closing the loop

Design for Recovery Guidelines:
Steel Packaging

a publication of GREENBLUE

steel


Abita
Samuel Adams Seasonal
BL
Bud Light
Lite
Alpine
Lager
Sierra Nevada
Pry Off
SweetWater
Big Red
Abita
Brewed with Spring Water
Kinley
Honey Weiss
Flying Dog
Bucegi
Corona Extra
Corona Extra
Labatt Blue
Miller Chill
Coors Light
Clipper City Brewing
American Ale
Company Tap Room Brewing
Alpine

Design for Recovery Guidelines: Steel Packaging

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When considering ways to enhance the sustainability of packaging, a primary goal must be to make wise use of material resources that are recoverable at the end of their useful life and re-used in industrial or biological cycles. To make this happen, it is critical to connect packaging design and manufacture with the available end-of-life recovery systems, creating "closed loop" material systems. However, in the United States, the two ends of the packaging supply chain—the packaging designers and the recyclers—often do not communicate effectively with each other, and non-recyclable packaging is created, material resources are lost to landfills, and closed-loop systems are never realized.

One of the barriers to effective communication along the packaging supply chain is the lack of an informational resource explaining how design decisions affect recyclability. The Association of Postconsumer Plastic Recyclers (APR) has done an excellent job providing its *Design for Recyclability Guidelines* for plastic bottles, explaining which plastic bottles, including their attachments, inks, coatings, and colorants, are compatible or incompatible with today's various recycling technologies. This type of information needs to be broadened to reach across all packaging material types to provide technical guidance on designing packaging that can be optimally recovered in the recycling process.

This document was created with the original intent of educating package designers about measures they may take to create steel packaging that does not negatively affect recycling operations. However, extensive research into steel recycling processes did not reveal any documentation of packaging that is incompatible with steel recycling. Because of the nature of steelmaking processes and the infrastructure of the steel industry, it is unlikely a package design decision would negatively affect the recyclability of steel packaging. Currently there is no steel packaging on the market known to be non-recyclable. This document details the steel recycling processes and elucidates the reasons steel packaging is currently always recyclable.

Steel is a widely used alloy consisting of iron with small amounts of carbon and other elements such as tungsten, chromium, molybdenum, manganese, and vanadium. Steel is renowned for its combination of sturdiness and formability, making it well-suited for a wide variety of applications. The advantages of steel as a packaging material include its strength, durability, tamper resistance, and the ability to act as an impenetrable barrier to light, air, and moisture, permitting long shelf-stability. Steel is also a highly recycled material. In 2008, steel containers were recycled at a rate of 65.2%, and including all other applications of steel, the overall steel recycling rate was 83.3% (Steel Recycling Institute [SRI], 2009).

Food cans are by far the largest steel packaging application, accounting for over 90% of all steel packaging by weight (U.S. Environmental Protection Agency [U.S. EPA], 2009a). In 2005, 20% of steel food cans were used for pet food (Can Manufacturers Institute, 2008a). Aerosol cans accounted for the majority of the steel packaging that was not food cans (Can Manufacturers Institute, 2008b). Other less common applications of steel packaging include paint cans, pails and drums, crown caps, jar lids, and containers used for miscellaneous products such as varnish and automotive products. In 2008, steel accounted for over 57% of metal packaging in the U.S. (3.3% of all U.S. packaging), 91% of the U.S. food can market by weight (U.S. EPA, 2009a), and 90% of the aerosol can market (Earth911, 2010).

Although there are numerous different types of steel alloys customized to suit different applications, there are two general classifications of steel: low carbon steel, also called mild steel, and high carbon steel. Low carbon steel is produced in the basic oxygen steelmaking process using up to 30% recovered steel scrap. High carbon steel is made in a different process, using an electric arc furnace capable of using up to 100% recovered steel scrap. The higher the carbon content of steel, the stiffer and less ductile it becomes, making it more difficult to mold or shape without losing strength. Packaging applications require metal that is formable, so low carbon steel is used for virtually all steel packaging. Therefore, steel packaging is limited to a maximum of 30% recycled content because of the technical specifications of the steel made in the basic oxygen steelmaking process.

In contrast to steel packaging, which is constructed from thin sheets of steel, the majority of manufactured steel products are "long products," such as axles and structural beams and rods for the construction and automotive industries. Because stiffness is generally the primary desired characteristic for these types of products, they are usually made from high carbon steel in an electric arc furnace. Also, due to the capability of the electric arc furnace to use a high amount of recovered steel scrap, the majority of recovered steel—both low carbon and high carbon—is used to make high carbon long products.

Did You Know?

The steelmaking process limits the recycled content in steel packaging to a maximum of 30%.

The construction and automotive industries dominate the steel industry as a whole, and the usage of steel by these industries dwarfs the amount of steel used in packaging. Of the 102.4 million tons of steel produced by the U.S. in 2008 (World Steel Association, 2009), only 2.8 million tons (less than 3%) were used in the packaging industry (American Iron and Steel [AISI], 2006). Because of this, most steel produced is high carbon steel created for the construction and automotive industries, and in relation, only a tiny amount of low carbon steel is produced for the packaging industry.

