Aluminum: The Element of Sustainability

A North American Aluminum Industry Sustainability Report

The Aluminum Association
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Executive Summary

As an elemental material, the basic properties of aluminum do not change with mechanical or physical processing. This means that aluminum is intrinsically sustainable: once produced, it can be recycled repeatedly without any loss in quality and reused in the manufacture of consumer and industrial products. In comparison, carbon-based organic compounds, such as wood, natural fiber and plastics, are composed of large molecules; repeated heating and cooling and/or mechanical processing destroys the bonding force and configuration within individual molecules, thereby changing the original properties of the material.

In addition to its elemental nature, aluminum also has unique physical properties when compared with other metallic materials. Some aluminum alloys have a very high strength-to-weight ratio, some have excellent thermal and electric conductivity, some are great in corrosion resistance, and most of them have perfect malleability, elasticity, and surface reflectivity. The intrinsic physical uniqueness of aluminum has enabled the aluminum industry to make a wide range of high-quality and sustainable products.

The aluminum industry has taken a life-cycle approach to manufacturing and designing its products. This approach emphasizes responsibilities in managing products, services, and/or business operations throughout the entire life of the product—from product to recycling to new product. In the case of aluminum, this involves the management of resources, minimizing energy consumption, emissions and waste releases to the environment, while keeping a focus on the overall economic, social and environmental benefits that the products bring to society.

Over the past two decades, the North American aluminum industry has achieved tremendous progress in sustainability. This includes progress in both corporate stewardship and product stewardship. Corporate stewardship encompasses many business management and operational areas, ranging from environmental management systems, energy, and climate to product responsibility. Corporate stewardship programs enable product stewardship improvements.

The North American aluminum industry has made consistent improvement in the production processes over the past two decades as measured by primary energy demand and greenhouse gas (GHG) emissions per ton of product produced.

- Primary Metal
  - ✓ Primary energy demand—decreased 17%
  - ✓ Cumulative greenhouse gas emissions—decreased 42%
- Secondary Metal
  - ✓ Primary energy demand—decreased 58%
  - ✓ Cumulative greenhouse gas emissions—decreased 65%

The industry can also illustrate that its major production activity—aluminum production—is largely offset by aluminum's advantages (as measured against competing materials) during the product-use phase of its life-cycle, and through persistent recycling efforts:

- 87% neutralization of energy consumption associated with all aluminum production via energy savings through aluminum's use in road vehicle downweighting in 2009; and
- 92% neutralization of cumulative greenhouse gas emissions associated with all aluminum production via GHG avoidance through aluminum's use in road vehicle downweighting in 2009.

Notwithstanding these achievements, significant challenges lie ahead for the North American aluminum industry to further improve its sustainability performance. These include:

- Technological Progress—Efforts in finding more revolutionary primary metal production technology have been ongoing for half a century but a breakthrough has yet to be achieved.
- Energy and Resource Use—This is a constant challenge to the industry going forward.
- Waste Minimization and Elimination—Research on minimizing large-quantity process waste has been ongoing for decades, but practical solutions have yet to be found.
- Business Operations—A responsible supply chain management and product post-sales tracking system have yet to be established by smaller firms, and there is potential for improvement with regard to setting clear targets for resource efficiency and waste reduction.
- Product End-of-Life—Challenges include implementing "design for recycling" and incentives for recycling, as well as instilling a better understanding of recycling. These are challenges not only for the aluminum industry, but also the general public and policy makers.

The aluminum industry is redoubling its efforts to disseminate information on, and improve the understanding of, its metal and the products made from it. This will encourage the use of aluminum for more extensive and expanded sustainable solutions—to lower the weight of transportation equipment, construct greener buildings, prevent food and beverage spoilage, and develop more sustainable sources of energy such as solar and wind power.

Introduction

One hundred and twenty-five years ago, Charles Martin Hall discovered a method to create aluminum by separating it from bauxite ore through electrolysis. Nearly 75 percent of the aluminum produced since then is still in use today—a testament to the material's durability and recyclability.

Aluminum has transformed modern society, helping people and the economy to operate more efficiently by enabling advancements in air, road, rail, and sea transport; food, beverage, and pharmaceutical packaging; construction; electronics; and electricity transmission. No other metal can match aluminum's sustainability advantage or its combination of useful physical properties, which include:

• *Strength*—Pure aluminum is soft enough to carve but, mixed with small amounts of other elements to form alloys, it can provide the strength of steel at only a third to half the weight.
• *Durability*—Aluminum is tough enough to withstand both the rigors of spaceflight and challenging climatic conditions such as those found in the Arctic and seaside (salty/damp) environments.
• *Flexibility*—Its physical properties allow aluminum and its alloys to be shaped easily by any of the primary industrial metalworking processes—forging, casting, rolling, or extrusion.
• *Impermeability*—Aluminum forms a superior barrier for food and beverage packaging by preventing air, water, light, and microorganisms from reaching the contents inside.
• *Low Weight*—Aluminum can lower vehicle weight, reducing fuel use and emissions; lighten structures' "dead load"; and in packaging applications shrink the environmental footprint associated with shipping.
• *Corrosion Resistance*—The metal's natural aluminum oxide coating provides highly effective protection against degradation from water, salt, air, and temperature variation.
• *Recyclability*—Once manufactured, aluminum can be recycled repeatedly, using only 5 percent of the energy, and generating only 5 percent of the emissions, associated with primary production.

Notwithstanding the above, stakeholders in the aluminum industry—including manufacturers, fabricators, consumers, and non-governmental organizations (NGOs)—are increasingly requiring detailed information about energy and resource inputs and environmental impacts associated with the aluminum incorporated into today's retail products. To that end, the Aluminum Association, under the leadership of its Sustainability Working Group, has begun developing the matrices and methodologies to respond to these informational needs of its customers and product market segments.

A Sustainability Initiative was launched in 2008 to address the economic, social and environmental performance of the industry in North America (U.S. and Canada). The initiative involves the assessment of aluminum's performance throughout its life-cycle, with the goal of developing a complete understanding of the positive contributions that aluminum makes to society's environmental and economic well-being, any negative economic or environmental impacts associated with its production and fabrication, and the balance between these positives and negatives during the life-cycle of the material.

During the past three years, several technical studies have been launched as part of this effort, including an aluminum can life-cycle assessment (LCA), an aluminum material flow analysis, and an LCA of semi-fabricated aluminum and auto products.

The Aluminum Beverage Can Life Cycle Assessment, completed in 2010, updated a similar study completed in 1993 to better understand the environmental footprint of aluminum beverage cans. The LCA documented a reduction in overall carbon footprint of the aluminum can of 43%.

A second ongoing LCA, of semi-fabricated aluminum and auto products, is examining the life-cycle environmental footprints of all major categories of semi-fabricated aluminum products, including flat-rolled, extruded, cast, and forged products.

A multi-year material flow analysis is being undertaken to understand the industry's resource preservation performance in North America—with particular focus on documenting historical productions, current in-use stocks, and the overall losses of aluminum.

The Association has developed and executed these projects with active support from member companies over a period of significant economic recession. The persistence of these efforts reflects the very serious commitment of the Association and industry to the initiative and the larger goals of sustainability.

In addition to developing appropriate matrices and methodologies for monitoring sustainability, these studies will help guide the industry's future directions on sustainable development.

The following report is intended to provide a snapshot of the aluminum industry in North America today, its approach to sustainability, and looming challenges. It is structured as follows:

- A brief overview of the aluminum industry in North America;
- A review of major activities that the Aluminum Association has carried out on sustainability over the past two years;
- An elaboration of the industry's view and approach to sustainability;
- A documentation of responsible production and processing—including description of the processes, issues, complexities and "hotspots"—highlighting changes and progress that have been made during the past 20 years;
- A documentation of the product use phase and end-of-life (recycling or disposal) phase, concentrating on quantifiable aspects where information and thorough understanding is available;

- An evaluation of the overall sustainability performance looking at both corporate stewardship of the industry and product stewardship of the material;
- An enumeration of challenges and opportunities facing the industry in the near and long term future, including suggestions for both the industry and the general public to cooperate and utilize these opportunities to make aluminum serve the needs of multiple generations.

Part I: Overview of the Aluminum Industry in North America

I.1. Industry Composition

Traditionally, North America has been one of the world's largest aluminum production regions and consumption markets. The industry in the region is comprised of four major sub-sectors:

- Alumina refining;
- Primary aluminum production;
- Secondary aluminum production; and
- Aluminum semi-fabrication (including foundries).

These sub-sectors cover the majority of elements of the value chain in the production stage of its life-cycle. In addition, aluminum wholesalers and metal service centers are also considered part of the aluminum industry—although no production or fabrication activities take place in these trade and service institutions.

I.2. Facilities, Employment, Payroll, Total Outputs and Shipment Value

It is estimated that more than 1,400 facilities in the region are involved in the manufacturing and processing of aluminum, with a direct employment of 156,000 (*see Table 1*). Upstream, the industry is relatively concentrated, with only a few large corporations involved; downstream, especially at the metal processing level, hundreds of individual firms are involved. Another characteristic is the vertical integration of large firms involved in both raw material production and metal processing/fabrication. Still other firms operate in all four of the above-mentioned sub-sectors. The size of individual facilities in the industry ranges from as small as mom-and-pop foundry shops with a few employees to large corporate facilities employing hundreds of people.

In 2010, the industry generated an estimated total value of $53 billion (value in shipment), and extended a payroll of $8.5 billion to its employees *(see Table 1 on next page).*

Direct Employment by Production Sector, North America

Production Sectors	Number of Facilities	Employment
Alumina	5	2,500
Primary Aluminum	25	19,100
Secondary Aluminum	237	6,400
Semi-Fabrication	1,146	101,000
Wholesalers & Metal Service	2,715	27,000

Table 1: Direct Employment by Production Sector, North America. Data Source: The Aluminum Association, based on publicly available information and industry expert estimates.
Note: The principles of U.S. antitrust law limit the ability of trade associations to collect economic value related information from their member companies. The economic and employment related information in this report is estimated based on publicly available information and experts' estimates. The purpose of providing such information in the report is to show a big picture of the industry on its economic and social contributions to society, which are essential components of the well-respected triple-bottom-line principles of sustainable development.

Over the past three decades, the output of primary aluminum has remained fairly stable, with fluctuations associated with the price of energy, primarily electricity, and the state of the larger regional economy (*see Figure 1 on next page*). Over the same period, secondary aluminum output (aluminum that is produced domestically by using recycled aluminum scrap, excluding metal recovery by other countries from scrap exported by Canada and the U.S.) has been consistently growing (*see Figure 2 on page 10*). Primary aluminum still accounts for the larger share of the industry, but secondary aluminum is increasingly significant, having grown from 22% of total raw metal output in 1980 to 38% today. Likewise, output of semi-fabricated aluminum has been consistently increasing, save for the period of the 2007-09 global financial crisis (*see Figure 3 on page 11*). As this crisis came to an end, the industry was able to rebuild on its strong foundation and move forward again. Preliminary statistical information for 2010 highlights this trend.

It is important to note that the aluminum industry is highly globalized. Essentially, raw material and products can be produced anywhere in the world and traded freely among countries and regions. Therefore, the law of comparative advantage in terms of capital, raw materials, energy, and labor force applies to aluminum and promotes regional efficiency and a competitive global industry. The main competitive advantage of the North American industry is its established technology leadership and innovation. The region has been consistently a global powerhouse of technology advancement and innovation in metal production, processing, joining, and surface treatment; alloys and tempers; and product and end-use applications. Globalization of the industry over the past half century may have shifted some of the economic activities to other parts of the world, especially developing countries, but North America has maintained its leadership position in technology and the high-value-added production and fabrication sectors.

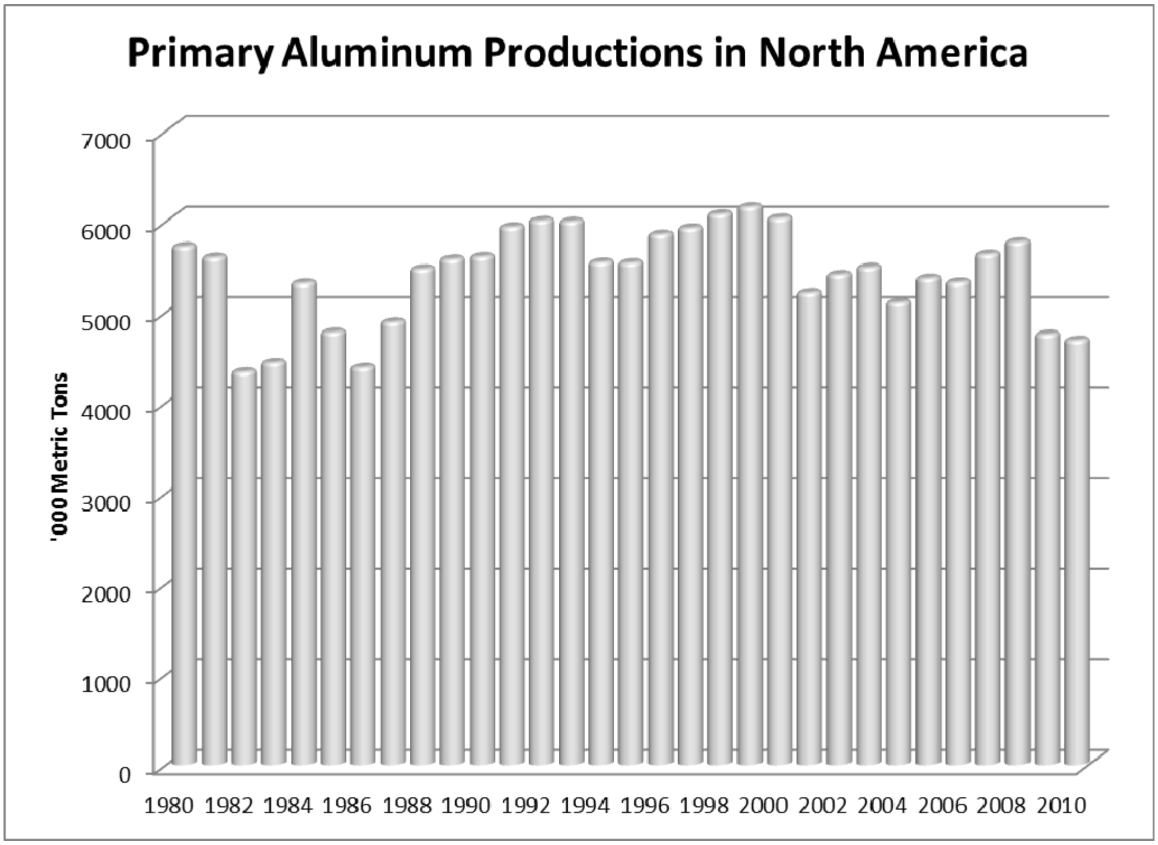


Figure 1: Primary aluminum outputs in North America. Data Source: U.S. Geological Survey, U.S. Department of Interior; Bureau of the Census, U.S. Department of Commerce; Natural Resources Canada; The Aluminum Association of Canada; and The Aluminum Association

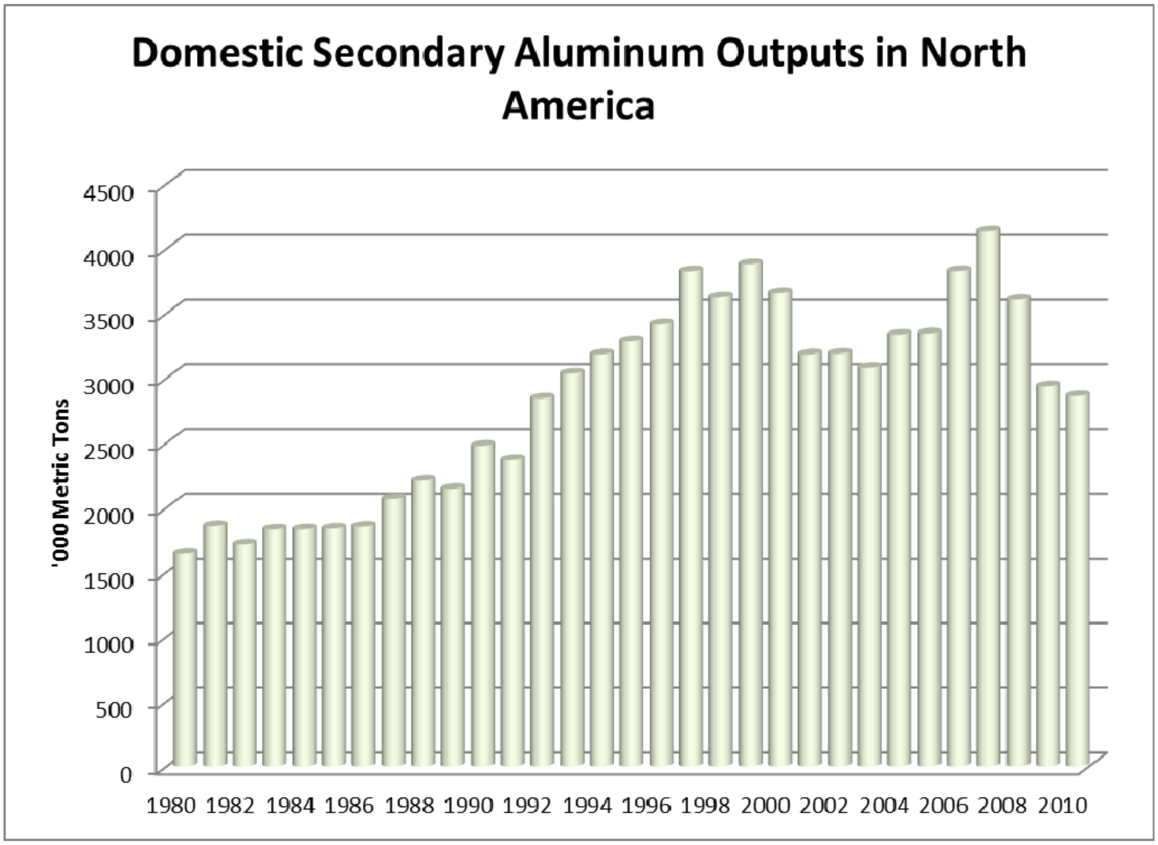


Figure 2: Secondary aluminum outputs (domestic recovery of aluminum from recycled scrap, excluding metal recovered in other countries from net imported North American scrap) in North America. Data Source: U.S. Geological Survey, U.S. Department of Interior; Bureau of the Census, U.S. Department of Commerce and The Aluminum Association

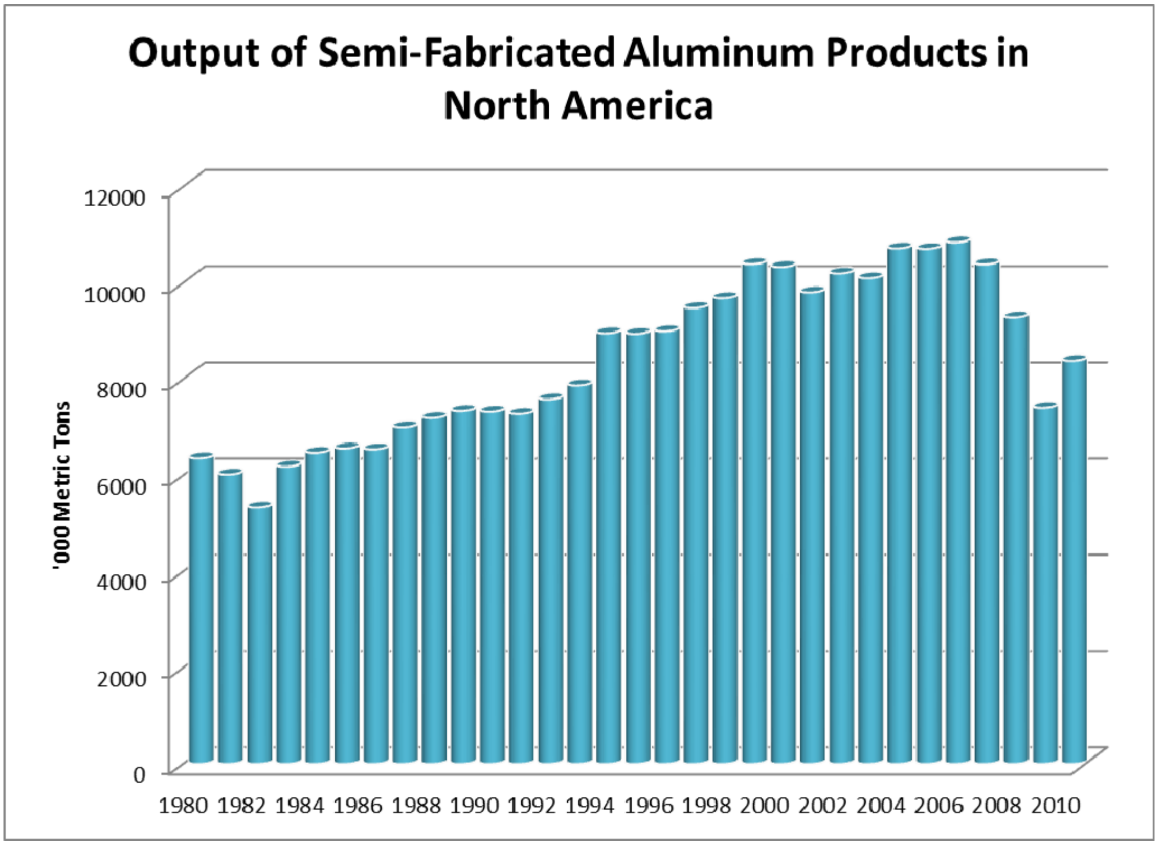
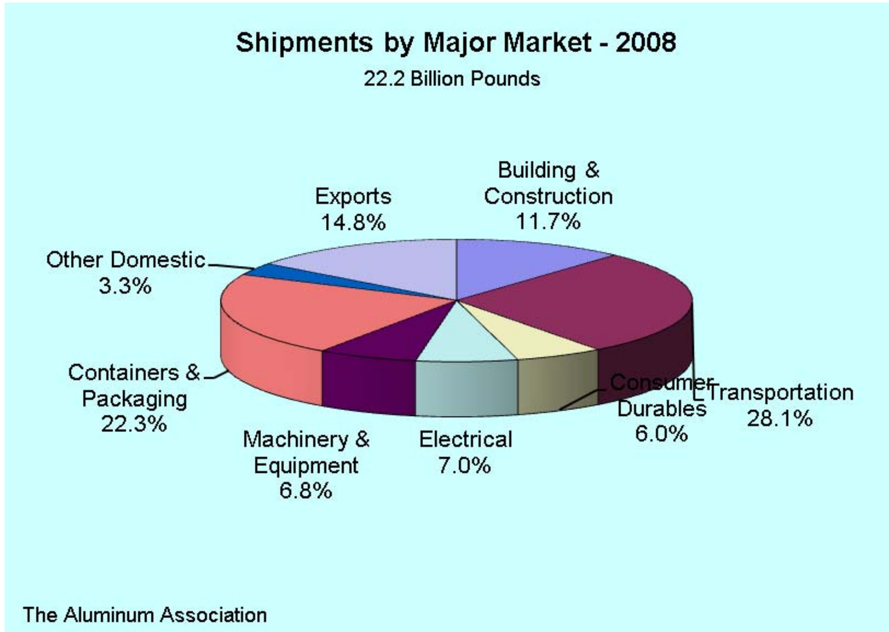


