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Considerations on the life cycle and recycling of aluminum beverage cans

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Abstract. The article provides an overview of aluminum beverage cans processing stages, from raw material to final product, the process of UBCs (used beverage cans) recycling and the advantages of recycling aluminum cans in terms of economics, environment and energy. The life cycle of beverage cans involvs a sequence of steps that include bauxite mining, alumina refining, primary smelting, ingot casting, rolling, can manufacturing, beverage can use phase and then the recycling stage begins by collecting, sorting, shredding, cleaning and melting, stage in which the recycled material becomes raw material. In Romania are produced annually about 350 million aluminum cans and are imported another 100 million cans but currently only 3% of these are recovered and the rest, over 10,000 tons of high purity aluminum end up in landfills.
Key Words: resource processing, energy consumption, environmental performance.

Introduction. At this moment the aluminum can is one of the most recycled packaging in the world thanks to the aluminum's most important feature, versatility, that allows the metal and its alloys to be used in a wide range of sectors, from transport to construction, electronics, packaging, furniture and industrial installations. There isn't any other material that offers the versatility and environmental benefits of aluminum, keeping in balance on one side, the demand of a growing economy and on the other the need to preserve the environment.

The aluminum can is the only packaging solution that is 100 percent recyclable with the highest recycling rate then any beverage container.

The life cycle of an aluminum beverage can is just 60 days from "can to can." In 60 days, a beverage can goes from the store shelf to the consumer, and then on to a recycling facility where it can be re-melted into can sheet and re-formed into another aluminum beverage can with exactly the same physical characteristics as the original can.

In Figure 1 are shown the main processes that occur during the life cycle of an aluminum can and the possibility of appling a „closed loop" approche to the recycling process.

Statistical data. Two out of three aluminum beverage cans are now being recycled in Europe. The percentage of recovery of such wastes varies between 40 and 70% and even more in Switzerland and Scandinavian countries. The European average, per head of the population, of aluminum waste is 175 kilograms, in Greece and Finland rates are less than 100 kilograms per head of the population. Ireland and France go beyond the level of 200 kilograms (www.mataliat.ro).

Global used aluminum beverage can recycling rates have grown through out the years. Figure 2 presents the evolution of aluminum can recycling rates in the United States of America, since 2003, until 2011 including.