The supply and demand dynamics of the steel industry suggest that the majority of recovered steel packaging is not immediately reprocessed to create new steel packaging. Like many other metals, steel is infinitely recyclable, but steel is unique in that there is not always a closed-loop recycling system for individual categories of steel products. For example, a steel aerosol can may be recycled to produce an automobile body, which may be recycled to produce an aircraft carrier, and eventually, the steel in the aircraft carrier may be recycled to produce a soup can.

However, there are barriers to steel recycling that are unrelated to design, such as the behavior of consumers, issues related to the collection and sorting processes, and the recycling program infrastructure in communities across the United States. This document is not intended to provide a comprehensive discussion of the overall issues surrounding the successful recovery of steel packaging.

Primary research for this document included interviews with stakeholders from various portions of the steel recycling process. Interviews were conducted with brand owners, operators of recycling programs, industry associations, and state and local agencies. In addition, a broad literature search was performed to find developments in steel recycling.

In contrast to the recycling systems of other materials, steel reprocessing operations are extremely tolerant of contaminants. For example, when materials such as glass and aluminum are thermochemically recycled, packaging components such as labels and closures often contaminate the reprocessing operation, ruining the consistency of the melt and the overall composition of the material. Often these contaminants will impede or disrupt the reprocessing operation and they may ultimately result in a product that is either of a lower quality than the original product or defective. If care is not taken to design glass and aluminum packaging that is optimal for the recycling operation, their impacts on the reprocessing operation may negate the value of recovering the material. This does not happen with steel reprocessing.

While steel processors undoubtedly prefer not to add any materials other than steel to their melting furnaces, the steel processing operation is the most forgiving of the presence of other materials because the furnace temperature may reach 3,000°F. This high temperature causes all plastic, glass, paper, and aluminum objects to vaporize, leaving the furnace as gaseous emissions. As the objects vaporize, some of their energy is captured and imparts a small amount of heat to the furnace, and the amount of fuel needed to heat the furnace is slightly reduced (G. Crawford, personal communication, March 15, 2010).

Although there is no design for recyclability guidance for steel packaging, the following information is valuable in understanding any problems with the steel recycling process that may result from packaging.

Did You Know?

Barriers to recycling steel are unrelated to package design, such as the lack of public participation in recycling programs and physical issues that can arise during collection and sorting.

STEEL PACKAGING

What is it? Where is it found?
Packaging made from steel is used to store a variety of products, including food, pet food, personal care products, paint, and oil. Steel cans are the most prevalent form of steel packaging. Steel cans range in size from pet food to fruit and vegetable cans, paint cans, and large steel drums. Steel is also used in packaging in the form of closures, such as jar lids and bottle caps.

Why is it used?
The advantages of steel as a packaging material include its strength, durability, tamper resistance, and ability to act as an impenetrable barrier to light, air, and moisture, which makes it ideal for items that require long-term shelf-stability.

Steel Packaging in Recycling
All steel packaging is fully recyclable, and it is rare for a packaging design decision to affect the steel recycling process negatively. Issues in recycling steel cans are most often due to the contents of the package, such as paint, which is typically collected as household hazardous waste and not sent through traditional recycling collection systems. Another issue is physical characteristics, like shape or size. Some flat or small steel packaging components, such as can lids or bottle caps, may become trapped in other materials or fall through conveyor belts at material recovery facilities. While recyclable, their shape or size means they do not usually get recycled.

Alternatives
No design alternatives are suggested because there is no recyclability issue for steel packaging. However, some steel containers are being replaced with plastic cans and bottles for reasons other than recyclability, such as weight, cost, or use requirements.

Did You Know?

Over 90% of all steel packaging in the U.S. is food cans.

STEEL AEROSOL CANS

What is it?
Aerosol cans are used to contain and dispense a variety of different liquids, creams, and gases. About 90% of aerosol cans are made from steel, while the remaining 10% are made from aluminum (Earth911, 2010). Steel aerosol cans are made with the same three-piece construction as steel food cans. The bottom of the can is domed inwards to counteract internal pressure, and the top of the container is given a wide mouth opening to which the spray valve is affixed.

The spray valve is a composite piece of plastic and metal components, and functions to regulate, direct, and dispense the contents. In order to force the contents out of the spray valve, aerosol cans are pressurized with a propellant, which may be one of several available types. There are two general classifications of propellants: hydrocarbon-based propellants, such as propane; and compressed gases, such as carbon dioxide. The product may be separated from the propellant by using an inner bag to contain the product or by placing a piston in between the liquid product and the gaseous propellant (Soroka, 2002).

Why is it used?
Aerosol cans have the unique ability to dispense a liquid product in a fine mist, which is useful for products that must be distributed over an area in a fine layer. They are also the only packaging type capable of containing and dispensing gases in a regulated manner.