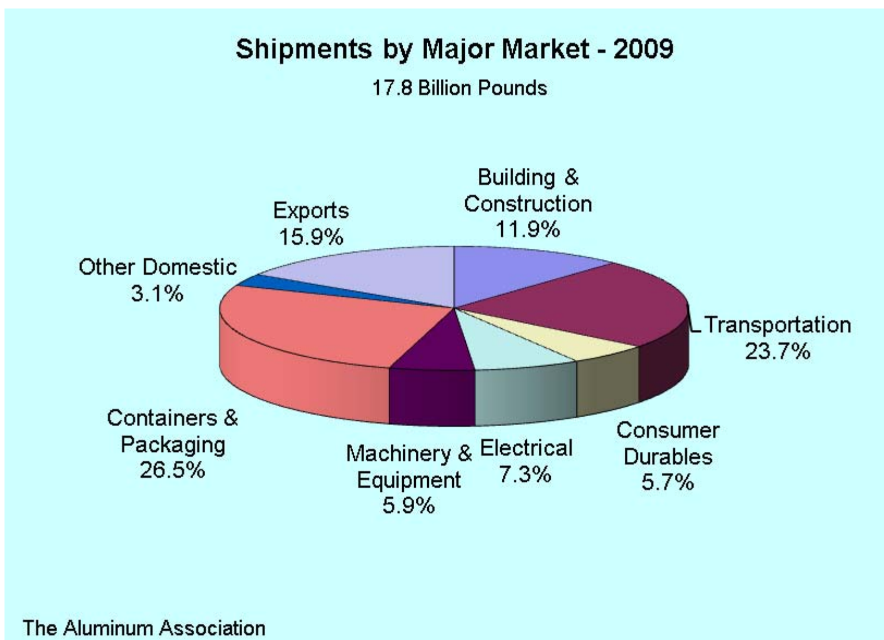
Figure 3: Output of semi-fabricated aluminum products in North America. Data Source: The Aluminum Association

I.3. Market Sectors and Historical Consumption

The aluminum industry provides products and services essential to virtually every aspect of daily life, from food and shelter to transportation and entertainment. Traditionally, for statistical reporting, seven major market sectors have been identified, including building and construction, consumer durables, electrical, machinery and equipment, packaging, transportation, and other miscellaneous uses. The aluminum products in use in each of these market sectors, as well as the proportion of overall aluminum in use represented by each sector, are constantly in evolution—as indeed aluminum has been transformed from a precious metal a century ago to one used in everyday life. Aluminum's evolution is truly a reflection of the progress of humanity over this same period.

The largest product markets for aluminum in North America for most of the past two decades have been, in descending order of importance, transportation, packaging, and building and construction, respectively. Shipments by market sectors in 2008, 2009 and 2010 are shown in Figure 4. It should be noted that in 2009, owing to the economic crisis and its dramatic effect on automobile shipments, aluminum use in transportation applications fell behind that in packaging for the first time in many years.


Shipments by Major Market - 2008
22.2 Billion Pounds
Exports
14.8%
Building &
Construction
11.7%
Other Domestic
3.3%
Containers &
Packaging
22.3%
Machinery &
Equipment
6.8%
Electrical
7.0%
Consumer
Durables
6.0%
Transportation
28.1%
The Aluminum Association


Shipments by Major Market - 2009
17.8 Billion Pounds
Exports
15.9%
Building &
Construction
11.9%
Other Domestic
3.1%
Transportation
23.7%
Containers &
Packaging
26.5%
Machinery &
Equipment
5.9%
Electrical
7.3%
Consumer
Durables
5.7%
The Aluminum Association

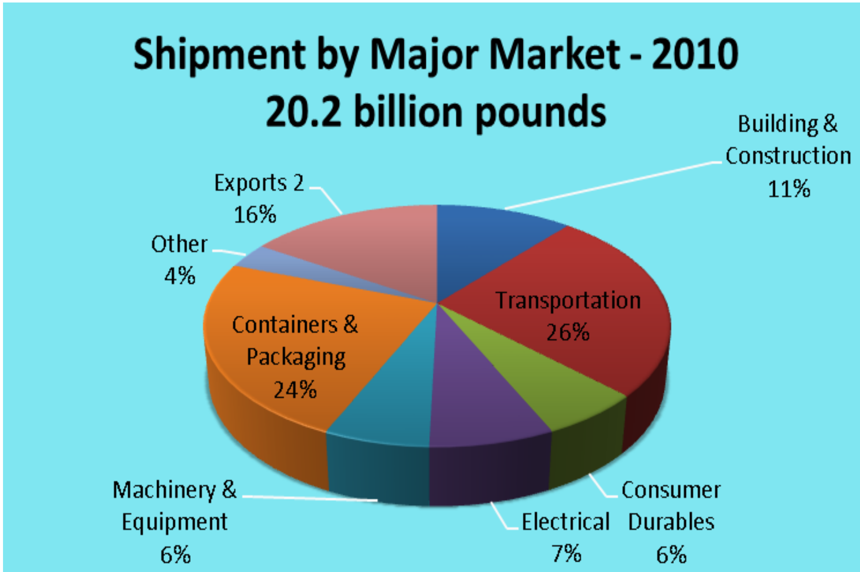


Figure 4: Shipments by major market sectors in 2008, 2009 and 2010 in North America. Data Source: The Aluminum Association.

The historical consumption of aluminum in North America is shown in Figure 5 *(see next page)*. Over the past 30 years, aluminum demand in the region has steadily increased as new applications for the metal have been developed. The 2007-2009 period, during which that upward trend was reversed, reflects the downturn in the building/construction and automobile markets. During this time, aluminum consumption fell 29% from its 2006 peak. From 2006 to 2009, transportation shipments fell 52% and building and construction shipments fell 40%.

Since the 2009 nadir, aluminum consumption has picked up considerably. Total consumption increased 14% in 2010 compared to 2009, with transportation-sector shipments up 25%.

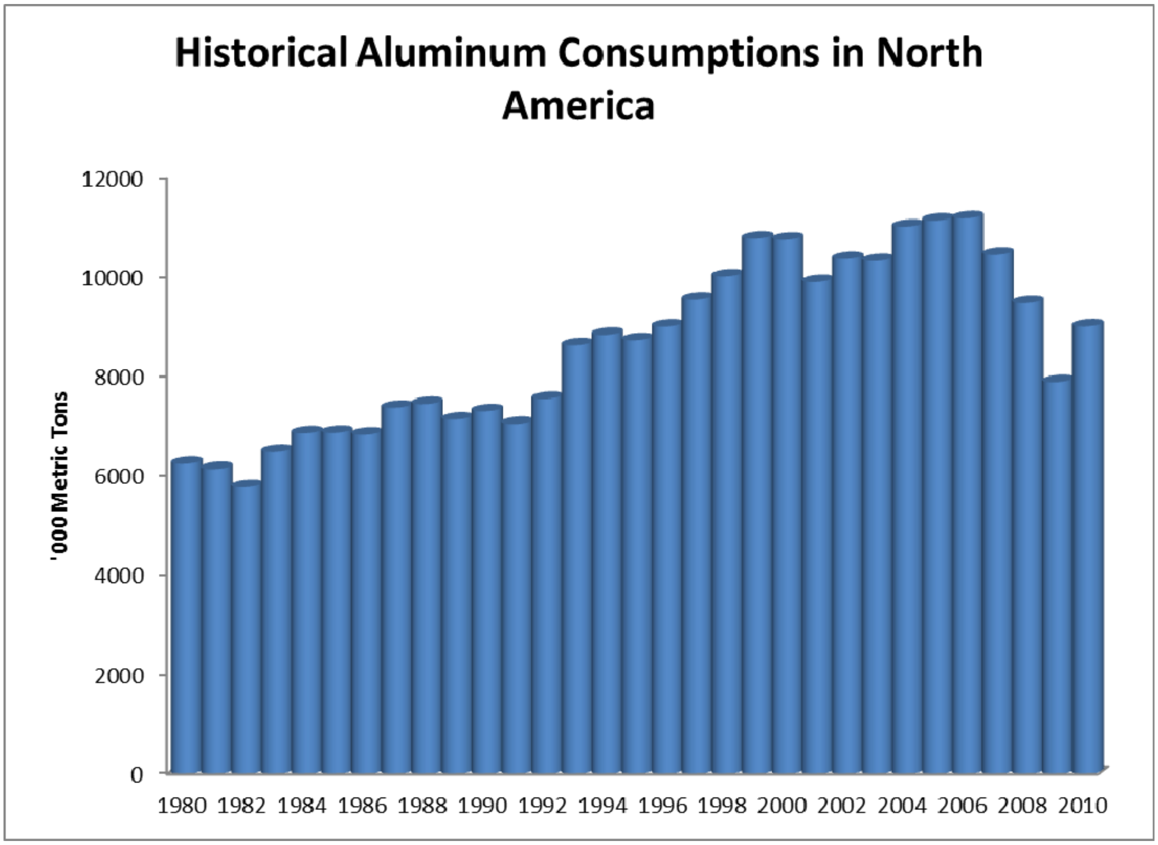


Figure 5: Historical aluminum consumptions in North America. Data Source: U.S. Geological Survey, U.S. Department of Interior; Bureau of the Census, U.S. Department of Commerce; Natural Resources Canada; The Aluminum Association of Canada; and The Aluminum Association

Part II: Sustainability Pathway: A Life-Cycle View and Approach

It has been a core business strategy and a long-term commitment of the aluminum industry in North America to deliver sustainable products. To achieve this, the industry has focused on all aspects of a globally accepted triple-bottom-line concept of sustainable development (*see Figure 6*): economic benefits, environmental soundness, and social well-being. A key approach the industry has taken to address sustainability is "life-cycle thinking" and management of its products.

Figure 6: The Triple Bottom Line of sustainability (adapted from UNEP, UNEP Guide to Life Cycle Management, 2005)

The traditional approach to the environmental management of industries and businesses largely focuses on facility-level compliance and control. This approach addresses only a single stage in the life-cycle of a product (including service) and therefore only a small proportion of the larger system.[1] This approach is inadequate because a product or industrial activity exists not in isolation but rather as part of a complex system.[2]

This larger system refers to all the stages in a product's life-cycle, including raw material extraction and processing; product design and manufacturing; packaging and delivery; use and maintenance; and reuse, recycling and/or disposal. The dynamic interaction of each life-cycle stage with the environment is shown in Figure 7 *(see next page)*. This diagram displays only the interaction with the environment; the addition of economic and social systems further increases the complexity.

[1] Azapagic.A, Perdan. S, and Clift. R. 2004. Sustainable Development in Practice: Case Studies for Engineers and Scientists. John Wiley & Sons, Chichester, pp437
[2] Graedel. T.E and Allenby. B.R. 2003. Industrial Ecology. Prentice Hall, pp17.

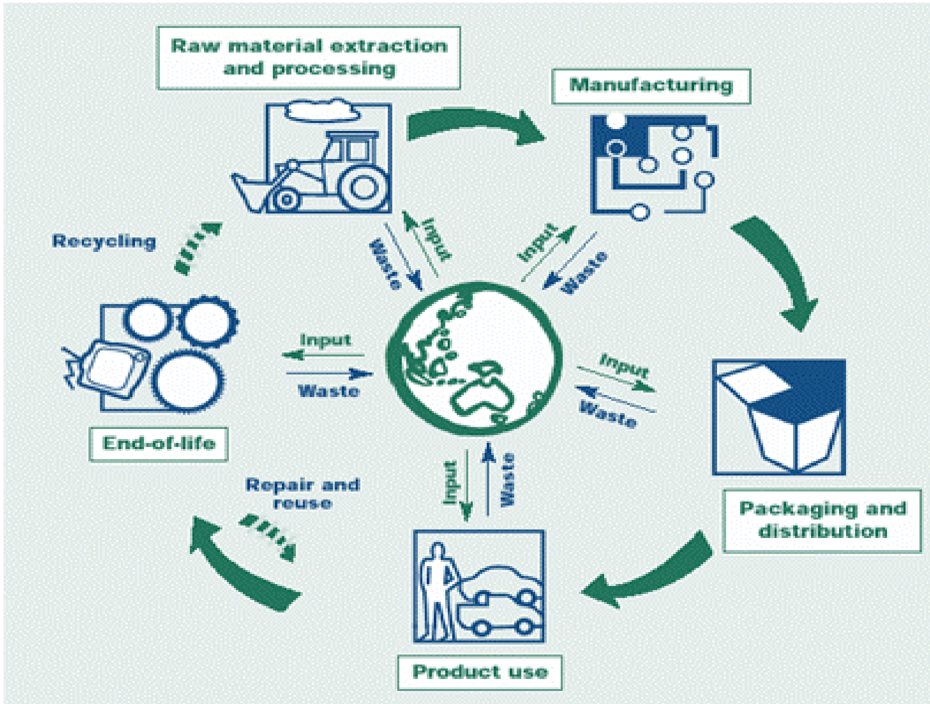


Figure 7: Product life-cycle stages and the interactions with the environmental system (picture republished from UNEP Guide to Life Cycle Management, UNEP 2005. The original source of the picture was from the Australian Department of Environment and Heritage).

To address system complexity, the entire life-cycle of the product must be considered ("life-cycle thinking"). A decision made based on life-cycle thinking is called "life-cycle approach."

Life-cycle approach is a system approach in product sustainability management taking into consideration the production of a product, consumption and end-of-life management. Life-cycle approach avoids the issue of shifting, i.e., problems that shift from one life-cycle stage, one location, one time, or one generation to another;[3] it transcends the traditional boundaries of single-stage focus and makes it possible to address all three aspects of the triple-bottom-line—economic, environmental and social—at the same time.

Like all other material industries, the aluminum industry requires substantial amounts of energy and natural resources, and releases wastes and emissions, during the material production and product fabrication processes. However, the practices currently employed by many of the extractive industries are not sustainable. The aluminum industry endeavors to differentiate itself by ensuring the sustainability of its products through their entire life-cycle: resource extraction, material production, product fabrication, product usage, and end-of-life treatment. The goal is to provide society with a material that is responsibly produced and fabricated, provides sustainable solutions and is recycled after its useful life so that it may be reused infinitely by future generations.

[3] UNEP, Life Cycle Approaches: The Road from Analysis to Practice, 2005.

Over the last two decades, the aluminum industry has undertaken extensive effort to monitor, understand and communicate the environmental impact of our industry's products from cradle to cradle—both at the regional and global levels. Responsibility for such effort has been clearly defined and shared by the aluminum industry via the International Aluminium Institute (IAI) and other regional associations including the Aluminum Association. IAI manages data collection on resource extraction (bauxite mining and alumina refining) and primary metal production, while secondary metal production, product semi-fabrication, product use and end-of-life recycling and disposal are managed at the regional or country level. Data collection categories include energy use, major natural resource and material consumption, major and/or sensitive environmental releases, product use patterns, and recycling/disposal rates of products at the end of life.

The regular collection of this information enables the industry to fully assess its environmental footprints and the net benefits of its products to humanity. Analysis of the data allows the industry to identify key issues to help guide the actions of individual firms, facilities and the larger global industry to achieve improvements. Using these data to fully disclose the life-cycle performance of aluminum products gives consumers and the general public the opportunity to understand more fully the environmental impacts associated with use of the material so that they can make informed purchasing decisions.

The aluminum industry is one of the lead industries in adopting a life-cycle approach to address sustainability issues. The industry manages its production and operational activities in a highly transparent manner, both at the global and regional levels.

The aluminum industry aspires to provide its stakeholders the highest level of transparency into the sustainability of its operations. The industry's view is that only via the release of comprehensive life-cycle data—of aluminum and competing material industries—can society objectively determine the environmental impacts associated with these materials and the products manufactured from them.

As detailed in the last section of this report, challenges remain for the aluminum industry to fully harness aluminum's potential as a sustainable material. These challenges involve energy and resource conservation, waste minimization, and thorough recycling and preservation of the used material for future generations. These difficult challenges can be turned into opportunities that guide the industry to a more sustainable future. The sustainability of a material like aluminum rests not only on industry efforts but on the collective efforts of the entire society. To assist in these efforts, the Aluminum Association continues to gather quality data; conduct state-of-the-art research, studies and analysis; and communicate the findings in a transparent manner to help inform the industry's many stakeholders—including consumers, manufacturers, government, and NGOs.

See *Part VIII: Case Studies* on page 57 for examples of aluminum's life-cycle performance in specific product applications.

Part III: Responsible Aluminum Production and Fabrication

Aluminum is an elemental material. Each metric ton of aluminum contains approximately 222,963 x 10^{23} aluminum atoms. In an ingot of pure aluminum, the aluminum atoms are tightly grouped with other aluminum atoms via an attractive force called metallic bonding characterized by a "delocalized sea of electrons" and a positive aluminum nucleus. This free mobility of electrons is what gives aluminum its noted electrical and heat conductivity. It is also what provides aluminum with the flexibility for it to be mechanically processed, i.e., via rolling, extruding, forging, drawing, casting, etc., without destroying the bonding forces. Atoms in solid aluminum are arranged in a three-dimensional lattice-type arrangement. Such arrangement is typical for all solid metals. When the material is heated to a certain level, the metal becomes liquid and the crystal structure is amorphous. When it is cooled, the crystal structure is restored.

In comparison, carbon-based organic compounds, such as wood, natural fiber and plastics, are composed of large carbon, hydrogen and oxygen element-based molecules; repeated heating-cooling and/or mechanical processing will destroy the bonding force and configuration within individual molecules, thereby changing the properties of the material.

The atomic number of aluminum is 13 and the standard atomic mass is 27. This means that aluminum is low in density and is significantly lower in weight compared to other common metals such as steel, copper, zinc, lead, and tin. The densities of aluminum, iron, and copper are 2.7, 7.8, and 8.9 g/cm^3 respectively.

Aluminum as a material is almost always used in alloyed form. When adding other atomic elements into pure aluminum, such as magnesium, zinc, copper, manganese, silicon, tin, etc., the original softness, reactivity and formability of aluminum change dramatically. Aluminum alloys can be made as strong as steel but with only half the weight of the same strength steel. Aluminum wire can be made as strong and ductile as copper wire but with only half the weight of copper wire of the same electrical conductivity.

Aluminum's elemental nature supports its claim as a sustainable material: once produced, it can be recycled repeatedly without any loss in quality and reused in the manufacture of consumer and industrial products. Coupled with the other physical properties of the metal and its alloys—its durability, high strength-to-weight ratio, excellent thermal and electrical conductivity, high corrosion resistance, great malleability, elasticity, and surface reflectivity—it has enabled the aluminum industry to manufacture products that promote sustainability during the production, use, and end-of-life phases. In the North American aluminum industry, we call this a process of building sustainability atoms into aluminum products.

The responsible production and fabrication of aluminum starts with responsible resource extraction, followed by responsible raw material production and responsible metal processing.

III.1. Resource Extraction

Aluminum can be produced from either of two source materials: bauxite or recycled scrap. Bauxite is used in the production of primary (virgin) aluminum, while scrap provides the feedstock for secondary ("recycled") aluminum. The production of aluminum from these two raw materials involves wholly different energy inputs and environmental impacts.

III.1.1. Bauxite Mining

Worldwide, the industry makes every possible effort to ensure maximum efficiency and minimum land and resource use and protect eco-sensitive areas and habitats from disturbance.

While aluminum is one of the most abundant mineral elements on earth, technological and efficiency constraints require the production of the material from certain forms of the ore bauxite that is located in specific deposits around the world. Bauxite generally contains 30-50% aluminum oxide. Regardless of where the metal is made, bauxite ore mining is concentrated in a few abundant deposits in Australia, Brazil, Ghana, Guinea, India, Jamaica, and parts of Russia and China.

Bauxite mining requires tree and vegetation removal; habitat disturbance; water, land and energy use; and generates solid wastes. Environmental and ecological considerations dictate that the bauxite mining industry offset these impacts. Worldwide, the industry makes every possible effort to ensure maximum efficiency and minimum land and resource use and protects eco-sensitive areas and habitats from disturbance. Great efforts are made to appropriately treat all the wastes generated, restore finished sites to their original status, and to bring maximum long-term social and economic benefits to local communities and residents where mining is conducted.

Energy consumption in the mining process is either in the form of fossil fuel combustion such as diesel, gasoline, natural gas and coal, or in electricity use. Approximately 150 MJ, or 0.14 MMBtu, of primary energy is used to produce one dry metric ton of bauxite. Bauxite mining is one of the least energy intensive processes in primary aluminum production, even with the inclusion of oceanic transportation. While there is the potential for improvement in the energy intensity of bauxite mining, the absolute levels of reduction possible are very limited.

The intensity of land use for aluminum resource extraction is comparatively lower than that for most other metal materials due to a variety of factors—among them, that the element content of aluminum in one unit of bauxite ore is higher than that of other metals in their respective mined ores. Second, bauxite ore deposits are relatively concentrated in large formations. Finally, the efficiency of conversion from ore into metal is higher for aluminum than it is for other metals (e.g., iron, copper, zinc, nickel, lead, etc.).[4] According to a multi-year IAI survey and assessment study on global bauxite mining,[5] during a 5-year period, on average, approximately 162 m^2 of land is required to produce 1,000 tons of bauxite. This translates to about 0.8 m^2 of land use per metric ton of primary aluminum produced. To offset land use and environmental disturbance, the industry has rehabilitated the same square footage of finished mining sites over this period, yielding a net rehabilitation approaching 100%. Rehabilitation is focused on "restoring the original ecosystem as close as possible, in terms of structure, function, and dynamics".[6]

Globally, approximately 30 km² of land is opened for bauxite mining each year. The same area of finished mining sites is rehabilitated, yielding 100% net rehabilitation.