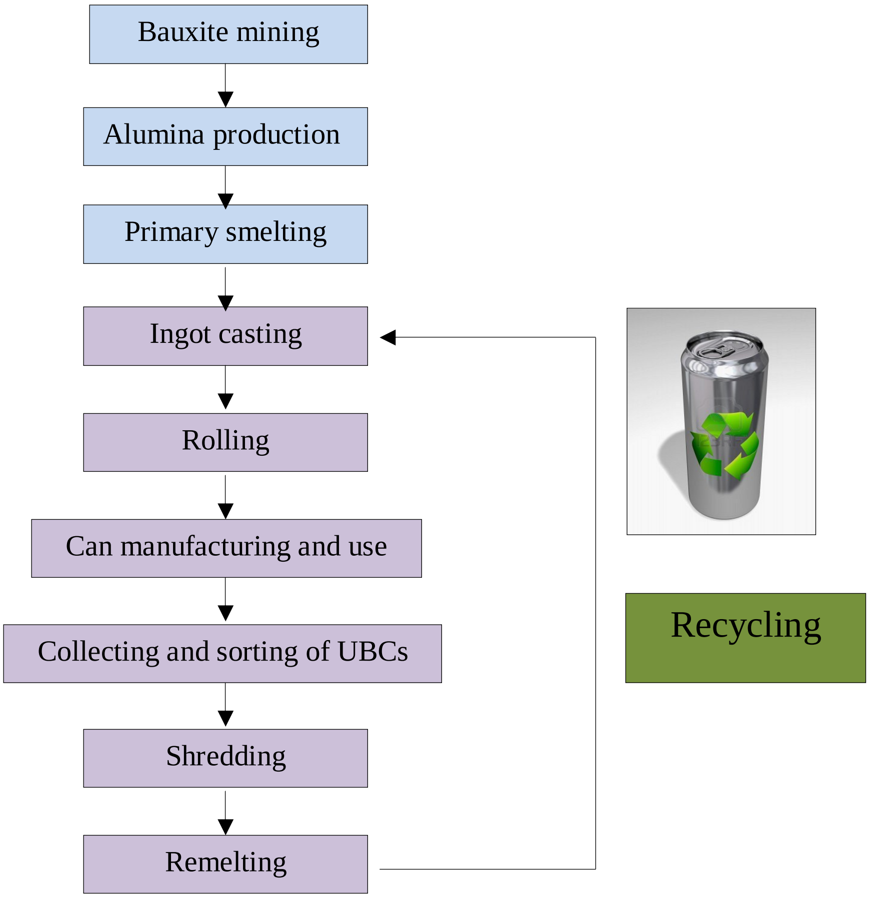

Figure 1. Simplified process flow diagram for aluminum can life cycle.

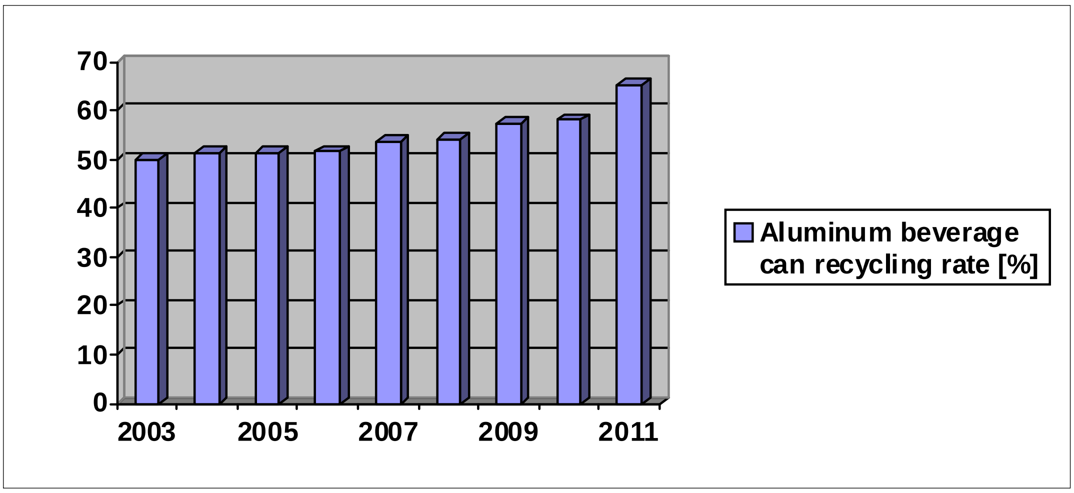

Figure 2. Used aluminum beverage can recycling rates in the U.S.A. (Can Manufacturers Institute 2012).

In some european countries, like Germany and Norway, the recycling of UBCs, has had a big succes, but in other countries like Hungary and Romania, the recycling rates are still low (Figure 3).

In order to meet the European regulation, in the next few years Romania has to get to recycling 50% of the quantity of aluminum placed on the market. To meet necessary consumption, in Romania are produced annually around 350 million aluminum cans and are imported other 100 million cans, but at present, the recycling rates are still low, and over 10,000 tonnes of high-purity aluminum end up in landfills (www.ecomagazin.ro).