Where is it found?
Aerosol cans are used for a very wide variety of products. Their most prevalent use is for personal care products, such as shaving cream, hair spray, and deodorants. Other less-common applications include air fresheners, cleaners and polishes, sunscreens, insect sprays, and paints. Aerosol cans are also used to contain and dispense gases, most commonly as an “air duster” or “canned air” (a misnomer because inert gases like difluoroethane are commonly used instead of compressed air).

Aerosol Cans in Recycling
Steel aerosol cans that are still pressurized present a potential hazard in the compacting and baling process at a material recovery facility, depending on the type of propellant gas they contain. While some steel aerosol cans contain a non-flammable propellant gas such as carbon dioxide or nitrous oxide, other steel aerosol cans use a flammable hydrocarbon-based propellant such as propane or an isobutane/propane mixture that may present hazards.

If a still-pressurized aerosol can containing a hydrocarbon-based propellant is punctured or ruptured during the compaction process, the propellant gas may ignite as it escapes the container, creating a fireball. Incidents are rare because proper operating procedures dictate that all flammable materials are to be kept away from the compactor and all personnel are to keep clear of the integral relief ports around the compression chamber. Nonetheless, there have been incidents of fire and injury resulting from pressurized aerosol cans (NZ Herald, 2007; Insure My Liability, 2009).

Alternatives
There are no functionally equivalent alternatives to aerosol cans; however, many products such as shaving cream and insect repellant may be dispensed using a plastic pump-operated container instead of a pressurized delivery system.

COMPOSITE STEEL PACKAGING

What is it? Where is it found?

Composite steel packaging is any package that includes steel components in combination with other materials. There are two major types of steel composite packaging. One type is frozen juice concentrate containers, which are cardboard tubes with steel ends. The other is bi-metal beverage cans, which have steel bodies with aluminum tops. Bi-metal beverage cans are prevalent elsewhere in the world, but they are not used in the U.S. with the exception of a small number of imported beverages (J. Hill, personal communication, March 29, 2010; G. Crawford, personal communication, March 15, 2010 & May 19, 2010).

Why is it used?

Composite steel packaging may be used for a variety of reasons, including strength and rigidity, cost, and marketing and shelf-appeal.

Composite Steel Packaging in Recycling

All steel composite packaging containing non-steel components is typically non-problematic in steel recycling; it is very rare for a packaging design decision to affect the steel recycling process negatively. It should be noted, however, that when composite packaging is recycled for its steel content, it prevents the non-steel components (e.g. aluminum or fiber) from being recycled in their respective material recycling operations.

Alternatives

Though there is no recyclability problem for the steel in composite packaging, packaging alternatives for juice concentrates include plastic containers, while aluminum cans are the typical alternative to bi-metal cans.

Did You Know?

While bimetal beverage cans are commonplace in countries around the world, they are relatively rare in the United States.

COATINGS & LACQUERS

What is it?
Coatings and lacquers are thin layers of substances, such as polymers or metals, used to cover the outside (coating) or inside (lacquer) of a steel package (GreenBlue Institute, 2009).

Where is it found?
Coatings for steel packaging are either metals or polymers. The metals used to coat steel packaging are applied electrolytically in micron-thin layers. Approximately two thirds of steel can sheet is coated in tin. The other one third of steel can sheet is coated using a light wash of chromium (SRI, n.d.) and is known as "tin-free" steel. These metal coatings are applied to both sides of a steel sheet prior to conversion into cans, as discussed in the Steel Production and Conversion section.

The polymer coatings typically in use are acrylic, polyester, alkyd, or epoxy (GreenBlue Institute, 2009).

Lacquers are polymers, and commonly include epoxy, polyester, organosol lacquers, and phenolic lacquers. Lacquers may also be used in combination with enamels, pigments, and varnishes to achieve color or glossy visual effects.

Why is it used?
Coatings are used to protect steel packaging from scuffing or corrosion. Coatings can also provide pigmentation for decorative purposes. Lacquers are used to cover the inside of a steel package, most often to prevent the contents from coming into contact with the steel package to prevent corrosion or preserve flavor. They also may be used for pigmentation purposes.

Coatings & Lacquers in Recycling
As noted above, the high temperatures in a steel furnace will vaporize any polymers that remain on steel packaging. As such, polymer coatings and lacquers do not present any problems to the recyclability of steel packaging.

Tin coatings do not present problems in the collection or sorting of steel packaging. In general, tin also does not present any problems to the recycling process for either basic oxygen furnace (BOF) or electric arc furnace (EAF) operations (SRI, n.d.). The presence of a tin alloy in steel can change the steel's mechanical properties, and in the mid-twentieth century, steel mills would not recycle steel packaging unless it has first been detinned (SRI, n.d.). The detinning process is no longer needed for steel packaging because the amount of tin used for coatings on steel packaging has been significantly reduced over the past 60 years, from 50 pounds of tin per ton of steel cans in the 1940s to less than four pounds per ton today (G. Crawford, personal communication, February 2, 2011).