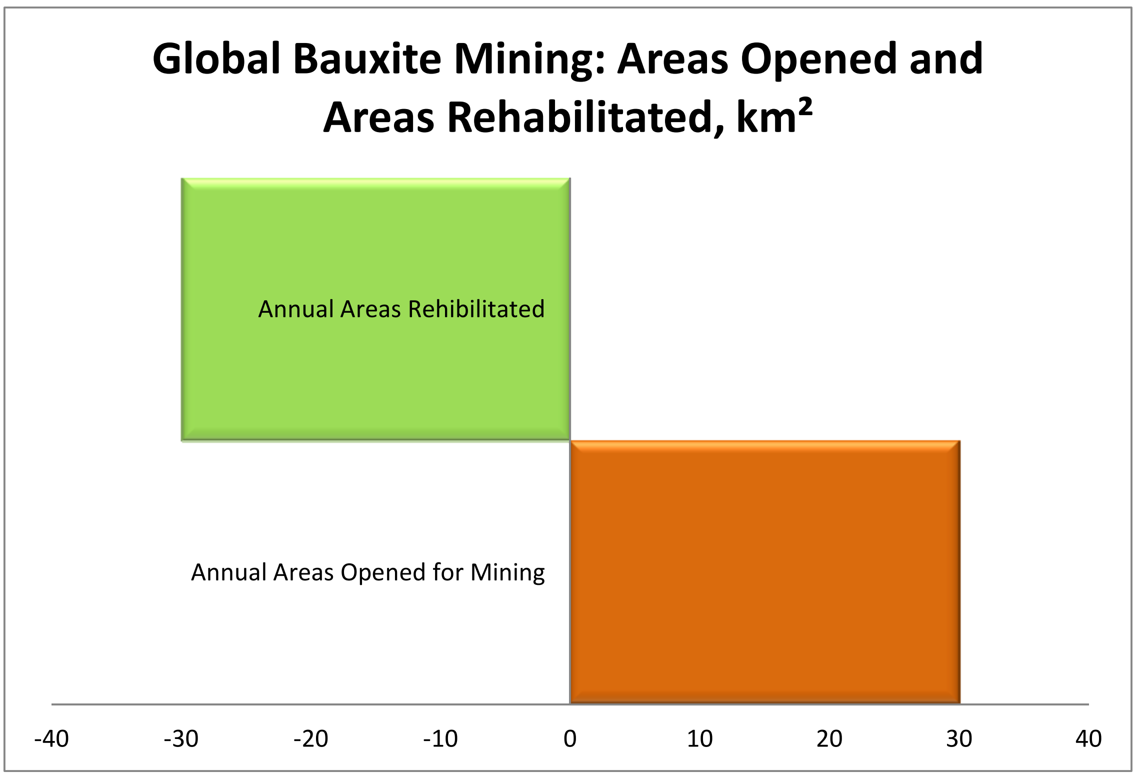


Figure 8: Global bauxite mining sites restoration/rehabilitation. Data Source: International Aluminium Institute.

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[4] Ecoinvent and PE International. Database for Metal Productions, 2006.
[5] IAI, Fourth Sustainable Bauxite Mining Report, 2009.
Available online at http://world-aluminium.org/cache/fl0000292.pdf
[6] IAI, Fourth Sustainable Bauxite Mining Report, 2009.
Available online at http://world-aluminium.org/cache/fl0000292.pdf.

In addressing the social and economic effects on mining localities, bauxite mining companies actively work to ensure that "wealth generated through mining is shared throughout the community and will also benefit future generations." Measures include adequately remunerating local labor; adherence to labor standards; creation of education and training programs; development of local industries, businesses, and infrastructure; compensation of disadvantaged and displaced groups; support of community and local programs; and payment of taxes.[7]

III.1.2. Alumina Refining

Approximately 14,200 MJ, or 13.5 MMBtu, of primary energy is used to produce one metric ton of metallurgical alumina.

Bauxite ore provides the raw material from which alumina (aluminum oxide) is extracted. The extraction process, called alumina refining, provides the material which is then used to produce virgin aluminum metal. In North America, only about 40% of the alumina required for primary aluminum production is produced in the region. The remainder is imported, notably from Australia, Suriname and Jamaica.

Alumina refining is a chemical process using water, energy and chemicals, including lime and caustic soda; the process releases a large volume of wastes in which the main content is sand and dirt. Globally, alumina refining is a scaled operation with large facilities; these facilities are often located near bauxite mines to reduce distances—and hence the costs and emissions—associated with the transportation of bulk ore.

Energy use in the alumina refining process is in the form of fossil fuel such as diesel, gasoline, natural gas and coal, or electricity. Approximately 14,200 MJ, or 13.5 MMBtu, of primary energy is used to produce one metric ton of metallurgical alumina. The potential for improvement in the energy efficiency associated with alumina refining is greater than those for all other primary aluminum production processes. This potential can be achieved by utilizing better-quality bauxite ores and adopting better calcination technologies.

In North America, approximately 1.91 tons of alumina is required to produce one ton of primary aluminum. Depending on the alumina content of the ore, approximately 5 tons of bauxite is needed to produce 1.91 tons of alumina; the non-aluminum oxide feedstock, which is mainly sand and dirt, will become waste at the end of the alumina refining process. The waste is a diluted or dense water-based slurry often called "red mud" for its reddish color.

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[7] IAI, Fourth Sustainable Bauxite Mining Report, 2009.
Available online at http://world-aluminium.org/cache/fl0000292.pdf.

Red mud reuse is a global challenge for the aluminum industry. Red mud exists in large volumes with limited reuse potential. The alkalinity property and the possibility of containing trace heavy metals and/or naturally occurring radioactive materials further limits the possibility of reuse. Common practice in red mud treatment and disposal is designated land storage in the form of lagooning/ponding, dry stacking, or dry cake.[8] Maximum alkalinity reduction and the reuse of all collected waste water are common practices at all global facilities. Active research into safe and economically viable red mud reuse is ongoing. The focus of this research is the possibility for construction, chemical, environmental, agronomic, and metallurgical applications.[9]

III.1.3. Aluminum Scrap Collection

Aluminum scrap is the bulk metal that is used as raw material to produce secondary aluminum and subsequently new aluminum products; it includes both "new" and "old" scrap. New scrap is generated from aluminum wrought and cast products as the metal is processed by fabricators into consumer or industrial products. Old scrap is retrieved from post-consumer products or discarded products of all types. Common sources for old scrap include automobile parts, beverage cans, aluminum siding, door and window frames, cables and wires, and consumer durable goods or parts.[10]

A quantitatively less important but symbolically significant source of secondary aluminum raw material source is dross. Dross is the kind of "waste" generated by both primary and secondary aluminum production facilities in which dross processing is not an area of expertise. A number of aluminum recycling facilities in North America specialize in making metal from dross.

To the surprise of some, scrap collection is one of the most important resource extraction activities for the aluminum industry today. More than 35% of North America's metal supply is from recycled metal, and the region is the world's most resource-abundant "secondary mining" site due to its long history of aluminum production and use. In addition to scrap collected and used for producing recycled metal for domestic use, nearly 2 million metric tons of scrap is net exported each year, representing one-third of the total global scrap supply. Without scrap "mining," the North American aluminum industry would be dramatically curtailed, and the global industry would have significant difficulty serving the increasing global demand for aluminum products.

Unlike bauxite mines, scrap "mining" sites are typically located in densely populated areas such as cities and suburbs. Additionally, there are no high-concentration deposits, as is the case with bauxite. The "deposits" are "retired" individual pieces of metal that are

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[8] IAI, Bauxite Residue, available online at http://www.world-aluminium.org/Sustainability/Environmental+Issues/Bauxite+residue+

[9] Asia-Pacific Partnership on Clean Development and Climate, Review of Bauxite Residue "Reuse" Options, available online at http://www.asiapacificpartnership.org/pdf/Projects/Aluminium/Review%20of%20Bauxite%20Residue%20Re-use%20Options_Aug09_sec.pdf

[10] The Aluminum Association. Aluminum Recycling Casebook. 1998.

either attached to an object or facility or loosely scattered around. They are beverage cans, cooking pots, lighting devices, computer cases, car components, window frames, chairs and tables, guard rails, electric wires, road signs, train cars (e.g., for coal shipment), and/or a certain proportion of refrigerators and washing machines.

Scrap collection is one of the world's greenest resource extraction activities. In most cases, this resource extraction involves the efforts of nearly all members of society, including children. Citizens are encouraged to identify retired or obsolete objects and recycle them, either on principle or for financial reward. Scrap "mining" is often considered a green-collar job, whose processes include largely manual and mechanical activities pertaining to collection, sorting, storage and transportation.

Energy and resource use for scrap mining varies greatly according to region and scrap type. The Aluminum Association's life-cycle assessments have shown that overall the share of energy and resource use in scrap collection process is very low compared to the total energy and resources used for secondary metal production. The environmental impact is lower because the initial steps of collection and transportation of aluminum scrap are often byproducts of other activities, such as shopping, auto repair, garbage collection, etc. This finding counteracts the image of recycling as "energy intensive" and "counter-productive."

III.2. Material Production

Aluminum can be manufactured via two different methods: primary production and secondary production. Primary aluminum is produced from bauxite via the electrolytic reduction method. Secondary aluminum is produced by melting aluminum scrap in a furnace. There is no material difference between the two types of aluminum; they have the same physical properties.

III.2.1. Primary Metal Production

The production of primary aluminum metal is an electrochemical reduction reaction using alumina as a raw material; it is often called smelting. Two distinct technologies are used worldwide in aluminum smelting: the Soderberg technology and the pre-baked technology. The difference between the two technologies is the mechanism of electrolytic anode production. In Soderberg technology, the anodes are baked simultaneously in the "pots," or the electrolytic cells. Conversely, in pre-baked technology, the anodes are baked in a separate facility. Soderberg technology is an old technology and is energy and emission intensive; pre-baked technology is more efficient and cleaner. Worldwide, the Soderberg technology is gradually being phased out as facilities reach retirement.

Other major material inputs include anode, a carbon based material that is "sacrificed" in a reaction with the oxygen generated via electrolysis, molten cryolite (Na_3AlF_6), and aluminum fluoride (AlF_3). Cryolite serves as electrolyte and dissolves alumina; aluminum fluoride serves to lower the melting point. Electricity acts as an energy source

Electricity use in the smelting process accounts for about 80% of the total primary energy demand for all aspects of primary production.

to decompose the super-stable chemical bond between the aluminum and the oxygen in the alumina, and it is also considered a “material” input in the electrochemical reactions.

Alumina consumption, carbon anode consumption and electricity use are the primary resource inputs in the smelting process. Greenhouse gas emissions, fluoride emissions, and a limited amount of solid waste are the primary environmental releases. On average, each ton of aluminum metal consumes approximately 1.9 tons of alumina, 437 kg of carbon anodes and 15,300 kWh of electricity. Consumption of molten cryolite and aluminum fluoride is insignificant; most cryolite is used in a closed-loop fashion such that it is recycled and reused again and again.

70% of electricity consumed in smelting facilities in North America is from renewable hydropower. Overall, in terms of secondary, or useful, energy, the share of renewable energy in the production of primary aluminum is greater than 50%, the highest of any common material in production.

Electric power consumption is the most critical issue in producing primary aluminum. Electricity use in the smelting process accounts for about 80% of the total primary energy demand of primary aluminum production. Electricity cost can be as high as 40% of the overall cost of primary aluminum production.

The industry makes every possible effort to reduce electricity consumption in the smelting process. Significant progress has been made over the past several decades as a result of technological progress. Today’s electric power consumption per ton of aluminum is about half of what it was 50 years ago and 7% lower than it was 20 years ago. As the industry approaches the maximum theoretical level of electric power efficiency, however, improvement becomes harder and harder to achieve. Figure 9 *(see next page)* gives a snapshot of trends in smelting electric power intensity over the past two decades. The year-to-year fluctuations reflect the varying levels of usage of production lines that utilize older technology vs. those that use the more energy intensive self-bake facilities.

On average, each ton of aluminum metal consumes approximately 1.9 tons of alumina, 437 kg of carbon anodes, and 15,300 kWh of electricity.

Due to the geographical locations of most smelting facilities in North America, about 70% of electricity consumed in smelting facilities comes from hydroelectric sources. Overall, in terms of secondary, or useful, energy, the share of renewable energy in the production of primary aluminum is greater than 50% (when inefficiencies associated with generators of electricity are included, renewable energy constitutes about 33% of primary energy demand)—higher than any other common material in production, including glass, concrete, steel, plastics, magnesium, composites, copper, etc.

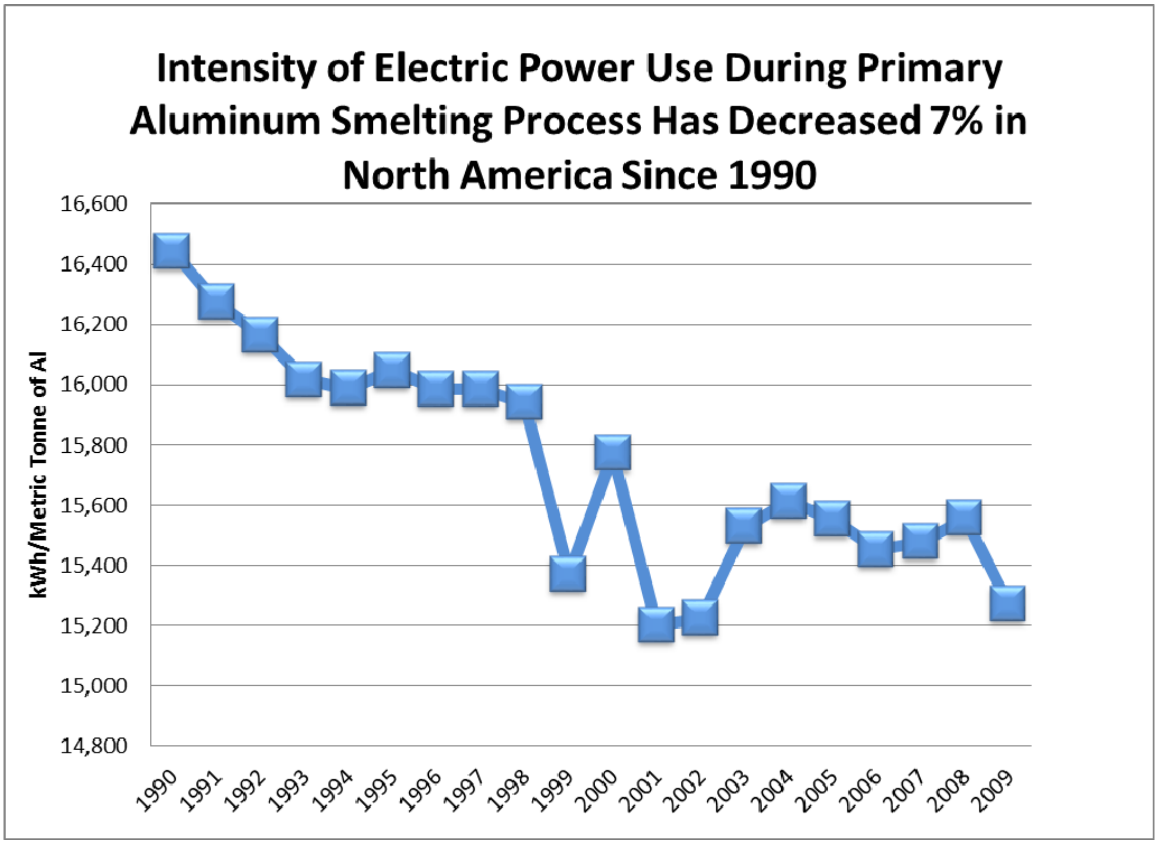

Figure 9: Electric power intensity of primary aluminum production in North America (1990-2009). Data Source: International Aluminium Institute and The Aluminum Association.

Currently, direct greenhouse gas emissions from primary aluminum production facilities are about 2.2 tons of CO_2 equivalent per ton of aluminum. This includes 1.6 tons of CO_2 and 0.6 tons of CO_2 equivalent of PFC emissions.

Greenhouse gases directly emitted in the aluminum smelting process include carbon dioxide (CO_2) and perfluorocarbons (PFCs). The current level of GHG emissions per ton of aluminum production is 1.6 tons of CO_2 and 0.6 tons of CO_2 equivalent of PFCs. The level of CO_2 emissions is fixed by anode consumption, while PFC emissions can be controlled by optimizing process operations and adopting automation technologies. During the last two decades, significant progress has been made in North America to reduce PFC emissions, through a voluntary program in cooperation with the Environmental Protection Agency (EPA). Figure 10 *(see next page)* illustrates PFC reductions in the industry in North America since 1990. An 85% reduction has been achieved as of 2010, and the industry is working toward elimination of PFC emissions altogether.

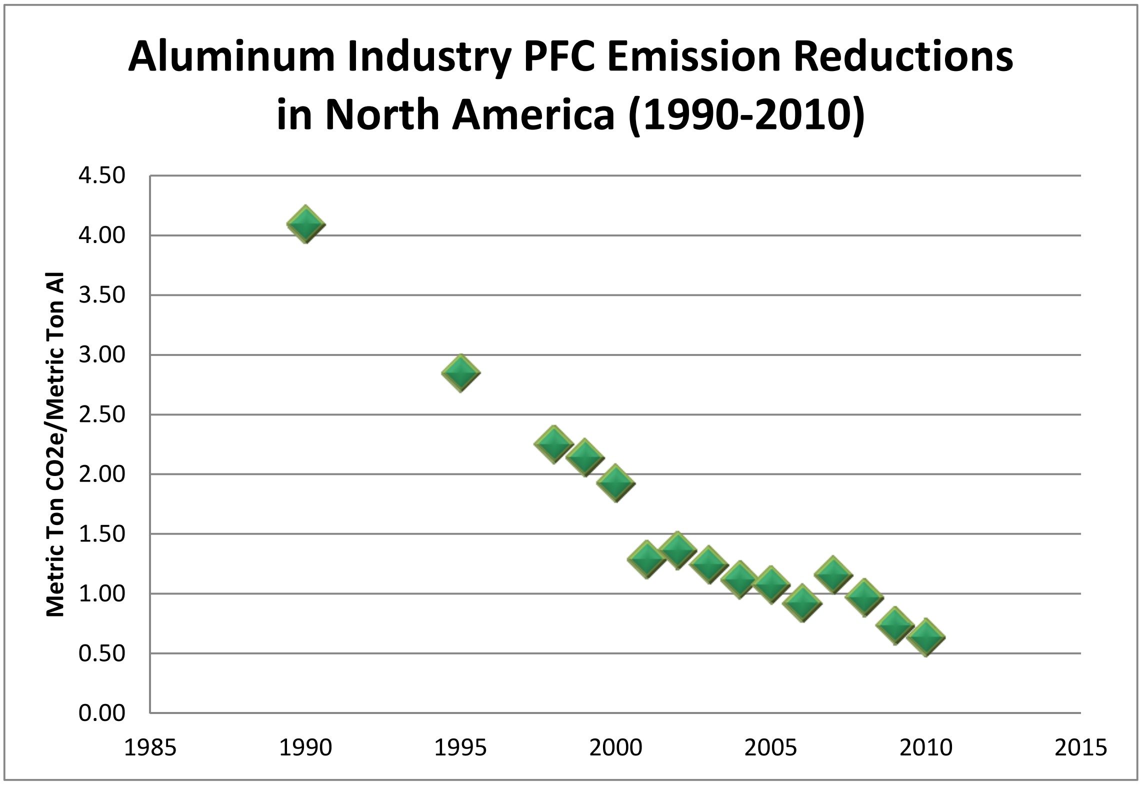

Figure 10: Aluminum industry PFC emission reductions in North America (1990-2010). Data Source: International Aluminium Institute and The Aluminum Association.

Fluoride is a toxic gas that is strictly regulated by the EPA. The emission of fluorides from most primary aluminum plants in North America has consistently been below 0.5 kg per ton of aluminum production—within EPA's permitted levels.

Solid waste in the aluminum smelting process includes dross, unused carbon, non-dissolved alumina, and spent pot liners. During the past two decades, the industry in North America has managed to recycle and reuse almost all of its dross, unused carbon, and non-dissolved alumina. Recent studies on the recycling and reuse of spent pot liners indicate that they may be a potential feedstock for the cement industry.

III.2.2. Secondary Metal Production

Secondary metal production uses scrap as a raw material. After scrap is "mined," or collected, it is sorted and cleaned before it is used in metal production. Scrap sorting involves separating aluminum from other materials and by the different alloy forms. Scrap cleaning involves the removal of oil, grease and other contaminants. Other standard pre-processing steps include shredding and crushing, drying and sweating, and decoating/delacquering. Scrap pre-processing helps reduce aluminum loss within the melting furnace and lowers emission of pollutants.

The core of secondary aluminum production is the melting and casting processes. Scrap is fed into melting furnaces to liquefy the metal. It is then purified, adjusted to the desired alloy, and produced into a form suitable for subsequent processing/fabrication.[11] The kinds of furnaces involved in scrap melt include reverbatory, rotary, and electric furnaces.

Energy efficiency, dust control, air emission control and solid waste minimization and/or reutilization are critical for responsible secondary aluminum production.

Almost all secondary metal production facilities in North America use natural gas and electric power as the primary sources of energy. Natural gas is the cleanest and the most efficient available energy source for aluminum melting. Electric furnaces use electric power as their major energy source. Approximately 5 GJ of energy is used in melting and casting operations to produce one metric ton of secondary aluminum. Cumulatively, approximately 7 GJ of energy is needed—from scrap collection to cast metal—to produce one metric ton of secondary aluminum.

Dust generation and air emissions are typical at both scrap pre-processing and melting facilities. Chloride gases, volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs—note: PAHs are a category of VOC) are representative substances emitted from these facilities as a result of scrap delacquering and evaporation of fluxing salt. Great effort has been made in the industry to ensure full compliance with the Clean Air Act and other relevant environmental laws and regulations. Modern furnace and equipment designs enable most air emissions to be confined and circulated inside the equipment so that they can be fully combusted, improving energy efficiency. Scrubbers and bag houses are also commonly used to control emissions and dust. Lime or calcium carbonate is used to capture both chloride gases and residue VOCs.

