Cullet Supply Issues and Technologies

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The Glass Manufacturing Industry Council
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The objective of this study is to provide information to assist GMIC members in gaining a better understanding of ways in which more post-consumer cullet can be recycled and to investigate technical changes GMIC could catalyze to make that happen. This White Paper Study was led by David Rue with input from Robert Lipetz (GMIC Executive Director) and input from experts on collection, processing, characterization, procurement, and re-use of cullet. The opinions of experts are often but not always in agreement. Efforts have been made to include input from all parties. To obtain the most open possible input, the names of all respondents have been excluded from this document. No proprietary information is included. Several company names are included, with the understanding that these references are for illustration and informational purposes and not as endorsement of the companies themselves.

Introduction

Glass is 100% recyclable. Recycled glass competes with raw material batch and must rely on cost to drive utilization. A wide range of factors affect the cost of cullet to the glass companies. Most surveys (EPA, Container Recycling Institute, GPI) agree that roughly 11 million tons of glass is disposed of each year in the US, and 32-34% of that glass is recycled. Approximately 2.7 million tons were recycled to container glass and 1 million tons to fiberglass in 2017 (Resource Recovery magazine, 2018). The recycling rate in the US peaked around 2010 and is either stable, plateaued (Strategic Materials, Inc. (SMI) term), or slightly declining.

The first step in recycling of glass cullet is collection from the waste stream. Efforts are not made to recover all post-consumer glass. The fate of post-consumer glass is dependent on the disposal method. Glass is distributed among the following waste streams. The labels for these streams are in common use but not universal.

Trash – Trash is waste or garbage that is not sorted. Glass thrown into the unsorted trash is rarely recovered and ends up in landfills.

Single stream recycling – In the majority of US locations, and in increasing amounts, glass is included with other recyclable materials and is sorted at a Material Recovery Facility (MRF). The equipment and technology utilized in the more than 400 US MRFs varies over a wide range. Many MRFs do not recover any glass while other MRFs recover as much glass as possible. The different processing approaches depend on the available sorting equipment but also on whether a market exists in that location for the separated cullet.

Multi-stream recycling – In some locations, glass is pre-sorted by consumers. This produces the highest available glass quality for recycle. Generally, this glass bypasses the MRFs and goes directly to cullet separation facilities.

Construction and demolition debris – Glass is a minor constituent of the CD stream, and glass is generally not recovered from this stream. While the great majority of glass in other waste streams is container glass, the CD stream glass is predominately flat glass and insulation glass. There is little market for post-consumer flat glass recycle in the US. The post-consumer flat glass that is recycled is returned to container or fiberglass makers. The reasons for this situation include the high quality standards of flat glass makers and the relatively small stream of clean flat glass cullet available.
There are many reasons why more glass is not recycled. For cullet to be melted into new products, the cullet must meet:

- Needed glass industry quality standards
- Consistency of composition in sufficient quantity
- Price targets to warrant use instead of raw batch materials.

When survey respondents were asked what matters most in recycling, some said quality and others said cost. After speaking to several dozen experts the answer is clear that both matter. If the price is too high, procurement staff will not buy cullet. If quality is too low, no matter what the price, the glass company will not buy the cullet. Consistency and availability of supply is important. A number of respondents pointed out that quality might be met but variation from load to load is a challenge and must also be acceptable. Availability is important because irregular access to sufficient quantities of cullet makes glass formulation more labor intensive. Many glass plants have access to cullet from only a single supplier. This makes competitive pricing and maintaining quality specifications challenging. The reverse is also true. If glass is collected in locations with no glass plant customer nearby, the economics of recovery and transportation may prevent economic sale of cullet to a glass plant.

Transportation costs factor into the cost of cullet, and transport costs are always a function of distance. Cullet local to a glass plant is much more economical than cullet that must be transported a long distance. The same economics apply to batch materials, and this factors in the economic decision between cullet and batch. There are no-cost factors that influence the choice of cullet over batch. For this reason, cullet suppliers and glass company procurement officers work to develop appropriate prices for cullet. Universally, respondents agreed that cullet provides benefits to the melting process. There are, however, disagreements regarding the value of these benefits. There are also limits on the fraction of cullet that can be melted in specific furnaces. The value of specific benefits of cullet can be a matter of disagreement between suppliers and glass companies.

**Glass Recycling Rates**

Current and historical glass recycling rates are published in a number of sources. The Appendices of this report present data from the US EPA and the Container Recycling Institute (CRI). These are excellent data compendiums that contain information from a wide range of sources in Europe and the US. Available data is for container glass only. Container glass makes up perhaps 90% or more of discarded glass by weight because 1) more than 60% of produced glass is container by weight, and 2) containers have a much shorter lifecycle than other glass.

European recycling rates for container glass vary significantly between EU countries. The figure below, published by CRI, shows most EU countries are recycling at 70% or more of the container glass. Recycling rates have increased dramatically over the last 20 years. This is a result of aggressive government efforts including convenient multi-stream recycling, consumer education, improved sorting processes, and other targeted programs. These impressive recycling rates confirm that high levels of recycling are possible and could be achieved in the US with the right collection approaches and consumer education. The larger transport distances in the US compared with Europe could make the maximum practical US recycling rates lower than the European rates.

The figure shows that US recycling rates have remained stagnant over the last 20 years. The overall US numbers do not tell the whole story. The US data must be broken down into smaller parts of the country to get a better picture of efforts that are underway, some of which have been very successful, to increase recycling rates. The most comprehensive publicly available data has been collected by the Container Recycling Institute.
The rate of container glass recovery and recycle varies a lot across North America. The table below, published by CRI, shows the recent range. The ten bottle bill States (States with bottle refunds) have higher recycling rates, as expected, but even locations with no bottle bill can have high recycle rates. Kansas City is home to Ripple Glass. Ripple has placed sixty purple bins for glass collection in strategic locations. This ensures a clean glass stream and leads directly to higher recycle rates. California and Oregon have had a 5 cent bottle value, bottle redemption centers, and dedicated, separated curbside collection. However, the bills have not covered wine and spirit bottles that make up one third of beverage containers. Oregon has recently expanded the bottle bill to a 10 cent redemption value covering more classes of containers. California is unique in the US in requiring 30 percent cullet content in insulation glass and 35% cullet content in container glass.

### Glass Recycling Rates by Country, 1996-2014

<table>
<thead>
<tr>
<th>Country</th>
<th>1996</th>
<th>2010</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Germany</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Italy</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2%</td>
<td>7%</td>
<td>12%</td>
</tr>
<tr>
<td>Norway</td>
<td>2%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Spain</td>
<td>2%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3%</td>
<td>6%</td>
<td>10%</td>
</tr>
<tr>
<td>U.K.</td>
<td>10%</td>
<td>20%</td>
<td>25%</td>
</tr>
<tr>
<td>U.S.</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Source: Container Recycling Institute, 2016. Figures come from the U.S. EPA and FEVE, the European federation of glass packaging producers.

### All Over the Map

A recent study by the Container Recycling Institute estimated how much furnace-ready glass is generated by recycling programs in a variety of areas.

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Cullet Recovered per Capita Annually</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohio</td>
<td>7 pounds</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>9 pounds</td>
</tr>
<tr>
<td>Kansas City</td>
<td>18 pounds</td>
</tr>
<tr>
<td>North Carolina</td>
<td>22 pounds</td>
</tr>
<tr>
<td>Leeds, U.K.</td>
<td>28 pounds</td>
</tr>
<tr>
<td>Fayetteville, Ark.</td>
<td>38 pounds</td>
</tr>
<tr>
<td>California/Oregon</td>
<td>41-42 pounds</td>
</tr>
<tr>
<td>British Columbia</td>
<td>44 pounds</td>
</tr>
<tr>
<td>Maine</td>
<td>73 pounds</td>
</tr>
</tbody>
</table>

A lot of work over many years has been devoted to increasing recycling rates by producing a cleaner glass stream. Multiple individuals and organizations have been and are currently involved in increasing the recycling rate in the US and North America. Some groups look at all recyclable materials, but the primary glass dedicated groups actively engaged in this effort are:

- Glass Packaging Institute (GPI)
• Glass Recycling Coalition (GRC)
• Container Recycling Institute (CRI)

Information is available on websites maintained by each of these groups. They maintain extensive lists of contacts, operate as coalitions, and pursue targeted engagement programs. Other groups with a broader mandate regarding recycling of solid materials including glass are:

• Institute of Scrap Recycling Industries (ISRI)
• Solid Waste Association of North America (SWANA)

These organizations work in different ways with state and municipal leaders, consumers, MRFs, and waste haulers. ISRI and SWANA pay more attention to other recyclable materials than to glass, but they do include glass in their efforts to increase recycling. Along with the strong advocacy of GPI and GRC with policymakers, several recent efforts are expected to help increase glass recycling.

1. ISRI, together with GPI, has issued voluntary guidelines for the quality of MRF glass being sent to cullet recovery companies. These guidelines are not yet universally followed, but efforts are underway to achieve that goal. The guidelines are presented on their website and in an Appendix and are discussed in more detail below.

2. GRC conducted a Glass Recycling Survey in 2017 which has been updated in 2018. The survey results are presented in an Appendix and on their website. Survey answers provide valuable insight into the status and possible future paths for US glass recycling.

3. CRI (as well as GPI and the US EPA) publishes comprehensive data on national and local glass recycling. This information is needed to provide guidance on advancing recycling in municipalities and States.

GMIC can work with these organizations from a more technical angle. While these organizations gather data, advocate for improved recycling and collection processes, work with policymakers, and establish MRF standards, among other crucial activities, GMIC can complement these efforts in a number of ways.

The Chain of Custody

Post-consumer glass that does not go into the trash and directly to a landfill passes through a chain of custody before eventually ending up back at a glass plant. Each step in the custody chain impacts quality and cost. Any improvement in cullet use depends on improving one or more of the links in that custody chain. A simplified description of the custody chain consists of the steps below. A number of trade associations, companies, and governmental bodies work to modify practices in one or more links of the chain. Some of the changes that would be beneficial are social and behavioral while others are technical. In general, the impacts of social changes are more important on the early steps in the chain, and the impacts of technical improvements are more important on later steps in the chain. The chain of custody is:

- Consumers and generators of glass of all types and their disposal of the glass
  - Approximately 11 million tons of year of glass is disposed of each year in the US. This glass is predominately container glass. While approximately 65% of US glass production is containers, containers have a much shorter lifecycle than other glass. Although no numbers can be found describing the fraction of container glass in the disposal stream, container glass easily constitutes 80 percent, and likely 90 percent or more of all glass in the trash and waste streams.
  - Consumers have a large impact on the first step of glass sorting
  - Different motivations drive the disposal of glass in waste, single stream, or multiple stream recycling
• Waste collectors and haulers
  o Waste haulers actions are driven entirely by economics. Haulers use the lowest cost methods allowable by their contracts to collect wastes and transport them either directly to landfills or to MRFs.
  o Waste is compacted in trucks by the haulers. This leads to crushing that converts a portion of the glass to unusable undersized particles and to blending that can complicate separation. Changes in equipment and methods to reduce glass crushing would help with cullet retrieval.

• MRFs – Materials Recovery Facilities – there are more than 400 MRFs in the US
  o MRFs use a multi-step process to recover materials of value for sale, with unsaleable materials sent to landfills.
  o Handling depends on the equipment available at a MRF, and on whether a market exists in that location for specific recycled materials. Materials that do not have a local market are sent to landfills.
  o The order of recovery of materials reflects the best income stream and best engineering organization of the facility. Respondents have explained that most MRFs remove glass as early in the sorting process as possible. The hardness of glass leads to excessive wear on equipment which MRFs attempt to avoid. Also, MRFs focus most attention on more valuable streams and seek to remove glass early so attention can be focused on other recyclables.
  o Glass has a low value compared with other recycled materials. Budgets for sorting equipment improvements favor other materials more than glass.
  o Excessive crushing and blending of glass with streams such as shredded paper and ‘muds’ can produce cullet that is not marketable.
  o The glass stream sent to cullet suppliers is only partially cleaned. ISRI and GPI have recently developed a protocol for MRFs to assure glass streams have met minimum standards.
  o Sometimes, and increasingly, a MRF finds it more economical to not separate the glass and to just send it on to a landfill.

• Cullet Suppliers
  o Facilities are located to get access to MRF feed and to minimize travel to glass plant customers. They are constrained by the limited number of customers for sorted cullet.
  o Cullet is primarily produced for container glass and fiberglass. fiberglass is dominantly insulation glass. There are indications that continuous fiberglass producers are interested in using cullet but do not use cullet today. Work in this area is proprietary and must overcome the low alkali limits for continuous fiberglass compared with container glass. Float glass gets little post-consumer glass due to the improper cullet Ca/Mg ratio, high optical quality standards, small fraction in the MRF stream, and larger potential impacts of off-spec glass contaminating the continuous sheet.
  o Cullet suppliers work with glass companies to meet specifications. This is done on a company by company basis and is not standardized across the industry. Some companies are more structured than others. As a general rule, fiberglass makers are more engaged than container makers, but this is not always true. Also, as a general rule, larger companies have a more highly engineered approach to cullet than smaller glass companies.
  o Pre-sorting to remove impurities (iron, aluminum, paper, cardboard, and organics) is always done. Then careful crushing is performed with a focus on minimizing fines. Respondents have provided different limits on particle size with minimum acceptable cullet ranging from ¼ to ½ inch. The cullet is then dried, also aiming to minimize fines formation. A polishing step then removes other materials and color sorting is done. Color sorting is not always done. For example, the fiberglass makers get a tri-mix of finer sized cullet.
• Glass companies
  o The procurement staff purchases the cullet as well as the batch used as furnace feed stocks. All companies have developed formulas to help calculate the value of cullet considering the cullet quality and benefits offered by the cullet. These formulas are proprietary and not standardized. Some formulas used by companies are more sophisticated than others.
  o The engineering staff establishes cullet quality standards, works with cullet suppliers, monitors delivered cullet (often intermittently), and handles the batching and furnace operations.
  o Some glass companies have joint ventures that supply cullet to their plants. This is more common in Europe than in the US.
  o The engineering staff will say that quality is the critical factor. Suppliers say this is a matter of cost. The equipment makers say quality is the responsibility of the MRFs.
  o Container companies can usually get the green and amber glass they want but are commonly limited on availability of flint cullet. Glass companies consistently say they would like more cullet if they can get sufficient quantities of cullet that meets specifications at a competitive price with batch.

Post-Consumer Glass
Post-consumer glass enters the waste treatment process in multiple ways. There are advantages and disadvantages to each path.

• Combined waste. All recyclable materials including recyclables, organics, yard waste, etc. is in a single stream
  o Pros – simplest and cheapest collection method, no education of consumers required, no training required for waste haulers, least amount of capital equipment for collection. Much of this type of waste is never sent to a MRF and goes directly to landfills.
  o Cons – most complex and costly sorting requirements, lowest yield of clean cullet, most glass in this stream ends up in landfills

• Single stream recycling. Consumer-separated recyclables including glass are combined by the consumer, collected, and delivered to a MRF for separation and sale for upgrading and recycle.
  o Pros – moderate cost increases for collection are offset by a cleaner recyclable stream that can be sent to a MRF. Consumer education is not excessive.
  o Cons – added cost compared to a combined waste stream, MRFs must be organized and paid for to handle separation of each type of recyclable material.

• Dual stream or multi-stream recycling. Glass, generally container glass, is collected separately from all other materials. Glass may be further separated by color by consumers.
  o Pros – highest yield of recoverable cullet, higher quality and value of cullet sold to cullet suppliers, decreased glass to landfills
  o Cons – significant consumer education, continued effort to maintain compliance, highest cost for collection

Post-consumer glass collection varies by location and municipality. Single stream recycling is the most common approach in the US, and single stream recycling is growing in popularity according to survey respondents. MRFs and cullet suppliers report that the quality of single stream recyclables is decreasing. Too often consumers combine non-recyclable materials in the recyclable stream. This presents a challenge and adds costs for MRFs that need to add more labor and equipment to separate recyclable materials for sale to metal, paper, plastic, and glass upgraders. Quality of MRF input streams also declines with disposal of plastic bags and fine paper particles such as from shredders.
Only the glass that is recovered and available and that then meets sufficient standards can be sold to cullet suppliers. The fraction of all discarded glass that is in the waste stream never gets upgraded, and a significant fraction of the glass entering MRFs also goes to landfills. Only dual stream glass is clean enough to ensure a high fraction of the discarded glass to bypass the MRFs and ends up sent directly to cullet suppliers.

**Waste Collection and Hauling**

Waste haulers act according to the rules in each municipality and charge accordingly. Any changes in waste streams or charges to meet contract requirements for collection are passed directly to municipalities whether they collect garbage themselves or contract a company such as Waste Management to do this work.

There are locations where the waste haulers also operate the MRFs. In this situation, the company has the ability to optimize the collection and sorting to maximize their income. Even in this situation, the waste collection and hauling is kept to the lowest possible cost.

In most places the waste collection system in the US could be improved to recover more glass. More glass (and other recyclables) could be collected with an improved waste collection system. Also, a cleaner post-consumer glass stream (and cleaner streams of other recyclables) would be more valuable. The challenge is to improve the waste collection process at less expense than the value of cleaner glass and non-glass recyclables is increased. Curbside separation is rare in the US but has been successfully implemented with substantial increase in glass recycling rates in some cities. For example, Fayetteville, Arkansas has a system in place where glass is sorted at curbside into bins in collection trucks. This produces a clean, high quality waste glass stream. Some areas have glass redemption centers, but the consumer must transport glass themselves to these facilities. Other locations, such as Kansas City, follow the European model and have a large number of drop-off bins for glass. Ultimately, the waste haulers perform the designation work whether collecting waste, collecting single stream recyclables, or collecting multi-stream recyclable.