Did You Know?

In the U.S., steel cans are commonly referred to as "tin cans" because of the tinplate coating.

Because tin does not readily oxidize, it cannot be transferred to the slag and removed from the steel in the way other metals, such as chromium, are removed (Savov et al., 2003). In practice, steel makers select scrap for inclusion in a given melt based on its anticipated chemistry and alloying elements. For example, a known quantity of steel packaging would be added to each melt, so that the overall tin contribution is small and falls below the known maximum metallurgical limits for residual metals. The Steel Recycling Institute routinely conducts outreach to communicate the chemistry of steel cans to steel makers and scrap dealers, and in the past 22 years has received no reports from steel makers regarding excessive tin from the use of steel can scrap (G. Crawford, personal communication, February 2, 2011).

Chromium coatings also do not present any difficulties to the collection, sorting, or recycling process for steel. Chromium is a commonly added alloy element in steel. If the chromium level does become too high, the chromium can be removed as slag, reclaimed, and sold (Peden et al., 1998). In practice, however, only one third of steel can sheet is coated with chromium and its contribution to the steel making process is extremely small. As mentioned above, steel makers are well aware of the amount of alloying metals present in a bale of steel can scrap. They incorporate specific quantities of the scrap in each melt so that alloying metals, such as chromium, are present in the correct proportion (G. Crawford, personal communication, February 2, 2011).

Alternatives
Though there is no recyclability problem with the coatings and lacquers used on steel packaging, packaging alternatives include glass or plastic containers or multi-laminate cartons that can be used to package products that might corrode or negatively interact with steel, such as acidic foods.

COPPER

What is it? Why is it used? Where is it found?
Copper is usually found in packaging materials for two reasons. First, it is an alloying element in the aluminum used for packaging applications. Second, it may be used to as the antenna material in a radio frequency identification tag (RFID).

Copper in Steel Recycling
Copper is slightly problematic to steel recycling because it changes the mechanical and chemical properties of steel, and it cannot be removed by the processes in which other impurities are removed (Savov et al., 2003). Excess copper can cause steel to be either softened or embrittled, making it unusable for its intended purpose (SRI, 2003). When copper is present in amounts higher than the acceptable levels, its concentration must be diluted by re-melting the steel with other steel or with virgin iron. Copper is the only problematic material that may be introduced by packaging to a steelmaking operation.

While copper is an alloying element in aluminum, the amount of aluminum included with steel scrap, either erroneously or via composite packaging containing both steel and aluminum, is small enough that its contribution of copper is negligible to the overall chemistry of a melted batch of steel. However, if steel is reprocessed again and again with aluminum, its copper content may slowly accumulate to an unacceptable level, so care is taken to exclude aluminum packaging that does not contain a worthwhile amount of steel.

The growing trend of using radio frequency identification (RFID) tags on packaging is of concern to steel processors because of the possibility that they contain copper (SRI, 2003). RFID tags consist of layers of paper, plastic, and adhesive sandwiching an antenna made from a metal foil or conductive ink. Some designs incorporate a small computer chip or battery. Aluminum and copper are the most commonly used metals for the construction of the antenna.

While aluminum will not incorporate itself into the chemistry of steel, copper will appear as a trace element. With consecutive iterations of reprocessing steel affixed with copper-based RFID tags, the problematic copper content will necessitate an increased use of virgin iron to dilute its concentration. The steel industry supports the use of aluminum-based RFID tags; it does not support the use of RFID tags made using copper antennae because of the potential impact on the mechanical and chemical properties of steel (SRI, 2003). Although RFID tags are not currently used in amounts that are cause for concern, it is expected that large industrial containers like steel drums may be among their first widespread recipients (O'Connor, 2008; European Commission, 2007; Maltby et al., 2005; SRI, 2003).

Alternatives
There are no design alternatives for steel that would eliminate copper from the recycling process, aside from avoiding the use of copper-containing RFID tags.

LABELS

What is it? Why is it used?
Labels are thin sheets of paper or plastic affixed by the use of an adhesive to a steel can to identify the brand, product, and ingredients packaged in the can. The label also serves a marketing role in advertising the product.

Where is it found?
Labels are commonly found on steel packaging for food, such as canned fruit and vegetables.

Labels in Recycling
As noted above, the high temperatures in a steel furnace will vaporize any paper or plastic labels or adhesives that remain on the packaging. As such, labels present no barrier to the recyclability of steel packaging.

Alternatives
Though labels do not present problems when recycling steel packaging, steel cans can be decorated and labeled by printing directly on the metal (pre-coated with a thin layer of polyethylene terephthalate resin).

OTHER CONTAMINANTS TO STEEL

There are a few materials, listed below, that are problematic in the production of steel. However, they are not found in packaging applications.

- Radioactive material is extremely problematic, but it is never introduced to steel processing operations by packaging (G. Crawford, personal communication, March 15, 2010).
- Lead is problematic, but it is legally banned from being present in packaging (EPA, 2009b; The Toxics in Packaging Clearinghouse, 2009).
- Nickel is slightly problematic to steel reprocessing, behaving in the same manner as copper. However, nickel is not used in packaging applications and is not introduced to the steel reprocessing operation by packaging.