Solid waste from secondary aluminum production facilities is mainly in the form of "salt cake." Salt is used to "flux" the dross formed at the surface of molten metal to eliminate contaminants and maximize metal recovery. The salt used is a combination of sodium chloride (NaCl), potassium chloride (KCl), and cryolite.[12] Salt cake is the spent flux oxides and other impurities discharged from melt furnaces. Most salt cake contains a small amount of metal. The aluminum industry makes every effort to retrieve the metal content and salts for reuse. A significant amount of salt cake is recycled either at the production facility or specialized dross recycling facilities. Recycling involves breaking the cake down into aluminum metal, aluminum oxides, and salt. After recycling, the rest of the residue is often landfilled at designated locations or can be used as feedstock in cement kilns.

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[11] The Aluminum Association. Aluminum Recycling Casebook. 1998.
[12] Schlesinger, M.E. *Aluminum Recycling*. CRC Press, 2007. P117.

III.3. Product Fabrication

There is no functional difference between primary and secondary aluminum; both virgin and secondary aluminum can be manufactured into semi-fabricated or final products. Fabrication involves rolling, extrusion, forging, or casting. The processes and technologies involved are extremely diversified and can be done on a very large scale (in the case of rolling and extrusion) or in small mom-and-pop shops (in the case of casting). Figure 11 gives a snapshot of the various fabrication processes.[13]

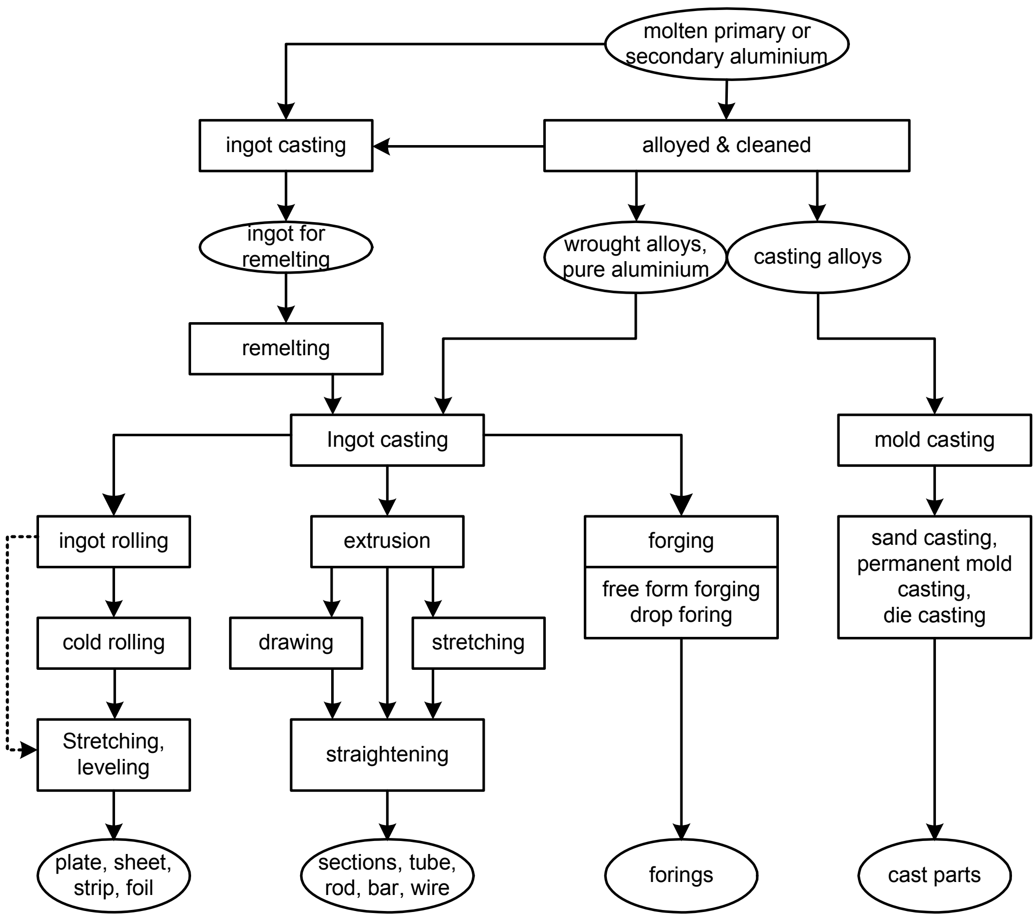

Figure 11: Typical aluminum fabrication processes.
Source: Altenpohl and Kaufman, Aluminum: Technology, Applications, and Environment, A Profile of A Modern Metal, TMS, 1998. Figure reproduced by T. Graedel and W. Chen, Yale University.

Issues of concern during fabrication are energy consumption, process material utilization efficiency, and environmental releases such as rolling sludge, dross, refractory materials, used casting molds, and some air and water-borne emissions.

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[13] Altenpohl and Kaufman. *Aluminum: Technology, Applications, and Environment*. TMS, 1998, Sixth Edition. p21. Figure reproduced by T. Graedel and W. Chen, Yale University.

Energy consumption in the fabrication processes in North America involves mainly natural gas and electricity. The amount of energy used per ton of aluminum product fabrication varies greatly depending on the specific form of fabrication, the technology employed, and the scale of the operation. A large proportion of energy is used to heat or melt the metal during fabrication. For this reason, large integrated aluminum producers are able to save more energy than small independent fabricators by streamlining the production processes in the same facility to avoid the ingot casting and re-melting processes.

Emissions and wastes are a less prominent problem in the aluminum fabrication processes than in the resource extraction and material production processes because the amounts are relatively smaller. Among the emissions, VOCs—a potential concern—are well controlled by the industry. Waste oil and dross are typically recycled and reused; waste refractory materials, spent molds, and/or “salt cakes” are usually landfilled. During the past two decades, no significant environmental regulatory violation has been recorded against the aluminum fabrication industries in North America.

III.4. Highlights of Improvements in Aluminum Making

During the past two decades, the Aluminum Association has sponsored three major LCA studies.

- The first study was carried out in 1992 and completed in 1993. It examined the cradle-to-grave life-cycle inventories of the 12-ounce aluminum beverage can (product use-phase excluded). The base year of the study (the year the production information was collected) was 1991.
- The second study, carried out in 1996 and completed in 1998, examined the cradle-to-grave life-cycle inventories for automotive products (final auto part fabrication, assembly and product use-phase excluded). The base year of the study was 1995.
- The third study, carried out in 2007 and completed in 2010, concentrated on a cradle-to-grave life-cycle inventory assessment of a mixture of aluminum beverage cans (beverage filling and product use-phase excluded). The base year of this study was 2006.

While the goals, scope, and products under study varied significantly, and LCA guidelines and methodologies have since been changed in certain respects, these studies provide critical baseline data to help develop an understanding of the energy and environmental inputs and impacts of aluminum products over their life-cycle. The studies reflect the industry’s commitment to data gathering and analysis toward the development of a platform for identifying future sustainable opportunities.

Material Inputs for Primary Metal Production: Flat Trend Reflecting Laws of Physics

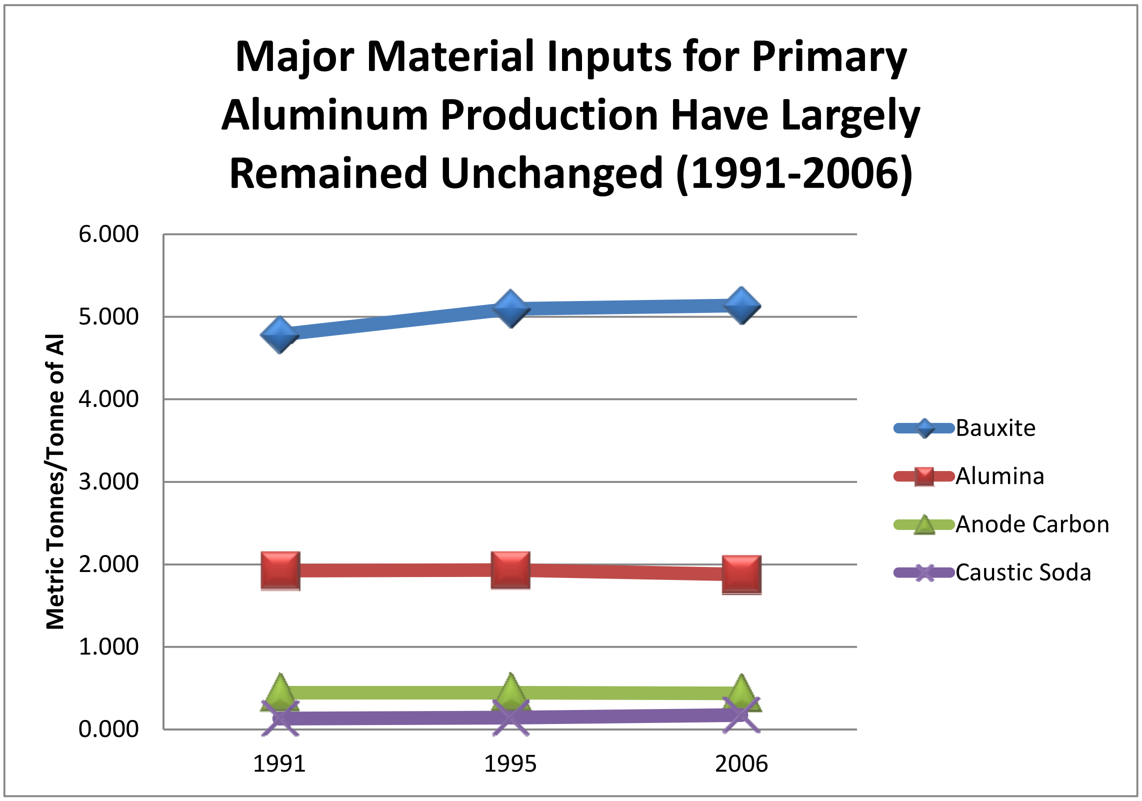

Figure 12: Trend of major material inputs for primary aluminum production (1991-2006). Data Source: Alcan, Alcoa, Reynolds, and Roy F. Weston Inc., 1993; The Aluminum Association and Roy F. Weston Inc., 1998; The Aluminum Association and PE Americas, 2010.
Note: The flat trend of raw material use in primary metal production reflects the reality of the laws of physics: it takes a fixed quantity of certain materials to produce another material. The slightly upward trend of bauxite use reflects the fact that the aluminum contents in bauxite ores mined from different regions and time periods are different.

Primary Energy Demand for Primary Metal Production: 17% Reduction

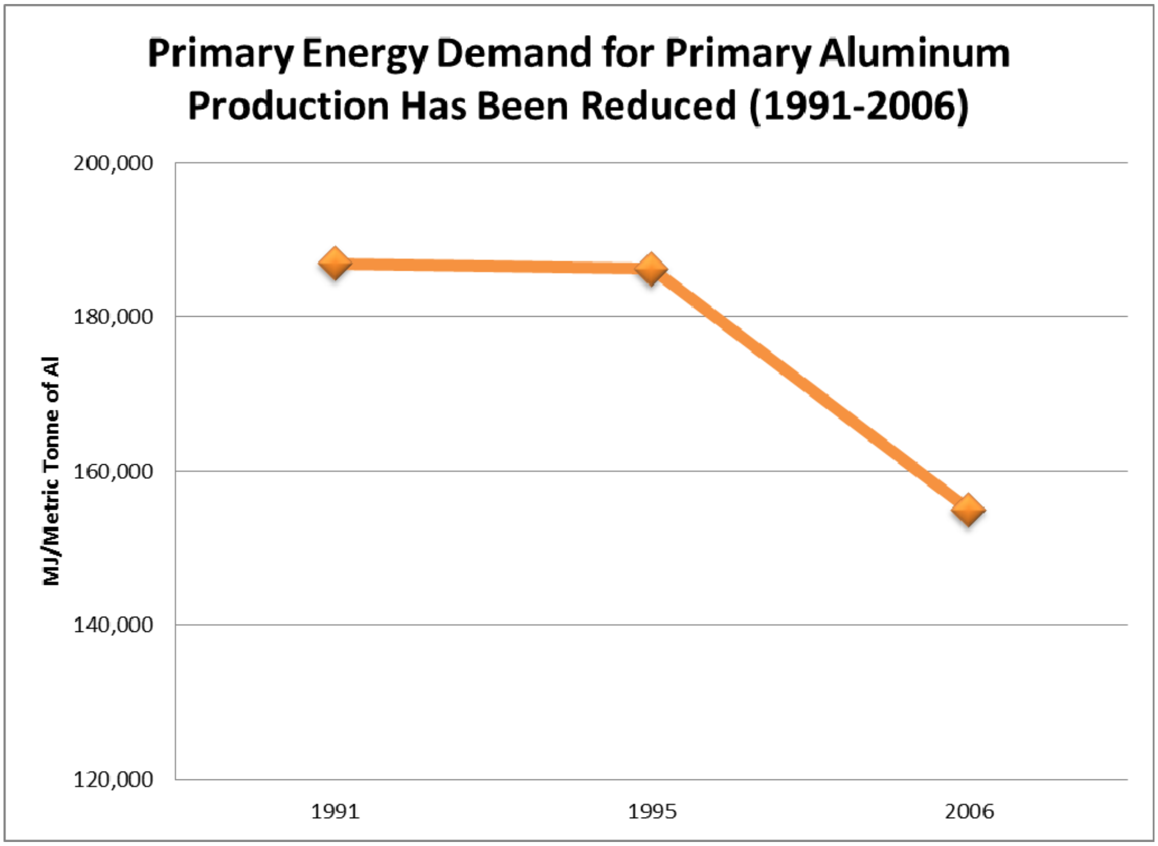

Figure 13: Trend of primary energy demand for primary metal production (1991-2006). Data Source: Alcan, Alcoa, Reynolds, and Roy F. Weston Inc., 1993; The Aluminum Association and Roy F. Weston Inc., 1998; The Aluminum Association and PE Americas, 2010.

Electric Power Consumption for Primary Metal Smelting: 7% Reduction

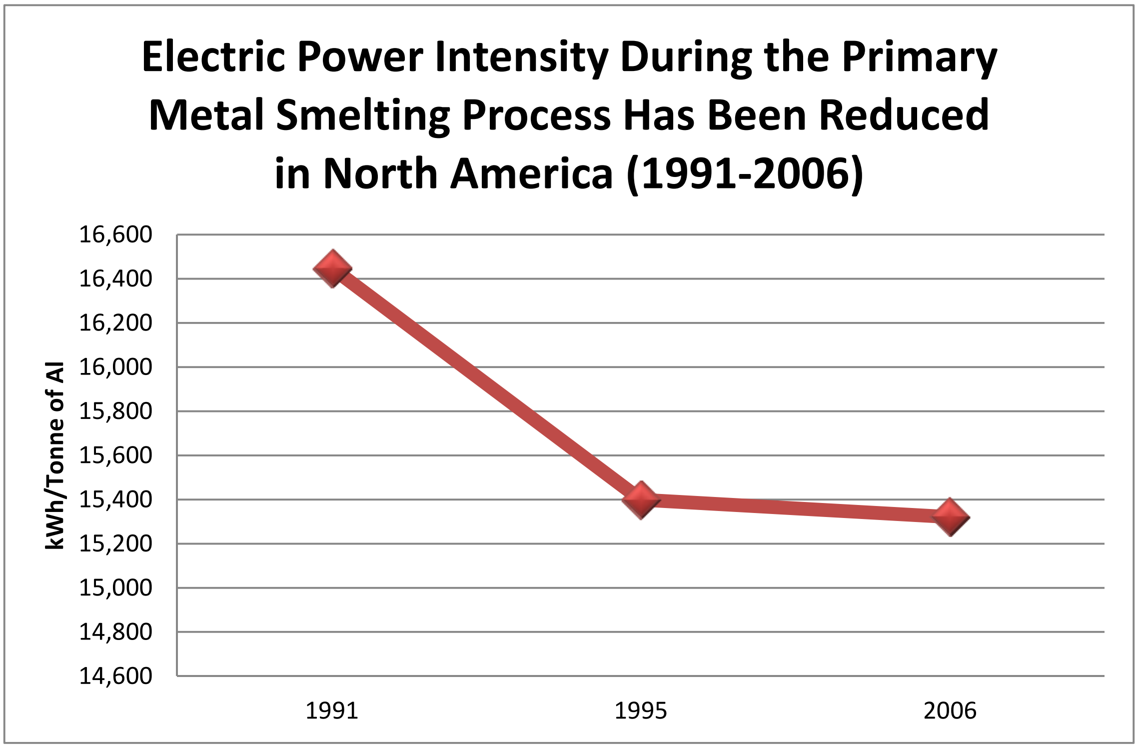

Figure 14: Trend of electric power consumption during primary aluminum smelting process (1991-2006). Data Source: Alcan, Alcoa, Reynolds, and Roy F. Weston Inc., 1993; The Aluminum Association and Roy F. Weston Inc., 1998; The Aluminum Association and PE Americas, 2010.
Note: Primary energy demand for primary metal production refers to the total amount of primary energy used, from mining all the way up to metal smelting and ingot casting (including energy demanded to produce auxilary materials and to treat emissions and wastes), to produce a ton of primary metals. Electric power consumption for primary metal smelting refers only to the electricity consumed during the smelting process.

Primary Energy Demand for Secondary Metal Production: 58% Reduction

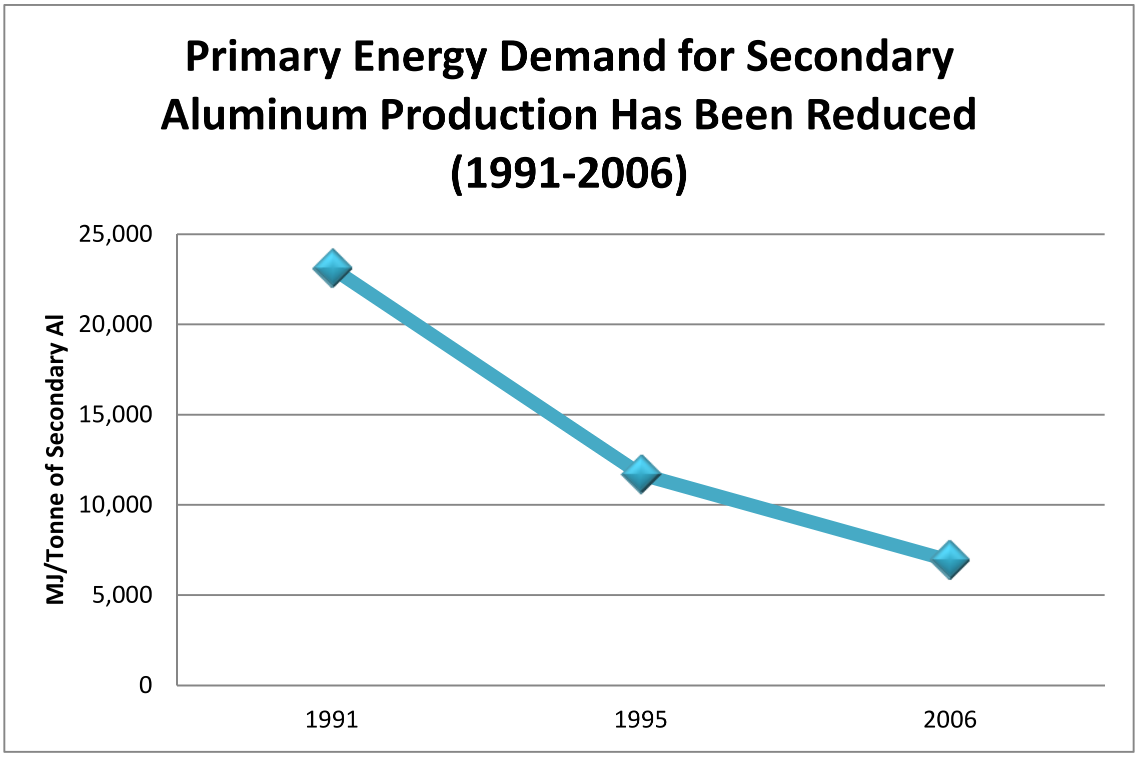

Figure 15: Trend of primary energy demand for secondary aluminum production (1991-2006). Note: The 2006 number represents the production of secondary ingots for beverage can making only. Data Source: Alcan, Alcoa, Reynolds, and Roy F. Weston Inc., 1993; The Aluminum Association and Roy F. Weston Inc., 1998; The Aluminum Association and PE Americas, 2010.

Direct GHG Emissions from Primary Metal Smelting Process: 50% Reduction

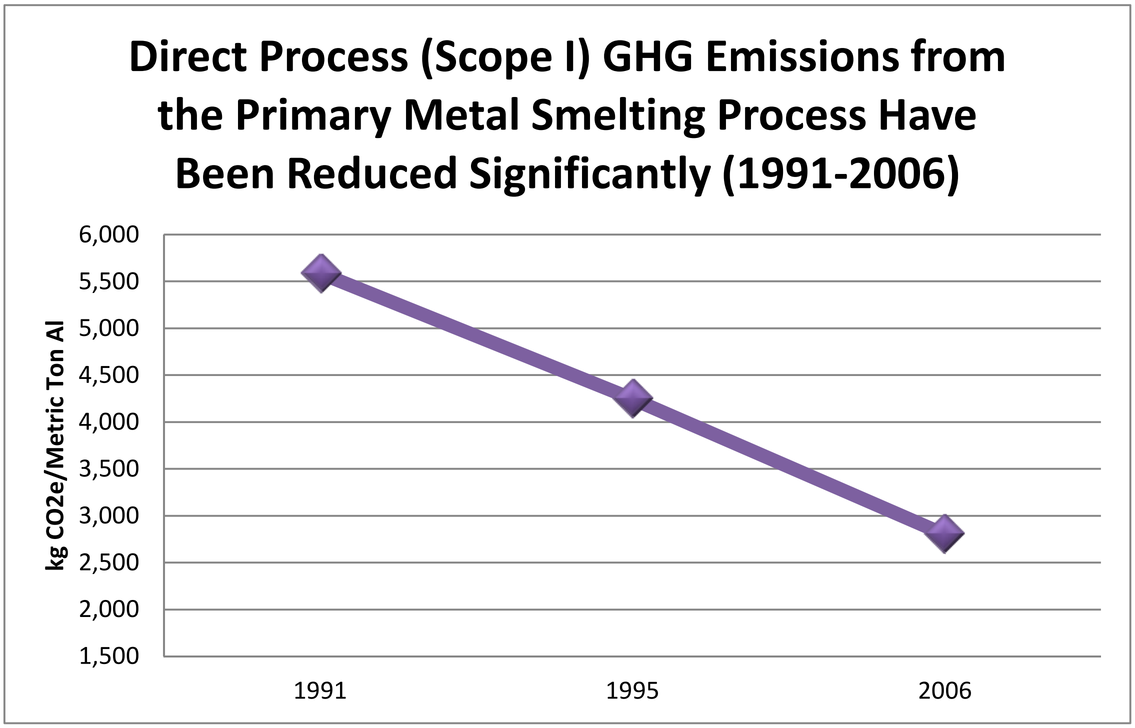

Figure 16: Trend of direct GHG emissions (Scope I emissions) for primary metal smelting (1991-2006). Data Source: Alcan, Alcoa, Reynolds, and Roy F. Weston Inc., 1993; The Aluminum Association and Roy F. Weston Inc., 1998; The Aluminum Association and PE Americas, 2010.

