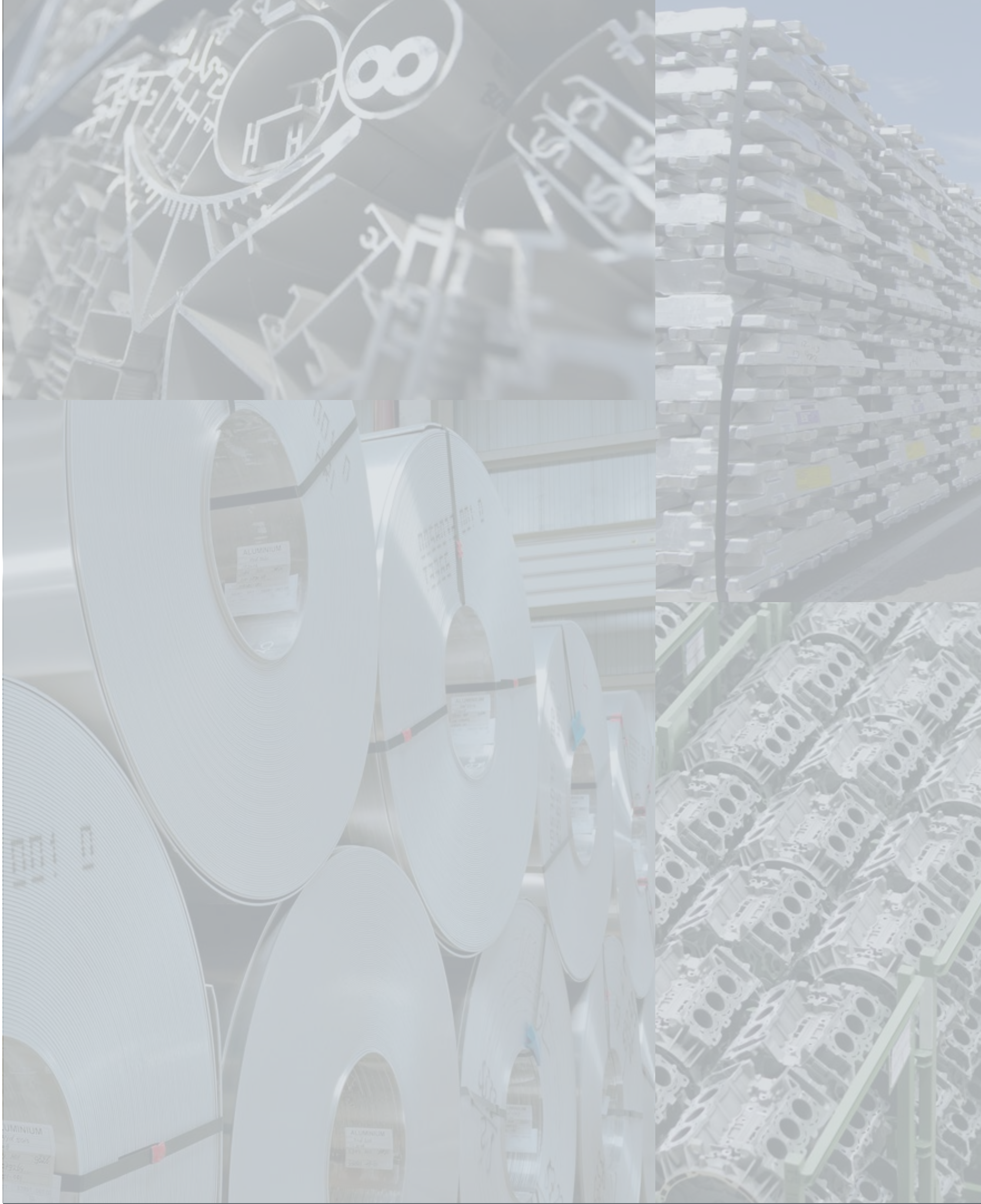

JANUARY 2022

The Environmental Footprint of Semi-Fabricated Aluminum Products in North America

EXECUTIVE SUMMARY

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SUMMARY

This report documents the life cycle inventory and impact assessment (LCI and LCIA) results of 1,000 kilograms (1 metric ton) primary, recycled and semi-fabricated aluminum products manufactured in North America (U.S. and Canada) in the production year of 2016. The study is an update to a previous study published in 2013 to respond to increasing market demand for up-to-date life cycle assessment (LCA) data to help the aluminum industry and its stakeholders, LCA practitioners, academic researchers and other interested parties better understand the potential environmental impact of aluminum products.