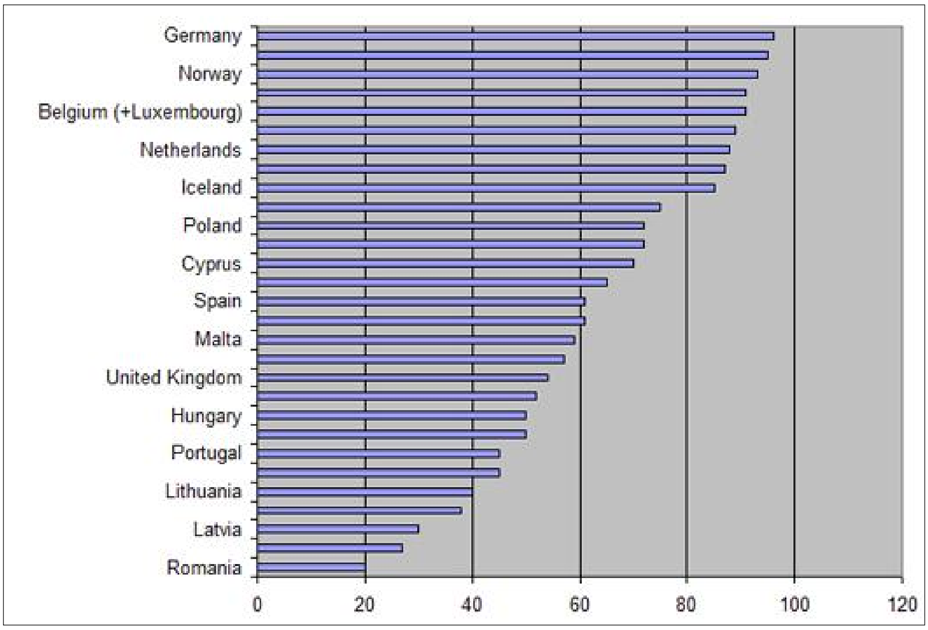

Figure 3. Used aluminum beverage can recycling rates in Europe 2010 (www.hydro.com).

Life cycle stages of aluminum beverage cans. As Figure 1 shows, the life cycle of aluminum cans is basicly divided in three major actions: the production of aluminum, can manufacturing and use and at the end, the recycling of used aluminum cans. In the life cycle of an aluminum can several steps take place.

Bauxite mining*.* Aluminum as a metallic element, is very prevalent in the earth's crust and it is present in a combined form. Aluminum is extracted from bauxite ore. Bauxite is basicly composed of hydrated aluminum oxides and impurities like silicon, titanium, iron compounds, and other materials and it is typically found at a depth of 0 to 180 m beneath the surface. In some cases, after the extraction, the bauxite is treated in order to remove the impurities by washing it with water. After the impurities have been removed, the bauxite is dried and shipped to an alumina refinery (Schweitzer 2003).

Figure 4. Bauxite mining (www.dtinews.vn).

Alumina production*.* In alumina refining, bauxite is converted to aluminum oxide (Al_2O_3, alumina) using the Bayer process. In the Bayer process, bauxite is crushed and digested by washing with a hot solution of sodium hydroxide, NaOH, at 175°C. This converts the aluminum oxide from the bauxite ore to sodium aluminate, $NaAl(OH)_4$. The other components of bauxite do not dissolve. The solution is clarified by filtering off the solid impurities. The mixture of solid impurities is called red mud, and presents a disposal problem. Next, the alkaline solution is cooled, and aluminum hydroxide precipitates as a white solid. Then, when heated to 980°C (calcined), the aluminum hydroxide decomposes to aluminum oxide, giving off water vapor in the process (Schmitz 2006).