Cumulative GHG Emissions Caused by Primary Metal Production: 42% Reduction

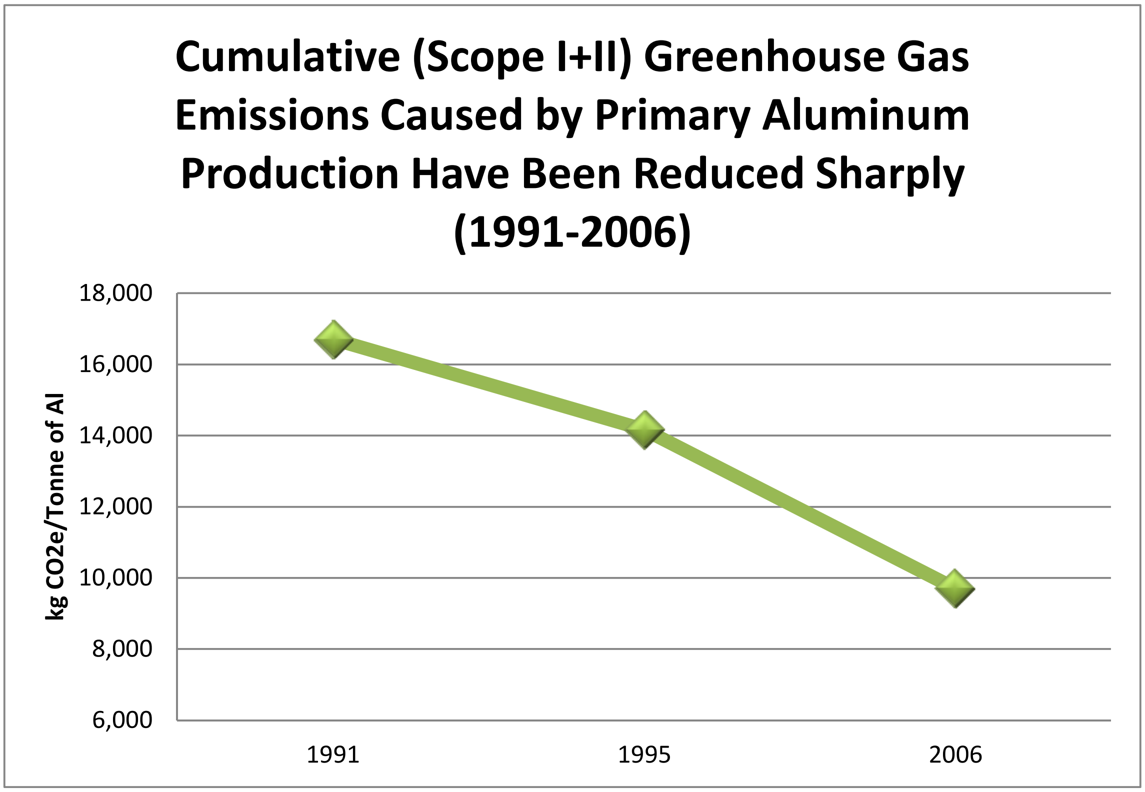

Figure 17: Trend of accumulative greenhouse gas emissions (Scope I+II emissions) caused by primary aluminum production (1991-2006). Data Source: Alcan, Alcoa, Reynolds, and Roy F. Weston Inc., 1993; The Aluminum Association and Roy F. Weston Inc., 1998; The Aluminum Association and PE Americas, 2010.

Cumulative GHG Emissions Caused by Secondary Metal Production: 65% Reduction

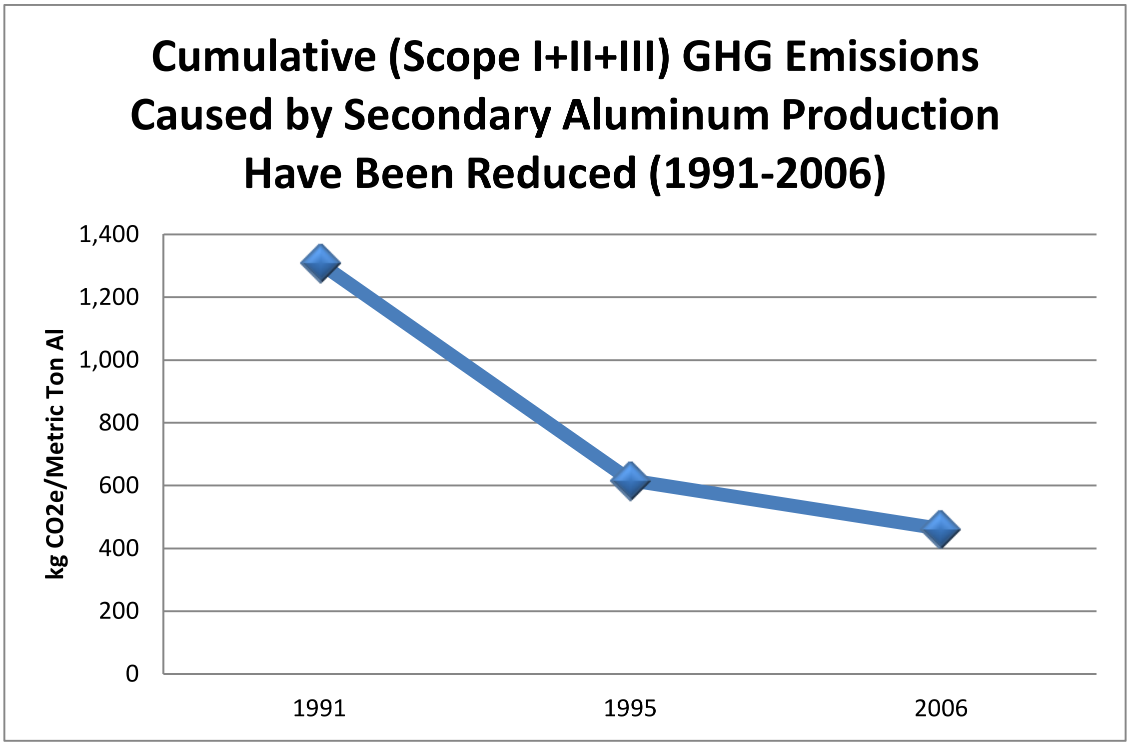

Figure 18: Trend of accumulative greenhouse gas emissions (Scope I+II+III emissions) caused by secondary aluminum production (1991-2006). Data Source: Alcan, Alcoa, Reynolds, and Roy F. Weston Inc., 1993; The Aluminum Association and Roy F. Weston Inc., 1998; The Aluminum Association and PE Americas, 2010.
Note: GHG emissions for primary metal smelting refers to the Scope I emissions caused by chemical reactions and direct fuel combustion in the smelting process only. Cumulative GHG emissions caused by primary metal and secondary metal productions refers to the Scope I+II (and Scope III in the case of secondary metal) emissions from all related production processes.

Process-Related Solid Waste Release from Primary Metal Production: 18% Increase

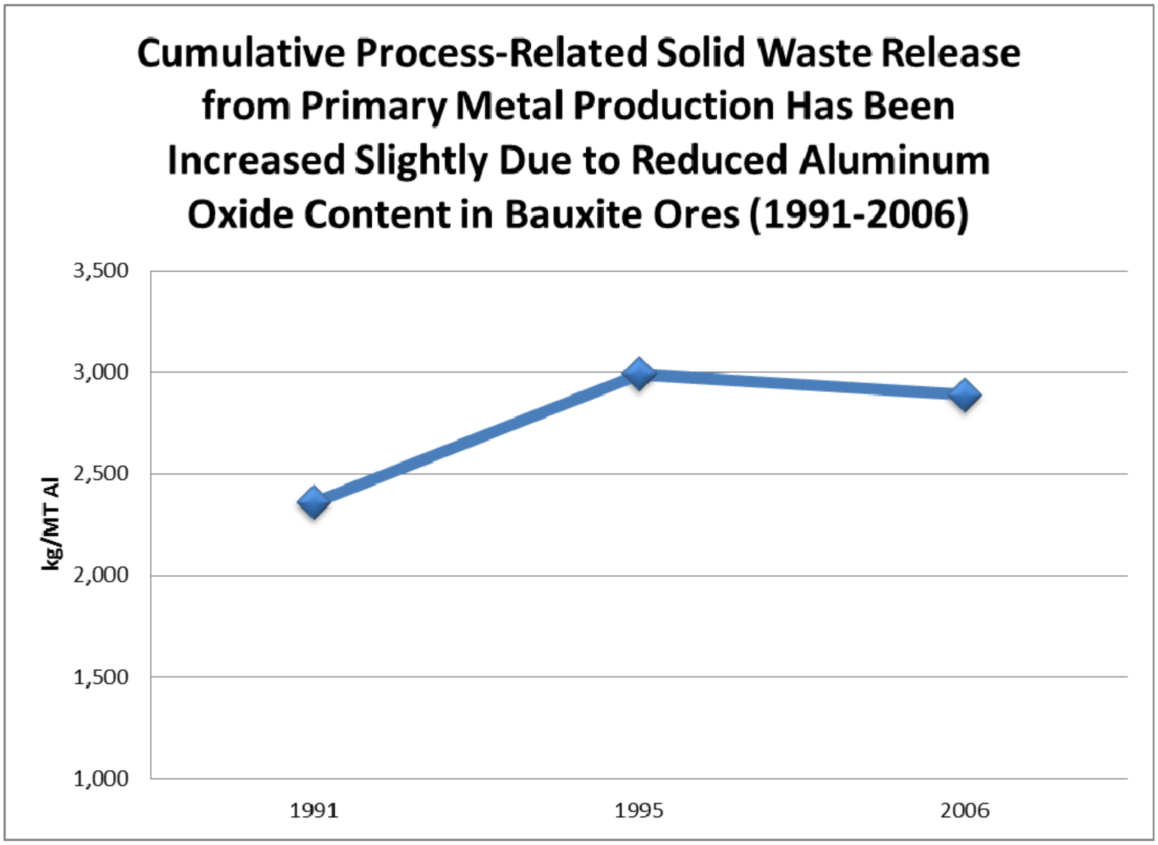

Figure 19: Trend of process related solid waste release caused by primary aluminum production (1991-2006). Data Source: Alcan, Alcoa, Reynolds, and Roy F. Weston Inc., 1993; The Aluminum Association and Roy F. Weston Inc., 1998; The Aluminum Association and PE Americas, 2010.
Note: Solid waste release related to primary metal production processes is largely determined by the alumina content in bauxite ores and the depth of sands and rocks that cover ore deposits at the mining sites. This upward trend may reflect the fact that the alumina content is smaller in the ores used in the recent decade and more rocks and sands have to be removed at the mining sites.

Process-Related Solid Waste Release from Secondary Metal Production: 57% Reduction

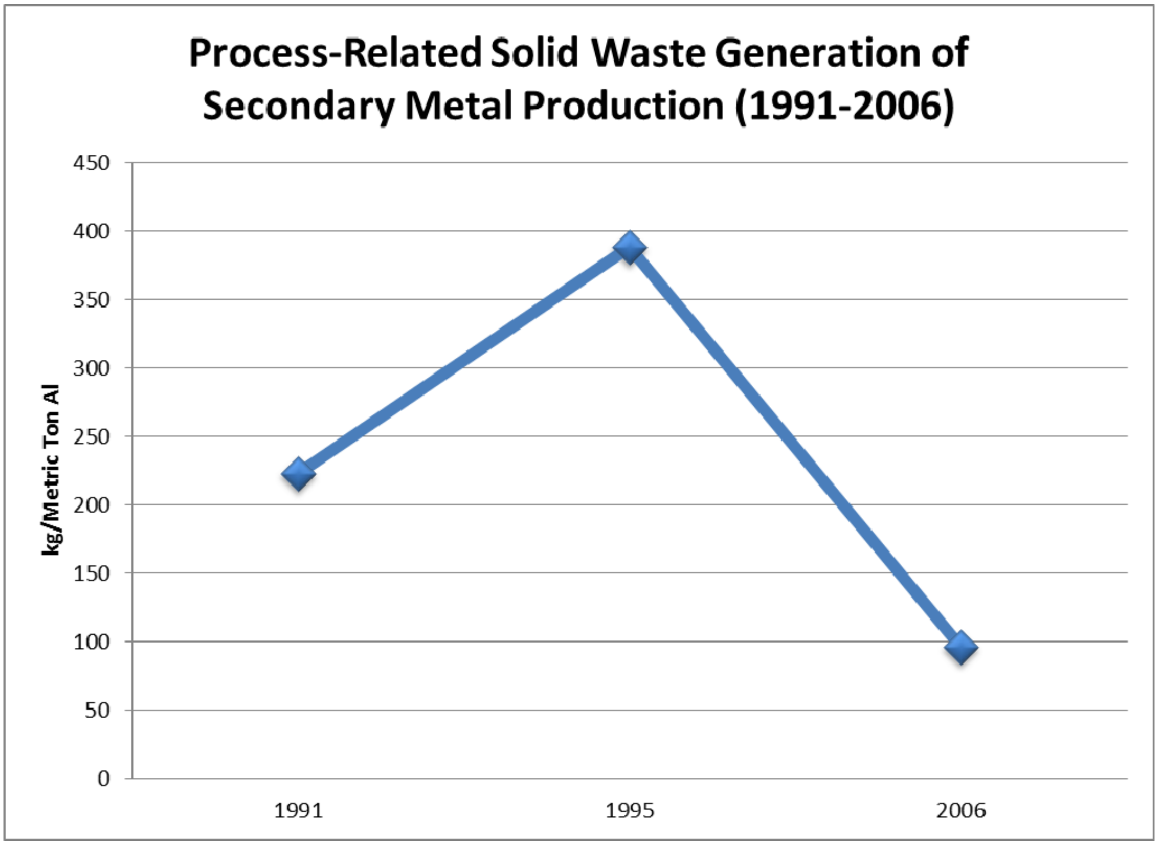

Figure 20: Trend of process related solid waste (including dross that is essentially further recycled) generation caused by secondary aluminum production (1991-2006). Data Source: Alcan, Alcoa, Reynolds, and Roy F. Weston Inc., 1993; The Aluminum Association and Roy F. Weston Inc., 1998; The Aluminum Association and PE Americas, 2010.

Note: Solid waste generation in secondary metal production refers to all recyclable and non-recyclable waste generated during the processes of scrap collection, storage & transportation, processing and melting. The quantity is largely determined by the level of aluminum scrap being separated from other recycled objects, the level of scrap cleanness, and the level of efficiency of melting technologies. The improvement during the studied 15 year period reflects the overall improvement of all three aspects.

Part IV: Sustainable Solutions for Society: Product Use

Materials are made to serve the needs of people in their daily lives. Aluminum is a key material in modern society, integral to the provision of food, shelter, mobility, and entertainment. Aluminum's ability to serve these various functions stems from the unique properties of the metal and its alloys: its high strength-to-weight ratio, durability, excellent heat and electrical conductivity, high corrosion resistance, and great formability, elasticity, and surface reflectivity. Major markets for the metal and its alloys include transportation, building and construction, machinery, consumer durables, packaging, and electrical. In most of these applications, aluminum faces competition from other materials. In other areas, such as overhead electric power transmission and distribution, aircraft and aerospace, and certain packaging applications, aluminum boasts a clear advantage relative to other materials for market share.

> *Strong, cool, light-weight, maintenance free, infinitely recyclable, and no releases of odors or unhealthy substances… That's why people like aluminum. It's everywhere in our life!*

In its use phase, aluminum does not involve energy or resource demands, nor does it release any particular environmental hazard. The metal and most of its alloy forms are very stable and last forever under most natural weather conditions. Maintenance may be required in some cases, but the resource demands and environmental releases are extremely limited compared with alternatives such as steel, plastics and wood. Given aluminum's lightweight properties, the amount of energy required to transport the material during the use phase is significantly lower than competing materials such as steel and copper.

The overall benefits and/or superiority of aluminum and aluminum alloys compared with alternative materials is difficult to quantify given the numerous applications of the material. Nevertheless, there are certain applications for which appropriate data can be collected and reasonable methodology developed to understand and quantify the material's advantages in terms of its potential energy and resource savings as well as the limiting/elimination of environmental releases. The approach employed to collect and evaluate such data is LCA; the results are comprehensive and widely accepted. These assessments are essential to better understand the overall sustainability footprint of aluminum and its ability to help society address difficult sustainability challenges.

The use of aluminum in ground transportation as a downweighting material is one example; the overall energy and greenhouse gas emission savings can be appropriately quantified.

A vehicle downweighting study, jointly sponsored by the Aluminum Association, IAI, and the European Aluminium Association (EAA),[14] found that on average, each kilogram of aluminum used in substitution of mild and high-strength steel and cast iron in passenger cars and light trucks saves 120 – 1,000 MJ of primary energy, or about 0.8 – 6.9 gallons of crude oil, throughout the lifetime of that vehicle. Lifetime greenhouse gas emission avoidance ranges from 8 to 73 kg CO_2 equivalent. Variation of savings is due to variations in total lifetime mileage and driving cycles. In the case of commercial vehicles such as buses, medium and heavy trucks and truck trailers, the lifetime energy savings range from 150 to 1,048 MJ, or 1.0 – 7.2 gallons of crude oil equivalent, and lifetime greenhouse gas emission avoidance ranges from 10 to 76 kg CO_2 equivalent. These findings have been largely supported by the results of other similar independent studies across the world. [15] [16] [17]

As a rule of thumb, each kilogram of aluminum used in substitution of mild and high-strength steel in passenger cars and light trucks helps save more than 2 gallons of fuel consumption and reduces GHG emissions by 22 kilograms of CO_2e throughout the lifetime of the vehicle.

In North America, the average lifetime mileage for passenger cars is approximately 152,000 miles and for light trucks is 180,000 miles.[18] The average lifetime mileage of most commercial vehicles is believed to be well beyond 300,000 miles.

The potential benefits of substitution of aluminum for heavier materials are tremendous. Numerous academic, private, and public-sector studies have demonstrated that the substitution of aluminum for steel can improve vehicle quality, safety and durability. Moreover, these substitutions do not sacrifice safety or longevity of the product. Additionally, the energy and greenhouse gas emission reductions represent a net environmental gain for society and a cost saving to consumers. Other savings—land, natural resources, solid wastes and other environmental releases—also accrue as a result of such substitutions.

108 million barrels of crude oil, or 5 days' worth of total U.S. consumption, is saved each year in North America through the use of lightweight aluminum in vehicles.

It is estimated that the total aluminum use in the current vehicle fleet in the United States and Canada amounts to 32

[14] IAI, EAA and The Aluminum Association. Improving Sustainability in the Transport Sector through Weight Reduction and the Application of Aluminum. 2008. Available online at http://transport.world-aluminium.org/uploads/media/1274789871IAI_EAA_AA_TranspoSustainability_final.pdf.

[15] Alain Dubreuil, et al. A Comparative Life Cycle Assessment of Magnesium Front End Autoparts. SAE 2010 World Congress and Exhibition. 2010.

[16] Audi. Environmental Report 2005 – Interim Review Acting with Responsibility at Audi. 2005.

[17] Christoph Koffler, et al. On the Calculation of Fuel Savings through Lightweight Design in Automotive Life Cycle Assessments. The Intl. Journal of Life Cycle Assessment. Volume 15, Number 1, 128-135. 2009.

[18] Oak Ridge National Laboratory and DOE, Transportation Energy Data Book, 29th Edition, 2010. Available online at http://cta.ornl.gov/data/tedb29/Edition29_Full_Doc.pdf.

million metric tons. Compared with a fleet of steel vehicles, this aluminum use enables an annual net saving of approximately 108 million barrels of crude oil equivalent of energy and an avoidance of 44 million tons of CO_2 equivalent in greenhouse gases emissions. The energy saved and greenhouse gas emissions avoided annually by the application of aluminum in road vehicles offset 87% of the energy required for, and 92% of greenhouse gas emissions associated with, all aluminum production in the region.