**Material Recovery Facilities (MRFs)**

There are more than 400 MRFs in the US of various sizes and ages. These facilities cover a wide range in capabilities based on age of equipment and regulations. Operations can vary, but a common sequence is:

- Waste haulers dump loads onto the tipping floor – this crushes glass further
- Frontend loaders and other equipment load waste onto conveyor belts
- Manual pre-sorting is carried out to remove undesired materials such as textiles, hoses, large pieces of metal and cardboard, etc.
- Light materials such as cardboard and paper are removed – one modern approach is to use widely spaced star screens which allow cardboard and some paper to pass across the top of the stars and everything else to drop between the star screens
- A second set of star screens set at an angle then separates out paper that climbs up the incline while all heavier materials passes through the screens
- Magnets are used to separate the iron
- Glass is removed using a glass breaking screen followed by a hammer mill to size the glass
- Eddy current devices are used to then separate out the aluminum
- At this point the stream consists of plastics and some residual paper, organics, and plastic film and bags
- Optical sorters are used to first remove the residual paper and then to sort different types of plastics
- Paper, cardboard, aluminum, and plastics of different types are bailed for sale
Glass and iron are sold to cullet suppliers and iron recyclers

Several good videos are available on line that show the MRF process. The Rhode Island MRF that serves all Rhode Island cities and towns is covered in this video:

https://www.youtube.com/watch?v=Jda_9_30-WU

Single stream recycling and MRFs are designed to work together. The integrated nature of recovery and recycling presents various challenges. First, the MRF equipment is expensive and operation is still labor-intensive with a requirement for manual pre-sorting. Second, the quality of the inlet stream affects operations. Plastic bags, organics, wet items, fine paper, and co-mingled materials impact operations. And, finally, markets must exist for the recovered materials. The Rhode Island facility, for example, was sending the MRF glass to SMI for cullet upgrading and sale. SMI’s primary customer, Ardagh, recently shut their beer bottle plant in Milford, Massachusetts. With no market for the recovered cullet, the MRF is now forced to find a new glass company customer (unlikely due to transport distance), send cullet to landfills, or have cullet used for ground cover.

The hardness of glass causes wear of MRF equipment. Efforts are made to remove glass as early in the sorting process as possible to decrease equipment wear. In many cases where a market does not exist for the MRF glass, glass is removed as early as possible and shunted to the landfill stream.

Another challenge for glass recovery at MRFs is that plastics and metals are more valuable than the cullet. For this reason, MRF operators invest in equipment to sort and upgrade these materials before spending resources to improve glass recovery rates or glass quality. When cullet can be sold, MRFs seek only to meet the standards required for sale. They leave the upgrading of the cullet to their cullet supplier customers. This has contributed to a gradual decrease in the quality of MRF glass available to the cullet suppliers.

GPI and ISRI have worked to address the MRF glass quality issue by developing the ISRI Scrap Specification Circular 2016. A copy of this cullet specification is attached as an Appendix. In summary, the specification deals with the following issues.

- Cullet value is directly related to non-glass residue and fraction of undersize glass.
- Load can be rejected for >0.025% pyro-ceramics, gypsum, wallboard, drywall, glass from construction debris, and moisture-absorbing dessicants.
- Load can be rejected for any CRT glass, leaded glass, tempered glass, flammables, radioactive materials, weapons, medical waste, insecticides, poisons, heavy metals, asbestos, and other hazardous wastes.

The ISRI cullet specification is planned as a voluntary guideline for MRFs and cullet suppliers. The specification has been adopted by a number of organizations but not yet by all of them. As an extension of this effort, the Container Recycling Institute has advocated for developing a national standard for glass specifications that would help MRFs meet higher standards with superior uniformity of product cullet.

Cullet Suppliers

There are a number of these companies in the US. According to GPI data from 2013 there were 46 glass container manufacturing plants operating in 22 states (this is container plants). 16 cullet supplier companies were operating 51 glass beneficiating facilities (aka "glass processing" plants) in 27 states. The largest cullet supplier by far is Strategic Materials, Inc. SMI currently has more than 40 facilities located around the country, most supplying cullet to glass companies and some supplying abrasives and roadbed material to other markets. Most other cullet suppliers operate only one or two
facilities. For example, Carry All Products (CAP) operates two facilities in Pennsylvania and ABCA Recycling in New Jersey has 15 employees and operates one facility.

In the past, cullet suppliers often built their own equipment, but today they almost always use purchased equipment. A number of companies build equipment used by the cullet suppliers (and by the MRFs). A high percentage of these equipment makers are headquartered in Europe. The higher cullet requirements and stricter regulations in Europe have driven equipment evolution which places the equipment developed in Europe at a higher development level than most American equipment. The major European equipment makers have American affiliates to work with MRFs and cullet suppliers in the US.

Cullet suppliers purchase MRF glass and cleaner glass from dual stream recycling. Cost to the cullet supplier is based on the quality of the input cullet. After sorting and upgrading, cullet is sold into multiple markets including container glass, fiberglass insulation, abrasives, and construction fill markets. Cullet makers are constrained by their customers, primarily the glass makers, on the price they can charge for clean cullet. At the same time, they must purchase, operate, and maintain costly equipment. They also upgrade their equipment as needed to meet tightening standards set by the glass companies. For example, one cullet supplier explained that recently quality standards have tightened and now require removal of all lead from the cullet stream. This adds cost to the cullet supplier with no way to pass that cost on to the customers. Cullet suppliers constantly strive to lower cullet costs by finding ways to process more tons of glass per hour through the same equipment and by utilizing better sorting and separation systems to improve cullet quality.

The photographs below from the *New York City Department of Sanitation (Processing and Marketing Recyclables in New York City, May 2004)* illustrate the large difference in quality between separated glass (or dual stream glass) and glass collected in single stream recycling. The dual stream glass is much more easily processed to marketable cullet with a much higher quality.

The cullet supplier sorting process is similar to that of a MRF but targeted at cullet upgrading. Equipment is a mix of older and newer hardware but with modern improvements. Conveyor belts, sensors, air jets, and collection bins are used. Drying chambers and glass breaking screens and/or hammer mills are also used at certain locations.

The following general sequence is followed by one cullet supplier:
• Inlet MRF glass or glass from glass recovery facilities is tested for quality to establish price to be paid to the MRF and glass recovery facility
• Impurities in the glass stream are then removed
• Paper and light organics are removed, often using a star screen and air blowers
• Metals are removed using magnets to push iron off the belt and eddy current to push aluminum off the belt
• Along with the glass, the stream now includes ceramics, stones, and porcelain (CSP), and glass ceramics
• If necessary, a drying step is included. The dryer can be a fluidized bed or other type but should not create glass undersized particles during drying
• Glass is sized as needed for sorting. A common range is ¼ inch to 2 inches. Anything below ¼ inch is sent either to tri-mix for fiberglass makers or to abrasives production
• Dried and sized cullet is then sorted. XRF and XRT have traditionally been used to separate out glass containing heavy metals such as lead. Today, this equipment is being replaced with spectral scanners. The scanners look at cullet pieces under specific wavelengths of light and then use air jets to blow undesired pieces into separate bins
• Ceramics and glass ceramics are then removed
• The final stream is glass only, and again spectral and hyperspectral imagining systems are used, this time to separate the cullet into amber, green, and flint streams
• The glass is then sized for the customer
• Quality is measured again
• Finally, the cullet is sent back to glass manufacturing plants
• The cullet sent for abrasives production is sized and bagged, often into a number of different size ranges. Abrasives are worth more per pound than cullet sent to glass manufacturers, but abrasives cost significantly more to prepare – one respondent stated that the cost to sorting and bagging the abrasives was more than the added income received
• Other undersize glass is sent either for roadbed material, construction aggregate, landfill cover, or landfill

A cullet supplier facility without sorting for glass ceramics has been depicted graphically by Dalmaiyn and Houwelingen (Glass, April 1996, 137-41). The sequence of operations is varied as needed. For example, the drying step may not be needed for part of the year, or the drying step may be set at different points in the sorting process dependent on the amount of water removal required.
Cullet sorting lines can be arranged in different ways. As another example listed below, another respondent described the sorting steps starting with MRF glass that is arranged to produce cullet for sale to container or fiberglass companies:

- **Pre-sorting**
  - Cullet from MRFs is transported up a conveyor
  - Magnets are used to remove ferrous material
  - Organics are then removed on a screen deck
  - Material is then crushed to size with care taken to minimize undersized cullet
  - Cullet drops through a screen to an organics separator – an air fan is used to blow out light paper and organics

- **Sorting**
  - Drying process – commonly a fluidized bed or vacuum dryer
  - Air blown through the dryer also removes residual paper, sand, and dust
  - Dried cullet is segregated by size for the sorters – a coarse cut and a finer cut
  - Cullet on belts with nozzles and air jets is used to blow glass into desired bins
  - XRF is used for leaded glass and heavy metals removal
  - Heat resistant materials (Pyrex, etc.) is removed
  - Secondary ferrous is removed – if needed
  - Eddy current is used to remove aluminum
  - Hyperspectral imaging is used to separate ceramics, stones, and porcelain
  - Additional imaging sensors are used to separate final glass by color – if needed

Technology and processes have improved over time. Quality requirements always match up against processing costs. In some facilities, cullet is run through the process twice to improve quality. Another effort is to process as many pounds of glass per hour as possible through the facility with the understand that final glass quality declines with increasing production rate. Most equipment is marketed by European companies to the US. The main types of sensors used are:

- **XRF** – used for lead and heavy metal detection. Use is decreasing as improvements are made available in imaging equipment
• Hyperspectral imaging – used for color separation and detection of ceramics and porcelain. These systems can operate in the UV, visible, and IR bands or with multiple wavelengths
• Magnets – iron removal
• Eddy current – aluminum removal
• Density and air streams – for paper and organics separation
• Drying – technology designed to dry cullet without crushing or dust formation. Fluidized beds are common with vacuum dryers gaining in popularity to reduce dusting

Recent process improvements have focused on ways to be more flexible while lowering labor and overall cullet processing costs per ton. Areas of improvement in cullet separation in the last 10 years include:

• Less expensive and more compact XRF
• Improved hyperspectral imaging
• More accurate cullet separation using more air nozzles with developers limited by the time lag of 2-3 msec between particle detection and air jet activation
• Improved controls and diagnostics leading to more accurate separation at faster speeds
• Higher throughput, faster speeds, and fewer passes to achieve needed cullet quality

Improvements in the cullet supplier process and in measuring glass quality are left to the companies carrying out this work and to the makers of the deployed hardware. Organizations working to increase recycling rates and to improve MRF separation rates do not generally look at issues of cullet sorting and upgrading after the cullet leaves either the MRF or the glass recovery facility.

Cullet is the most valuable product from a cullet supplier. Not all glass meets the needed standards, so companies make some cullet into less valuable products. Products in the order of most value are:

• Flint glass cullet
• Green and amber glass cullet
• Tri-color glass cullet
• Abrasives – higher price than cullet to glass makers but more costly to produce
• Highway beads
• Almost none is sold as aggregate – aggregate has almost no value

Cullet suppliers and glass companies interact on a one-on-one basis. In practice this means that cullet suppliers must meet the requirements established by glass company procurement officers and the specifications established by glass company technical staffs. With some customers, cullet suppliers provide information on the quality of glass cullet. With other customers, cullet suppliers work regularly and actively with glass companies to establish and maintain cullet specifications.

Cullet suppliers must establish prices for their product that glass companies will accept so cullet can be sold. Cullet is a replacement for raw batch, but the two feed materials are not identical. Cullet offers several advantages over batch. These include:

• Energy savings – Energy costs drop about 2-3% for every 10% cullet used in the manufacturing process (GPI)
• Longer furnace life – cullet can lower melt temperature and have less LOI and volatiles materials
• Higher production rate – this benefit is not independent but is at the expense of energy savings and extended furnace life
• Decreased CO₂ emissions - One ton of carbon dioxide is reduced for every six tons of recycled container glass used in the manufacturing process (GPI)
• Social and marketing value – use of cullet is marketable as a ‘green’ technology but is hard to quantify

Not all parties agree on the quantitative value of different benefits and savings provided by the use of cullet. The energy savings are generally accepted and are factored into the value of cullet by cullet suppliers and glass procurement staff. Longer furnace life and higher production rate are real but not achievable under all circumstances. Furnace life extension is most valuable at the end of a furnace campaign and not highly valued early in the campaign. Furnace production rate increase is only valuable during periods when furnaces are pulled at maximum or somewhat above maximum design pull rate. Longer furnace life and higher production rate are considered most valuable when a furnace is run steadily for long periods with the same batch formula. Changes in batch formula and furnace adjustments are seen as minimizing or eliminating these benefits of using cullet. Cullet is shown to reduce CO2 emissions because fuel per ton is decreased and because cullet contains no carbonates that decompose during the melting process. Most glass companies in the US, however, are not CO2-constrained and place no dollar value on evolved CO2 emissions. This prevents procurement staff from placing a dollar benefit on CO2 emission reductions. There is social, marketing, and governmental regulatory benefit to using cullet. Placing a dollar value on this benefit is difficult, and procurement staff will claim it has no cash value. In some locations, specifically California, regulations require new containers must be made using at least 35% cullet. In these types of locations, the social benefit is minimal since regulations require all glass makers to use cullet.

Glass Companies

Although all glass can be remelted into new product glass, many industry segments do not recycle glass. Most recycled cullet is melted in container furnaces. Cullet is also melted in insulation fiberglass furnaces. There are efforts underway to accept cullet in continuous fiberglass furnaces, but information on the development status in this area is not publicly available. Continuous fiberglass has strict European and US alkali content limits that prevent use of high volumes as higher alkali-content cullet such as from container glass.

The primary reasons most cullet is sold to container makers is that the vast majority of the waste stream glass in container glass (likely 90% or more). This makes recovery of sufficient quantities of other types of glass too costly to be practical. Container glass can be used in insulation fiberglass furnaces because these furnaces can utilize a certain amount of properly sized tri-mix container glass cullet. The second reason other glass industry segments do not accept post-consumer cullet is the higher quality standards for other glass products such as flat glass.

Glass segments that do not purchase post-consumer cullet are making efforts to melt in-plant or dedicated external cullet. This allows these glass makers access to higher quality cullet with compositions either matching or similar to the glass being melted. These efforts are being undertaken on a company by company basis, often in cooperation with cullet suppliers who have the needed equipment and expertise for cullet sorting and upgrading.

The vast majority of the MRF glass stream is sorted by cullet suppliers into clear (flint), amber, and green cullet. Some cullet is not sorted by color. This tri-mix of 3-mix glass is sold to fiberglass companies, is used to make abrasives, is sold for construction needs, or ends up as landfill cover. Cullet separated by volume is available in different quantities, has different specifications, and has different value. One general specification quoted was that flint must be at least 90% flint while amber needs to only be 70% amber. Specifications differ from plant to plant and company to company.
Glass companies carry out minimal inspection of the received cullet according to most respondents. The quantities are too large to inspect the received cullet without spending a large amount of labor. Past practices included regular inspection, but these practices have been largely abandoned. Glass companies rely on specifications of delivered cullet provided by cullet suppliers. This practice puts pressure on cullet suppliers to maintain needed quality standards. If specifications are not met the cullet supplier risks having delivered cullet loads returned or rejected.

A problem for glass companies is that often there is only one source of cullet. This limits flexibility in supply and batching operations. Also, supplies vary depending on the glass color. Amber glass is most readily available and can be obtained most easily in desired quantities. Green cullet is less available, and flint cullet is in shortest supply. Multiple container glass companies stated that they would melt more flint cullet if there was more available supply.

As noted with cullet suppliers, glass company procurement staff must buy cullet that meets specifications and is available with needed quantity and consistency. The sophistication of pricing models varies between glass companies and these formulas are proprietary. The larger companies tend to have invested in development of pricing formulas that account for quality of cullet. These formulas are unique to each glass company and are not shared since they are proprietary and competitive information.

**Cullet Sorting and Sensors – Quality Improvements**

Experts in dealing with cullet have identified multiple situations that occur with MRF glass and the glass recycling facility glass that can affect the cost and complexity of obtaining a clean, high quality cullet stream. These issues are not present at all cullet supplier facilities. The largest issues include:

- **Fine paper** – Very small paper particles can be difficult to separate from fine cullet particles. Better ways to remove this paper are of interest. Some respondents indicated this is a growing problem, while other respondents stated that this is not a problem.

- **Water** – Wet cullet is much more difficult to sort than dry cullet. The challenge is to develop efficient, fast drying processes that do not create undesirable undersized particles. Fluidized bed dryers are fast but can generate undersized cullet. Partial vacuum dryers are now being deployed to address the concerns of other dryers. This is not a universal concern. Wet inlet cullet is a concern at some cullet supplier facilities but not at all of them.

- **Undersized particles** – Steps in the cullet chain of custody, including hammer mills designed to reduce the top size, produce undersized particles. Currently undersized particles (< ¼ inch) are used to produce glass abrasives or sorted and sold to fiberglass companies as a finer unsorted cullet tri-mix. Several respondents stated that fiberglass furnace operators are able to accept a finer particle size cullet than are container glass furnace operators.