Of the above contaminants, lead is the only one to have been used for packaging purposes. Historically, it was used to solder steel can seams together. However, the use of lead in steel food cans is no longer permitted in the United States (Soroka, 2002).

Overview of Steel Production

Steel is produced by melting and refining a combination of recovered steel scrap and raw iron. There are two main manufacturing operations differentiated by their manufacturing equipment and the amount of steel scrap that they use. Basic oxygen steelmaking (BOS) uses majority raw iron and 20-30% steel scrap to create steel using the basic oxygen process (BOP) with a basic oxygen furnace (BOF). Steel made in an electric arc furnace (EAF) may be produced using 100% recovered steel scrap, although small amounts of raw iron are often used to adjust the steel chemistry. BOP steelmaking is often done in an integrated mill where processes for smelting iron are combined with the steelmaking operation. EAF steelmaking is often done in a mini-mill, which only has the furnace operations for steelmaking. In 2006, 57% of the total amount of steel produced in the U.S. was produced in mini-mills (U.S. EPA, 2009c).

Despite the fact that both processes use recovered steel scrap, BOP steelmaking is often referred to as “primary production” and EAF steelmaking is often referred to as “secondary production.” To further complicate the terminology, “primary steelmaking” is often used to refer to either BOP or EAF steelmaking while “secondary steelmaking” is used to refer to the refining operation that occurs after the steel is removed from the BOF or EAF. This document uses the latter denotations of “primary” and “secondary.”

Iron Smelting

Virgin steel is made from iron (pig iron), which is produced from iron ore in a blast furnace (AISI, 2010). Iron is almost universally found in nature as iron oxides, bound in minerals such as hematite (70% iron content) and magnetite (72% iron content) (Mineral Information Institute, 2008). In order to produce elemental iron, the smelting process uses several chemical reactions to remove as many non-iron components of the ore as possible.

Primary Steelmaking

BASIC OXYGEN STEELMAKING

Although a substantial amount of impurities are removed from the iron in the blast furnace, the carbon content of pig iron is usually around 3-4%, which is high enough to cause the metal to be brittle and easily breakable (Assure, 2003). The main purpose of the BOS steelmaking process is to remove enough carbon to make the metal ductile. Additional flux materials are added to remove impurities. The degree to which impurities are removed depends on the purity of the incoming pig iron and the desired quality of the resulting steel.

To rid the metal of its carbon content, a water-cooled tube called a lance is lowered over a mixture of molten pig iron and steel scrap, where it blows a high-velocity stream of 99% pure oxygen. The oxygen combines with the residual carbon, causing it to ignite and form carbon dioxide and carbon monoxide gases. The purpose of including steel scrap is to absorb the large amount of heat released when the carbon is ignited and burnt. The steel scrap then melts into the de-carbonated iron, and the process does not produce any 'waste' heat. Following the de-carbonation process, alloying materials are added to the molten metal in accordance with the desired properties of the finished steel. The BOS process results in low carbon steel containing over 99% iron and as little as 0.001% carbon (Stubbles, 2010). After the carbon content is sufficiently lowered, the steel is tapped from the basic oxygen furnace and transferred to a ladle metallurgical furnace where its composition is further modified and refined.

ELECTRIC ARC FURNACE STEELMAKING

The EAF steelmaking process produces steel with a higher carbon content than the BOP. The process typically uses steel scrap with both high and low carbon contents, known in the process as "heavy melt" and "light gauge," respectively. The steel scrap is melted by a heat-generating electric arc, created by applying an immense electrical current through one or more large graphite electrodes that are lowered into the furnace. While the electric arc melts the steel, oxygen is blown into the furnace to ignite and combust some of the impurities, creating additional heat that assists the melting process. Once the metal is entirely melted, fluxes are introduced to remove impurities, and additional oxygen is lanced in to combust any impurities that cannot be efficiently removed with fluxes. Some impurities such as nickel and copper cannot be removed with fluxes or oxygen lancing because they have a poorer affinity for oxygen than iron—the amount of oxygen it would take to oxidize these elements would also oxidize the iron in the steel. When impurities such as these are too prevalent in the steel scrap, virgin iron must be mixed with the steel scrap to dilute their concentrations down to acceptable levels (Jones, 2010).

Secondary Steelmaking and Casting

Secondary steelmaking refers to any processes performed after steel is tapped from a BOF or EAF and before it is cast. Secondary steelmaking operations are most often done in a ladle which transports the liquid steel from the furnace to the casting equipment. The melt is constantly stirred while in the ladle to keep its composition and temperature homogenous. Stirring is performed either by bubbling argon gas through the melt or by applying a varying electromagnetic field, which stirs the liquid steel because it is magnetic. Bubbling argon through the melt also rids the steel of sulfur. Some ladles are equipped with arc-generating electrodes to heat the melt (World Steel Association, 2010a).