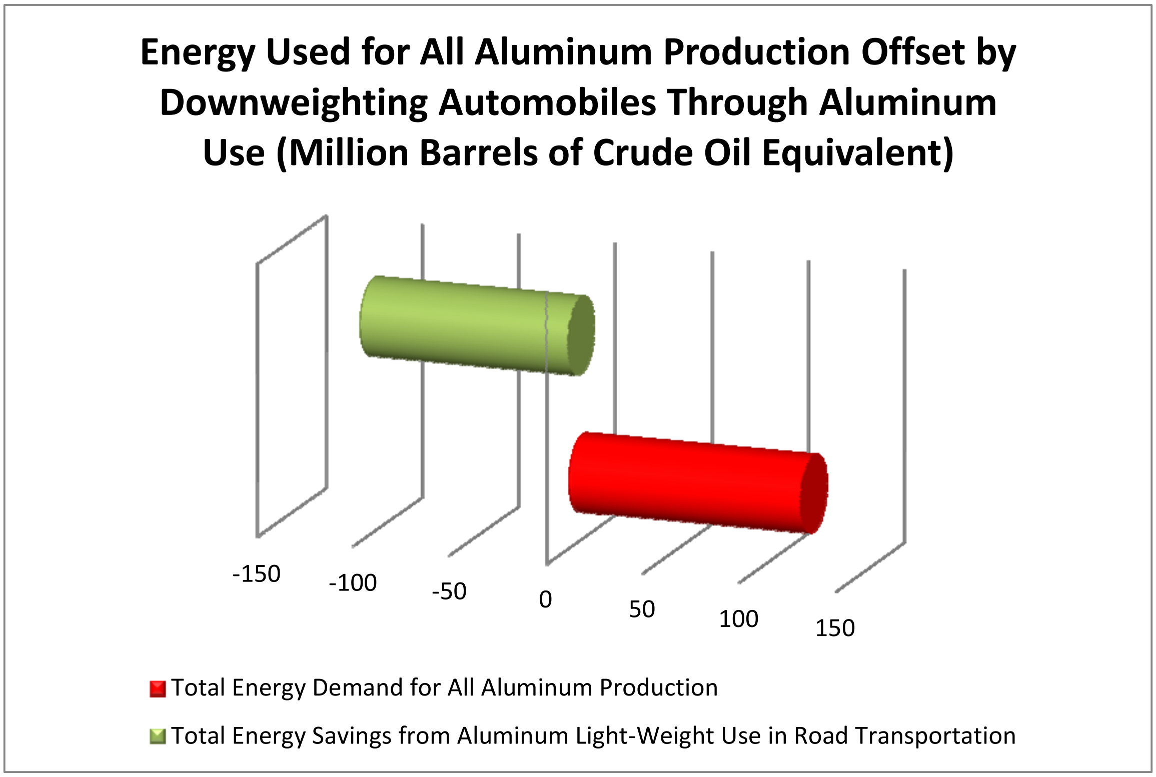

Figure 21: Energy used for all aluminum production in 2009 offset by downweighting automobiles through aluminum use. Data Source: Vehicle Fleet and Vehicle Driving Cycles Data from Oak Ridge National Laboratory, US Department of Energy, US Department of Transportation, and North America Transportation Statistics Database; Material Intensity Data from Ward's Auto, Ducker Worldwide, and The Aluminum Association; Life Cycle Assessment Data from International Aluminium Institute, European Aluminium Association, and The Aluminum Association.

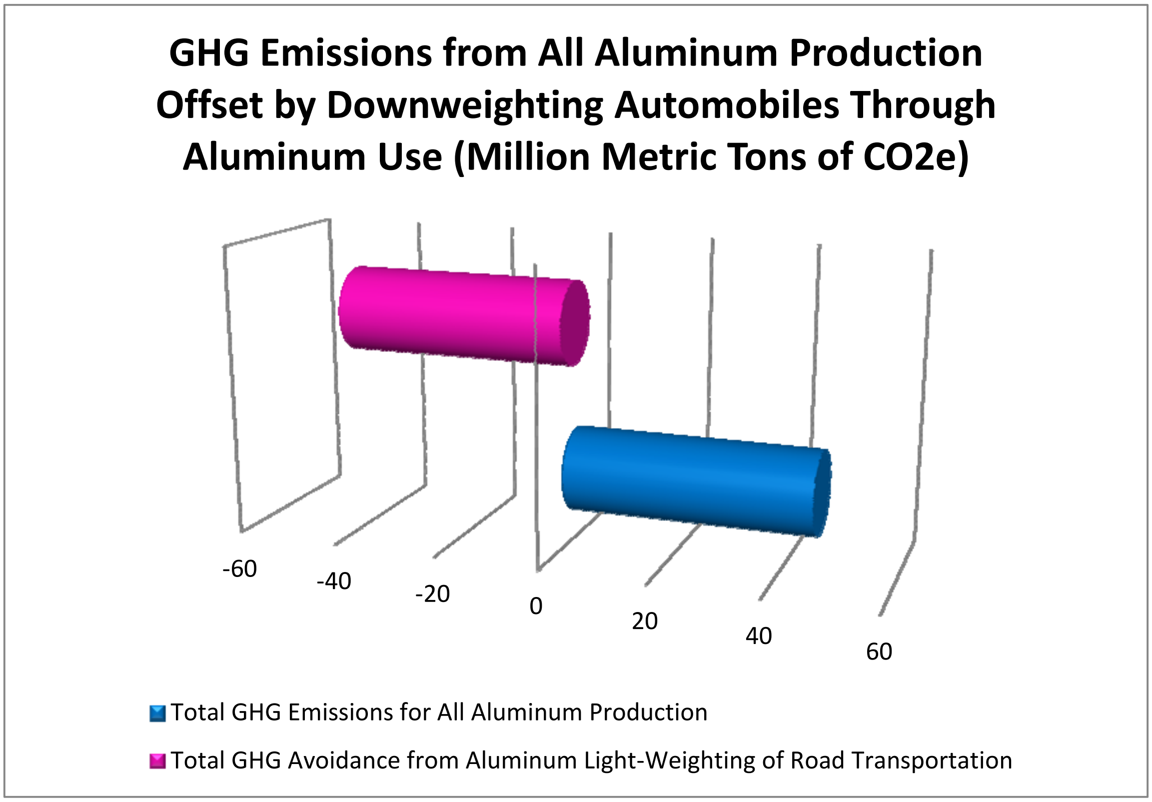

Figure 22: GHG emissions from all aluminum production in 2009 offset by downweighting automobiles through aluminum use. Data Source: Vehicle Fleet and Vehicle Driving Cycles Data from Oak Ridge National Laboratory, US Department of Energy, US Department of Transportation, and North America Transportation Statistics Database; Material Intensity Data from Ward's Auto, Ducker Worldwide, and The Aluminum Association; Life Cycle Assessment Data from International Aluminium Institute, European Aluminium Association, and The Aluminum Association.

Other major aluminum applications also yield net sustainability benefits to society (beyond performing their designated functions)—for example:

- It is estimated that, from a life-cycle perspective, compared to alternative materials (such as plastics and steel), aluminum use in buildings as a systemic solution helps save hundreds of millions of barrels of oil equivalent of energy and reduces greenhouse gas emissions by tens of millions of tons of CO_2 equivalent each year. In addition, it also helps significantly improve people's comfort and reduce health risks pertaining to other materials' use-period toxic releases. These systemic applications include an integrated combination of part or all of the following: roofs, cladding/siding, windows, curtain-walls, facades, natural lighting systems, automated sunshade and screen systems, renewable energy systems (e.g., solar energy devices and micro wind turbines), smart interior decoration systems, and heating, ventilation, and air-conditioning systems.
- Aluminum use in beverage packaging saves space, energy, and costs associated with shipping; shortens cooling times; increases efficient use of refrigerators; and greatly improves the recyclability of the packages.

- Aluminum use in food and pharmaceutical packaging helps prevent damage to merchandise and prolongs the lifetime of the packaged goods, thus allowing them to be shipped to more customers and remain fresh for longer periods. Studies have shown that aluminum packaging can help maintain the most exposure-sensitive nutritional items in food—e.g., vitamins and others—at least 35 days longer than other packaging solutions such as plastics and paper.[19] From a life-cycle point of view, it is estimated that aluminum used for food and pharmaceutical packaging to prevent the packaged content from spoilage alone saves energy up to hundreds of millions of barrels of oil equivalent and reduces greenhouse gas emissions by up to tens of millions of tons of CO_2 equivalent.
- Aluminum use in durable consumer goods such as computers and home appliances significantly improves the recyclability of those products at the end of their useful life, thus saving precious resources and reducing landfill volumes.

Much potential exists for aluminum to replace steel in vehicle bodies to reduce weight. A Ducker Worldwide survey of North American automakers indicates that by 2016 average aluminum application in light vehicles will reach 180 kg, and by 2025 will reach 250 kg. This would translate into a net addition of 9.6 million tons of aluminum to the vehicle fleet by 2016 and 26 million tons by 2025—yielding an additional annual net energy saving of 31 million barrels of crude oil and greenhouse gas (GHG) reductions of 13 million tons of CO2 by 2016, and 86 million barrels of crude oil and 35 million tons of GHGs by 2025.

An aluminum body-in-white (BIW) for a car weighs 150-300 kg (depending on the size of the car) and—through direct and indirect weight savings–reduces weight by 150 to 300 kg over a steel system. If all future light vehicle production in North America used aluminum BIW systems, it would save at least 110 million barrels of crude oil equivalent of energy and avoid at least 45 million tons of CO_2 equivalent of GHG emissions. Substitution of all current light vehicles having steel BIW systems with aluminum systems would help Americans save an additional 132-211 million barrels of crude oil and avoid 54-86 million tons of GHG emissions each year.

Studies have shown the potential for over 1,000 kg, or 14%, of additional weight reduction for heavy commercial vehicles via the use of aluminum. If realized, this would translate to increased load capacity and savings of tens of thousands of gallons of fuel per vehicle over its lifetime.

[19] European Aluminium Foil Association (EAFA). A Global Moment with Alufoil. 2011.

- Aluminum use in renewable energy facilities such as wind farms and solar power devices helps lower the overall construction and maintenance costs of such facilities and thereby the costs of renewable energy for consumers.

Understanding and quantifying the net sustainability benefits of aluminum use will remain a constant challenge for the industry. However, the industry is committed to developing this data and communicating it to consumers to assist them in making informed purchasing decisions.

See *Part VIII: Case Studies* on page 57 for examples of aluminum's life-cycle performance in specific product applications.

Part V: Aluminum for Future Generations: Recycling

In North America, approximately 5 million tons of aluminum is recycled each year (including net exported scrap)—more than 3 million tons of it from post-consumer material.

Scientific evidence and rational economic theories have repeatedly shown that recycling is the most critical and efficient pathway to sustainable human development. Recycling an aluminum product at the end of its useful life will generate a piece of metal with exactly the same properties as the metal used to manufacture the recycled product. Once the new product reaches the end of its useful life, the same process can be performed again and again. In the recycling process, almost all of the quantity of the material is preserved. This process can be repeated almost infinitely; in metal materials, the atomic structure allows for repeated liquefaction and solidification through heating and cooling.

Aluminum recycling saves huge economic and environmental costs compared with the creation of virgin metal. Each ton of aluminum recycled saves one square meter of land use and 24 barrels of crude oil equivalent of energy. It saves more than 15 tons of fresh or sea water use, eliminates more than 9 tons of CO_2 equivalent of greenhouse gas emissions, and avoids 2.5 tons of solid waste and hundreds of kilograms of other air and water-borne emissions and effluents. The benefits of aluminum recycling are obvious from the math alone.

Recycling is a core business operation of the aluminum industry. In North America, the industry recycles approximately 5 million tons of aluminum each year, of which about 3 million tons is melted and cast domestically and about 2 million tons is exported in the form of aluminum scrap and ultimately melted and cast in other countries and regions. This level of recycling almost completely offsets the industry's primary production in the region (*see Figure 23 on next page*).

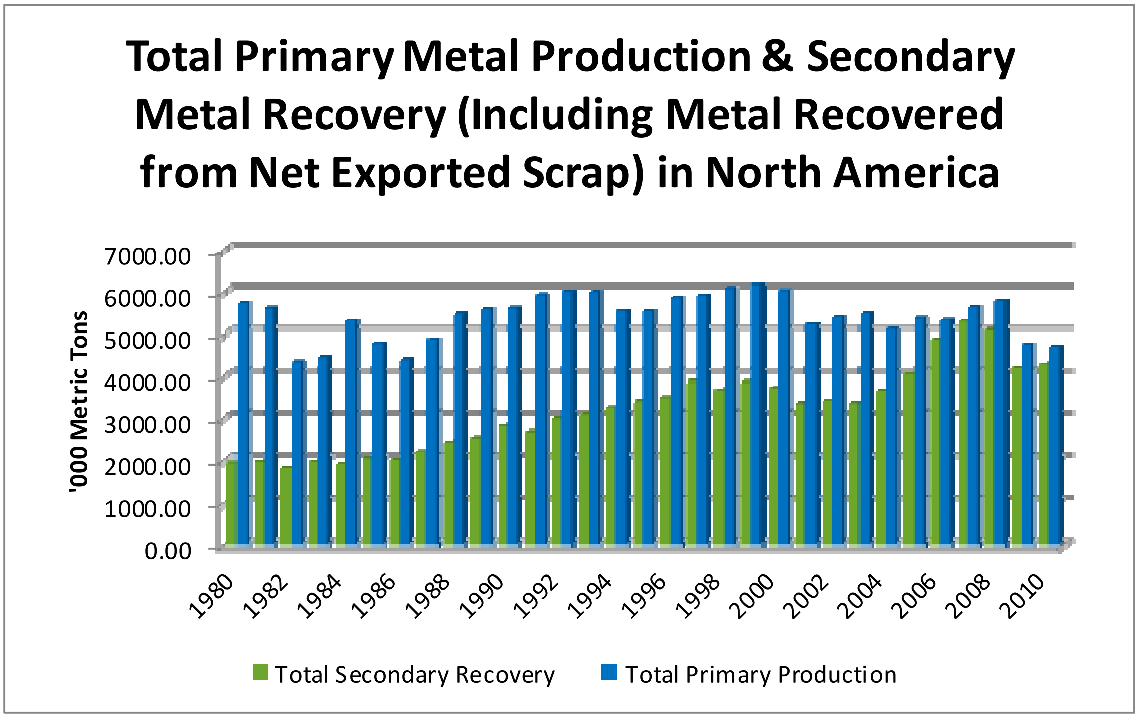

Figure 23: Primary metal production and secondary metal recovery from new and old scrap in North America, including metal recovered from net exported scrap.
Data Source: US Geological Survey, Institute of Scrap Recycling Industries and The Aluminum Association.
Note: Metal recovery from scrap is calculated by the total amount of scrap collected, subtracting non-aluminum alloy substances and contaminations contained in the scrap and the possible melting losses in melting furnaces. In aluminum industry statistics, the amount of scrap collected in a given year does not include the so called run-around scrap, which refers to pre-consumer scrap generated in most large semi-fabrication facilities and subsequently remelted in the same facility.

It is estimated that about 3 million of the 5 million tons of recycled aluminum is post-consumer scrap *(see Figure 24 on next page)*. This scale of post-consumer recycling has massive economic and environmental implications. It provides hundreds of thousands of stable employment opportunities and billions of dollars in annual revenue, and prevents the following economic and environmental consequences, annually:

- A total of 70 million barrels of crude oil equivalent of energy is saved—enough oil to feed U.S. consumption for 3 days, or nearly one day of the world's oil supply;
- A total of 2.4 million square meters of land is saved, the size of the City of London (Note: City of London refers to the city center of London);
- More than 45 million tons of fresh and sea water use is avoided—enough water to provide for the needs of New York City's 8 million people for 10 days;
- Approximately 7.5 million tons of solid waste is avoided;
- 27 million tons of CO_2 equivalent of greenhouse gas emissions is avoided, equivalent to eliminating five large (1,000 MW) coal-fired power plants.

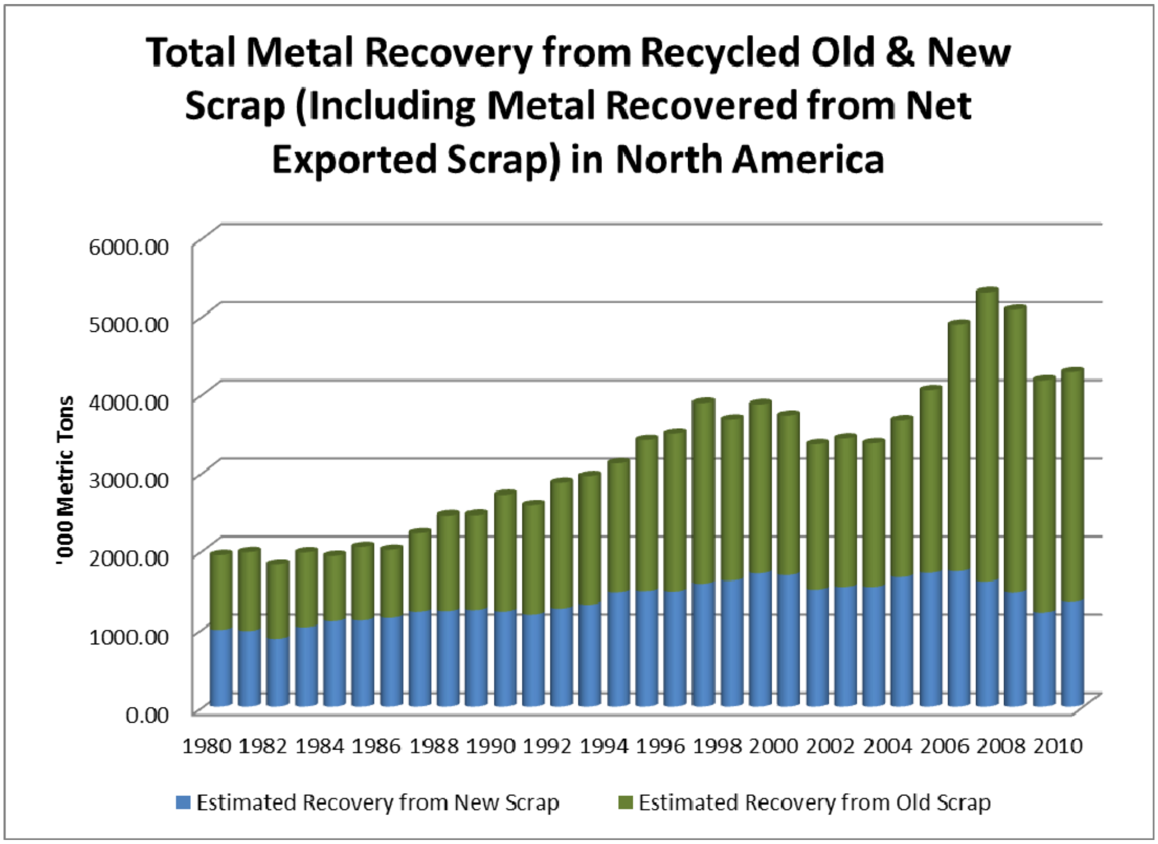

Figure 24: Aluminum recovery from old and new scrap in North America, including metal recovered from net exported scrap.
Data Source: US Geological Survey, Institute of Scrap Recycling Industries and The Aluminum Association.
Note: The shares of metal recovery from old and new scrap is estimated through a bottom-up mass flow analysis at the semi-fabrication and fabrication stages, by The Aluminum Association. The results are slightly different from the past USGS and The Aluminum Association publications. The approach used here is more reflective to the reality.

An estimated one million tons of aluminum is lost to landfilling each year in North America. The loss is comprised mostly of small pieces contained in consumer products such as packaging and tiny electronic devices.

While large-item applications such as those in transportation, building and construction, electric power, and larger consumer durables typically are recycled at rates of 80% - 95% at the end of useful lives, rates for small consumer items are comparatively much lower. Beverage can recycling in the United States has hovered between 50% and 60% in recent years. Aluminum foil used in food, beverage, and medicine packaging has largely not been recycled due to public health and safety regulations and a variety of other issues.

Helping to offset the environmental footprints associated with these lesser-recycled products, individual manufacturers have increased the recycled content of their products. For example, the average recycled content of aluminum beverage cans sold in the United

Sates in 2007 was 68%, and 100% recycled aluminum foil can now be purchased in the market.

The million tons of aluminum scrap lost annually represents a sizable economic and environmental loss to the region—and an unnecessary one. Relatively little attention has been paid by the general public, policy makers, and the business community to fixing the problem. The aluminum industry alone cannot mandate recycling, because without appropriate regulations or economic incentives to recycle in place, once the product is in the hands of the consumer, he/she has the right to through away the item. Maximizing the recycling of an extremely valuable material like aluminum at the end of its useful life merely requires policy makers to include economic and environmental variables in their political calculations.

The industry's view of the sustainability of its material is that each piece of the metal ever made should be used, recycled, and reused for multiple generations and none should be landfilled or permanently destroyed. The implications of this vision for the permanent existence of the material are tremendous for our society. If achieved, the carrying capacity of the planet will increase tremendously—and the outlook for all humanity will brighten. Increasing recycling is absolutely essential for the aluminum industry to achieve its sustainability goals.

Part VI: Aluminum Stewardship

The complexity of the life-cycle of aluminum, and the varied nature of the industry itself, make it difficult to conduct a thorough sustainability performance assessment based on a scientifically designed assessment system. Instead, the concentration has been on developing a simplified stewardship management system to emphasize the industry's key concerns and commitment to a sustainable development pathway.

The stewardship management system looks at two distinctive aspects: corporate stewardship and product stewardship. Corporate stewardship concerns the structure of operations of individual firms and the level of commitment that companies devote in their day-to-day business practices. Product stewardship focuses on the life-cycle footprint of aluminum products and emphasizes consistent improvements in production processes and overall "environmental footprint neutralization."

VI.1. Corporate and Product Stewardship

Corporate stewardship encompasses many business management and operation areas, ranging from environmental management systems; energy and climate to product responsibility. Corporate stewardship programs enable product stewardship improvements. These improvements are reflected in two indicators. The first indicator measures constant improvement over time in the production and manufacturing processes, in terms of material utilization efficiency, primary energy consumption, greenhouse gas emissions, and solid waste release A summary of the improvements is listed again in the following table.

Products	Indicators	% Improvement
Primary metal	Material utilization efficiency	Flat
	Primary energy demand	17%
	Cumulative greenhouse gas emissions	42%
	Solid waste release	-18%
Secondary metal	Material utilization efficiency	1.7%
	Primary energy demand	58%
	Cumulative greenhouse gas emissions	65%
	Solid waste release	57%

Notes: Information on semi-fabrication indicators is currently not available due to the fact that most historical LCA studies were concentrated on specific final products rather than general semi-fabricated products. A baseline for comparison is therefore yet to be established. It is expected that the next sustainability report will track the performances of semi-fabrications.

Solid waste release related to primary metal production processes is largely determined by the alumina content in bauxite ores and the depth of sands and rocks that cover ore deposits at the mining sites. The upward trend of solid waste release here may reflect the fact that the alumina content is smaller in the ores used in the recent decade and more rocks and sands have to be removed at the mining sites.

The second indicator evaluates the “environmental footprint neutralization” of products during their life-cycle. Environmental footprint neutralization refers to the offsetting of *net* “costs” or burdens of one activity by the net benefits or gains of another activity, through either routine or intentional means. Examples of such neutralization include logging companies planting trees; fossil fuel-fired power generators building renewable energy generation capacity; greenhouse gas emitters involved in reforestation activities; and natural resource extraction companies in the recycling business. In environmental footprint neutralization, net “costs” or “benefits” are evaluated based on a life-cycle approach to prevent environmental burdens from spilling from one place or one time to another. The level/scale of neutralization is calculated based on largely understood and quantifiable information. Cost or benefit calculations are based either on prevailing alternative solutions, or on the impact of no action.