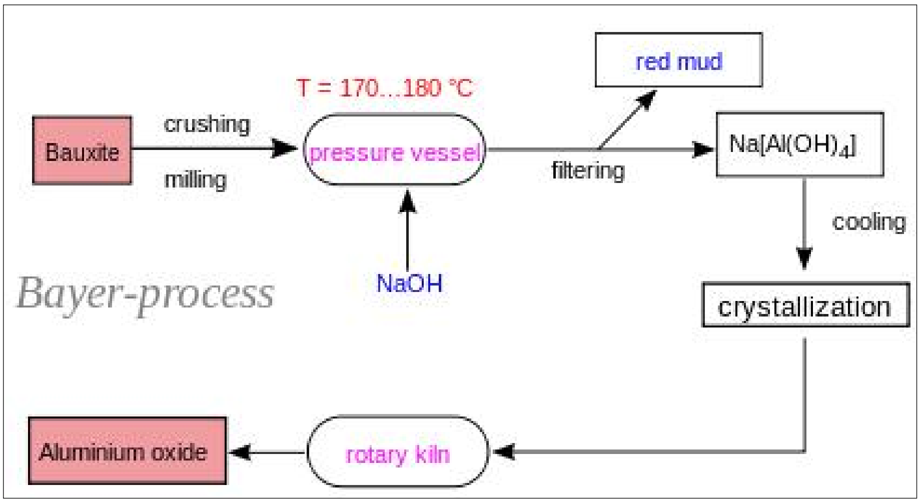

Figure 5. Alumina production using the Bayer process (www.answers.com).

Aluminum smelting and ingot casting. Primary aluminum is produced in reduction plants (or "smelters"), where pure aluminum is extracted from alumina by the Hall-Héroult process (Figure 6). This involves two steps: dissolving the alumina in a molten cryolitic bath, and passing electric current through this solution, thereby decomposing the alumina into aluminum and carbon dioxide. The reduction of alumina into liquid aluminum is operated at around 950^{o}Celsius in a fluorinated bath under high intensity electrical current. This process takes place in electrolytic cells (or "pots"), where carbon cathodes form the bottom of the pot and act as the negative electrode. Anodes (positive electrodes) are held at the top of the pot and are consumed during the process when they react with the oxygen coming from the alumina. There are two types of anodes currently in use: prebake and Soderberg.

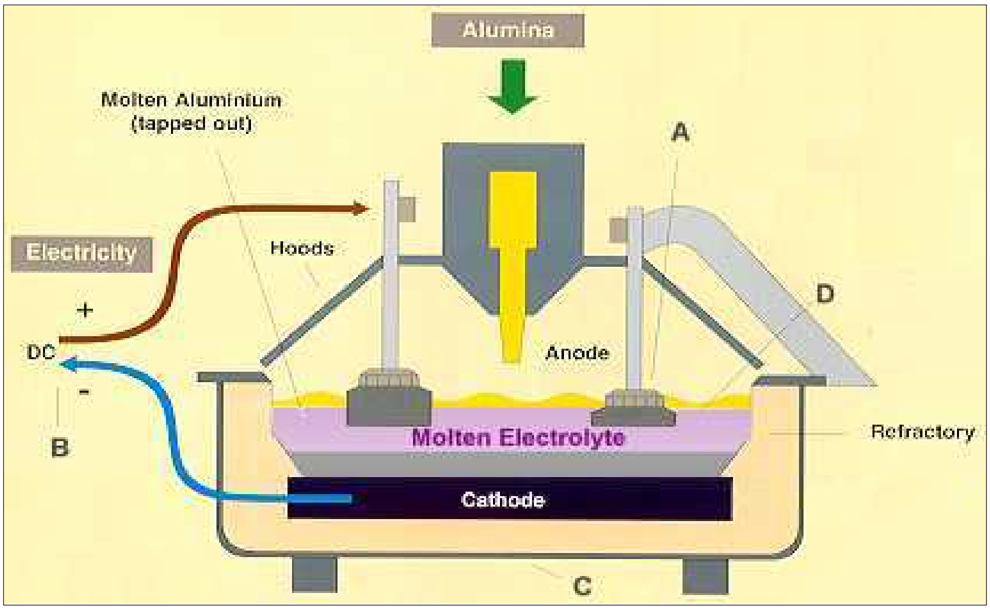

Figure 6. The Hall-Héroult process of producing aluminum (www.emt-india.net).

The process from Figure 6 is described in the following lines.

A. Suspended above each cathode are several closely arranged carbon blocks that serve as the anode (positive electrode). The anodes are suspended by rods in the bath of molten electrolyte in which the alumina is dissolved.