MRF glass and recycling facility glass often contains small amounts of metals, plastic, and paper that must be removed from the glass stream. Processes similar to those used in MRFs are deployed to reject these materials. Air jets, star separators, and gravity/density separators is used to remove plastics and paper. Iron is removed using magnetic separators. Special note must be made regarding glass with wire mesh inside. This material must be removed by magnetic separation. Eddy current separators are used to remove aluminum and other metals. Magnetic separators operate by pulling iron and steel pieces from the mixed stream. Eddy current separators create a varying electric field that creates repulsive forces in metals that push them away from the mixed stream.

After removal of residual metals, plastics, and paper, the cullet stream is dried if necessary. The stream now contains mixed glass along with glass ceramics and a certain amount of ceramic, stone (small, crystalline particles), and porcelain (CSP) contaminants.
When the cullet stream contains CRT glass, other leaded glass, or glass containing heavy metals, these glasses must be removed. Older facilities relied on x-ray fluorescence (XRF) detectors that easily spot these heavy metals. X-ray based systems, or x-ray transmission (XRT), is a relatively fast, indirect sorting technique that can capture x-ray images in a few milliseconds. An imaging module focuses high-intensity x-rays into a sample. Some of this energy is absorbed and the rest is transmitted to a detector below the sample. The detected radiation provides information about sample atomic density, and this information is used to spot cullet containing lead and other heavy metals. X-ray sorting is generally performed with either dual-energy x-ray transmission (DE-XRT) or x-ray fluorescence (XRF) instruments.

These XRF and x-ray transmission (XRT) devices have become more compact, but they are being displaced in the most modern sorting facilities. Removal of XRF and XRT devices eliminates the need for safety requirements with x-rays, and new imaging systems are less expensive.

The change from CRT-based televisions to LCD and LED displays initially led to high volumes of discarded CRT glass, but the process has advanced to the point that less CRT glass is currently entering the waste stream. CRT glass can also be recycled, but this is not a common practice today in the US. Recycling requires melting the CRT glass and recovering the lead in a reduced metal form. The largest stockpiles of CRT glass in the US were amassed by Closed Loop Refining and Recovery. Closed Loop closed in 2016 having amassed the largest stockpiles of CRT glass. They left behind stockpiles estimated at 326 million pounds in Arizona (158 million pounds at multiple sites) and Ohio (168 million pounds at two sites). Disposition of these stockpiles to landfills is under negotiations (Resources Recycling, June 2018).

After removal of glass containing lead and heavy metals, optical sorters using spectral imaging are used to remove glass-ceramic and CSP contaminants from the cullet stream. These systems usually operate at wavelengths outside the visible range. Both UV and IR imaging are employed as is multiple wavelength imaging. In practice, cullet moves along a belt. Each piece is scanned and diagnostics are used to determine if the piece is glass or one of the contaminants. Air jets are used to knock contaminants off the belt and into collection bins. There is a lag time of 2-3 milliseconds between a diagnostic decision to remove a piece and activation of the air nozzle. This time delay is factored into the process. Also, the number and precision of air jets has improved with the latest models.

The latest sorting systems used after removal of metals, paper, and plastics are optical and hyperspectral imaging systems.

In optical sorting systems, the sensor scans and measures the attenuation of light of various colors which pass in view of the sensor. This technique is used in both the visible and ultraviolet regions. The figure below from Gundupalli, et.al. (Waste Management, Feb. 2017) shows that glass first passes through an inspection zone and is illuminated by red, blue, and green LEDs. The cullet samples attenuates the LED lights depending on their color, and the attenuation is compared with reference colors to identify cullet color. Compressed air jets then knock the cullet into color-segregated bins. Where paper labels are a problem in sorting, infrared and ultraviolet light can be used to see through the labels and carry out the sorting process.
Ultraviolet light (UV) is used for separating glass ceramics, leaded glass, borosilicate glass, and other non-container glasses from the cullet stream. Samples on a belt are irradiated with UV light. Based on glass properties and composition, the UV light is absorbed and attenuated. The intensity of attenuation is compared with reference values to identify each cullet piece. Air jets are used to reject non-container glass into prepared bins. The latest developments in fused sensors combine both UV and visible sensors so that glass ceramics and metal-bearing glasses can be rejected and colored glass can be sorted in a unified operation.

A number of spectral imaging systems for sorting are gaining prominence. Spectral imaging combines spectral reflectance measurements with image processing. Systems have been described for near-infrared (NIR), visible (VIS), and hyperspectral (HIS) imaging. A hyperspectral imaging system is similar to a laboratory spectrometer and can produce images over a continuous range of narrow spectral bands. In the real-world system, cullet on a belt passes under a monitor and a spectral CCD camera acquires spectral data continuously at a designed frequency. After data processing, cullet pieces are classified using a classification algorithm. As with other sorting systems, air jets are triggered by the diagnostics to separate cullet into segregated bins. An important area of development is in improving the performance of the classification algorithms. For example, for NIR imaging, principal component analysis is being applied to reduce the dimensionality for classification of the spectral data. The image below from Gundupalli, et.al. (Waste Management, Feb. 2017) illustrates the hyperspectral imaging sorting of glass ceramic contaminants. The system includes a CMOS spectrometer camera, a conveyor belt, air jet ejection system, and collection bins.
HIS systems operating in the mid-infrared range have been proposed, but commercial systems tend to operate using radiation in the NIR and visible regions. Many MRFs and cullet supplier facilities employ these devices. NIR is used in particular to classify glass ceramic materials.

A list of references related to optical and hyperspectral imaging is presented in Appendix E. Discussions with experts have not yet determined which of the patented approaches have been reduced to practice at this time.

A number of companies manufacture and support equipment for separating cullet from other recyclables and waste and for sorting the glass. Most of these companies are based in Europe. Major companies operating in this area include:

- KRS Recycling Systems – [www.krsrecyclingsystems.us](http://www.krsrecyclingsystems.us) – optical and hyperspectral sorting equipment, full line of equipment for sorting cullet
- Austin AI – [www.austinai.com](http://www.austinai.com) – XRF, LIBS, and terahertz sorting equipment
- Redwave – [www.redwave-us.com](http://www.redwave-us.com) – leader in XRF technology, also optical sensor, full turnkey plant design and support
- Binder+Co AG – [www.binder-co.com](http://www.binder-co.com) – world leader in optical sorting equipment, CLARITY systems used by SMI
- SEA – [www.seasort.com](http://www.seasort.com) – part of Cimbria group – optical and hyperspectral sorters
- Sesotec – [www.sesotec.us](http://www.sesotec.us) – S+S glass sorting systems

In conversations with representatives of these companies, several trends are clear. All respondents agree that optical sorting and hyperspectral imaging are the areas receiving the most current attention and achieving the largest improvements. Most respondents claim that their equipment is better than the results actually achieved in American cullet separation facilities. With proper design and expenditure, they argue that US facilities could achieve much higher product cullet standards. No respondent felt metals or plastics are a major challenge because they can be quantitatively removed. Various responses regarding challenges include fine paper, moisture (drying), undersized cullet particles, and organic material. Equipment to deal with these stream contaminants is costly. A further challenge is the variability of the cullet supplied from different MRFs. Cullet separation facilities can be adjusted for variable make-up of the inlet cullet stream, but this adds cost and complexity that is usually not included in US cullet separation facilities. To put the sorting challenge into perspective, the photo below shows the mixed inlet cullet supply to an SMI facility.
Despite the new ISRI standard for cullet leaving MRFs, cullet suppliers have pointed out that most are not yet working with or meeting that standard.

**Ways Identified to Increase US Glass Recycling**

A number of challenges facing cullet recycling in the US have been identified. Many of these challenges that must be implemented by policymakers and consumer practices are being addressed by other organizations. The technical aspects of improving cullet quality and lowering the cost of separating cullet streams are left to equipment manufacturers. Challenges of note that were listed by multiple respondents include:

- The decreasing quality of available cullet from MRFs using single stream recycling. There are multiple reasons for this decline, but the largest seem to be a decline in the quality of the MRF inlet stream and a MRF focus on other recyclable materials with less attention paid to glass.
- A significant fraction of glass enters waste streams never enter MRFs and goes directly to landfills. This problem must be addressed on a municipal level. Programs such as bottle bills, glass recycling centers, and curbside sorting (e.g. Fayetteville, AR) are needed to generate cleaner cullet streams.
- There is a wide variation of sorting equipment in use in MRFs across the country. The quality of MRF glass improves when MRFs are modernized. This modernization must be locally supported with enough municipal and State officials backing the efforts.
A significant fraction of the glass entering MRFs ends up in the landfill stream and not in the MRF glass stream. This is partly the result of handling practices and available equipment. Some loss of glass in the MRF is unavoidable. Changing practices is difficult because glass is the least valuable recyclable material sent to MRFs. MRF operators invest more in equipment to sort plastics than on equipment to sort glass or in practices to collect more cullet.

MRFs often do not have a ready market for glass. There are over 400 US MRFs and only a little more than 50 cullet supplier facilities. Transportation costs limit the distance for affordable hauling of MRF glass to a cullet supplier facility. The practical distance, however, increases with the quality of cullet. This means dual-stream glass or sorted glass can be profitably hauled a much further distance.

Many MRFs make more money by taking recycling credits and avoiding cullet transportation costs, with cullet ending up in landfills.

The single stream of recyclables is more valuable when glass is not included in the stream. For this reason, some MRFs and some single stream recycling programs do not accept glass. This can be a positive situation if glass is separated into a separate, clean stream either by consumers or at curbside. This can be a negative situation if glass is discarded in the general waste stream going to landfills.

There are location challenges with glass when MRFs are not near enough to the locations of glass recovery facilities and glass plants.

The high cost of cullet transport limits how much cullet is returned to glass plants.

Cullet supplier facilities are costly, and this cost must be recouped by selling cullet to glass companies. Cullet suppliers are price constrained because cullet competes against raw batch as an feed stock material.

The quality of MRF glass to cullet supplier facilities is variable. The ISRI quality standard for MRFs in helpful but not universally implemented.

The tonnage rate through cullet recycling facilities and the precision of separating the cullet is a hardware challenge. The goal is to lower capital cost per ton of product cullet while achieving the highest quality of cullet possible.

On-line sensors and the diagnostics for separation process control are constantly evolving. Sensors that enable rapid adjustments to monitor and maintain quality are critical to high quality cullet production.

Sensors for detecting glass with heavy metals (especially lead), CSP (ceramic, stones, porcelain), glass ceramics, and glass colors must evolve to meet tightening standards for glass company delivery.

There is no accepted standard for pricing the benefits of cullet. Suppliers and glass companies put different values on the benefits offered by using cullet.

Glass companies rely on cullet suppliers to meet the claimed quality in each load delivered. The ability to cross-check the quality of cullet would help improve the consistency of cullet and would help furnace operators better calculate furnace formulations.

Education on the benefits of cullet varies between members of the cullet chain of custody, including glass company staff. Better information would teach plant operators how cullet can best be used to lower energy costs and to improve glass production.

The information in this survey has been gathered through reading, study of publications, facility visits, and discussions with professionals actively involved in dealing with glass cullet. Many more companies and equipment makers could be contacted, but the picture presented is believed to be complete enough to provide the reader with a fair understanding of how post-consumer glass is collected, processed and ultimately returned as clean cullet to glass makers. This survey has also identified the primary types of organizations involved in the steps in the chain of custody.
Increasing the amount of recycled glass in the US can be considered as a two-fold problem.

1. Actions to increase the amount and quality of glass entering and passing through the chain of custody
2. Actions to improve the quality and lower the cost of recycled cullet along with actions to educate organizations in the chain of custody

A number of organizations are actively engaged in the first activity area. These include GPI, CRI, the Glass Recycling Coalition, municipal and State officials, ISRI, and others. Actions in the second area in the US have been primarily carried out by private companies. The second area is where GMIC appears to be suited to provide the largest impact. GMIC activities could include:

- Support of organizations working to increase the fraction of post-consumer glass collected and processed through MRFs
- Lifecycle analysis of post-consumer glass. An open-source, neutral analysis would provide the information needed by all organizations in the chain of custody, but particularly the cullet suppliers and glass companies, to assess the value of cullet. This analysis would provide means to compare the full cost of cullet against the full cost of batch materials. The analysis would also provide users the ability to assess the impact of quality changes. All benefits of cullet would be included with the option to weight the benefits in specific situations.
- Education of organizations in the chain of custody and forums to showcase the lifecycle analysis and new technologies used as sensors and sorting equipment in cullet processing. Education can also include development of more comprehensive and standardized, open cullet quality guidelines as well as vetted protocols for confirming cullet composition and properties.
- Leading research efforts into full MRF and cullet supplier facility automation and advanced sensors. Improvements are being made, but more development is needed in advanced areas. Specific sensor improvements cited by survey respondents include:
  - On-line sensors for ultra-fast monitoring of cullet during the upgrading process. These sensors must tie into advanced diagnostics. A promising area of research is in multi-sensor fusing and data fusing tied into advanced diagnostic systems (Gundupalli, Thakir, Hait, A Review of Automated Sorting of Source Separated Municipal Solid Waste for Recycling, Waste Management, Feb, 2017).
  - Further development of hyperspectral imaging sensors. These sensors have become very powerful, and they have become fairly inexpensive. As quality requirements tighten, there is a continued need for developing better camera systems.
  - Whole new classes of sensors using other material properties could be helpful. Examples include Raman spectroscopy and Laser Induced Breakdown Spectroscopy (LIBS) that are currently both too expensive to be used in real-world situations.
  - Portable sensors and open protocols for glass companies to check and monitor the quality of cullet. The large quantities involved make this a challenge, but such devices and protocols would provide glass companies ways to have more control over cullet analysis rather than relying completely on data provided by cullet suppliers.
- Supporting research into alternative markets for cullet

Ways GMIC Could Support Cullet Recycling

No areas have been identified that would be considered transformational in cullet handling that GMIC could support. However, several research areas have been identified that could make a significant impact on the quantity and quality of cullet recycled to the glass industry. These identified areas include:
1. **Fines or undersize particles** – Fines are usually sent from MRFs to landfills and never recycled. In cullet separation facilities fines below 2-4 mm are separated out as either a waste stream or as a feed stream to make marketable glass abrasives. Fine particles can cause handling problems, and identifying fine particles as glass and determining color is difficult. Finding ways to recover and use these undersize particles would immediately increase the amount of recycled cullet because these fines are already in the MRF-cullet facility chain of custody. Multiple options include 1) briquetting the fines, 2) using fines for alternative markets, and 3) developing sensors that can sort fine particles.
   a. Briquetting is promising but presents challenges including color separation, equipment and binder cost, impact of organic binders on the glass melting process, and stability of the briquettes.
   b. Alternative markets have economic challenges in that the glass may have less value then for glass making. Promising higher-value markets include filtration media and bricks with superior strength and water resistance.

2. **New classes of sensors** – The larger sensor companies (such as Redwave) claim to regularly look at sensors based on other approaches, but are not selling them because they are currently too costly to develop and sell. Research to develop Raman spectroscopy, LIBS, terahertz cameras, NIR absorption spectroscopy and other approaches would yield separation advantages in certain separations if the devices were fast enough, reliable enough, and inexpensive enough.

3. **True cost, lifecycle analyses, and characterization** – Often the true cost of cullet compared with raw batch is not known accurately enough. Many factors must be considered and the benefits perceived by cullet suppliers may not be realized by the glass maker. An open-source, unbiased cost analysis with variable inputs could help increase cullet use and develop stable and growing markets. Development of tools and protocols to characterize cullet compositions, color, and properties would enable clearer pricing and market paths.

4. **Real-time sensors and spot sensors** – Several companies have technology to monitor cullet moving through the cullet separation facility. This technology is rarely used in the US but could help improve cullet quality if implemented in a cost effective way. Less expensive methods with better diagnostic interfaces would be beneficial. At the end of the cullet separation process, suppliers analyze the product cullet sent to glass companies. Faster, more reliable, and less expensive hardware and protocols to conduct this analysis at the cullet separation facility and at the glass plant would help the chain of custody produce more reliable streams of cullet meeting ever tightening standards of quality demanded by glass makers.

As a trade association, GMIC is best suited to carry out activities with the most interest to the largest number of its members. Of the identified areas in which GMIC is suited to participate, true cost, lifecycle analysis, and characterization is an area in line with the interests of the most GMIC members and the broad glass industry. Work in this area would need to include organizations including at least one major university with expertise in lifecycle analysis and economic calculations, cullet suppliers, glass companies that purchase post-consumer cullet, and standards developers such as NIST. A validated, open-source effort could be made available to all GMIC members as a benefit of association membership.

The other technical areas in which GMIC can potentially guide developments include utilization of undersized particles to directly increase cullet recycle, in-line sensors for use during cullet separation operations, and practical, inexpensive, and reliable sensors to monitor the properties of cullet delivered to glass companies.
Final Thoughts – Expanding Glass Recycling – Alternate Cullet Applications

Container glass accounts for the vast majority of glass in the post-consumer waste stream. But other glass compositions are also discarded. Construction and demolition waste (CD) can include a large amount of window glass, both glazed and laminated. CD waste is sent to landfills. Automotive windows are disassembled to recover the binder, and this glass can be recycled if markets exist. But this glass is not shipped to container glass makers. CRT glass is no longer manufactured in the US, so this glass cannot be returned to make new CRTs. CRT glass does have other potential applications such as for lead smelter feed stock, but its use to make bricks or stemware is limited. The recycle of fluorescent lighting tubes is complicated by the presence of mercury. Some fluorescent tubes are recycled to the insulation fiberglass market.