In evaluating aluminum industry’s environmental footprint neutralization in North America, we focused on the thoroughly understood and representative environmental categories: energy consumption and greenhouse gas emissions. We further examined the net benefits of aluminum applications in road vehicles as compared to the alternative steel solution to find the level of neutralization against the net burdens of all aluminum production in the region in terms of a specific time period. As elaborated upon in previous chapters, all data used in the assessment are derived from industry life-cycle assessment studies and published data and statistics.

Indicators	**Level of Neutralization**
Neutralization of Energy Consumption in All Aluminum Production via Energy Savings through Aluminum Use in Road Vehicle Downweighting (in 2009)	87%
Neutralization of Cumulative GHG Emissions in All Aluminum Production via GHG Avoidance through Aluminum Use in Road Vehicle Downweighting (in 2009)	92%

It is worth noting again that other aluminum applications create similar net sustainability benefits, aside from performing their designated function, when compared with alternative material solutions. For instance, the net energy and greenhouse gas savings of systemic aluminum building solutions and aluminum food and pharmaceutical packaging applications are estimated in the same range as the benefits of road transportation applications. However, detailed research, data and information collection, and longer-term assessment are needed to reach precise conclusions.

Part VII: Sustainability Looking Forward: Challenges and Opportunities

As seen in previous sections, owing to its durability, light weight, and recyclability, aluminum's life-cycle performance makes it a material uniquely suited to society's sustainability challenge. The more aluminum is recycled, the greater the benefits to society.

Looking forward, challenges lie ahead that will require producer as well as consumer action to achieve a truly sustainable society. For aluminum producers, the challenge is to continue to make improvements in energy efficiency and environmental releases associated with their upstream operations. Together with end users of aluminum—both product manufacturers and consumers—the industry must also work to increase recycling rates at the end of products' useful life. These efforts will require coordination among the industry, policy makers, manufacturers and the general public.

In addition, the aluminum industry must, and shall, work harder to disseminate its best knowledge and understanding of its metal and products to encourage society to use the material for more extensive and expanded sustainable solutions—to lower the weight of transportation equipment, construct greener buildings, prevent food and beverage spoilage, and develop more sustainable sources of energy such as solar and wind power.

VII.1. Technological Progress

Technology is critical to developing sustainable solutions for modern society. Technological breakthroughs over the past several decades—including better equipment design and optimizing process and operational control—have dramatically improved the energy efficiency of, and reduced the emissions associated with, the aluminum production and fabrication processes. They have also helped make aluminum products stronger and more durable while using less metal.

The aluminum industry continues to work with the Department of Energy to develop more efficient primary aluminum production techniques. One such technology involves the development of a multipolar aluminum electrolysis cell using an inert anode, a wetted cathode, and low-temperature electrolyte. Replacing consumable carbon anodes with inert anodes would dramatically reduce the emission of greenhouse gases associated with the production of primary aluminum and the manufacture of carbon anodes. Use of wetted cathodes would allow for decreased anode-cathode distances, accompanied by reduced cell voltage, temperature, and energy consumption. The combination of these technology improvements has the potential to produce a transformational improvement in aluminum manufacturing efficiency and a similar reduction in emissions and production costs.

VII.2. Energy and Resource Use

Energy and resource use continue to be the top challenges for the industry to manage in the course of producing aluminum to serve society's needs. Aluminum demand will continue to increase for the foreseeable future, and a significant proportion of the supply to meet that demand will come from virgin resources. As aluminum is a material in which energy accounts for as much as 40% of the total cost of primary production, the industry will continue to be challenged by the increasing cost of energy and tighter regulations related to greenhouse gas emissions.

For policy makers considering climate change regulations and legislation, it is essential to understand that aluminum serves more as a solution to greenhouse gas emission than a contributor. Most greenhouse gas emissions associated with aluminum are indirect emissions from other industries—in particular the energy, fuel, and electricity supply sectors. The measure of aluminum's value to sustainable development can be determined only from comprehensive life-cycle analyses that incorporate the savings of energy and reductions of greenhouse gas emissions that result from its application during products' usage and end-of-life phases.

VII.3. Waste Minimization/Elimination

The industry has made significant progress in finding solutions to reduce, re-utilize and/or eliminate most of the wastes involved in mining, anode production, electrolysis, cast house operations, and secondary aluminum production. A remaining challenge is the minimization and elimination of "red mud" that is a solid-waste byproduct of the bauxite refining process. The North American industry looks to global cooperative research, and participation in multilateral programs such as the Asia-Pacific Partnership on Clean Production and Climate, to guide progress towards a solution to this challenge.

VII.4. End-of-Life

The challenge at the end of life for aluminum is the issue of material lost to landfills. Given the tremendous sustainability benefits of aluminum recycling and the infinite recyclability of the metal, every piece of aluminum lost to landfills is a net loss of sustainability to society.

Recycling is theoretically one of the easiest and most cost effective actions that society can undertake to conserve resources, preserve the environment, and provide economic benefits. Ironically, achieving optimal recycling rates can be difficult, especially in developed, advanced economies such as that in North America. This is a reflection of many complex parameters that must be overcome to make real progress on achieving a truly sustainable society.

We need policy makers to understand that there are current policies in place that discourage recycling and those policies need to be removed or mitigated. There are also policies that could be created to encourage further recycling.

VII.4.1. Design for Recycling

Design for the Environment (DfE)—an initiative of the Environmental Protection Agency—aims to encourage product designs that can be easily reused or recycled at the end-of-life. Apple Computers, for one, has embraced this principle. Their engineers, who use aluminum extensively in many of their electronic devices, have taken to creating whole-piece designs. This makes it very easy to disassemble, separate, and recycle at the end-of-life.

The challenge for Design for the Environment is also an informational challenge. Designers require high-quality information to evaluate the overall costs and benefits of alternative choices; this information can be hard to come by. Life-cycle inventory information on materials has long been confined to a small professional circle, and industries have been quite reluctant to disclose it to the general public in a transparent manner. This trend has begun to reverse but it will take many years before a majority of designers have the ability to access, absorb, and utilize high-quality life-cycle data on the materials that underpin their designs.

See *Part VIII: Case Studies* on page 57 for examples of aluminum's life-cycle performance in specific product applications.

VII.4.2. Understanding Recycling

The long lifespan of aluminum, and the numerous stakeholders involved at each stage of its life, make it a challenge to manage life-cycle sustainability issues in an efficient manner. Tracking the fate of a single piece of metal through its often long use time, multiple ownership changes, and the highly changeable end-of-life collection and recycling paths is typically not feasible. To make quantifiable progress in sustainability management, science must work to develop appropriate approaches to understanding the exact level of loss of material during the end-of-life and the cause of that loss.

Scientists have developed a number of methods to understand product recycling, including statistical surveys and systemic modeling. These approaches include consumer sector and subsector-based survey and analysis, product service life analysis, and product/material flow analysis. No single method can achieve complete understanding of common material recycling independently; a combination of different approaches is required. The application of these methodologies is often time-consuming and costly.

Technological and societal developments that permit firms to collect and disclose sustainability-related information also provide potential opportunities for broader future understanding of recycling. Internet-based information is widely available to the public, and increasingly firms are willing to disclose information on how their practices and operations are conducted. Although the technology is not yet fully developed, it is anticipated that, in the future, the application of mobile communication technologies, GPS, and product bar-code reading technologies will enable tracking of the flow path and final fate of a particular product.

VII.5. Aluminum for a Brighter Societal Future

Facing a 21st century of rapidly increasing global population, diminishing natural resources, and a deteriorating environment, the aluminum industry is obliged to do more in guiding society to extend and deepen the utilization of aluminum for sustainable solutions. This is both an obligation and opportunity for the industry.

It is up to the aluminum industry to educate engineers, product designers, and developers on the sustainability of aluminum products and applications, in addition to their functionality. Aerospace engineers, for example, must be educated as to the life-cycle energy-saving and emission-reduction potential of aluminum-lithium alloys as compared to other material solutions—in addition to differences in functional performance. Similarly, both manufacturers and consumers in the renewable energy and consumer electronics industries must be educated as to the net cost savings and societal sustainability gains of aluminum solutions in comparison with other material solutions, particularly plastics.

The sophistication and complexity of today's society demand products that provide *systemic* solutions to people's daily needs, while preserving ecosystems and natural resources, and recycling materials for use by future generations. While aluminum use in buildings can help save energy and improve comfort, maximizing the efficiencies involves integration of aluminum fenestration (windows, facades, curtainwalls), roofs and roof-based natural light devices, siding, renewable energy devices, sunshades and screens, HVAC systems, toxin- and emission-free decorations, etc.

The demand for sustainable solutions has never been more urgent than now. Melding sustainability with functionality is the ultimate challenge and opportunity not only for the aluminum industry but for its competitors as well. Whichever industries best respond to this reality will emerge as the market leaders in the new century. Among the materials industries, aluminum is uniquely positioned to offer both sustainable and functional solutions for society.

VII.6. Role of the Aluminum Association

The central role of the Aluminum Association in the industry's sustainability movement is to develop information and matrices that guide the industry and society to consistently remain on the sustainable development path. To fulfill this critical role, significant capacity development is needed in terms of knowledge, expertise, and resources. The Association traditionally has been underfunded compared to most other material industries in the region. Greater funding is required, and global efforts more closely coordinated, to reflect the reality of aluminum as a global product.

Significant steps have already been taken. The Association has determined that it will concentrate its future efforts in the following areas:

- Regular and streamlined data collection of annual energy and material consumption and environmental emissions and releases from the industry's production facilities in the region;
- Data and information collection on the use phase of major categories of aluminum products in terms of functionality, use pattern, service life, energy and material demand for maintenance, and quantifiable potential overall benefits brought to the society compared to alternative materials;
- Regular and optimized data and information collection on recycling of products in major market sectors;
- Data and information analyses on the life-cycle performances of the material;
- Development and monitoring of a sustainability matrix in the region, including environmental, economic and social aspects;
- Push for appropriate regulation and legislation on recycling; and
- Active communications with stakeholders and the general public.

These actions are not a silver bullet that will lead to the sustainability of a material or the industry. Sustainability itself is a constant movement that requires all members of society to participate; most sustainability efforts do not lead to immediate or dramatic results. Sustainability must be fully incorporated and embedded into people's daily lives, business practices, and community operations. The Association is proud of the industry's past performance and, at the same time, clearly aware of the challenges and opportunities lying ahead of it. The Association has absolute confidence in the industry's and aluminum's future as a sustainable solution for our planet.

Part VIII: Case Studies

VIII.1. Aluminum and Green Building

On average, people spend 90% of their daily lives indoors;[20] but the indoor air quality is often worse than outdoors due to enclosed spaces, confined air flows and transfers, and pollutants emitted from construction and decorative materials. Buildings account for 39% of total primary energy consumption and 72% of total electricity consumption in the United States.[21] Building "green" buildings therefore requires not only the creation of comfortable and healthy living conditions, it also means to help save critical natural resources and reducing emissions and wastes to the environment, further aiding in improving quality of life.

Aluminum serves as a critical construction material for creating green buildings. Unlike most petroleum-, mineral-, and/or renewable resource-based (i.e., organic carbon-based) building materials, aluminum does not release harmful substances or odors, nor does it change colors, shapes, or properties when exposed to weather. It is a nontoxic material suitable for use in both indoor and outdoor building and construction applications. The surface of aluminum can be treated with different kinds of permanent colors, touches and gloss and helps provide variety and beauty to the built environment.

The most prominent characteristic of aluminum as a building material is its ability to provide comprehensive and systemic solutions for buildings' energy efficiency. It allows for controlled and balanced functionalities among heating, cooling, lighting, and ventilation. The metal can be made very strong to serve structural purposes or soft to facilitate the functioning of other objects. It can be made to deliver beneficial natural daylight into an entire room or shade off glare and reflect direct sunshine. It can be made to insulate against heat transfers between inside and the outdoors or give full access for heat and air exchange. Aluminum is also the pre-eminent building material for providing solutions for shapes, structures, and curvatures, enabling architects to design from their imagination with few constraints—yet without compromising safety or functionality.

Smart and systemic solutions are the key to aluminum building applications. The energy performance of aluminum building components or systems is often simulated by computer programs or tools through the virtual functioning of the entire building at the design stage.

Examples of systemic aluminum building energy efficiency solutions include:

[20] U.S. Environmental Protection Agency, Healthy Buildings, Healthy People: A Vision for the 21st Century, 2001. Available online at http://www.epa.gov/iaq/pdfs/hbhp_report.pdf.

[21] U.S. Department of Energy, 2009 Building Energy Data Book, 2009. Available online at http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2009_BEDB_Updated.pdf.

- Cool roofs and insulated cladding/siding systems—prevent urban heat island effect and improve indoor energy performance;
- Thermally insulated and intelligence enabled windows, skylights, and sunshades and screens—optimize energy performance in all seasons and all weather conditions;
- Structural supportive curtain walls, façades, daylight rooms and natural air devices – balance thermal comfortableness, natural lighting and fresh air, ultimately saving energy;
- Automated heating, cooling and ventilation systems—light-weight thermal and indoor air management solutions;
- Renewable energy systems—the ultimate energy neutralization solutions.

Once built or installed, aluminum serves its designated function for decades or even centuries. In comparison, petroleum-based materials like vinyl have a shorter service life because polymer molecules change their structure and properties under repeated heating and cooling when exposed to the natural environment. Similarly, steel rusts and wood rots under normal weather and environmental conditions.

At the end-of-service-life, aluminum can be completely recycled into the same material with the same properties and used in buildings again to serve the same functions for future generations. In reality, more than 90% of aluminum used in buildings is recycled after service, making it one of the most recycled building materials in the world.

On top of energy efficiency performance as a systemic building solution, aluminum also gives great advantages to architects, builders, and building operators in complying with green building standards and codes and in acquiring voluntary green building certifications.

For instance, Leadership in Energy and Environmental Design (LEED) is an internationally recognized green building certification system developed by the US Green Building Council (USGBC). LEED "provides building owners and operators with a framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions".[22] As one of the most prominent basic building materials, aluminum significantly helps contribute to LEED scores in many aspects, from Sustainable Sites to Energy & Atmosphere to Innovation in Design. The following list gives a brief overview of aluminum products' possible contributions to LEED scores.

- SS Credit 7.2: Heat Island Effect—Roof: 1 Point
- EA Credit 1: Optimize Energy Performance: 1-19 Points
- EA Credit 2: On-site Renewable Energy: 1-7 Points
- MR Credit 4: Recycled Content: 1-2 Points
- IEQ Credit 2: Increased Ventilation: 1 Point
- IEQ Credit 7.1: Thermal Comfort—Design: 1 Point

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[22] USGBC, online at http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1988.

- IEQ Credit 7.2: Thermal Comfort—Verification: 1 point
- IEQ Credit 8.1: Daylight and Views—Daylight: 1 Point
- IEQ Credit 8.2: Daylight and Views—Views: 1 Point
- ID Credit 1: Innovation in Design: 1-5 Points

Many similar green building certification and standard/code systems exist across the world. In all such cases in which builders or building operators make efforts to certify their buildings or comply with standards and codes, aluminum makes similar contributions.

VIII.2. The All-Aluminum Body of Audi Cars

The earliest automotive aluminum applications in widespread use were engine components and wheels. Gradually, aluminum use has extended to other individual components such as interior decorations, bumper beams, brake components, etc. More recently aluminum has been adopted for use in body-in-white, chassis, suspension, and front-end systems. One example of the latter is the Audi Space Frame (ASF) system.

Figure 25: The all-aluminum Audi Space Frame (ASF) system, for illustration purpose only, courtesy of Audiusa.com.

In 1994, Audi rolled out the all-aluminum ASF body system for its flagship model A8 in order to "reverse the spiraling trend for increased weight in the luxury sector." The system comprised an aluminum space frame structure and body panels for the entire body-in-white of the car. It was manufactured with extruded, die-cast, and flat rolled high-strength aluminum and weighed 40% less than a conventional steel body. The ASF system also indirectly reduced the weight of the vehicle through "reduced chassis and surrounding area," a lighter-weight fuel tank, and lower aerodynamic resistance. The ASF is an engineering innovation that enables Audi to achieve dramatic vehicle weight reduction and, at the same time, a safer vehicle that is easier to handle and more comfortable. In Audi's words, the ASF has "remarkable rigidity, which envelops passengers like a protective shell to provide best-in-class safety with a lower weight."[23] The ASF's "stiffness helps enhance handling by enabling the car to be more responsive, more precise and more stable. Another benefit of the extensive use of aluminum is its ability to absorb vibration, creating a smoother, quieter ride."[24]

The A8's first-generation ASF aluminum body weighed 273 kg, compared to 478 kg for the steel body of a similar-sized car. The point at which the increased energy required to produce the aluminum body is offset by the fuel savings generated by the lower weight of the car during its use phase is after 90,000 kilometers (56,000 miles) of driving, according to Audi's life-cycle study.[25] Following that point, fuel savings and emission reductions accrue as the Audi is driven. The second-generation ASF used in the A8 weighed only 239 kg. Today, the newest Audi A8 aluminum ASF system weighs just 220 kg. This represents a 20% weight reduction compared to the first generation.[26]

An all-aluminum body is not necessarily the sole right of luxury cars. Audi has shown the world that aluminum can be economically used to produce lighter and safer mass-production vehicles. In 1999, Audi rolled out the first ASF all-aluminum-bodied mass-production car, the A2. The A2 was a full-size family passenger car that used the ASF aluminum BIW technology and converted other components from iron and steel into aluminum, including the engine and wheels. These components are standard features on many passenger cars today. The A2 aluminum body weighed just 156 kg, 43% less than a comparable steel body. The entire weight of the A2 1.2 TDI model was only 855 kg and achieved a 3-liter-per-100 km, or 78-mile-per-gallon, diesel fuel consumption performance.[27]

The newest showcase application of the ASF is the Audi A8L Security, launched earlier this year. This highly armored security sedan is designed to be "capable of withstanding an attack with military hand grenade."[28] The application of an aluminum-based body for this car refutes any notion that an aluminum vehicle compromises safety. The armored

[23] Audi, Environmental Report 2005 – Interim Review Acting with Responsibility at Audi, 2005. Available online at http://www.audiusa.com/us/brand/en/exp/commitment/environmental/environmental_protection_at_audi.html#source=http://www.audiusa.com/us/brand/en/exp/commitment/environmental/environmental_protection_at_audi.html&container=page.
[24] Audi, Explore the Audi A8. Available online at http://www.audiusa.com/us/brand/en/models/a8/explore/a8_asf.html.
[25] Audi, Environmental Report 2005 – Interim Review Acting with Responsibility at Audi, 2005. Available online at http://www.audiusa.com/us/brand/en/exp/commitment/environmental/environmental_protection_at_audi.html#source=http://www.audiusa.com/us/brand/en/exp/commitment/environmental/environmental_protection_at_audi.html&container=page.
[26] Audi, Efficiency Lexicon, Audi Space Frame. Available online at http://www.audi-journals.com/press/en/main.html.
[27] Audi, Historical Background on Use of Aluminum at Audi, 2002. Available online at http://www.audiworld.com/news/02/aluminum/content1.shtml.
[28] Audi, High Security Version Audi A8 Soon to Be Launched, 2011. Available online at http://www.audiusa.com/us/brand/en/models/a8/learn/news_reviews.detail.2011~02~high-security_version.html.

floor is made of a special aluminum alloy to "protect against explosive weapons." Passing some of the strictest crash and ballistic protection performance testing, the A8L Security speaks to the safety of aluminum-bodied cars.

Audi's experience in successfully building safe, highly performing aluminum vehicles highlights the material's superb potential as a solution to reduce vehicle weight while improving fuel efficiency, safety, riding comfort, and affordability. Building passenger cars from aluminum allows consumers to account for not only driving and safety performance when making a purchasing decision—but for energy-efficiency and environmental performance as well.

If all passenger vehicles in the United States and Canada were to be built with aluminum BIWs, it would require at least an additional 40 million tons of aluminum and would save 132-211 million barrels of crude oil and 54-86 million tons of CO_2 equivalent in GHG emission reductions annually.

VIII.3. The Apple Phenomenon – Design for the Environment with Aluminum

The challenge to sustainability created by the exponentially increased use of electronic devices in our society is tremendous. With computer and mobile communication devices reaching individuals in almost every corner of the planet, enormous amounts of precious non-renewable natural resources such as fossil fuels and minerals have been permanently lost as these devices are landfilled. In the U.S., the largest consumer electronics market, only about 18% of retired electronics are recycled, meaning 82% are disposed of, mainly in landfills.[29] The landfilled electronics waste is the equivalent of 2 million tons of mixed materials, primarily made from non-renewable resources. Some of the resources used to make those materials are extremely rare and environmentally destructive to extract and produce. The majority of that 2 million tons of landfill is plastics and glass. These materials are considered recyclable but, in practice, can be difficult to recycle or reuse and have little value for waste managers and recyclers.

However, this disposable mentality can and is being changed by manufacturers who design their products with DfE in mind. One already doing so is Apple Computers.

Apple, one of the world's leading consumer electronics manufacturers, produces a range of devices, from computers to cell phones to music players. Tens of millions of units are produced and sold each year. Two decades ago, the company developed environmental policies to minimize the environmental impact of its products. Apple's efforts have been concentrated in the design stage of its products—through minimizing or eliminating toxic substances, improving product energy efficiency, and reducing product packaging.

[29] US EPA, Electronics Waste Management in the Untied States, 2008. Available online at http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm.

In 2008, Apple made dramatic progress in its product design: maximizing the use of perfectly recyclable materials in the bulk components of all of its products. The use of unibody aluminum computer and iPad cases was considered revolutionary in the electronics manufacturing world. The impact is obvious: the recycling value of computers and devices has been dramatically increased and has enabled waste managers to easily collect and recycle these materials. This design movement has also enabled Apple to close its product life-cycle loop: all aluminum cases of these devices can be closed-loop recycled into new computer cases, again and again.

Figure 26: The MacBook Air unibody aluminum case, for illustration purposes only, courtesy of Apple.com.