The chemical composition of the steel may be refined by adding or removing elements in the ladle. Performing such metallurgical adjustments is more common in an integrated mill using the BOP. Refining is chiefly done in the EAF in a mini-mill. Further decarburization may be performed by injecting oxygen or a mixture of oxygen and argon, enhancing the efficiency of the process. Alloying elements may be added by feeding in steel wires that have cores of the alloying elements or by injecting the elements into the melt in powder form (World Steel, Association 2010a).

After the secondary steelmaking operations are completed and the melt is transported to the casting equipment, the liquid steel is poured into casting equipment and solidified. Most manufacturers use the continuous casting method, where the melt is poured into a reservoir and then funneled through a series of water-cooled molds and rollers. The steel solidifies as it passes through the continuous casting system, and mechanical shears or high-temperature torches cut the steel into standardized lengths as it exits the caster. The cut slabs may be immediately hot rolled to take advantage of their high temperature. Less commonly, single stationary molds are used instead of continuous casting. This method of casting produces steel ingots once the mold is stripped away from the metal (U.S. EPA, 2009c).

Steel Rolling

To create the steel sheet used to create packaging, the continually-casted steel slabs are pressed through a series of rollers that flatten and reshape them. Hot rolling at a temperature of 1200°C flattens the 240mm-thick slab to a 3mm-thick plate, and then cold rolling near room temperature flattens the steel plate to steel sheet with a thickness around 0.25mm. To prepare for rolling, the scale of iron oxide that forms on the steel surface is removed using high pressure water jets, and the metal is sized to determine the amount of rolling that is necessary. After cold rolling is completed, the steel is annealed to impart the softness necessary for container forming, and washed in hydrochloric or sulfuric acid to remove the layer of scale one final time in a process known as pickling (World Steel Association, 2010b).

Next, both sides of the sheet are coated with tin or chromium using an electrolytic process. The steel is passed through two electrodes that are surrounded by tin or chromium wire, fusing the metal coating from the wire to the steel. Steel coated with chromium is often referred to as tin-free steel and is used for packaging components that do not need to be welded, such as lids, ends, crown caps, and aerosol can tops and bottoms. Tinplate steel is used for components such as the bodies of food cans, aerosol cans, and paint cans. After the appropriate coating is applied, the cold rolled steel sheet is wound into a coil and sold to a steel converter (Soroka, 2002).