B. An electric current of up to 315 000 amps enters the pot via the anode blocks and reduces the alumina by electrolysis into aluminum and oxygen. The oxygen is deposited on the carbon anode where it burns the carbon to form carbon dioxide. The aluminum, being heavier than the electrolyte, collects at the base of the pot. The equation for the basic reaction is:

$$2Al_2O_3 + 3C = 4Al + 3CO_2$$

C. Each pot consists of a steel shell that is lined with refractory and carbon blocks to serve as the cathode (negative electrode).

D. Cryolite, the predominant constituent of the electrolyte, is a sodium aluminum fluoride salt which, when held molten at a temperature of around 960°C, can dissolve alumina (www.emt-india.net).

At regular intervals, molten aluminum tapped from the pots is transported to the cast house where it is alloyed in holding furnaces, the composition is adjusted to the specific alloy requested by a customer. In the process of aluminum alloying, a number of phenomena and operations take place and the quality of the final alloy depends on the recognition and management of them (Carcea 2012).

In some cases, is necessairy a hot metal treatment, like, fluxing. Fluxing consists of slowly bubbling a combination of nitrogen and chlorine or of carbon monoxide, argon, and chlorine through the metal in order to remove impurities and reduce gas content. After fluxing, the molten aluminum is cast into ingots. There are many methods of ingot casting: open molds used for remelt ingots, through direct chill molds for various fabrication shapes, electromagnetic molds for sheet ingots and through continuous casters for aluminum coils (Profit Earth - Profit Enterprise Americas 2010).

Aluminum ingot rolling, can manufacturing and use. Rolled aluminum is classified into three categories: foil, sheet and plate. Foil is rolled aluminum that is less than 0.2 mm in thickness and it is used for the packaging industry for aluminum cans and other applications.

The process of rolling is separated into a 2-part process: hot rolling and cold rolling. Ingots made during casting pass through a scalping machine where surface oxides are scraped off providing a smooth rolling surface. Ingots are then passed through a hot rolling mill before transferring into a cold rolling mill. Aluminum is presented in a form of ingot state that can be up to 600 mm in thickness. This ingot is heated to around 500°C and passed through the hot rolling mill several times to reduce the thickness to around 6 mm.

The thinner aluminum is then coiled onto a cylinder and transported to the cold rolling mill for further processing. Subsequent rolling and annealing of the cold metal increases the strength of the aluminum alloy. There are various types of cold rolling mills that are used to produce various types of rolled product with thickness as low as 0.05 mm (Mingqian 2006).

The most frequently used manufacturing process for thin-walled aluminum cans is called drawing and ironing (Folle et al 2008). Cans are generally produced through a mechanical cold forming process that starts with punching a flat blank from very stiff cold-rolled sheet. This sheet is typically alloy 3104-H19 or 3004-H19, which is aluminum with about 1% manganese and 1% magnesium to give it strength and formability. The flat blank is first formed into a cup about three inches in diameter. This cup is then pushed through a different forming process called "ironing" which forms the can. The bottom of the can is also shaped at this time. The malleable metal deforms into the shape of an open-top can. With the sophisticated technology of the dies and the forming machines, the side of the can is significantly thinner than either the top and bottom areas, where stiffness is required. A single can-making production line can turn out up to 2400 cans per minute (www.fabricatingandmetalworking.com).

Plain lids (known as shells) are stamped from a coil of aluminum, typically alloy 5182-H48, and transferred to another press that converts them to easy-open ends.

Finally, the top rim of the can is trimmed and pressed inward or "necked" to form a taper conical where the can will later be filled and the lid (usually made of an aluminum alloy with magnesium) attached.

The material properties of the aluminium alloy influence the formability of the cans but it is the friction at the tool/metal interface that determines the day-to-day runnability of the drawing and ironing process in a given manufacturing plant (Kang 2009).

Aluminum cans are coated internally to protect the aluminum from oxidizing. Chemical compounds used in the internal coating of the can include types of epoxy resin (made from BPA). After being coated, the cans and the lids of the cans are shipped to companies for filling and from there to different markets.