Apple's use of aluminum extends beyond considerations of its recyclability; it is also functional. Aluminum's conductivity helps release heat generated during product use and reduces the need for the separate micro-motor fan system commonly found in most plastic-encased computers. This design element reduces material use in the product manufacturing phase and energy consumption in the product use phase.

The designs of Apple's products are based on actual life-cycle assessment studies. In fact, the life-cycle footprint is an indicator in Apple's environmental management practices. Apple is the first consumer electronics manufacturing company to calculate, disclose and monitor both product life-cycle environmental footprints and corporate environmental footprints, such as energy consumption, greenhouse gas emissions, and use of restricted substances in products.

What's more, Apple's leading status in the industry has created a ripple effect. Philips Electronics has recently announced the introduction of an all-aluminum TV set; a significant proportion of the aluminum used in the Philips TV is recycled aluminum. The product has since won several green product awards.

VIII.4. Assessing Aluminum Beverage Cans from a Life-Cycle Approach

The beverage container is considered an ideal end-use aluminum product on which to perform a full life-cycle assessment (excluding the beverage content itself, the shipments of beverages for wholesale and retail, and the cooling of beverages during consumption) because:

- The product system is relatively independent and few co-products or by-products can be found throughout the life-cycle chain, thus eliminating the necessity and complication of "allocations";
- The production of both materials and final products is relatively concentrated; only a small number of companies are involved in aluminum can sheet production and aluminum can making, thereby enabling full coverage by survey of all parties to obtain directly measured production data and information, including energy and material inputs and environmental releases;
- The lifetime of beverage cans is relatively short and the use phase uncertainty relatively low; and
- The product is a mass-production consumer good manufactured to known standards.

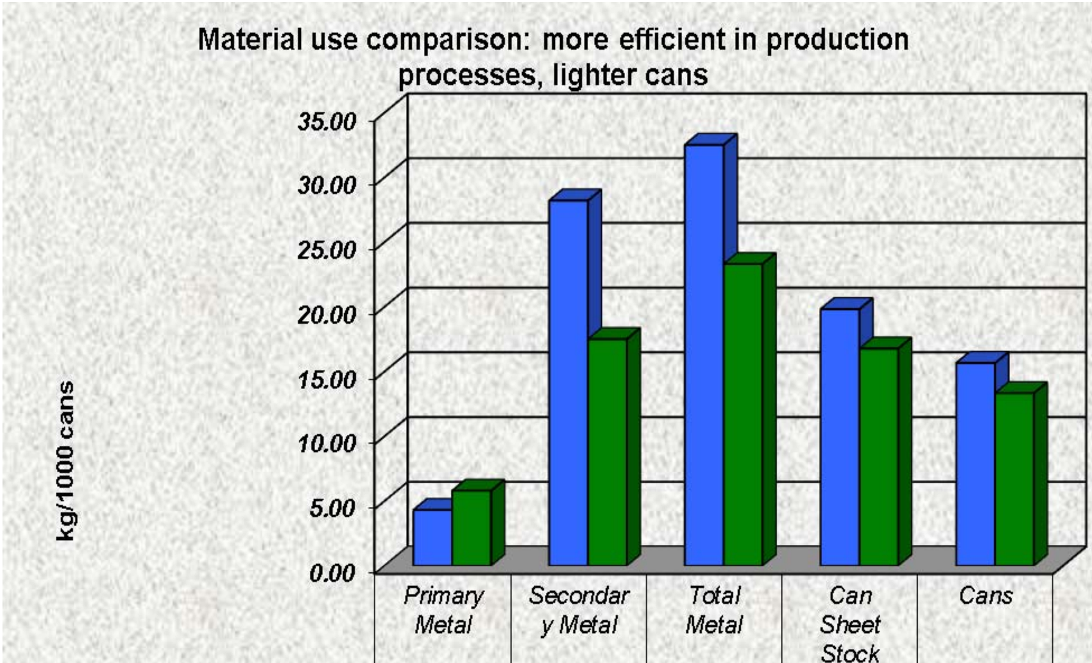
During the past 20 years, the Aluminum Association has sponsored two major LCA studies on beverage cans, and the results of the two studies have enabled a comprehensive evaluation regarding life-cycle performance and trend development over time.

LCA is a quantitative evaluation of a product from its birth to its death or rebirth. Theoretically, it calculates the cumulative energy and resource inputs and environmental outputs of a product over all of its life stages, and subsequently assesses the overall environmental impact that the product has caused.

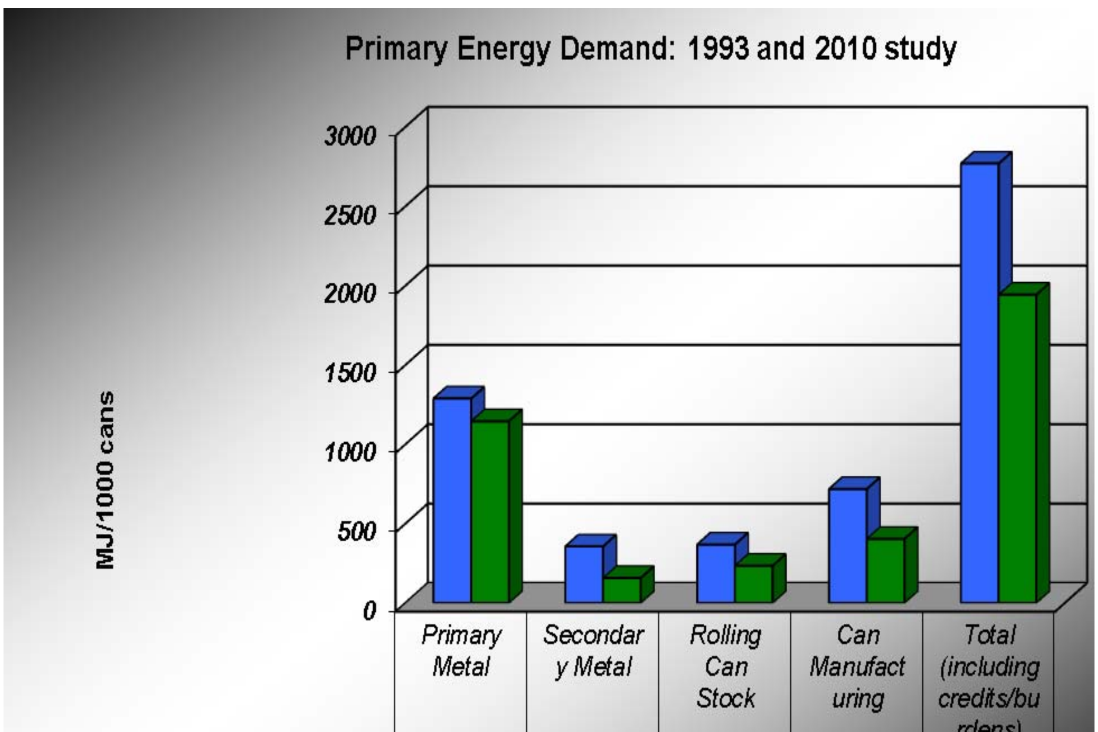
In practice, certain life-cycle stages of a product are excluded from the assessment, given high uncertainty in terms of energy and resource inputs and environmental releases, or negligible significance of the inputs and outputs compared to the rest of the life-cycle stages. The use phrase is generally excluded unless a reasonable level of certainty of consumer practice exists or its use requires a significant quantity of resource use or environmental release.

In the beverage can LCA studies, the use phase had been excluded based on "all else being equal" considerations—meaning that all other beverage containers would contain the same beverage, travel the same distance, and stay on the shelf or in cooling devices for the same length of time.

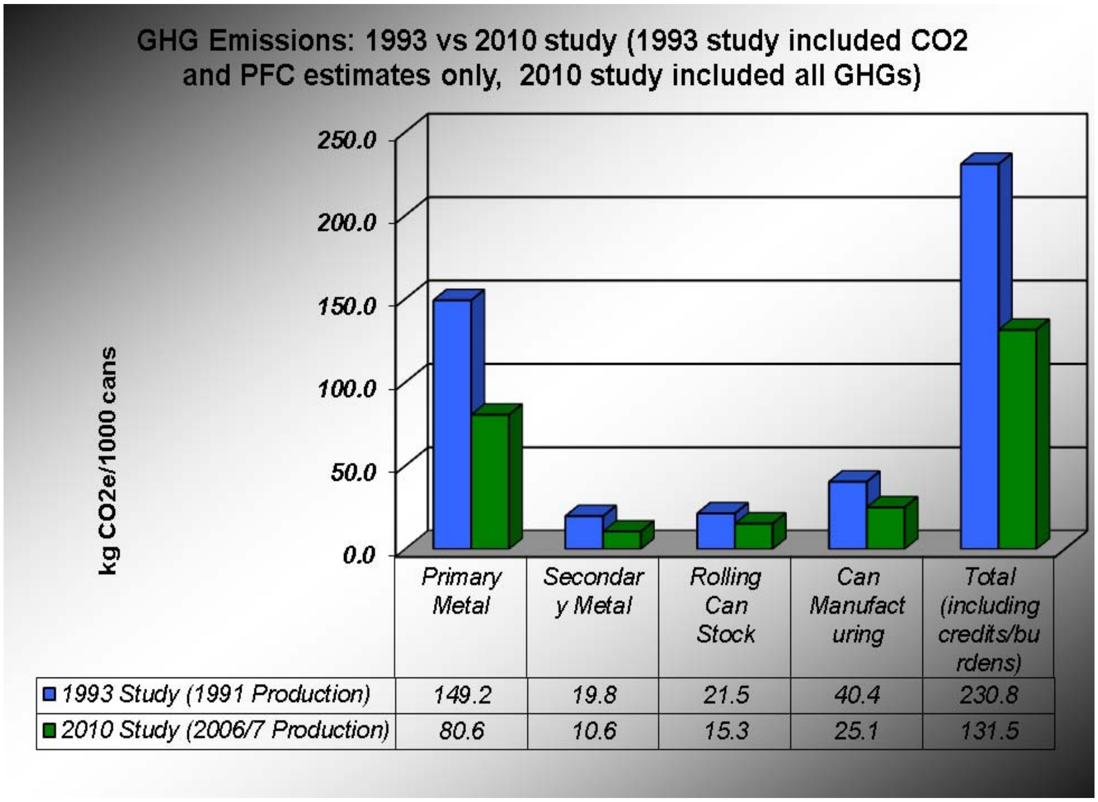
A snapshot of the results of the two past studies follows on the next two pages:



	Primary Metal	Secondary Metal	Total Metal	Can Sheet Stock	Cans
1993 Study (1991 Products)	4.31	28.21	32.52	19.82	15.66
2010 Study (2006/7 Products)	5.8	17.51	23.31	16.78	13.34



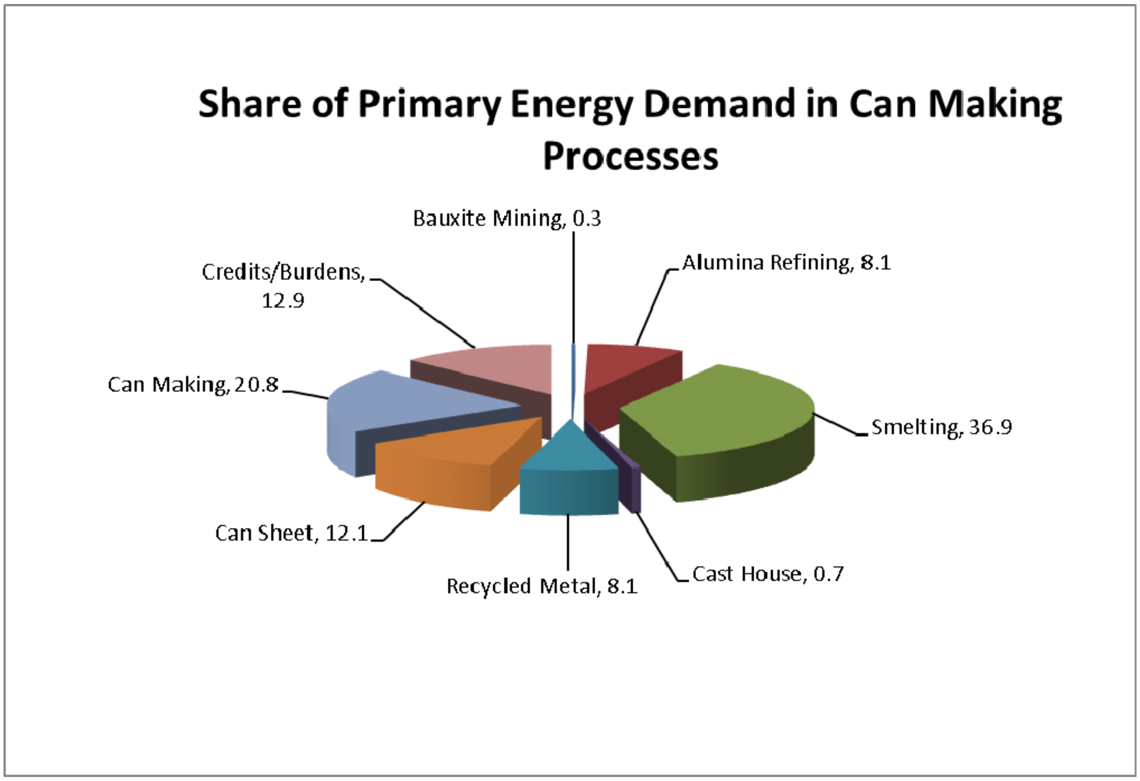
	Primary Metal	Secondary Metal	Rolling Can Stock	Can Manufacturing	Total (including credits/burdens)
1993 Study (1991 Production)	1289	357	369	719	2770
2010 Study (2006/7 Production)	1,146	158	235	404	1,943

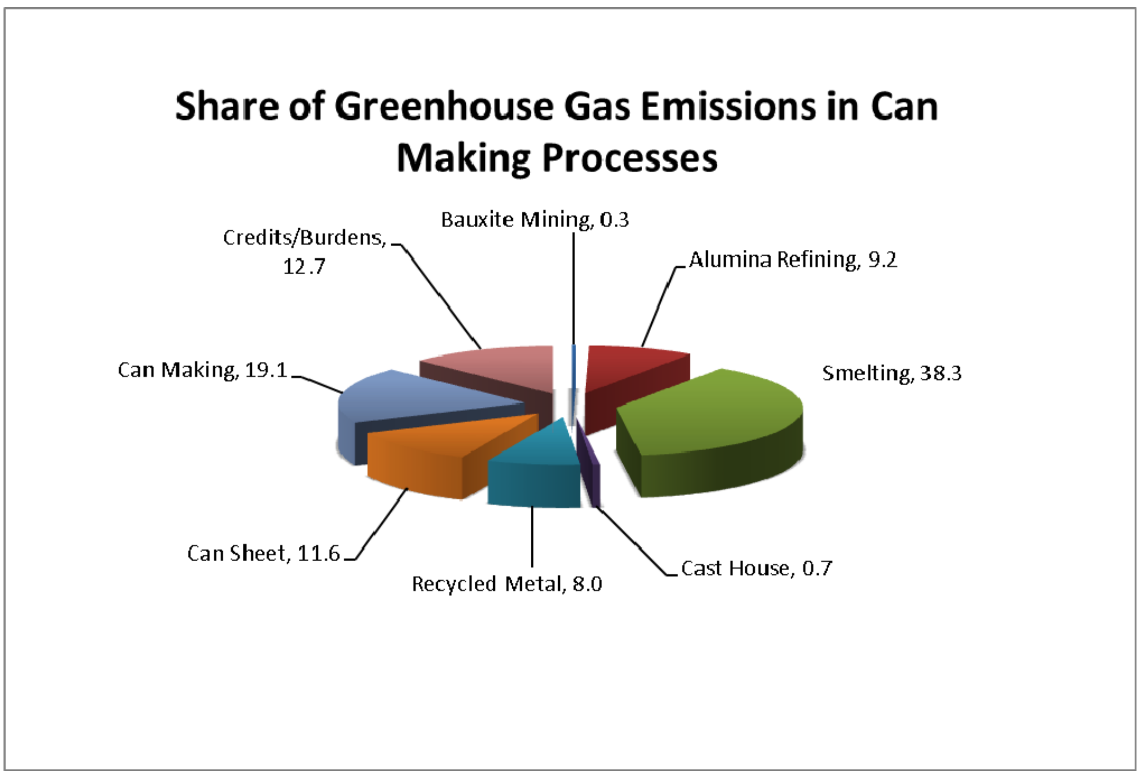


In the two representative categories—primary energy demand and greenhouse gas emissions—significant improvements were recorded during the 15-year period between the two studies. Aluminum cans are indeed becoming "greener." The 2006 cans used 30% less energy in their manufacturing and emitted 43% less greenhouse gases on a per can basis. Similar trends can be found in other areas of the production process related to solid wastes and air emissions.

Part of the improvement is a direct result of product downweighting; less material is used to produce the same size can performing the same function–so overall environmental impact is reduced. Other improvements relate to individual production processes. For instance, producing primary metal was 17% more energy efficient in 2006 than in 1991; producing secondary metal was 58% more energy efficient in 2006 than in 1991.

The studies showed primary aluminum production has a significant influence on the overall environmental footprint of beverage cans; among the various processes of primary aluminum production, smelting accounts for the majority of the footprint (*see charts on next page*.) The source of the heavy environmental load for smelting is the fossil fuels used for power generation by the electric power industry.


Share of Primary Energy Demand in Can Making Processes
Bauxite Mining, 0.3
Alumina Refining, 8.1
Smelting, 36.9
Cast House, 0.7
Recycled Metal, 8.1
Can Sheet, 12.1
Can Making, 20.8
Credits/Burdens, 12.9


Share of Greenhouse Gas Emissions in Can Making Processes
Bauxite Mining, 0.3
Alumina Refining, 9.2
Smelting, 38.3
Cast House, 0.7
Recycled Metal, 8.0
Can Sheet, 11.6
Can Making, 19.1
Credits/Burdens, 12.7

Three major approaches can help reduce the environmental footprint of aluminum cans:

- Efficiency improvements (both energy efficiency and material efficiency) in all production processes;
- Shifting to cleaner energy sources, especially from fossil fuel-fired electric power to hydropower; and
- Increasing end-of-life recycling and using more recycled metal in production.

Among these options, efficiency improvement has limits; the closer that manufacturers approach these limits, the harder it is to make continued progress. Shifting to cleaner energy sources will depend on the availability of these alternative sources, particularly electricity. A manufacturing facility located in a fossil fuel-exclusive electric power grid does not have this option.

Therefore, increasing end-of-life recycling or using more recycled metal in production is the most reasonable and desired approach. The more recent LCA study found that the average aluminum beverage can contains 68% recycled metal (49% post-consumer and 19% post-industrial content), and an end-of-life recycling rate of 52% was achieved. The environmental footprint of beverage cans is estimated as the lowest when compared to plastic and glass bottle alternatives.

Beyond aluminum beverage cans' best-in-class environmental footprint, they boast additional sustainable advantages compared with competing materials, including:

- Their lightweight design saves shipping costs and fuel;
- Their efficient shape reduces space occupancy (during shipment, storage and shelving);
- Cans' impermeability to light, moisture, and oxygen preserves such desirable beverage attributes as nutrition, freshness, scent and flavor;
- Cans' efficient heat conductivity ensures fast chilling and therefore fast rotation of refrigeration spaces; and
- Their greater economic value in the recycling stream, compared with competing beverage packaging materials, makes beverage container recycling comparatively more viable.

Greater challenges face the industry as it becomes more and more efficient in production. A highly sustainable scenario provides society with the unique functions of the product while preserving as much material as possible through recycling in the municipal waste stream. The industry has a near-term goal of achieving a 75% recycling rate; longer term, it seeks 90% and beyond. These goals are lofty but not unobtainable; a number of other countries have comparable rates.

VIII.4.1. Consumer Tip #1: Closed-Loop Recycling

Closed-loop recycling is a technologically feasible concept in which a manufacturing-use-recycling-remanufacturing-reuse cycle can be repeated infinitely. Such cycles save significantly on energy, resource, and environmental releases without sacrificing the functionality of the product.

In both theory and practice, aluminum beverage cans may be produced from a closed-loop recycling process, i.e., making a can from primary metal, collecting it after its service life, and remelting it to make a new can. During this cycle, about 2-5% of the metal is lost in the remelting furnace, and the amount of lost metal is replaced with new primary metal.

With existing technology, this cycle can be repeated infinitely. From a mathematical standpoint, the original piece of metal can serve the beverage packaging need infinitely; in practice, it can do so thousands of times. Only metal packaging like aluminum and tin-plated steel have the capability of being closed-loop recycled repeatedly.

In reality, used beverage cans are a valuable global commodity, and competition sets the market price. Used beverage containers (UBCs) can conceivably be reused in an airplane, a train, a car, a window, a piece of furniture, or a computer. Conversely, beverage can manufacturers can conceivably use aluminum sourced from recycled computer cases, bicycle frames, aluminum cooking pots, or used window frames. This was found to be the case from the LCA studies.

VIII.4.2. Consumer Tip #2: How Recycling Benefits Are Calculated

To calculate the net benefit of aluminum can recycling, all elements of a can's life-cycle must be included. It cannot be limited to aluminum-related energy, resource, and environmental burdens, but must also include such elements as the labor used in creating caustic soda, carbon anodes, various oils and lubricants, and the inks used to paint and print logos and nutrition labels.

Generally, the "costs" of a can composed of primary metal are compared to the "costs" of a can composed of recycled metal. Creating a ton of primary metal from ore requires a total of 155,000 MJ of energy; making a ton of recycled metal from scrap requires only 6,909 MJ, a 95.5% energy savings. Similar savings apply in other categories such as greenhouse gas emissions, resource use, solid waste releases, etc. The level of savings in these other categories is roughly the same: a 95% reduction.

VIII.4.3. Consumer Tip #3: Benefits of Recycling One Aluminum Can

- Energy savings: 1.88 MJ
- Greenhouse gas reductions: 0.134 kg CO^2 equivalent
- Resource savings: >96%
- Other waste and emission reductions: >95%

VIII.4.4. Consumer Tip #4: What Can the Saved Energy Do (When in the Form of Electric Power)?

- Power a 46-inch TV for 3 hours
- Power a desktop computer for 5 hours
- Power a 75-watt-incandescent-light-bulb-lumin-equivalent LED light bulb for 60 hours