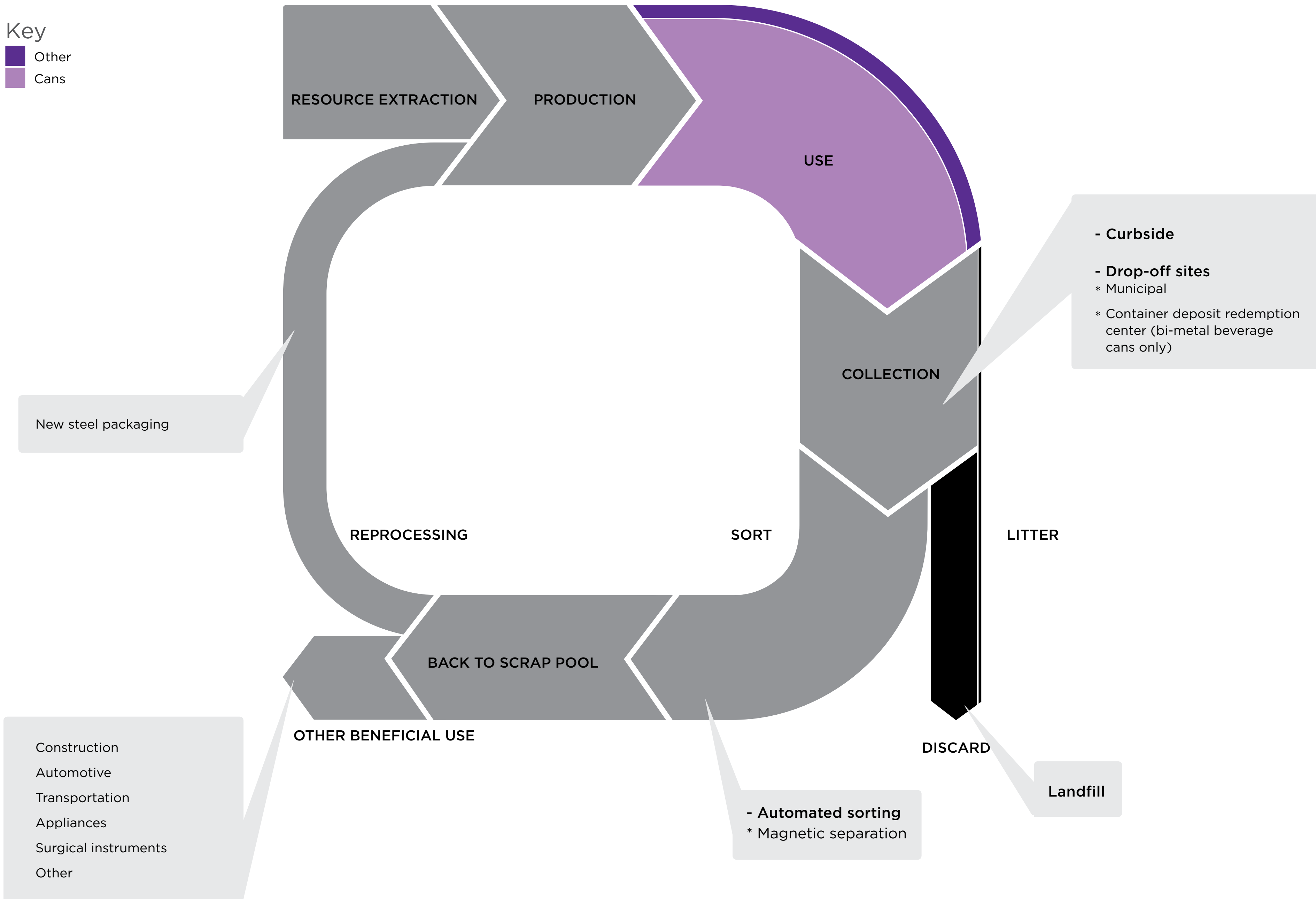
Steel Conversion

Conversion is the process of transforming steel coil into steel products. To create the bodies for steel food cans, paint cans, and aerosol cans, the sheets of steel are uncoiled and cut into rectangles that are each curled into a tube and welded together with an application of copper wire, pressure, and electricity. An acrylic or vinyl coating is then sprayed over the welded seam in the interior of each can so that the contents do not come in contact with the seam, and the spray is cured by sending the cans through an oven. Next the ends of the bodies are necked and flanged in preparation to receive the can ends. If the cans will be retorted (heat sterilized), they are given a set of concentric ridges to add strength to the can so that it does not collapse in the retorting process. The bottom of the can is then mechanically interlocked and crimped to the can body, and on aerosol cans the bottom is domed upwards to withstand the internal pressure. The tops are also mechanically crimped on after the can has been filled with a product (Ball Packaging Americas, 2010).

The shallower, non-cylindrical steel packaging components—can ends, jar lids, crown caps, paint can lids, and shallow containers—are created from small circular pieces that are punched out from the steel sheet. To curl the edges of components such as jar lids and crown caps, the circular pieces are "drawn"—pushed through a die that forces them to conform to a cuplike shape. Jar lids, crown caps, and food can ends are given a layer of a plastic compound to ensure a tight seal and to prevent the metal from coming into contact with the contents of the container.

The following overview of the steel recycling process details the operations that allow used steel packaging to be recycled into new steel products by primary and secondary steel producers. Reuse of steel packaging represents the highest end-of-life scenario according to the waste hierarchy, but the reuse of steel packaging is currently limited to large industrial steel drums. Both primary and secondary steel production processes require steel scrap, and therefore recycling represents the most beneficial end-of-life option for steel packaging. Because steel packaging is not suitable for composting or waste-to-energy, recycling in primary or secondary steel production is the only beneficial end-of-life option available.

Steel | Material Flow



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

Overview of the Recycling Process: Collection, Sorting, and Reprocessing

COLLECTION

Steel packaging collection is managed under residential and commercial recycling programs. Recycling programs typically employ drop-off sites, a curbside collection system, or both. In states with container deposit legislation that applies to bimetal beverage cans, consumers may return steel beverage cans at designated redemption centers for a small refund. Only very few imported beverage cans are made with steel, and most container deposit programs do not apply to any steel packaging.

Residential recycling programs are each managed differently, and collection practices vary by locality. Curbside collection is predominantly used in municipalities where the population density is high enough for the operation of a truck fleet to be efficient and cost-effective. It is typically not used in loosely populated areas. The manner in which curbside collection is operated also varies regionally. Some systems operate as “single stream” recycling and use one bin for all recyclables, while other programs employ one additional recycling bin for glass or paper recyclables. Municipalities may use one or more drop-off sites, either to provide a method for collecting recyclables excluded from a curbside collection program, or simply to provide a method for collecting loads of recyclables too large for curbside collection. Because curbside collection is not usually feasible in rural areas, drop-off sites are the only option for some rural residents who wish to participate in recycling.

While steel food cans are nearly always collected in any recycling program, collection practices for other types of steel packaging differ with each program. Many programs do not collect any steel packaging other than cans, because they may be too small for effective sorting (e.g., crown caps and jar lids) at a material recovery facility (MRF), or they may contain a household hazardous waste (e.g., paint cans and aerosol cans). According to Greg Crawford of the Steel Recycling Institute, 7,506 out of 7,765 curbside collection programs in the U.S. (97%), and 10,236 out of 12,535 drop-off sites in the U.S. (82%) include at least steel food cans (personal communication, March 15, 2010).