Recycle of cullet back to new containers provides a closed loop process. Cullet prices vary but currently are in the range of $90/ton. The price of cullet is highest for flint, followed by amber, and then green glass. Note that (according to a Carry All Product expert) the small fraction of blue glass ends up mixed together either with amber or green cullet. The figure below illustrates the historic variation in cullet prices and the differences in prices for different cullet colors. This information is current only through 2005 and is specific to New York City, but the trends are relevant across the US.

![Chart 1-4 Recycled Glass Prices](chart.png)

Many organizations, companies, and municipalities have looked for alternative uses for recycled cullet. Cullet is routinely used to produce abrasives and used in a number of cement and road bed filler applications. In the early 2000s New York City produced glassphalt, asphalt with glass cullet replacing aggregate. Development found that cullet particle size was critical for success. Also, the asphalt binder sticks better to aggregate than to cullet. Despite these difficulties, the program was operated continuously for several years. Ultimately the program ended when cullet became in short supply. Also, new methods of recycling old asphalt into new road surfaces led to a 40% decrease in the amount of new asphalt needed for road surface repair. Despite these challenges, glassphalt remains an interesting opportunity for cullet recycling.
In 2003 the EPA published a well-sourced report examining the full range of possible alternative markets for cullet (Reuse/Recycle of Glass Cullet for Non-Container Uses, John Reindl, July 2003). The details of this study make for interesting reading. Offered here is the list of the non-container uses for cullet cited in the EPA report.

- Art glass
- Blasting abrasives
- Industrial fillers
- Component in paint
- Septic filtration medium
- Water filtration medium
- Construction aggregate
- Structural fill material
- Dust control at construction sites
- Glass with epoxy binders for countertops and decorative applications
- Glassphalt

Other applications of cullet listed by other developers but not described in the EPA report include:

- Playground surfaces
- In-ground pipe bedding material
- Glass bricks
- Landscaping for both structural and decorative applications
- CRT glass cullet used for lead smelter fluxing

Real markets exist for many of these applications. Some markets are small and have room for development. This list is intended to show the wide range of possible cullet applications. New applications are of interest to the recycling community.

One challenge in the recycling of large volumes of cullet is that in many practical situations there is an oversupply of green and amber cullet and an undersupply of flint cullet. Researchers have experimented with approaches to convert colored glass into clear glass that can then be used to make new flint containers. Investigation has found these are all laboratory concepts at this time, but they are interesting approaches. Several of the studies may lead to future innovations in cullet handling and recycling. The British Waste and Resources Action Programme published a report titled Feasibility of the Reduction of Colour within the Glass Furnace (March, 2004, ISBN: 1-84405-090-4). Topics covered in this report include:

- Dilution, decolorizing, and color balancing
- Crystallization and phase separation
- Reductive melting
- Electro-chemical methods
- Wet chemical extraction
- Irradiation as an alternative coloring system

While certainly not an exhaustive list, these approaches to color modification and removal of color demonstrate that means may exist to alter cullet chemistry to broaden commercial sale and recycling. Examining these and other cullet modification techniques is beyond the scope of this survey but may be of interest to the readers.
Appendix A – From Glass Packaging Institute’s Web Page (www.gpi.org)

Glass Facts

- Glass is 100% recyclable and can be recycled endlessly without loss in quality or purity.
- Glass is made from readily-available domestic materials, such as sand, soda ash, limestone and “cullet,” the industry term for furnace-ready recycled glass.
- The only material used in greater volumes than cullet is sand. These materials are mixed, or “batched,” heated to a temperature of 2600 to 2800 degrees Fahrenheit and molded into the desired shape.
- Recycled glass can be substituted for up to 95% of raw materials.
- Manufacturers benefit from recycling in several ways: Recycled glass reduces emissions and consumption of raw materials, extends the life of plant equipment, such as furnaces, and saves energy.
- Recycled glass containers are always needed because glass manufacturers require high-quality recycled container glass to meet market demands for new glass containers.
- Recycled glass is always part of the recipe for glass, and the more that is used, the greater the decrease in energy used in the furnace. This makes using recycled glass profitable in the long run, lowering costs for glass container manufacturers—and benefiting the environment.
- Glass containers for food and beverages are 100% recyclable, but not with other types of glass. Other kinds of glass, like windows, ovenware, Pyrex, crystal, etc. are manufactured through a different process. If these materials are introduced into the glass container manufacturing process, they can cause production problems and defective containers.
- Furnace-ready cullet must also be free of contaminants such as metals, ceramics, gravel, stones, etc.
- Color sorting makes a difference, too. Glass manufacturers are limited in the amount of mixed color-cullet (called “3 mix”) they can use to manufacture new containers. Separating recycled container glass by color allows the industry to ensure that new bottles match the color standards required by glass container customers.
- Some recycled glass containers are not able to be used in the manufacture of new glass bottles and jars or to make fiberglass. This may be because there is too much contamination or the recycled glass pieces are too small to meet manufacturing specifications. Or, it may be that there is not a nearby market for bottle-to-bottle recycling. This recovered glass is then used for non-container glass products. These “secondary” uses for recycled container glass can include tile, filtration, sand blasting, concrete pavements and parking lots.
- The recycling approach that the industry favors is any recycling program that results in contaminant-free recycled glass. This helps ensure that these materials are recycled into new glass containers. While curbside collection of glass recyclables can generate high participation and large amounts of recyclables, drop-off and commercial collection programs tend to yield higher quality recovered container glass.

Glass Recycling Statistics

- Glass bottles and jars are 100% recyclable and can be recycled endlessly without any loss in purity or quality.
- The container and fiberglass industries collectively purchase 3 million tons of recycled glass annually, which is remelted and repurposed for use in the production of new containers and fiberglass products.
- Over a ton of natural resources are saved for every ton of glass recycled.
- Energy costs drop about 2-3% for every 10% cullet used in the manufacturing process.
- One ton of carbon dioxide is reduced for every six tons of recycled container glass used in the manufacturing process.
- There are 46 glass manufacturing plants operating in 22 states. 16 companies operate 51 glass beneficiating facilities (aka “glass processing” plants) in 27 states. At the glass processing plants, recycled glass is further cleaned and sorted to spec, then resold to the glass container manufacturing companies for remelting into new food and beverage containers.
- In 2013, 41.3% of beer and soft drink bottles were recovered for recycling, according to the U.S. EPA. Another 34.5% of wine and liquor bottles and 15% of food and other glass jars were recycled. In total, 34% of all glass containers were recycled, equivalent to taking 210,000 cars off the road each year.
• States with container deposit legislation have an average glass container recycling rate of just over 63%, while non-deposit states only reach about 24%, according to the Container Recycling Institute.
• Beverage container deposit systems provide 11 to 38 times more direct jobs than curbside recycling systems for beverage containers. (Source: The Container Recycling Institute, "Returning to Work: Understanding the Jobs Impacts from Different Methods of Recycling Beverage Containers").
• About 18% of beverages are consumed on premise, like a bar, restaurant, or hotel. And glass makes up to about 80% of that container mix.
• In 2008, NC passed a law requiring all Alcohol Beverage Permit holders to recycle their beverage containers. Since then, they have boosted the amount of glass bottles recovered for recycling from about 45,000 tons/year before the ABC law to more than 86,000 tons in 2011.
• Glass bottles have been reduced in weight approximately 40% over the past 30 years.
• Recycled glass is substituted for up to 95% of raw materials.
• Manufacturers benefit from recycling in several ways—it reduces emissions and consumption of raw materials, extends the life of plant equipment, such as furnaces, and saves energy.
• An estimated 80% of all glass containers recovered for recycling are remelted in furnaces, and used in the manufacture of new glass containers. Source, Strategic Materials, Inc.
• Recycling 1,000 tons of glass creates slightly over 8 jobs. (Source: 2011 Container Recycling Institute).
2018 Glass Recycling Survey

RESULTS

Glass Recycling Coalition | June 2018
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Introduction

The Glass Recycling Coalition (GRC) is a non-competitive, collaborative coalition focused on making glass recycling work. In the spring of 2017, GRC conducted its first survey of the following groups in order to measure how different members of the glass recycling chain viewed the current state of glass recycling, to better provide services to improve it:

- public sector (recycling coordinators and solid waste staff from cities, counties, solid waste districts, and state environmental departments)
- materials recovery facilities (MRFs)
- end market representatives (brands, bottle manufacturers, fiberglass representatives, and processors)

GRC conducted the survey again in 2018 to measure changes in attitude, track progress in improving glass recycling, report out on current conditions, and guide the direction of future GRC efforts.

This report presents the results of the 2018 Glass Recycling Survey with a comparison to the 2017 results. These findings provide a real-time attitudinal snapshot of how glass is currently recycled, how it is collected and processed, and where it ends up. The findings also show current beliefs about glass recycling from numerous perspectives. Finally, the survey offers insight into the types and extent of glass recycling challenges, as well as interest in tools and financial resources to aid with these concerns. GRC intends to conduct this survey annually to mold GRC effectiveness.

KEY FINDINGS

The attitudes and experiences about glass recycling found in the 2017 survey largely held true in 2018, with notable changes noted below.

- Expectations of consumers and residents to be able to recycle glass decreased slightly. Ninety-three percent of respondents from the public-sector, and 92 percent of the total three groups surveyed indicated that their residents/customers expect to recycle glass compared to 96 percent and 95 percent, respectively, in 2017.

- Concern about glass recycling decreased by 14 percent among public-sector respondents from 2017, while concern increased among glass industry respondents by 14 percent. Both sectors identified cost-effectiveness as a top concern.

- Respondents care what happens to recycled glass; 53 percent of public-sector
respondents and 74 percent of glass industry respondents indicated that the final
destination of recovered glass is important to them (down from 75 percent and 85
percent, respectively, in 2017). Both groups ranked bottle-to-bottle recycling as
their preferred end use of recovered glass

- Twenty-seven percent of MRF respondents have additional glass cleanup
equipment, compared to 40 percent of MRF respondents in 2017.

- About 50-60 percent each of public-sector and glass industry respondents facing
glass recycling challenges expressed interest in public-private partnerships and
grants to improve glass recycling.

- Nearly 80 percent of respondents from each of the three groups surveyed believe
the cost of collecting and processing recyclables should be shared among
various members of the recycling chain, up from half of each group in 2017.
ABOUT THE GLASS RECYCLING COALITION

The Glass Recycling Coalition (GRC) brings together a diverse membership of 40 companies and organizations representing glass container and fiberglass manufacturers, brands that use glass to showcase their products, haulers, processors, material recovery facility, capital markets and end-markets to make glass recycling work.

Established in April 2016, GRC is a non-competitive coalition of U.S. value chain members involved in glass recycling and dedicated to supporting the most accessible and viable glass recovery and recycling options for consumers. The coalition encourages financially sustainable mechanisms that produce quality cullet and strengthen glass markets. For more information, contact info@glassrecycles.org

GRC Members:

- Allagash Brewing Company
- Ardagh Group
- Balcones Resources
- Bell’s Brewery
- Binder USA
- Brewer’s Association
- Diageo
- CP Group
- Emterra Group
- Gallo Glass
- Good Planet Laboratories
- Goose Island
- Glass Packaging Institute
- Heineken
- Institute of Scrap Recycling Industries (ISRI)
- Knauf Insulation
- Machinex
- National Waste & Recycling Association
- Northeast Recycling Council (NERC)
- New Belgium Brewing
- North American Insulation Manufacturers Association (NAIMA)
- O-I
- Owens Corning
- Rumpke Recycling
- PACE Glass
- Pernod Ricard USA
- Pratt Industries
- Republic Services
- Ripple Glass
- Rocky Mountain Bottle Company
- Sierra Nevada Brewing Company
- Sims Municipal Solutions
- Southeast Recycling Development Council (SERDC)
- Strategic Materials
- The Recycling Partnership
- Urban Mining NE
- Waste Management

Government Advisory Council Members:

- Massachusetts Department of Environmental Protection
- State of Washington State Department of Ecology
- City of Fort Collins Waste Reduction & Recycling
- Rhode Island Resource Recovery Corporation
- City of Houston Solid Waste Management Department
Survey Results

The GRC offered the survey to public-sector representatives, MRFs, and glass industry members nationwide for six weeks from the end of April through beginning of June 2018. Over 5,400 municipal officials, MRF contacts, and glass industry members received an email with an electronic link to the survey; 289 recipients clicked the survey link from these emails. Additionally, the survey was posted on the GRC website and social media pages and was promoted to the audience GRC’s webinar “Glass Recycling Solutions and the Role of Fiberglass as a Consumer and Industrial End Market” on April 26, 2018.

More than 300 representatives throughout the glass recycling value chain provided their perspectives on the state of glass recycling in the survey. Figure 1 shows the breakdown of respondents amongst the public-sector (203 respondents), MRFs (82 respondents), and the glass industry (19 respondents) (note: some public-sector respondents also represent a MRF, and are counted under both sectors). Public-sector respondents represented 77 percent of total survey respondents. The 2018 survey received approximately 50 additional responses over the 2017 survey. The number of respondents increased in each sector increased; however, the 2017 survey grouped “other” respondents in with the glass industry though this category was removed in the 2018 survey.

Each sector answered a set of questions that pertained to their sector; the survey results are presented in this report by these groups. While a number of questions only pertained to one sector, the survey included common questions across each category to provide comparative analysis. Given the small number of MRF and glass industry representatives that responded to the survey, comparisons can only be made for the survey respondents, and may not represent the industry as a whole for those groups. Furthermore, changes in survey results between 2017 and 2018 are due in part to the increase in survey respondents (e.g., the number of MRF responses more than doubled), not purely changes in the US recycling landscape.

Figure 2 illustrates where respondents are from in the US. Survey participation was highest in the southeast.
Figure 2- Geographic Representation of All Respondents
Public Sector Responses
PUBLIC SECTOR

Public-sector representatives from municipalities, counties, solid waste districts, and states provided insight on community recycling programs and the glass recycling challenges they face. Many are the respective policy makers in their jurisdictions, but this characteristic was not measured. Public-sector responses increased from 175 in 2017 to 203 this year.

Community Recycling Programs

Table 1 shows the prevalence of different collection systems used to collect glass in respondents’ communities (note that percentages add to over 100 percent because communities may have more than one system for collecting glass). More than half of respondents have glass collection available through a drop-off program. Glass may also be collected at curbside in some of these communities, while in others it may be the only collection method used for glass. More than half of respondents collect glass through a single stream curbside program. Eleven percent of public-sector respondents do not recycle glass, similar to the findings from the public-sector in 2017. Finally, single stream recycling with glass continued to grow while older residential methods decreased, despite current difficulties with markets for many materials due to dramatic changes (i.e. China, tariffs, etc.) year over year.

Table 1 - Prevalence of different systems to collect glass among public-sector respondents

<table>
<thead>
<tr>
<th>Collection System</th>
<th>Percent of Respondents That Use Collection System, 2018</th>
<th>Percent of Respondents That Use Collection System, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single stream curbside</td>
<td>55%</td>
<td>49%</td>
</tr>
<tr>
<td>Dual stream curbside</td>
<td>6%</td>
<td>9%</td>
</tr>
<tr>
<td>Glass collected separately at curbside</td>
<td>9%</td>
<td>13%</td>
</tr>
<tr>
<td>Source separated curbside collection</td>
<td>5%</td>
<td>8%</td>
</tr>
<tr>
<td>Drop off</td>
<td>59%</td>
<td>65%</td>
</tr>
<tr>
<td>None</td>
<td>11%</td>
<td>12%</td>
</tr>
<tr>
<td>Other</td>
<td>7%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Two-thirds of public-sector respondents have made changes to their recycling programs in the face of current market conditions (Figure 3). Over half of public-sector respondents have increased recycling education. One-third of public-sector respondents have made no changes in response to market conditions. Several respondents who selected “other” have increased manual sorting to reduce contamination.
Residents overwhelmingly want to recycle glass: 93 percent of public-sector respondents indicated that residents in their community expect to recycle glass. The public sector’s responses illustrate the influence of their residents in their decisions around recycling. Respondents were asked for the top three reasons glass should be kept in recycling programs, and they most commonly selected “Residents want to recycle glass” (selected by 72 percent of respondents, down from 86 percent in 2017). The influence of residents’ concerns is not specific to glass recycling, but to recycling programs on the whole.
Figure 4- Public-sector respondents’ top reasons glass should be kept in recycling programs. Common “Other” responses were to support manufacturers/jobs or that glass should not be recycled.

When asked for the top three program priorities for recycling in their community (Figure 5), respondents most commonly selected “resident satisfaction” (65 percent of respondents). The top reasons to keep glass in recycling and recycling program priorities were largely consistent with responses from 2017; however, one noteworthy finding is that the desire to reduce contamination in community recycling programs increased by 13 percentage points in 2018 as quality restricted market choices severely for residential programs in 2018.
Figure 5- Public-sector respondents’ top priorities for community recycling programs

Figure 6a illustrates which member(s) of the recycling value chain public-sector respondents suggested should cover the cost of collecting and processing recyclables. Over three-quarters of public-sector respondents believe that two or more entities should share these costs, up from about half of respondents in 2017. Of the respondents that selected one entity to cover the costs of recycling, most selected either residents or packaging manufacturers.

Figure 6b breaks down which groups public-sector respondents believe glass recycling net costs should be shared with. Residents were most often selected. Packaging manufacturers, the most common selection in 2017, was second. Over half of these respondents indicated that cities/counties should share the service costs of recycling glass.
Figure 6a- Public-sector respondents’ choices of which group(s) should cover the costs of recycling in 2018 compared to 2017
Final Destination of Glass

About half of public-sector respondents indicated that the final destination of their community’s glass is “very important” or “somewhat important” to them, (Figure 87), down from 75 percent last year.