An empty aluminum can weighs approximately 15 g. In most of Europe standard cans are 330 ml but there is a second standard can size, 500 ml that is being used (www.wikipedia.com).

According to a study made by the Aluminum Association (Can Manufacturers Institute 2012), the aluminum can is by far the most favorably viewed of the three beverage packages, significantly outdistancing either glass or plastic bottles as it is presented in the Table 1.

Table 1

Survey results regarding beverage packaging material favorability
(Can Manufacturers Institute 2012)

Packaging Material	*Favorable*	*Unfavorable*	*Net Favorability*
Aluminum can	74%	22%	+52
Glass bottle	58%	39%	+19
Plastic bottle	54%	43%	+11

Recycling of UBCs. Used beverage cans (UBCs) can be recycled with low energy consumption and repeated recycling does not decrease the quality of the aluminum, but the efficiency of the recycling process is influenced by the form in which these waste are found and the way they are further processed (Zheng et al 2004).

As Figure 7 describes, the recycling process of UBCs starts with the collecting stage. The UBCs are received from collection centers as bales weighing 400 kg or as briquettes with a maximum density of 500 kg/m^3. These bales and briquettes are broken apart and the cans are shredded and separated using a magnetic separator that removes ferrous contaminants. The shredded aluminum cans are then delacquered (process by which, the interior and exterior coatings from the aluminum cans are removed). There are different ways to remove the coatings from aluminum cans, de-coating by sand blasting, de-coating by solvent extraction or thermal de-coating (Rabah 2003).

There are two basic approaches to thermal delacquering. One is based on a relatively long exposure time at a safe temperature (approximately 520°C), and the other is based on staged temperature increases to just below melting for as short an exposure time as possible (the temperature in the last stage is near 615°C). Thermal delacquering in a closed system includes suitable cleaning of gases and reuse of paint combustion energy (NTNU 2010).

After delacquering the UBCs are taken to melting facilities. At present, most melting facilities for UBCs throughout the industry are dedicated units designed to handle the enormous volumes and to minimize the melt losses inherent in melting thin-walled material. Significant amounts of skim - the mixture of metal, oxides, other contaminants, and trapped gas that floats on top of the melt - are removed and treated for metal recovery (Nunes et al 1992).

The metal from these dedicated melters is often transferred to on-line melting furnaces, where additional bulky scrap is remelted and primary unalloyed metal is charged to create the desired volume of the proper alloy composition. From these furnaces, the metal is transferred to the holding furnaces, where minor composition adjustments are made and metal quality treatments are performed (for example, gas fluxing to remove hydrogen). Some metal treatment, for example, inclusion removal, can be done in so called in-line treatment units.

The clean and on composition metal is cast into ingots that are typically scalped to remove nonuniform surface and subsurface structure and thermomechanically processed to finished sheet dimensions (Green 2007).

Figure 7. The flow of aluminum can recycling (www.unican.co).

Economical, environmental and energy savings in recycling aluminum cans. The main advantages in the recycling of aluminum cans are:

- recovery of precious material without lowering quality;
- energy savings in relation to primary production;
- reducing emissions that cause the greenhouse effect;
- reduction of mining activities;
- reducing the amount of waste.

The Table 2 shows the consumption of materials and energy for the production of primary aluminum which can be reduced if recycling levels would increase.

The Table 3 shows the difference in resources consumption between primary and secondary casting and, primary and secondary rolling of aluminum.

As seen in the Figure 8, by recycling, considerable energy savings are accomplished (about 94%).

Accordingly, energy efficiency and environmental performance of the aluminum industry as a whole, will continue to improve as far as recycling rates increase.

