal communication, May 21, 2010).

### Did You Know?

The highest quality, color-sorted cullet is used for the production of new containers and fiberglass. Other beneficial uses of glass, such as roadbed aggregate and abrasive material, can tolerate more contaminants, small shards, and mixed colors.

If a recycling facility does not possess sufficient sorting technology, there are no glass manufacturers within a reasonable distance to provide a market, or the glass is broken into pieces that are too small for optical sorting during the collection and sorting processes, the recovered glass is often sold for beneficial uses other than containers or fiberglass. Other uses for cullet include use as a substitute for aggregate in asphalt used to construct roads (termed "glassphalt"), use as a substitute for sand as an abrasive or filtering material, and use for aesthetic purposes in art and landscaping. The majority of these other uses are not affected by the color of cullet. Many of these uses are also capable of using cullet that contains contaminants that would otherwise be unacceptable, such as non-soda-lime types of glass (Reindl, 2003; Skumatz & Freeman, 2007).

This type of recovered glass may also be used as an alternative material for daily landfill cover. This use for recovered glass is not regarded as a beneficial end-of-life option, since it is ultimately buried in a landfill.

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