Sixty percent of public-sector respondents know the final destination of the glass recovered in their community. One reason for this low number is the turn-key aspect of many recycling programs where the service
provider ‘owns’ the recycling material after it is collected.

Another 12 percent of respondents do not accept glass in their recycling programs, and the remainder do not know the destination of their collected glass for recycling.

Public-sector respondents held very similar preferences for glass recycling end uses in 2018 and 2017. Respondents rated different glass end uses on a scale of one to five (one being the best end use and five being the worst end use). Figure 88 plots the weighted average score for each end use from most to least favorable; the lower the weighted average, the more preferable the end use. Public-sector respondents ranked bottle-to-bottle recycling most favorably and sending glass to the landfill with garbage least favorably.
Figure 8: Weighted averages of public-sector respondents’ preferred glass end uses, in order from most to least preferable
Glass Recycling Concerns & Opportunities

Fifty-four percent of public-sector respondents indicated that they have some concerns with glass recycling, down from 63 percent of public-sector respondents in 2017. This answer surprised researchers. Table 2 details the challenges that these communities face. Not surprisingly, the most prevalent challenge among these respondents is contamination, with 34 percent of this group indicating they have a concern relating to contamination. Other main concerns pertain to end markets (for instance, they have no or few end markets nearby, or their nearby end markets will not consistently accept their community’s glass) and the cost-effectiveness of glass recycling.

Table 2- Percent of public-sector respondents facing specific glass recycling challenges in their community

<table>
<thead>
<tr>
<th>Glass Recycling Challenges</th>
<th>% Public-sector Respondents Facing Challenge in Their Community, 2018</th>
<th>% Public-sector Respondents Facing Challenge in Their Community, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contamination issues</td>
<td>34%</td>
<td>60%</td>
</tr>
<tr>
<td>End markets (e.g. few/unreliable options)</td>
<td>22%</td>
<td>82%</td>
</tr>
<tr>
<td>Cost-effectiveness</td>
<td>22%</td>
<td>45%</td>
</tr>
<tr>
<td>Hauler/MRF stopped accepting glass</td>
<td>14%</td>
<td>16%</td>
</tr>
<tr>
<td>Processing capability</td>
<td>12%</td>
<td>22%</td>
</tr>
<tr>
<td>Hauler raised price to keep glass in the program</td>
<td>12%</td>
<td>16%</td>
</tr>
</tbody>
</table>
Respondents who expressed concerns with glass recycling were asked about their interest in financial resources. Over 60 percent of this group expressed interest in grants and public-private partnerships, down from over 70 percent of public-sector respondents in 2017 (Figure 9).

Respondents facing glass recycling challenges were also asked to select tools or information that would be useful to increase quality glass recycling in their community. The top three tools, each of which were selected by approximately 45 percent of those who are facing glass recycling challenges, were types of glass end markets, case studies of local governments making glass recycling work, and information on grant funding for glass recycling (Table 3). Interest in information about glass recycling for legislators and decision makers increased from 29 percent of respondents to 44 percent of respondents, while interest in options for preserving glass in recycling collection decreased from 40 percent of respondents to 24 percent of respondents. Almost 75 percent of these respondents indicated that webinars and presentations are the best way to share these tools and information; the response was similar in 2017 (Table 4).
### Table 3- Percent of public-sector respondents experiencing challenges with glass recycling that would find the following tools to be useful

<table>
<thead>
<tr>
<th>Tool/Information</th>
<th>Percent, 2018</th>
<th>Percent, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of end markets that are available for glass</td>
<td>45%</td>
<td>54%</td>
</tr>
<tr>
<td>Case studies of local governments making glass recycling work</td>
<td>45%</td>
<td>40%</td>
</tr>
<tr>
<td>Information on grant funding for glass recycling</td>
<td>44%</td>
<td>45%</td>
</tr>
<tr>
<td>Information about glass recycling for legislators/decision makers</td>
<td>44%</td>
<td>29%</td>
</tr>
<tr>
<td>Best practices in glass recycling collection or processing</td>
<td>43%</td>
<td>50%</td>
</tr>
<tr>
<td>Options for preserving glass in recycling collection</td>
<td>24%</td>
<td>40%</td>
</tr>
<tr>
<td>A list of top considerations when making recycling program changes</td>
<td>19%</td>
<td>16%</td>
</tr>
<tr>
<td>Process of how glass is recycled into new containers</td>
<td>14%</td>
<td>20%</td>
</tr>
<tr>
<td>Other</td>
<td>12%</td>
<td>12%</td>
</tr>
</tbody>
</table>

### Table 4- Preferred platforms for sharing tools and information among public-sector respondents experiencing challenges with glass recycling

<table>
<thead>
<tr>
<th>Platform</th>
<th>Percent, 2018</th>
<th>Percent, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Webinars/presentations</td>
<td>72%</td>
<td>77%</td>
</tr>
<tr>
<td>Email alerts</td>
<td>68%</td>
<td>58%</td>
</tr>
<tr>
<td>Newsletters</td>
<td>45%</td>
<td>45%</td>
</tr>
<tr>
<td>Social media</td>
<td>22%</td>
<td>13%</td>
</tr>
</tbody>
</table>
Glass Industry Responses
GLASS INDUSTRY

Representatives from the glass industry answered many of the same questions as the public-sector. The glass industry respondents provided similar feedback on the state of glass recycling to that from public-sector respondents. Glass industry responses consisted of 12 glass industry representatives and 38 “other” respondents in 2017, compared to 19 glass industry representatives (no “other” respondents) in 2018.

Who should pay for recycling?

Figure 10a illustrates which member(s) of the recycling value chain glass industry respondents suggested should cover the cost of collecting and processing recyclables. Similar to the public-sector, 84 percent of glass industry respondents believe that two or more entities should share these costs. Of those that indicated that the cost should be shared, 87 percent selected cities/counties as one of the groups that should share in the costs of recycling, up from 28 percent in 2017 (Figure 10b).

Figure 10a- Glass industry respondents’ choices of which group(s) should cover the costs of recycling
Figure 10b- Glass industry respondents’ choices of which groups should share the costs of recycling
**Why should glass be recycled?**

Like the public-sector, glass industry representatives revealed a push from the public to recycle glass. Ninety percent of their customers expect to recycle glass. Furthermore, when glass industry respondents were asked to select their top three reasons that glass should be kept in recycling programs, they, like the public-sector, most commonly selected “people want to recycle glass” though by ten fewer percentage points than in 2017 (tied with “glass is a core recyclable”, which was selected by 63 percent of glass industry respondents up from 52 percent in 2017) (Figure 11).

![Figure 11- Glass industry respondents' top reasons glass should be kept in recycling programs](image)

**Final Destination of Glass**

Glass industry respondents also revealed that they are concerned with the final destination of recovered glass; 74 percent of glass industry respondents rated the final destination of recovered glass as “very important” or “somewhat important” (Figure 12), though 85 percent of glass industry respondents selected these options last year. The glass industry further revealed their concern about the final destination of their glass by rating different glass end uses on a scale of one to five (one being the best end use and five being the worst end use).
Figure 13 plots the weighted average score for each end use from most to least favorable; the lower the weighted average, the more preferable the end use. Glass industry respondents ranked glass end uses in nearly the same order of preference as the public-sector respondents. Not surprisingly, respondents ranked bottle-to-bottle recycling most favorably and sending glass to the landfill with garbage least favorably.
Any recovery option is acceptable (no direct landfill)

Bottle-to-Bottle Fiberglass

Glass sent to the landfill as garbage

1 2 3 4 5
(Most preferred) Sandblast medium (Least preferred)

Road base (aggregate)

Figure 13 - Weighted averages of glass industry respondents’ preferred glass end uses, in order from most to least preferable
Glass Recycling Concerns & Opportunities

Seventy-nine percent of glass industry respondents indicated that they have concerns with glass recycling. Glass recycling challenges they identified are listed in Table 5. Like the public-sector, the glass industry identified contamination as a top concern, though this was tied with a recognition of service providers that stop accepting glass and that not enough glass is being recycled. Interestingly, although contamination was selected as a top concern, only 26 percent of glass industry respondents identified a lack of advanced glass cleaning systems in MRFs as a challenge. End markets, surprisingly, has decreased considerably as a concern in the glass industry, similar to the public-sector, though this is an often-cited problem in the media.

Table 5- Percent of glass industry respondents who identified specific glass recycling challenges

<table>
<thead>
<tr>
<th>Glass Recycling Challenges</th>
<th>Percent of Glass Industry Respondents, 2018</th>
<th>Percent of Glass Industry Respondents, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contamination/quality issues</td>
<td>53%</td>
<td>64%</td>
</tr>
<tr>
<td>Some recycling service providers have stopped accepting glass</td>
<td>53%</td>
<td>55%</td>
</tr>
<tr>
<td>Not enough glass is being recycled</td>
<td>53%</td>
<td>22%</td>
</tr>
<tr>
<td>Cost-effectiveness</td>
<td>47%</td>
<td>56%</td>
</tr>
<tr>
<td>Lack of glass processing options</td>
<td>42%</td>
<td>40%</td>
</tr>
<tr>
<td>End markets</td>
<td>37%</td>
<td>51%</td>
</tr>
<tr>
<td>Lack of advanced glass cleaning systems in MRFs</td>
<td>26%</td>
<td>38%</td>
</tr>
<tr>
<td>Opponents’ efforts to remove glass</td>
<td>26%</td>
<td>16%</td>
</tr>
<tr>
<td>Customer service issues trying to move glass</td>
<td>11%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Glass industry respondents were also asked about their interest in financial resources to improve glass recycling. The glass industry, like the public-sector, expressed more interest in public-private partnerships and grants than in other types of financial resources, but less interest than expressed in 2017 (Figure 14).
Figure 14- Interest in certain financial resources from glass industry respondents
Material Recovery Facility Responses
MRFS

Materials Recovery Facility respondents provided a glimpse into how recycled glass is currently processed and where it is sold. MRF responses increased from 31 in 2017 to 82 this year.

Glass Processing

MRF respondents were asked which type(s) of processing system they operate for glass (Figure 15). The most commonly used processing system by MRF respondents is single stream or mixed recyclables; 55 percent of MRF respondents use single stream processing for glass (regardless of whether they use additional glass cleaning equipment). Although the percentage of public-sector respondents that do not accept glass remained consistent from last year, the percentage of MRF respondents that do not accept glass increased from four percent in 2017 to 15 percent in 2018. The general decline in MRF commodity revenue from market uncertainties over the past year is the likely cause of the increase as MRFs sought to shed existing net cost centers, though this needs to be tested.

Twenty-seven percent of MRF respondents have additional glass cleaning equipment. Figure 16 shows the types of glass cleaning equipment these respondents use; most (64 percent) use air knives, vacuums or blowers to remove paper and organics. Another seven percent of MRF respondents indicated that they do not have additional glass cleaning equipment but would consider it, and 10 percent have already considered additional equipment but determined it too costly.

![Figure 15- Processing systems used by MRF respondents for glass](image-url)
When asked about changes made to recycling operations in the face of current market conditions (Figure 17), only 15 percent have installed cleaning equipment. Most commonly, MRFs have increased recycling education, with 41 percent of MRF respondents doing so. Over a quarter of MRF respondents have made no changes in response to market conditions. Several respondents who selected “other” have begun landfilling recyclables.

**Figure 16- Additional glass clean up equipment used by MRF respondents**
Figure 17 Changes made to MRF respondents’ recycling operations in response to current market conditions

Destination of Collected Glass

MRF respondents were asked to provide all of the end uses of the glass processed at their facility (Table 6). The MRFs’ most utilized end use is bottle-to-bottle recycling. 43 percent of MRF respondents indicated that at least some of their glass becomes cullet to be recycled into glass bottles, and this now represents a minority of responding facilities compared to 2017.

Table 6- Final destinations of glass processed by MRF respondents. Most “Other” responses named specific companies that may use the glass in multiple ways.

<table>
<thead>
<tr>
<th>Glass End Use</th>
<th>% MRF respondents, 2018</th>
<th>% MRF respondents, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass into cullet recycled into glass bottles</td>
<td>43%</td>
<td>58%</td>
</tr>
<tr>
<td>Other</td>
<td>23%</td>
<td>8%</td>
</tr>
<tr>
<td>Used as Alternative Daily Cover (ADC) in a landfill</td>
<td>21%</td>
<td>19%</td>
</tr>
<tr>
<td>Recovered for fiberglass</td>
<td>16%</td>
<td>23%</td>
</tr>
<tr>
<td>Recovered as road base (aggregate)</td>
<td>15%</td>
<td>15%</td>
</tr>
</tbody>
</table>
Any option for recycling glass is acceptable, as long as it isn't landfilled with garbage. | 11% | 23%
---|---|---
N/A: We don't accept glass in our recycling program | 11% | 19%
Recovered as sandblast medium | 11% | 12%
It goes to the landfill as garbage, although glass is still accepted in our recycling program | 9% | Not asked in 2017

MRF respondents provided up to three factors determining where they sell their glass (Table 7). Like last year, the top factors selected suggest that respondents prioritize cost, although the percentage of MRF respondents that selected factors related to cost decreased 15 percentage points or more from 2017. While public-sector and glass industry respondents reported that people’s desire to recycle glass is a primary reason that glass should be recycled, MRF respondents did not reveal a similar pressure in decision-making to act on customer’s desires. In fact, only 5 percent of MRF respondents indicated that customer expectations for recycled glass to be used in glass manufacturing is a top consideration in determining where they sell their glass – despite 90 percent of MRF respondents reporting that their customers expect to recycle glass. Several of the MRF representatives who responded with “other” specified that they only have one outlet for their glass.
Table 7- Determining factors of where MRFs sell their glass

<table>
<thead>
<tr>
<th>Determining Factor of Where Glass is Sold</th>
<th>% MRF Respondents, 2018</th>
<th>% MRF Respondents, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation cost</td>
<td>39%</td>
<td>54%</td>
</tr>
<tr>
<td>Highest price paid per ton/lowest cost per ton</td>
<td>28%</td>
<td>46%</td>
</tr>
<tr>
<td>Highest and best end use</td>
<td>27%</td>
<td>27%</td>
</tr>
<tr>
<td>Processor will take all glass I bring</td>
<td>16%</td>
<td>42%</td>
</tr>
<tr>
<td>Other</td>
<td>16%</td>
<td>15%</td>
</tr>
<tr>
<td>Any option for recycling glass is acceptable, as long as it isn’t landfilled with garbage</td>
<td>15%</td>
<td>23%</td>
</tr>
<tr>
<td>Contractual obligations</td>
<td>15%</td>
<td>4%</td>
</tr>
<tr>
<td>Landfilling is most convenient or cheapest option</td>
<td>10%</td>
<td>8%</td>
</tr>
<tr>
<td>N/A: We don’t accept glass in our recycling program</td>
<td>9%</td>
<td>4%</td>
</tr>
<tr>
<td>Landfill construction material substitution (ADC, road base, French drains) fulfills recycling obligation</td>
<td>7%</td>
<td>8%</td>
</tr>
<tr>
<td>Most glass yielded ( recovered)</td>
<td>5%</td>
<td>8%</td>
</tr>
<tr>
<td>Customer expectations for recycled glass to be used in glass manufacturing</td>
<td>5%</td>
<td>8%</td>
</tr>
</tbody>
</table>
Who should cover costs?

Figure 18a illustrates which member(s) of the recycling value chain MRF respondents suggested should cover the cost of collecting and processing recyclables. As with the other two groups, about 80 percent of respondents believe that two or more entities should share these costs. Of the respondents that selected one entity to cover the costs of recycling, most selected packaging manufacturers. Figure 18b shows which groups MRFs who believe the costs of recycling should be shared should actually share these costs. Eighty-two percent of these MRF respondents indicated that residents should share the costs. MRFs were second-least often selected and privately run MRFs would expect to be compensated for service costs.

![Figure 18a- Breakdown of MRF respondents’ choices of which group(s) should cover the costs of recycling](image-url)

*Figure 18a- Breakdown of MRF respondents’ choices of which group(s) should cover the costs of recycling*
Figure 18b- Breakdown of MRF respondents’ choices of which groups should share the costs of recycling

Conclusion

Values and vision about glass recycling are shared among the public-sector, MRF operators, and glass industry respondents who participated in this survey. All three groups face high expectations from their customers to recycle glass. Public-sector and glass industry respondents agree that the end use of recovered glass is important, but more than half of these respondents expressed concerns with glass recycling. Generally, both groups face glass recycling challenges pertaining to end markets, contamination and cost-effectiveness, and indicated that financial resources such as public-private partnerships and grants could be beneficial in addressing these concerns. Lastly, a large share of all three groups believe that costs associated with recycling should be shared among the members of the glass recycling value chain. These overall attitudes are similar to responses in the 2017 survey. GRC will continue to observe changes in perceptions on end markets, MRFs not taking glass (which should be monitored), and more transparency about who should pay for glass recycling services to see where trends may be developing.
Appendix C – EPA Report on Recycling Rates
Introduction

U.S. Environmental Protection Agency (EPA) has collected and reported data on the generation and disposition of waste in the United States for more than 30 years. We use this information to measure the success of waste reduction and recycling programs across the country and characterize our national waste stream. These facts and figures are current through calendar year 2014.

In 2014, in the United States, about 258 million tons (U.S. short tons unless specified) of municipal solid waste (MSW) were generated. Over 99 million tons of MSW were recycled and composted, equivalent to a 34.6 percent recycling rate (see Figure 1 and Figure 2). In addition, over 33 million tons of MSW were combusted with energy recovery and 136 million tons were landfilled (see Table 1).