Commercial collection systems may be operated in the same manner as residential collection systems or they may be designed to cater to the specific types of recyclable waste that are generated by a business. Because restaurants are particularly likely to generate a large quantity of steel food cans, they may be given a large receptacle dedicated to steel as part of their collection system. Though participation in commercial recycling is usually voluntary, some states and municipalities have enacted mandatory recycling requirements for certain businesses, such as those with alcoholic beverage permits (North Carolina, 2005).

SORTING

Any steel collected in a commingled recycling system must be sorted out from the other materials before it may be reprocessed. Collected materials are typically sorted at a MRF by a series of automated mechanisms that separate materials by different physical properties. Steel is typically separated by a magnet, which exploits the magnetism that is inherent to steel but absent in aluminum. The magnetic separator may be positioned overhead to pull the steel away from the mixed stream or a different configuration may be used in which the steel pieces are magnetically pulled from the rest of the recyclables to a separate conveyor belt. An electromagnet is commonly used, but some designs use permanent ferrous magnets or magnets made of rare earth metals.

Because steel is the only recycled material that is magnetic, the magnetic separator is very effective at removing only steel from a mixed stream of recyclable materials. Since steel may be removed so efficiently, the magnetic separator is usually situated very early in the sorting line, decreasing the size of the mixed stream and reducing the wear on the other sorting mechanisms. One notable consequence of filtering out steel before other materials is that any object containing an appreciable amount of steel will be removed with the magnet even if there are non-steel components in its construction. Such recyclables include frozen juice concentrate containers, which are cardboard tubes with steel ends, and bi-metal beverage cans, which have steel bodies with aluminum tops. The bi-metal beverage cans are prevalent elsewhere in the world, but they are not present in the U.S. with the exception of a small number of imported beverages (J. Hill, personal communication, March 29, 2010; G. Crawford, personal communication, March 15, 2010 & May 19, 2010).

Did You Know?

Steel is the only packaging material that is magnetic, which makes sorting easy.

Some MRFs have configurations of sorting equipment that erroneously remove some steel packaging before the magnetic separator because of their size and shape. Screening equipment is often used early in the line to rid the mixed stream of small bits of trash, pieces of broken glass, and any other materials too small to be effectively sorted by the automated equipment. Small pieces of steel, notably the steel crown caps used on glass bottles, are prone to being removed by screening equipment and thrown out as garbage. Also, many MRFs will precede the magnetic separator with a piece of sorting equipment, known as a star screen or disc screen, that separates flat objects from container-shaped objects. The purpose of this machine is to remove the flat, two-dimensional paper and corrugated cardboard that makes up a large portion of the mixed stream. The machine will, however, indiscriminately remove flat pieces of any material, and so flat steel components, like jar lids and food can ends, may be incorrectly sorted with paper products (S. McClelland, personal communication, March 11, 2010; B. Clark, personal communication, March 31, 2010; & A. Dmitriew, personal communication, March 9, 2010).

BALING AND SHIPPING

Once all the steel materials are filtered out from the recycling stream, they are compacted and baled to be efficiently transported to a reprocessor. Steel aerosol cans that are still pressurized present a potential hazard in this process, depending on the type of propellant gas they contain. While many steel aerosol cans contain a non-flammable propellant gas such as carbon dioxide or nitrous oxide, some steel aerosol cans use a flammable hydrocarbon-based propellant such as propane or an isobutane/propane mixture. If a still-pressurized aerosol can containing a hydrocarbon-based propellant is punctured or ruptured during the compaction process, the propellant gas may ignite as it escapes the container, creating a fireball. Incidents are rare because proper operating procedures dictate that all flammable materials are to be kept away from the compactor and all personnel are to keep clear of the integral relief ports around the compression chamber. Nonetheless, there have been incidents of fire and injury resulting from pressurized aerosol cans (NZ Herald, 2007; Insure My Liability, 2009). These incidents have influenced some recycling programs to prohibit all aerosol cans from being collected and remove the cans by hand sorting if they are mistakenly collected. There are many efforts underway to persuade consumers to completely empty their aerosol cans before recycling them, eliminating the risk of hazard at the MRF (Soroka, 2002; Chemical Specialties Manufacturers Association, 1996; G. Crawford, personal communication, March 15, 2010 & May 12, 2010; G. Walsh, personal communication, March 1, 2010; S. Carpenter, personal communication, May 14, 2010).

Bales of compacted recovered steel are then sold by the MRF to a scrap dealer or directly to a steel manufacturer. If the steel scrap is sold to a scrap dealer, the scrap dealer may require that each bale complies with one of the categories of specifications set forth by the Institute of Scrap Recycling Industries, Inc. (ISRI) (2009). Each category is associated with parameters, such as the density of the bale and the dimensions of its size. If the steel bales are sold directly to a steel manufacturer, specifications are usually agreed on between the two parties (ISRI, 2009).

Did You Know?

Steel aerosol cans that contain flammable propellant can cause fire during the compacting and baling process at a material recovery facility.

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