Table 2

Resources consumption for the production of primary aluminum (Green 2007)

Process	*Materials*	*Energy consumption*	*Environmental releases*	*Products*	*Wastes*
Bauxite mining	1154 kg bauxite rich soil, 0.6 m^2 land use, 18 kg lube oil, 205 L water	0.4 kWh electricity, 1 kg fuel oil, 4 L diesel	2.4 kg PM	1000 kg bauxite	136 kg residues
Alumina refining	2640 kg bauxite, 74 kg caustic soda, 46 kg lime, 1480 L water	109 kWh electricity, 225 m^3 naturel gas, 93 kg fuel oil	0.6 kg PM	1000 kg alumina	944 kg bauxite residues, 170 kg other wastes
Anode production	820 kg calcined coke, 231 kg pitch, 85 kg green coke, 667 L water	226 kWh electricity, 97 m^3 natural gas, 4 kg fuel oil	388 kg CO_2 3 kg SO_x 3 kg PM	1000 kg anode	23 kg residues
Aluminum smelting	1930 kg alumina, 19 kg AIF_3, 446 kg anode carbon, 9 kg cathode carbon, 827 L water	15.400 kWh electricity	1520 kg CO_2 67 kg CO 17 kg SO_x 0.4 kg CF_4 0.6 kg HF 0.4 kg PFC 1.2 kg COS	1000 kg aluminum metal	46 kg spent potliner, 13 kg other wastes

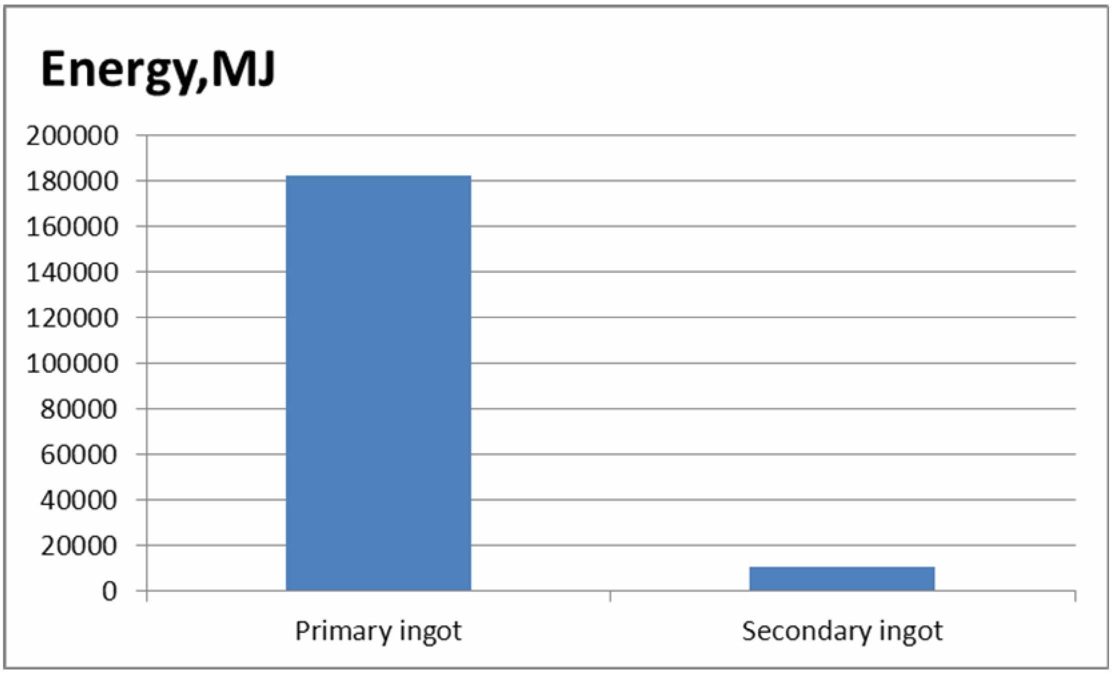

Figure 8. Energy consumption comparison of recycled (secondary) ingot to primary ingot (Green 2007).