Recycling and composting of MSW results in greenhouse gas (GHG) emissions reduction. In 2014, the 99 million tons of MSW recycled and composted provided an annual reduction of over 181 million metric tons of carbon dioxide equivalent (MMT CO₂E) emissions, comparable to the annual emissions from over 38 million passenger cars.¹

As the title for the annual report suggests, EPA is thinking beyond waste. Sustainable Materials Management (SMM) refers to the use and reuse of materials in the most productive and sustainable way across their entire life cycle. SMM conserves resources, reduces waste, slows climate change and minimizes the environmental impacts of the materials we use.

Figure 1. MSW Generation Rates, 1960 to 2014
The sustainable management of natural capital has become increasingly important with expanding demand for finite resources on the global scale. For economic growth to reliably continue, responsible use of natural resources must consider the environmental and human health impacts. Considering the entire life cycle of the needed materials, businesses are able to reduce environmental and human health risk while enhancing and sustaining their value proposition.

According to the United Nations Environment Programme, International Resources Panel (UNEP IRP), “data suggest that while long-run relative decoupling of material extraction from GDP (gross domestic product) can be observed at a global level, this relative decoupling is not sufficient to prevent a persistent increasing trend in absolute resource extraction. Indeed, in contrast to the long-run relative decoupling trend over the 20th century, recent years’ data suggest that resource extraction has begun to increase at a faster rate than GDP, suggestive of ‘recoupling’.”1 In a subsequent report, the UNEP IRP expands upon these observations: “the material intensity of the world economy has been increasing for the past decade, driven by the great acceleration that has occurred since the year 2000. Globally, more material per unit of GDP is now required. Production has shifted from very material-efficient countries to countries that have low material efficiency, resulting in an overall decline in material efficiency.”2
Trends in Municipal Solid Waste in 2014

Our trash, or MSW, is comprised of various items Americans commonly throw away after being used. These items include packaging, food, yard trimmings, furniture, electronics, tires and appliances. MSW does not include industrial, hazardous or construction waste.

In 2014, about 66.4 million tons of MSW were recycled, 23 million tons were composted, 33.1 million tons were combusted with energy recovery and 136 million tons were landfilled.

In 2014, the rate of lead-acid battery recycling was about 99 percent (2.81 million tons). The rate of corrugated box recycling was over 89 percent (27.3 million tons), and over 61 percent (21.1 million tons) of yard trimmings were composted (see Figure 3). About 135.9 million tons of MSW (52.6 percent) were landfilled in 2014 (see Figure 4).

Three materials had composting or recycling rates that rose from 2013 to 2014 — yard trimmings, selected consumer electronics and food. In 2014, the rate of yard trimmings composting was 61.1 percent (21.1 million tons), up from 60.2 percent (20.6 million tons). The rate of yard trimmings composting was 51.7 percent in the year 2000. In 2014, the rate of selected consumer electronics recycling was 41.7 percent (1.4 million tons) up from 37.8 percent in 2013 (1.3 million tons). This was a further increase from the year 2000, when selected consumer electronics were recycled at 10.0 percent. In 2014, the rate of food composting was 5.1 percent (1.94 million tons), up from 5.0 percent in 2013 (1.84 million tons). The rate of food composting was 2.2 percent in the year 2000.

Sources of MSW

Sources of MSW include residential waste (including waste from multi-family housing) and waste from commercial and institutional locations, such as businesses, schools and hospitals.

Over the last few decades, the generation, recycling, composting, combustion with energy recovery and landd landfilling of MSW changed substantially. Solid waste generation per person per day peaked in 2000. The 4.4 pounds per person per day in 2014 is about the same as in 2013, and is one of the lowest rates since before 1990. The recycling and composting rate has increased from less than 10 percent of generated MSW in 1980 to over 34 percent in 2014. Combustion with energy recovery increased from less than two percent of generation in 1980 to 12.8 percent in 2014. Landfilling of waste decreased from 89 percent in 1980 to under 53 percent in 2014.
Figure 3. Recycling and Composting Rates of Selected Products, 2014*

*Does not include combustion with energy recovery.

Figure 4. Management of MSW in the United States, 2014

- Landfilled: 52.6%
- Recycling and Composting: 34.6%
- Combustion with Energy Recovery: 12.8%
Analyzing MSW

EPA analyzes waste by material, such as plastics, or paper and paperboard, as well as by major product categories, which include durable goods (such as furniture), nondurable goods (such as paper or clothing), containers and packaging (such as milk cartons and plastic wrap) and other materials (such as food).

Nationally, in 2014, Americans recycled and composted over 89 million tons of municipal solid waste. This provides an annual reduction of more than 181 MMT CO₂E, comparable to the annual GHG emissions from over 38 million passenger vehicles.

Materials In MSW

Total MSW generation in 2014 was 258.5 million tons. Figure 5 shows the breakdown of MSW generation by material. Organic materials such as paper and paperboard, yard trimmings and food continued to be the largest component of MSW. Paper and paperboard accounted for over 26 percent, and yard trimmings and food accounted for another 28.2 percent. Plastics comprised about 13 percent of MSW; rubber, leather, and textiles accounted for over nine percent; and metals made up nine percent. Wood followed at over six percent, and glass over four percent. Other miscellaneous wastes made up approximately three percent of the MSW generated in 2014.

Total MSW recycling and composting in 2014 was over 89 million tons. Figure 6 shows that in 2014, paper and paperboard accounted for about 50 percent of all recycling, yard trimmings accounted for over 23 percent while food accounted for another two percent. Metals comprised about nine percent and glass, plastic and wood made up about three percent each. Other miscellaneous materials made up about six percent of MSW recycling and composting.

The highest recycling and composting rates were achieved in paper and paperboard, yard trimmings and metals. More than 64 percent of the paper and paperboard generated was recycled. Over 21 million tons of yard trimmings were composted (almost a five-fold increase since 1990). In 2014, 34 percent of metal was recycled. Recycling and composting these three materials alone kept over 28 percent of generated MSW out of landfills.

In 2014, 33 million tons of MSW were combusted with energy recovery. Food made up the largest component of MSW combusted (over 21 percent). Rubber, leather and textiles accounted for over 17 percent of MSW combustion. Plastics comprised about 15 percent; and paper and paperboard made up over 14 percent. The other materials accounted for less than 10 percent each (see Figure 7).

In 2014, about 136 million tons of MSW were landfilled. Food was the largest component (over 21 percent). Plastics accounted for over 18 percent, paper and paperboard made up over 14 percent and rubber, leather and textiles comprised over 10 percent. Other materials accounted for less than 10 percent each (see Figure 8).

Table 1 provides recycling, composting, combustion with energy recovery and landfill amounts and rates (as percent of generation) for all materials in 2014.
<table>
<thead>
<tr>
<th>Material</th>
<th>Weight Generated (in millions of tons)</th>
<th>Weight Composted (in millions of tons)</th>
<th>Weight Recycled (in millions of tons)</th>
<th>Landfilling (in millions of tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>11.48</td>
<td>2.36</td>
<td>6.24</td>
<td>2.36</td>
</tr>
<tr>
<td>Wood</td>
<td>5.03</td>
<td>0.53</td>
<td>4.50</td>
<td>0.53</td>
</tr>
<tr>
<td>Paper and pulpboard</td>
<td>44.40</td>
<td>4.74</td>
<td>39.74</td>
<td>4.74</td>
</tr>
<tr>
<td>Glass</td>
<td>1.20</td>
<td>0.25</td>
<td>0.75</td>
<td>0.25</td>
</tr>
<tr>
<td>Other materials</td>
<td>3.53</td>
<td>0.47</td>
<td>3.06</td>
<td>0.47</td>
</tr>
<tr>
<td>Total waste</td>
<td>181.59</td>
<td>20.56</td>
<td>161.03</td>
<td>20.56</td>
</tr>
<tr>
<td>Recyclable waste</td>
<td>108.4</td>
<td>18.50</td>
<td>89.90</td>
<td>18.50</td>
</tr>
<tr>
<td>Total compostable waste</td>
<td>73.15</td>
<td>4.00</td>
<td>69.15</td>
<td>4.00</td>
</tr>
<tr>
<td>Other waste</td>
<td>23.02</td>
<td>2.04</td>
<td>21.00</td>
<td>2.04</td>
</tr>
</tbody>
</table>

Table 1. Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling of Materials in MSW 2014*
Products In MSW

The breakdown of the 258 million tons of MSW generated in 2014 by product category follows. Containers and packaging made up the largest portion of MSW generated: 29.7 percent, or over 76 million tons. Nondurable and durable goods each made up about 20 percent (over 52 million tons) each. Food made up 14.9 percent (38.4 million tons), yard trimmings made up 13.3 percent (34.5 million tons) and other wastes made up 1.5 percent (4 million tons).

Table 2 shows the generation, recycling, composting, combustion with energy recovery and landfiling of materials in the product categories, by weight and as percent of generation. This table shows that the recycling of containers and packaging was the highest of the four product categories, with over 51 percent of the generated materials recycled. Paper products, steel and aluminum were the most recycled materials by percentage in this category. Over 75 percent of paper and paperboard containers and packaging was recycled. Over 72 percent of steel packaging (mostly cans) was recycled. The recycling rate for aluminum packaging was almost 39 percent, including over 55 percent of aluminum beverage cans.

Over 32 percent of glass containers was recycled, while over 26 percent of wood packaging (mostly wood pallets) was recycled. Almost 15 percent of plastic containers and packaging was recycled—mostly from soft drink, milk and water bottles. Plastic bottles were the most recycled plastic products. Polyethylene terephthalate (PET) bottles and jars were recycled at over 31 percent. Recycling of high density polyethylene (HDPE) natural (white translucent) bottles was estimated at over 29 percent (see 2014 data tables).

Nondurable goods generally last less than three years. Overall recycling of nondurable goods was about 33 percent in 2014. Newspapers/mechanical papers and other paper products were the most recycled nondurable goods. Newspapers/mechanical papers include newspapers, directories, inserts, and some advertisement and direct mail printing. Sixty-eight percent of newspapers/mechanical papers were recycled. Collectively, the recycling of other paper products such as office paper and magazines was over 44 percent in 2014. Clothing, footwear and other textile products are included in the nondurable goods category. These products were recycled at a rate of over 17 percent.

Overall, 18 percent of durable goods was recycled in 2014. Due to the high rate of lead recycling from lead-acid batteries, nonferrous metals (other than aluminum) had one of the highest recycling rates. With an almost 99 percent recycling rate, lead-acid batteries continued to be one of the most recycled products. Recycling of steel in all durable goods was over 27 percent, with high rates of recycling from appliances and other miscellaneous items. Recycling of selected consumer electronics (ranging from TVs, computers and cell phones to fax machines) was over 41 percent (see Figure 3).

Measured by percentage of generation, products with the highest recycling rates in 2014 were lead-acid batteries (98.9 percent), corrugated boxes (89.5 percent), steel cans (70.7 percent), newspapers/mechanical papers (68.2 percent), yard trimmings (61.1 percent), major appliances (58.3 percent), aluminum cans (55.1 percent), mixed paper (44.4 percent), selected consumer electronics (41.7 percent), and tires (40.5 percent) (see 2014 data tables).
### Table 2. Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling of Materials in MSW, 2014*  
(in millions of tons and percent of generation of each product)

<table>
<thead>
<tr>
<th>Products</th>
<th>Weight Generated</th>
<th>Weight Recycled</th>
<th>Weight Composted</th>
<th>Weight Composted with Energy Recovery</th>
<th>Weight Landfilled</th>
<th>Recycling as Percent of Generation</th>
<th>Composting as Percent of Generation</th>
<th>Combustion as Percent of Generation</th>
<th>Landfilling as Percent of Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durable goods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>15.52</td>
<td>4.25</td>
<td>1.90</td>
<td>9.36</td>
<td>27.4%</td>
<td>12.2%</td>
<td>60.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>1.52</td>
<td></td>
<td>0.21</td>
<td>1.31</td>
<td>Not Available</td>
<td>13.8%</td>
<td>86.2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other non-ferrous metals</td>
<td>2.04</td>
<td>1.36</td>
<td>0.05</td>
<td>0.63</td>
<td>66.7%</td>
<td>2.5%</td>
<td>30.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>2.28</td>
<td>Negligible</td>
<td>0.23</td>
<td>2.05</td>
<td>Negligible</td>
<td>10.1%</td>
<td>89.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastics</td>
<td>12.15</td>
<td>0.91</td>
<td>1.28</td>
<td>9.96</td>
<td>7.5%</td>
<td>10.5%</td>
<td>82.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubber and leather</td>
<td>7.12</td>
<td>1.44</td>
<td>2.41</td>
<td>3.27</td>
<td>20.2%</td>
<td>33.2%</td>
<td>45.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td>6.39</td>
<td>Negligible</td>
<td>1.14</td>
<td>5.25</td>
<td>Negligible</td>
<td>17.8%</td>
<td>82.2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Textiles</td>
<td>3.96</td>
<td>0.48</td>
<td>1.16</td>
<td>2.31</td>
<td>12.4%</td>
<td>29.3%</td>
<td>58.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other materials</td>
<td>1.67</td>
<td>1.29</td>
<td>0.03</td>
<td>0.35</td>
<td>77.2%</td>
<td>1.8%</td>
<td>21.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total durable goods</td>
<td>52.65</td>
<td>9.75</td>
<td>8.41</td>
<td>34.49</td>
<td>18.5%</td>
<td>16.0%</td>
<td>65.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nondurable goods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repair and paperboard</td>
<td>29.47</td>
<td>14.91</td>
<td>2.85</td>
<td>11.71</td>
<td>50.0%</td>
<td>9.7%</td>
<td>39.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastics</td>
<td>6.78</td>
<td>0.14</td>
<td>1.31</td>
<td>5.33</td>
<td>2.1%</td>
<td>19.3%</td>
<td>78.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubber and leather</td>
<td>1.09</td>
<td>Negligible</td>
<td>0.21</td>
<td>0.88</td>
<td>Negligible</td>
<td>19.3%</td>
<td>80.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Textiles</td>
<td>11.95</td>
<td>2.13</td>
<td>1.52</td>
<td>7.90</td>
<td>17.8%</td>
<td>16.1%</td>
<td>66.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other materials</td>
<td>2.98</td>
<td>Negligible</td>
<td>0.58</td>
<td>2.40</td>
<td>Negligible</td>
<td>19.5%</td>
<td>80.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nondurable goods</td>
<td>52.27</td>
<td>17.18</td>
<td>6.87</td>
<td>28.22</td>
<td>32.9%</td>
<td>13.1%</td>
<td>54.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*(table continued...)*
<table>
<thead>
<tr>
<th>Products</th>
<th>Weight Generated (in millions of tons)</th>
<th>Weight Composted (in millions of tons)</th>
<th>Weight Landfilled (in millions of tons)</th>
<th>Weight Recovered (in millions of tons)</th>
<th>Percent Composted</th>
<th>Percent Landfilled</th>
<th>Percent Recovered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>259.2</td>
<td>55.0</td>
<td>23.0</td>
<td>69.2</td>
<td>21.5%</td>
<td>8.9%</td>
<td>26.3%</td>
</tr>
<tr>
<td>Other residues</td>
<td>76.6</td>
<td>39.4</td>
<td>7.3</td>
<td>2.9</td>
<td>51.5%</td>
<td>9.5%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Total combustibles and packaging</td>
<td>65.6</td>
<td>18.6</td>
<td>2.7</td>
<td>0.3</td>
<td>28.6%</td>
<td>41.2%</td>
<td>41.2%</td>
</tr>
<tr>
<td>Wood</td>
<td>9.7</td>
<td>2.57</td>
<td>1.4</td>
<td>0.25</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td>Other materials</td>
<td>0.31</td>
<td>0.06</td>
<td>0.25</td>
<td>0.25</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td>Yard trimmings</td>
<td>3.450</td>
<td>2.103</td>
<td>0.23</td>
<td>0.22</td>
<td>61.1%</td>
<td>9.7%</td>
<td>9.7%</td>
</tr>
<tr>
<td>Miscellaneous/demolished waste</td>
<td>3.97</td>
<td>0.18</td>
<td>0.18</td>
<td>0.18</td>
<td>4.7%</td>
<td>4.7%</td>
<td>4.7%</td>
</tr>
<tr>
<td>Total other wastes</td>
<td>76.6</td>
<td>39.4</td>
<td>7.3</td>
<td>2.9</td>
<td>51.5%</td>
<td>9.5%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Total residential solid waste</td>
<td>258.8</td>
<td>65.3</td>
<td>23.0</td>
<td>69.2</td>
<td>21.5%</td>
<td>8.9%</td>
<td>26.3%</td>
</tr>
</tbody>
</table>
Combustion with Energy Recovery
Most of the MSW combustion in the U.S. incorporates recovery of an energy product (generally steam or electricity).
- In 2014, about 33.1 million tons (12.8 percent) of materials were combusted for energy recovery (see Table 3).
- From 1990 to 2000, the quantity of MSW combusted with energy recovery increased over 13 percent to about 34 million tons.
- MSW combustion for energy recovery has decreased from about 34 million tons in 2000 to 33.1 million tons in 2014.