Table 3

Resources consumption comparison (Green 2007)

Process	*Raw materials*	*Ancillary materials*	*Energy consumption*	*Air emissions*	*Products*	*Wastes*
Primary ingot	5090 kg bauxite, 3 m^2 land, 16577 L water	143 kg caustic soda, 366 kg calcined coke, 103 kg pitch, 88 kg lime, 93 kg lube oil	186.262 MJ total energy, 69.406 MJ nonfossil, 116.856 MJ fossil	11.564 kg CO_2, 74 kg CO, 85 kg Sox, 40 kg Nox, 43 kg PM	1000 kg ingot	4590 kg residues
Secondary ingot	1133 kg metal (scrap), 963 L water	21 kg alloys, 9 kg treatment salts, 8 kg water treatment chemicals	11.690 MJ total energy, 108 MJ nonfossil, 11.583 MJ fossil	617 kg CO_2 1 kg CO, 5 kg Sox, 3 kg Nox, 1 kg PM	1000 kg ingot	388 kg residues
Primary rolled aluminum	5090 kg bauxite, 3 m^2 land, 18782 L water	143 kg caustic soda, 366 kg calcined coke, 103 kg pitch, 88 kg lime, 93 kg lube oil	200.882 MJ total energy, 70.087 MJ nonfossil, 130.794 MJ fossil	12.476 kg CO_2, 78 kg CO, 90 kg Sox, 44 kg Nox, 46 kg PM	1000 kg rolled aluminum	4810 kg residues
Secondary rolled aluminum	1655 kg metal (scrap), 3170 L water	30 kg alloys, 13 kg treatment salts, 12 kg water treatment chemicals, 7 kg rolling oil	28.590 MJ total energy, 809 MJ nonfossil, 27.781 MJ fossil	1685 kg CO_2, 4 kg CO, 11 kg SO_x, 26 kg Nox, 4 kg PM	1000 kg rolled aluminum	729 kg residues

Trends in UBC recycling. The production of aluminum beverage cans around the world is growing by billions of cans per year. In the face of this rising demand, the future of the beverage can seems to lie in designs that save money and materials. The trends in the aluminum can industry go towards smaller lids, as well as smaller neck diameters, but other changes may not be so obvious to the consumer. Manufacturers use rigorous diagnostic techniques to study can sheet, for example, examining the crystalline structure of the metal with X-ray diffraction, in order to discover better ways of casting the ingots or rolling the sheets. Advances in the way the alloy is cooled after casting, or the thickness to which the can sheet is rolled, or even changes in the composition of the aluminum alloy, will lead to more economical can manufacture in the future (www.madehow.com).

As the recycling rate continues to increase, composition control and the corresponding contamination avoidance become technical challenges as important as melt loss reduction. It appears that prudent use of salt fluxes may hold the key to improvements in these areas (Green 2007).

Conclusions. The life cycle of an aluminum can from mining to recycling is 60 days. In 60 days, a beverage can goes from the store shelf to the consumer, and then on to a recycling facility where it can be re-melted into can sheet and re-formed into another aluminum beverage can with exactly the same physical characteristics as the original can.

The processes that take place in the life cycle of an aluminum can include bauxite mining, alumina refining, primary smelting, ingot casting, rolling, can manufacturing, beverage can use phase and then the recycling stage begins by collecting, sorting, shredding, cleaning and melting, stage in which the recycled material becomes raw material.

The primary aluminum production process is a large consumer of both energy and material resources. Recycling aluminum saves 95% of the energy used in comparison with the development of the metal from the original bauxite ore and emits only about 4% CO_2 compared with primary production. Secondary aluminum is the equivalent of primary aluminum, even after multiple cycles of life.

The process by which beverage cans are recycled is quick, easy and cost-effective. It is much less expensive to recycle an old can than to produce a new one, since it uses less energy.

Beverage cans are no longer simply homes for carbonated soft drinks or beer. Cans are used today for energy drinks, coffee and even wine. They're also uniquely suited for dairy beverages and for beverages with medical or health benefits, known as nutraceuticals.

Energy efficiency and environmental performance of the aluminum industry as a whole, will continue to improve as far as recycling rates increase.

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