Landfilling of MSW
While the number of U.S. landfills has steadily declined over the years, the average landfill size has increased. At the national level, landfill capacity appears to be sufficient for our current practices—although it is limited in some areas.
- Since 1990, the total amount of MSW going to landfills dropped by 9.3 million tons, from 145.3 million to 136 million tons in 2014 (see Table 3).
- The net per capita 2014 landfilling rate (after recycling, composting and combustion with energy recovery) was 2.3 pounds per day, lower than the 3.2 per capita rate in 1990 (see Table 4).
- From 1985 to 1995 there was a rapid rise in the cost to manage MSW going to landfills, followed by a steady decrease from 1995 to 2004. Since 2004, there has been a steady increase in landfill tipping fees (see Figure 9). The tipping fees are expressed in constant 2014 dollars.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation</td>
<td>88.1</td>
<td>121.1</td>
<td>151.6</td>
<td>208.3</td>
<td>242.5</td>
<td>253.7</td>
<td>251.1</td>
<td>251.8</td>
<td>255.0</td>
<td>258.5</td>
</tr>
<tr>
<td>Recycling</td>
<td>5.6</td>
<td>8.0</td>
<td>14.5</td>
<td>29.0</td>
<td>53.0</td>
<td>59.2</td>
<td>65.3</td>
<td>65.6</td>
<td>65.1</td>
<td>66.4</td>
</tr>
<tr>
<td>Composting*</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>4.2</td>
<td>16.5</td>
<td>20.6</td>
<td>20.2</td>
<td>21.3</td>
<td>22.4</td>
<td>23.0</td>
</tr>
<tr>
<td>Combustion with energy recovery†</td>
<td>0.0</td>
<td>0.5</td>
<td>2.8</td>
<td>29.8</td>
<td>33.7</td>
<td>31.7</td>
<td>29.3</td>
<td>32.5</td>
<td>33.2</td>
<td>33.1</td>
</tr>
<tr>
<td>Landfilling and other disposal†</td>
<td>82.5</td>
<td>112.6</td>
<td>134.3</td>
<td>145.3</td>
<td>140.3</td>
<td>142.2</td>
<td>136.3</td>
<td>132.4</td>
<td>134.3</td>
<td>136.0</td>
</tr>
</tbody>
</table>

* Composting of yard trimmings, food and other MSW organic material. Does not include backyard composting.
† Includes combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery of source separated materials in MSW (e.g., wood pallets, tire-derived fuel).
‡ Landfilling after recycling, composting and combustion with energy recovery, includes combustion without energy recovery. Details may not add to totals due to rounding.
Neg. Negligible = less than 0,000 tons or 0.05 percent.

Table 4. Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling of MSW, 1960 to 2014 (in pounds per person per day)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation</td>
<td>2.7</td>
<td>3.3</td>
<td>3.7</td>
<td>4.6</td>
<td>4.7</td>
<td>4.7</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Recycling</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>1.0</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Composting*</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>0.1</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Combustion with energy recovery†</td>
<td>0.0</td>
<td>neg.</td>
<td>0.1</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Landfilling and other disposal†</td>
<td>2.5</td>
<td>3.1</td>
<td>3.2</td>
<td>3.2</td>
<td>2.7</td>
<td>2.6</td>
<td>2.4</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Population (In millions)</td>
<td>180.0</td>
<td>204.0</td>
<td>227.3</td>
<td>249.9</td>
<td>281.4</td>
<td>296.4</td>
<td>309.1</td>
<td>313.9</td>
<td>316.1</td>
<td>318.9</td>
</tr>
</tbody>
</table>

* Composting of yard trimmings, food and other MSW-organic material. Does not include backyard composting.
† Indicates combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery of source separated materials in MSW (e.g., wood pallets, tire-derived fuel).
‡ Landfilling after recycling, composting and combustion with energy recovery, includes combustion without energy recovery. Details may not add to totals due to rounding.
Neg. Negligible = less than 0,000 tons or 0.05 percent.
Figure 9. National Landfill Tipping Fees, 1982-2013 ($2014 per ton)

National mean annual landfill tipping fees were normalized to constant $2014 using the consumer price index (CPI) from the Bureau of Labor Statistics to allow meaningful comparisons. This figure shows an average increase from 1985 to 1995 of $3.15 per year followed by a steady decrease of $0.77 per year followed by an increase of $2.85 from 2004 to 2013.


The Benefits of Recycling and Composting

The energy and GHG benefits of recycling, composting and combustion with energy recovery shown in Table 5 are calculated using EPA's WARM (Waste Reduction Model) methodology (see https://www.epa.gov/warm). WARM calculates and totals GHG emissions of baseline and alternative waste management practices, including source reduction, recycling, composting, combustion and landfilling. Paper and paperboard recycling, at about 44.4 million tons, resulted in a reduction of over 138 MMTCO2E in 2014. This reduction is equivalent to removing over 29 million cars from the road for one year.

In 2014, over 89 million tons of MSW were recycled and composted. These activities provided an annual reduction of more than 181 MMTCO2E comparable to removing the emissions from over 38 million passenger vehicles from the road in one year.
Table 5. Greenhouse Gas Benefits Associated with Recycling and Composting of Specific Materials, 2014* (in millions of tons recycled and composted, MMTCO₂E and in numbers of cars taken off the road per year)

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight Recycled and Composted (millions of tons)</th>
<th>GHG Benefits MMTCO₂E</th>
<th>Numbers of Cars Taken Off the Road per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and paperboard</td>
<td>44.4</td>
<td>138.4</td>
<td>29.2 million</td>
</tr>
<tr>
<td>Glass</td>
<td>2.99</td>
<td>0.8</td>
<td>175 thousand</td>
</tr>
<tr>
<td>Metals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>5.84</td>
<td>10.6</td>
<td>2.2 million</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.7</td>
<td>6.4</td>
<td>1.3 million</td>
</tr>
<tr>
<td>Other nonferrous metals†</td>
<td>1.36</td>
<td>5.9</td>
<td>1.25 million</td>
</tr>
<tr>
<td>Total metals</td>
<td>7.9</td>
<td>22.9</td>
<td>4.8 million</td>
</tr>
<tr>
<td>Plastics</td>
<td>3.17</td>
<td>3.2</td>
<td>670 thousand</td>
</tr>
<tr>
<td>Rubber and leather</td>
<td>1.44</td>
<td>0.5</td>
<td>114 thousand</td>
</tr>
<tr>
<td>Textiles</td>
<td>2.62</td>
<td>6.2</td>
<td>1.3 million</td>
</tr>
<tr>
<td>Wood</td>
<td>2.57</td>
<td>6.3</td>
<td>1.3 million</td>
</tr>
<tr>
<td>Other wastes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food, other†</td>
<td>1.94</td>
<td>0.3</td>
<td>72 thousand</td>
</tr>
<tr>
<td>Yard trimmings</td>
<td>2.108</td>
<td>3.1</td>
<td>651 thousand</td>
</tr>
</tbody>
</table>

* Includes materials from residential, commercial and institutional sources.
† Includes lead from lead-acid batteries. Other nonferrous metal calculated to WARM as mixed metals.
‡ Recycling only includes rubber from tires.
¶ Includes collection of other MSW organics for composting.
These calculations do not include an additional 1.29 million tons of MSW recycled that could not be addressed in the WARM model. MMTCO₂E is millions metric tons of carbon dioxide equivalent.

Composting Collection Programs*†
- About 3,560 community composting programs were documented in 2014—an increase from 3,227 in 2002.
- Road composting collection programs served over 2.8 million households in 2014.
MSW Generation and Household Spending

Over the years, the change in the amount of MSW generated typically imitated trends in how much money U.S. households spent on goods and services. Personal Consumer Expenditures (PCE) measure U.S. household spending on goods and services such as food, clothing, vehicles and recreation services. PCE accounts for approximately 70 percent of U.S. Gross Domestic Product, a key indicator of economic growth. PCE adjusted for inflation is referred to as real PCE. This metric is more useful in making comparisons over time because it normalizes the value of a dollar by considering how much a dollar could purchase in the past versus today. Figure 10 explores the relationship between MSW generated and real PCE since 1960.

Figure 10 is an indexed graph showing the relative changes in real PCE, MSW generated and MSW generated per capita over time. It is indexed to allow all three of these metrics to be shown on the same graph and compare their relative rates of change since 1960. The indexed value indicates the change in the value of the data since 1960. For example, if for a given year the value is three, then the data value for that year would be three times the 1960 value. In this case, if the 1960 value was 200, then the resulting year’s value would be 600. The 2014 MSW per capita generation indexed value is 1.7, which means MSW per capita generation has increased by 70 percent since 1960.

Figure 10 shows that real PCE has increased at a faster rate than MSW generation, and the disparity has become even more distinct since the mid 1990s. This metric indicates the amount of MSW generated per dollar spent is falling. In other words, the U.S. economy has been able to enjoy dramatic increases in household spending on consumer goods and services without the societal impact of similarly increasing MSW generation rates. This figure also shows that the MSW generated per capita leveled off in the early-to-mid 2000s and has since fallen. This is important because as population continues to grow, it will be necessary for MSW generated per capita to continue to fall to maintain or decrease the total amount of MSW generated as a country.

Figure 10. Indexed MSW Generated and Real PCE over Time (1960-2014)
Construction and Demolition (C&D) Debris Generation Results

C&D debris is a type of waste which is not included in MSW. Materials included in C&D are steel, wood products, drywall and plaster, brick, clay tile, asphalt shingles, concrete and asphalt concrete. These materials are used in building as well as road and bridge sectors. The generation estimate represents C&D amounts from construction, renovation and demolition activities for buildings, roads and bridges.

In 2014, 534 million tons of C&D debris were generated. Figure 11 shows the 2014 generation composition for C&D. Concrete was the largest portion (70 percent), followed by asphalt concrete (14 percent). Wood products made up seven percent and the other products accounted for nine percent combined. The 2014 generation estimates are presented in more detail in Table 6. As shown in Figure 12, demolition represented over 90 percent of total C&D debris generation as opposed to construction which represented under 10 percent.

Figure 11. C&D Generation Composition by Material, 2014
534 Million Tons (before recycling)
Table 6. C&D Debris Generation by Material and Activity (million tons)

<table>
<thead>
<tr>
<th>Material</th>
<th>Waste During Construction</th>
<th>Demolition Debris</th>
<th>Total C&amp;D Debris</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>21.7</td>
<td>353.6</td>
<td>375.3</td>
</tr>
<tr>
<td>Wood Products</td>
<td>2.9</td>
<td>35.8</td>
<td>38.7</td>
</tr>
<tr>
<td>Drywall and Plasters</td>
<td>3.3</td>
<td>10.3</td>
<td>13.6</td>
</tr>
<tr>
<td>Steel</td>
<td>0.0</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Brick and Clay Tile</td>
<td>0.2</td>
<td>11.8</td>
<td>12.0</td>
</tr>
<tr>
<td>Asphalt Shingles</td>
<td>0.8</td>
<td>12.7</td>
<td>13.5</td>
</tr>
<tr>
<td>Asphalt Concrete</td>
<td>0.0</td>
<td>76.6</td>
<td>76.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>28.9</strong></td>
<td><strong>505.1</strong></td>
<td><strong>534.0</strong></td>
</tr>
</tbody>
</table>

Figure 12. Contribution of Construction and Demolition Phases to Total 2014 C&D Debris Generation
Table 7 displays the amount of C&D debris generation from buildings, roads and bridges and other structures for each material. The other structures category includes communication, power, transportation, sewer and waste disposal, water supply, conservation and development and manufacturing infrastructure. In 2014, roads and bridges contributed significantly more to C&D debris generation than buildings and other structures, and concrete made up the largest share of C&D debris generation for all three categories.8

Table 7. C&D Debris Generation by Source (million tons)

<table>
<thead>
<tr>
<th>Material</th>
<th>Buildings</th>
<th>Roads and Bridges</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>2014</td>
<td>2014</td>
<td>123.1</td>
</tr>
<tr>
<td>Wood Products</td>
<td>84.8</td>
<td>157.4</td>
<td>13.3</td>
</tr>
<tr>
<td>Drywall and Plasters</td>
<td>13.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>4.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick and Clay Tile</td>
<td>12.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt Shingles</td>
<td>13.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt Concrete</td>
<td>165.6</td>
<td>76.6</td>
<td>134.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>165.6</strong></td>
<td><strong>234.0</strong></td>
<td><strong>134.5</strong></td>
</tr>
</tbody>
</table>

* Wood consumption in buildings also includes some lumber consumed for the construction of other structures. Data were not available to allocate lumber consumption for non-residential and unspecified uses between buildings and other structures except for railroad ties. Once non-residential buildings such as barns, warehouses and small commercial buildings are assumed to consume a greater amount of lumber than other structures, the amount of lumber for construction remaining after the amount for railroad ties is split out, is included in the buildings source category.

* Steel consumption in buildings also includes steel consumed for the construction of roads and bridges. Data were not available to allocate steel consumption across all sources; but buildings are assumed to consume the largest portion of steel for construction.

**Thinking Beyond Waste**

EPA is helping change the way our society protects the environment and conserves resources for future generations by thinking beyond recycling, composting, combustion with energy recovery and landfilling. Building on the familiar concept of Reduce, Reuse, Recycle, the Agency is employing a systemic approach that seeks to reduce materials use and associated environmental impacts over their entire life cycle, called sustainable materials management (SMM). This process starts with extraction of natural resources and material processing through product design and manufacturing, then the product use stage, followed by collection/processing and final end of life. By examining how materials are used throughout their life cycle, an SMM approach seeks to use materials in the most productive way with an emphasis on using fewer materials and products, reducing toxic chemicals and environmental impacts throughout the material’s life cycle and ensuring we have sufficient resources to meet today’s needs and those of the future. Data on MSW generation, recycling, composting, combustion with energy recovery and landfilling is an important starting point for the full SMM approach.
Resources

The data summarized in this fact sheet characterizes the MSW stream as a whole by using a materials flow methodology that relies on a mass balance approach. EPA recognizes that there are several approaches to measuring material flows (e.g., volume). To be consistent, EPA reports the materials quantities in tons in the current fact sheet but will continue to explore options for alternative measurement quantifications to describe materials management in the U.S.

EPA has consistently used materials flow analysis (MFA) to allow for comparison of data over the last three decades. EPA recognizes this methodology differs from other methodologies that also estimate generation of MSW and other waste data. EPA will continue to work with stakeholders to identify methodologies and additional publicly available data to improve our national understanding of materials flow in the U.S.

The following provides an example of how the materials flow methodology is used in the fact sheet. To determine the amounts of paper recycled, information is gathered on the amounts processed by paper mills and made into new paper on a national basis plus recycled paper exported, instead of counting paper collected for recycling on a state-by-state basis. Using data gathered from industry associations, businesses and government sources, such as the U.S. Department of Commerce and the U.S. Census Bureau we estimate tons of materials and products generated, recycled, composted, combusted with energy recovery and landfilled. Other sources of data, such as waste characterizations and research reports performed by governments, industry or the press, supplement these data. The data on C&D debris generated summarized in this report is also developed using a materials flow methodology.

The benefits of MSW recycling and composting, such as elimination of GHG emissions, are calculated using EPA’s WARM methodology. WARM calculates and totals GHG emissions of baseline and alternative waste management practices including source reduction, recycling, composting, combustion and landfilling. The model calculates emissions in metric tons of carbon equivalent (MTCE) and energy units (million Btu) across a wide range of material types commonly found in MSW. EPA developed GHG emissions reduction factors through a life-cycle assessment methodology. Please see: https://www.epa.gov/warm.

The 2014 data tables and Summaries of the MSW characterization methodology and WARM are available on the EPA website along with information about waste reduction, recycling and sustainable materials management.

Please see:
https://www.epa.gov/recycle
https://www.epa.gov/smm
Endnotes


Appendix D – ISRI MRF Glass Specification

ISRI REVIEW: MRF Glass Specification

Material Recovery Facility-derived 3-Color Mixed Container Glass ("MRF Glass") DESCRIPTION FOR ISRI REVIEW:
MRF Glass consists of crushed or whole scrap Flint (clear), Amber (brown), and Green (emerald) container/bottle glass made from soda-lime-silica. These standards and practices apply to 3-color mixed glass for purchase or sale in the United States and Canada. Transactions covering shipments to or from other countries may also be in accordance with these standards and practices and may be modified by mutual agreement between buyer and seller. These specifications are guidelines for buying and selling MRF glass and are always subject to the buyer and seller’s agreement. It is recognized that MRF Glass may be mixed with other materials as a result of recycling collection convenience and efficiency, and that quality levels and pricing varies widely based on the amount of contamination mixed in with the glass.

Since there are many different generations of Material Recovery Facilities (MRFs), cleaning equipment in operation, and curbside collection programs, the quality generated by MRFs varies widely. Processors evaluate this heterogeneous material by evaluating the amount of:

- **Residue** (non-glass residue): Higher amounts of residue result in a lower rank as the processor must separate this residue and dispose of it.
- **Undersize**: Undersize is otherwise known as "fines". Higher amounts of undersize result in quality issues as very small pieces of glass can't be optically sorted. If a disproportional amount of the stream is too small, it can overwhelm the processor's capabilities

Value is directly proportional to the amount of each in the MRF Glass.
Contamination:

*Non-Glass Residue* – Materials found in dual stream and single stream curbside collection programs entering a Material Recovery Facility (MRF). Examples of this material may be: paper, wood, food or organic material, metal/plastic closures, labels, corks, rock, dirt, and other inert materials. See chart above for tolerance limits; maximum tolerance - 35%.

*Undersized or Pulverized Material (“Fines”) – This material consists of mixed color glass particles crushed so small as to render current optical sortation unfeasible. Glass particles less than 1/8th are typically considered to be fines. See chart above for tolerance limits; maximum tolerance - 30%.

*Ceramics* – This material consists of broken bits of household ceramic. Examples of ceramic materials are dinner plates, mugs, cups, etc. Tolerance – 2% Maximum.

*Moisture* – This is considered excessive water mixed with glass. Examples of moisture are small fibers soaked by rain, ice or snow. Organic materials and dirt can also contain moisture. Tolerance – 5% maximum.

**Prohibitives:** This material is not allowed and can subject a load to rejection procedure.

- **.025% of total load allowed:**
  - Pyro Ceramics (Fireplace glass)
  - Gypsum, wallboard, drywall, glass from construction & demolition debris mixed with CaCO3 fines
  - Common moisture-absorbing desiccants (silica gels beads, alumina pellets, closet paks, etc.)

- **0% of total load allowed:**
  - CRT glass
  - Lead glass
  - Tempered window glass
  - Flammables
  - Radioactive waste
  - Weapons
  - Medical Waste
  - Insecticides
  - Poisons
  - Heavy Metals
  - Asbestos
  - Other materials that can be classified as hazardous or harmful to human health or the environment
CURBSIDE RECYCLING GUIDELINES

INBOUND RESIDENTIAL CURBSIDE MIXED RECYCLABLES for MATERIAL RECOVERY FACILITIES

SPECIFICATION & ADDITIONAL MATERIALS
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</tr>
<tr>
<td>SECTION 3 – Current ISRI Guidance on Additional Materials: Pros and Cons</td>
<td>5</td>
</tr>
</tbody>
</table>
1 Introduction and How Document is Laid Out

- Section 2 presents a recommended Material Recovery Facility (MRF) standard specification for inbound curbside residential single stream and dual stream materials, mirroring the ISRI practices included in the ISRI Scrap Specifications Circular 2016 (for detailed specifications of outbound MRF materials please refer to the ISRI Circular). The purpose of this stand-alone document is to assist ISRI members, markets, and municipalities in designing effective programs with the most common and included recyclable materials, while aiding with the buying and selling of the commodities derived from such programs. It can also be utilized as a resource for teaching recycling curricula and to provide up to date information on inbound residential recyclables. ISRI recommends that residential programs utilize at least this base specification for inbound recyclable materials from residential programs into a MRF.

- Section 3 presents “Additional Inbound Materials” that have, and may be accepted in curbside residential single stream and dual stream programs based on local practices, goals, and capabilities. ISRI offers a simple checklist of up to date pros and cons derived from consulting its Paper and Plastic division membership and subject matter experts for additional materials that are sometimes added in curbside residential single stream and dual stream programs.

* Section 2 and 3 are not inclusive and, from time to time, ISRI reserves the right to change its opinion, and add, modify, or delete the comments provided. The sections may not cover a particular local condition or program. Programs should consult published papers and research, along with other advisements, including the MRFs and markets themselves, to ascertain whether to include any given material in the inbound specification for a particular program.
Curbside Recycling Guidelines & Specifications

2 Inbound Material Recovery Specifications- Minimum Recommended Materials List

NOTE: The information provided by ISRI is for general guidance only and not for legal purposes. Anyone utilizing these specifications or the Additional Materials which may be added to Curbside residential single stream and dual stream programs (below) is advised to consult with their legal counsel on all matters with respect to any particular situation involving contracts and agreements implied or written, or any other potentially litigious situations. The application and impact of laws can vary widely based on the specific locality and facts involved, and this document is not meant to be inclusive of all situations.

Materials accepted may be modified by mutual agreement between local governments, homeowner associations, and recyclables collectors ("buyer" of MRF separating, cleaning and marketing services) and Material Recovery Facilities ("Provider" of MRF services). For local purposes, parties to a local Residential recycling transaction may specify particular variations, additions or deletions, as are suited for their specific programs and for their individual convenience. Whatever is decided should be mutually agreed to and so stipulated in writing.

- The parties should use their own due diligence to ensure that materials collected in Curbside Residential Single Stream or Dual Stream programs, and sold from MRFs after processing, consist of properly packaged materials suitable for recycling. Failure to maintain quality in residential recycling, and lack of diligence, are the chief reasons for problems arising from such programs.
- Arbitrary deductions, valuations, cancellations and/or rejections in MRF transactions are counter to acceptable good trade practices.
- Buyers will supply the agreed-upon quality of Curbside residential single stream or dual stream material into a MRF and shall not be responsible for the use of that material thereafter when sold for recycling if material is accepted by the seller of MRF services, unless such materials contain hazardous waste.

<table>
<thead>
<tr>
<th>Paper/Acceptable Fiber (Acceptable)</th>
<th>Paper (not preferred or may be prohibited) with examples (not inclusive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• All full-sheet office paper, white paper</td>
<td>• Shredded Paper</td>
</tr>
<tr>
<td>• Colored paper</td>
<td>• Napkins</td>
</tr>
<tr>
<td>• Newspaper (plastic bags and strings removed)</td>
<td>• Tissue paper</td>
</tr>
<tr>
<td>• Magazines (all types), catalogs (all types)</td>
<td>• Wall paper</td>
</tr>
<tr>
<td>• Phonebooks (all types)</td>
<td>• Paper towels</td>
</tr>
<tr>
<td>• Junk mail</td>
<td>• Wax paper</td>
</tr>
<tr>
<td>• Paperboard</td>
<td>• Wrapping paper</td>
</tr>
<tr>
<td>• Tissue boxes and tissue/towel rolls</td>
<td>• Any paper which has the potential to be contaminated with bodily fluid</td>
</tr>
<tr>
<td>• Paper office folders</td>
<td></td>
</tr>
<tr>
<td>• Paper towel and toilet paper rolls</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cardboard (OCC) Acceptable</th>
<th>Cardboard (not preferred or may be prohibited) with examples (not inclusive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Paper Boxes- Packing boxes, corrugated liners, boxboard (i.e. shoeboxes, gift boxes, cereal boxes), Brown or Kraft paper bags, brown wrapping paper, corrugated packing material.</td>
<td>• Cardboard lined with plastic (i.e. bubble wrap boxes)</td>
</tr>
<tr>
<td></td>
<td>• Wax/proof cardboard.</td>
</tr>
<tr>
<td></td>
<td>• Boxes containing food (i.e. contaminated boxes containing pizza, excessive oil, or cheese), excessive liquids, or other materials. Acceptable delivery boxes shall not contain any of these.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cartons</th>
<th>Non Acceptable (Some Examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Food and Beverage Cartons- such as milk, juice, aseptics and broth (must be empty, clean and dry)</td>
<td>• Containers with moisture, other materials, or food residue still present, straws, etc.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plastics Acceptable</th>
<th>Plastics (not preferred or may be prohibited) with examples</th>
</tr>
</thead>
</table>
### Curbside Recycling Guidelines & Specifications

<table>
<thead>
<tr>
<th>Metals Acceptable</th>
<th>Metals (not preferred or prohibited) with examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Aluminum and tin beverage and product containers (Food, beverage, and other containers' materials must be completely empty of contents clean and dry)</td>
<td>• Metal containers with paper or plastic attached.</td>
</tr>
<tr>
<td></td>
<td>• Paint cans.</td>
</tr>
<tr>
<td></td>
<td>• Aerosol cans with liquids, propellants or pressure still in the can are prohibited.</td>
</tr>
<tr>
<td></td>
<td>• Metal containers with hazardous materials still in them are prohibited.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Glass Acceptable</th>
<th>Glass (not preferred or prohibited) with examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Bottles and Jars only (materials must be dry and clean) with minimum breakage</td>
<td>• All glass types not listed in the “Glass Acceptable Section”, (window pane glass, leaded crystal, borosilicate glass, clear ceramic products, etc.).</td>
</tr>
</tbody>
</table>

### PROHIBITIVES: Unacceptable in any quantity. Subject to Immediate Rejection due to Health, Safety or Product Suitability Concerns:

- E-waste and Electronics – such as Cell phones, IPad, IPods, any Computers, TV’s, wires, Controllers, Printers, Printer rolls, and other materials
- Radioactive Materials of any kind.
- Hazardous Materials – such as Oil, Paint, Antifreezes, Powders, free or attached Asbestos or Asbestos-containing products, and Fertilizers.
- Corrosives – such as Batteries, containers with Acid or Base Residue.
- Compressed Gas Cylinders and other containers holding or formerly containing Flammable, Pressurized or Combustible Materials such as fire extinguishers, Process vessels, bulk Storage Tanks, (see restrictions on aerosol containers above).
- Lead and other Heavy Metals.
- Other Hazardous Wastes – such as Pesticides, Poisons, used Oil filters, Mercury-containing materials such as Switches and Thermometers, Biohazards, Fluorescents Lights, Tube toss.
- Refrigerants – such as Freon/Puron/Substitutes, Compressors, Air Conditioners, Refrigerators, Freezers.
- PCBs – such as Capacitors, Transformers, Ballast.
- Explosives – such as Firearms, Ammunition, Shells, Fireworks, used Gasoline Cans.
- Medical Waste – such as Needles, Syringes, Biohazard-labeled Containers, etc.
- Biological waste of any kind such as Animal carcasses, Infestations, Skins, Leather, Bones, Organs.
- Other Hazardous Materials which may harm human health or cause property/workplace damage.
- Any Materials containing human liquids or wastes – such as Diapers, Tissue, etc.
### Additional Materials

The goals of municipalities for establishing and maintaining curbside programs vary throughout the country. For various reasons such as mandates, policies, plant capabilities, customs, local markets (i.e., access to ocean export), and other factors, additional compatible materials may be collected in addition to the above materials for separation at material recovery facilities. The following chart offers ISRI’s current guidance, which shall be updated from time to time as markets and conditions change, on the current pros and cons for each material for the majority of curbside programs in the U.S. ISRI reserves the right to change any opinion below as it receives feedback from its members and others in the industry. The opinions expressed do not necessarily apply to all circumstances and programs, but are guidelines in today’s market. Notwithstanding the below, to be acceptable to material recovery facilities, all such materials, if accepted in a mixed recyclable curbside recycling program, should be subject to the same standards as the ISRI inbound curbside material “Standards” above, in terms of Source-separation, Handling, Moisture, Health Size Suitability, Material Market Suitability, and Quality. A material is not recyclable unless there is a secondary non-landfill use or market for its consumption. Use of ISRI Scrap Circular specifications is recommended as a guide.

<table>
<thead>
<tr>
<th>Material</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| #1 - #7 mixed plastics | • Markets do form regionally, locally, or export for mixed plastic bales.  
• Markets also fluctuate and can disappear with oil/resin prices changes.  
• Allows curbside programs to be permissive. | • Only stable domestic markets are for #1, #2, and #5 plastics.  
• #1 - #7 mixed plastic bales are sometimes not marketable from some locations.  
• Generally, bales are made from all plastic materials entering the MRF, not just bottles (i.e., plastic tableware, straws, etc.) which may make them more difficult to sort for re-use.  
• Must assure brokered #1 - #7 mixed bales, especially exports, do not go through secondary processing utilizing child or unfair labor practices, or causes any environmental damage (i.e. open burning of residuals).  
• Yield from these bales may be limited after all costs of shipping and sorting are applied to #5’s #1, #2, and #5 plastics. |
| #3 - #7 Plastics | • Markets do form regionally, locally, or export for mixed plastic bales.  
• Allows curbside programs to be permissive. | • Most volatile material baled in a MRF. While this grade is often sold as bales for secondary processing, usual materials recovered are #1, #2, and #5 |
<table>
<thead>
<tr>
<th>Polystyrene and Expanded Polystyrene (PS)</th>
<th>plastics not recovered at the MRF. Some polystyrene resins are also being recovered.</th>
</tr>
</thead>
<tbody>
<tr>
<td>#6 Polystyrene and Expanded Polystyrene (PS)</td>
<td>• #3-#7 mixed plastic bales are not often marketable in down markets.</td>
</tr>
<tr>
<td></td>
<td>• Generally, bales are made from all plastic materials entering the MRF, not just bottles (i.e., plastic tableware, straws, etc.) which may make them more difficult to sort for re-use, especially after baling.</td>
</tr>
<tr>
<td></td>
<td>• Sellers must assure brokered #3-#7 mixed bales, especially exports, do not go through secondary processing utilizing child or unfair labor practices or causes any environmental damage (i.e. open burning of residuals).</td>
</tr>
<tr>
<td></td>
<td>• Yield from these bales may be very limited after all costs of sorting and shipping are applied.</td>
</tr>
<tr>
<td></td>
<td>• Generally, bales are made after the separation of #1, #2, and #5 bottles from all plastic materials entering the MRF, not just remaining bottles (i.e., plastic tableware, straws, etc.) which may make them more difficult to sort for re-use.</td>
</tr>
<tr>
<td></td>
<td>• Some states and local govt.'s target this material.</td>
</tr>
<tr>
<td></td>
<td>• New extruding technologies and processes, like air-classification to optical sorter, to PS extruder may offer better recovery than in the past at MRFs.</td>
</tr>
<tr>
<td></td>
<td>• Outside of rare pilot program instances, markets are scarce to nonexistent for MRF-derived #6;</td>
</tr>
<tr>
<td></td>
<td>• The lightweight properties of EPS take long period of storage time to get to truckload quantities</td>
</tr>
<tr>
<td></td>
<td>• Test programs have high degree of failure so far.</td>
</tr>
</tbody>
</table>
## Curbside Recycling Guidelines & Specifications

<table>
<thead>
<tr>
<th>Flexible Packaging</th>
<th>Mixed household film (bagged in bag)</th>
<th>Mixed household film in mixed recyclables (‘pick-line film’)</th>
<th>Clean, dry double-polycoat food packages</th>
<th>Thermoform food or bakery containers (delicatessen, fresh food) clear i.e. ‘clamshells’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material over 1% of inbound flow at some MRFs.</td>
<td>A number of programs throughout the U.S. have added this commodity where residents stuff a plastic bag with household film (“bag in bag”)</td>
<td>Required by some programs and contracts</td>
<td>May be acceptable in limited quantities in mixed paper grades</td>
<td>Some markets limit the amount of #1, #2, and #5 thermoforms allowed. Check with local markets for limits or restrictions.</td>
</tr>
<tr>
<td>May be recovered for energy value as a pellet.</td>
<td>Can be used as pelletized or RDF fuel</td>
<td>Can be used as pelletized or RDF fuel</td>
<td>Often contains high moisture and contaminating materials, i.e. ink, plastic caps, straws, etc.</td>
<td>Some programs may not take them or be able to market them with PET bottles</td>
</tr>
<tr>
<td>May be recovered in bag-in-bag programs.</td>
<td>Bags can store recyclables in some collection programs, i.e. New York City</td>
<td>Markets are marginal at best and can be non-existent for long periods.</td>
<td>Some mills will reject if quantities are too high in mixed residential grades.</td>
<td>Optical sorters cannot distinguish thermoform from bottle PET, HDPE, and PP, making QC difficult.</td>
</tr>
<tr>
<td>New technologies and processes are emerging for both sorting and emulsifying to separate polymers.</td>
<td>Markets can be negative or prohibitive to non-existent with oil/resin fluctuations.</td>
<td>Take back programs at grocery stores allow full recycling.</td>
<td>Downgrades for premium plastics occur in some markets</td>
<td>Downgrades for premium plastics occur in some markets</td>
</tr>
<tr>
<td>Not acceptable as a recyclable grade because of laminate properties and bounded chemistry of different layers presently. Only use is conversion.</td>
<td>In most cases, cannot be exported.</td>
<td>In most cases, cannot be exported.</td>
<td>Some thermoform polystyrene containers cannot be distinguished manually from other thermoforms and</td>
<td></td>
</tr>
<tr>
<td>Contaminates paper.</td>
<td>Contamination can often be high.</td>
<td>Contamination is inherently high.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High food waste content.</td>
<td>Do not include in programs without tackling these issues.</td>
<td>Residents often put good recyclables in bags causing belt to stop or loss of recyclables to occur.</td>
<td>Causes major screen wrapping, downtime and maintenance in material recovery centers.</td>
<td></td>
</tr>
<tr>
<td>Do not include in programs without tackling these issues.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
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7
<table>
<thead>
<tr>
<th><strong>Thermoform PET food or bakery containers</strong> (clear top, black bottom)</th>
<th>Some markets limit the amount of #1, #2, and #5 thermoforms allowed. Check with local markets for limits or restrictions.</th>
<th>Some programs may not take them or be able to market them together with PET bottles. In MRFs where hand-sorting occurs, sorters cannot distinguish PP from PS or polyethylenes. Some optical sorters cannot distinguish black bottom thermoform. Downgrades for premium plastics occur in some markets.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aluminum Foil</strong></td>
<td>• Is acceptable in some export bales and very limited quantities in UBC. • Some programs on MRF residual recover Al foil.</td>
<td>• Hard to generate in a clean form from residential sources. • Many restrictive export countries will not take foil which has been used with food and could reject bales. • Foil disintegrates and flakes with age. If in small pieces, foil flashes in an aluminum furnace. • Foil can contain high moisture food/household oil waste, which can explode when introduced into a furnace. • Domestic markets can be less tolerant than export. • Before accepting check with market.</td>
</tr>
<tr>
<td><strong>Shredded Paper &lt;1” diameter loose</strong></td>
<td>• Is acceptable in some of curbside programs. • Can be captured with some later technology MRFs through light fraction separation and optical sorting. • May be acceptable in Kraft bags in some mixed paper producing MRFs.</td>
<td>• Does not get captured because of size recognition limitations at some MRFs and leaves MRFs as residue or in fines products like glass. • Holds moisture and raises content of moisture in paper bales and in glass. • Size of fiber strands makes it less recyclable.</td>
</tr>
</tbody>
</table>
Appendix E – References for Optical and Hyperspectral Imaging