A life cycle assessment of a product quantifies all material and energy use, all environmental releases, and the potential environmental impacts over its entire life cycle from raw material acquisition through to ultimate recycling and/or disposal. The functional unit of the study is 1,000 kg aluminum in various forms. The study includes both “cradle-to-gate” and “cradle-to-grave” LCAs. Cradle-to-gate refers to life cycle stages from the extraction of raw materials to the completion of “products” (i.e., ingot, sheet, extrusion, casting, etc.). Cradle-to-grave refers to life cycle stages from the extraction of raw materials to the recycling or disposal of end-of-life (EOL) products. Excluded in the study are final product forming and assembly, as well as the product’s use phase.

To be specific, the “products” (or product systems) of this study include:

- primary aluminum ingot;
- recycled aluminum ingot;
- extruded aluminum including both generic products and products for automotive applications;
- aluminum sheet including non-automotive and non-can sheet, and sheet for automotive applications;
- aluminum foil; and
- die cast products.

Original production data (primary data) of each individual unit process was directly collected either by the Aluminum Association (AA) or the International Aluminium Institute (IAI), from more than 100 production facilities representing a large majority of the industry in Canada and the United States. The methodology used for the goal and scope definition and inventory analysis is consistent with the methodology described in the ISO 14040/14044 Standards. Cradle-to-gate LCA models are developed by using a cut-off method. Meanwhile, cradle-to-grave LCA models are developed by using a net scrap substitution approach, which is a variant of the substitution method. A transparent approach is taken for this study throughout the processes including data collection, modeling, and reporting. Information is disclosed at a maximum level where it is legally permitted. All significant inventories are listed. And a combination of results is provided for users with different purposes.

SUMMARY

The intended use of the study is to:

- Establish an up-to-date life cycle inventory database for semi-fabricated aluminum products in North America. Such a database can assist the aluminum industry and its stakeholders in a variety of LCI data designated applications;
- Improve understanding of the potential environmental implications of product manufacturing, and the overall life cycle burdens and benefits of aluminum products;
- Facilitate assessment of alternative design options (for instance, alternative process design, technology, etc.), compare corresponding datasets (benchmarking), and guide the evaluation of modifications for improvement;
- Provide information for use in strategic planning and sustainable development;
- Develop communication messages such as Carbon Footprint of Products (CFPs), Environmental Product Declarations (EPDs), and industry sustainability reports.

The study is not intended for:

- Use as the sole criteria in raw material or product selection decisions;
- Partially, selectively, or inappropriately being used to claim against the aluminum industry and its products;
- Use as a base for federal, state and/or local level government environmental regulations against the manufacturing activities of the aluminum industry

RESULTS

The results of the study, in terms of "cradle-to-gate" and "cradle-to-grave" potential environmental impacts, are shown in Table 0-1, Table 0-2, Table 0-3, Table 0-4 and Table 0-5. Note that the cradle-to-gate results for semi-fabricated products are based on the weighted average of the actual mix of primary and recycled aluminum feedstock reported by all survey responders for the baseline production year of 2016. The cradle-to-grave results, on the other hand, are based on an assumed EOL recycling rate of 95 percent for each product system. It is a snapshot of potential life cycle impacts of the products when the use phase is excluded and when the indicated EOL recycling rate is achieved. Different assumptions for EOL recycling rates will generate very different cradle-to-grave results. From this perspective, the report also provides additional information to assist users to calculate results under different recycling rates.

Assessment parameter	Unit	Bauxite mining	Alumina refining	Electrolysis	Cast house	Total
Primary energy demand	GJ	0.61	32.87	99.93	1.91	135.32
Global warming potential	kg CO2e	48.49	2801.58	5489.62	115.62	8455.31
Acidification potential	kg SO2e	0.24	10.96	25.54	0.25	36.99
Eutrophication potential	kg Ne	0.01	0.47	0.33	0.01	0.82
Smog formation potential	kg O3e	2.81	184.31	81.35	5.40	273.87

Table 0-1: Cradle-to-gate LCIA results for the production of 1,000 kg of domestic primary aluminum in North America

Inventory parameter	Primary energy demand (GJ)	Global warming potential (kg CO2 eq.)	Acidification potential (kg SO2 eq.)	Eutrophication potential (kg N eq.)	Smog formation potential (kg O3 eq.)
North America	109.88	6865.71	30.03	0.67	222.38
Russia	12.81	639.65	3.43	0.08	38.65
U.A.E.	5.62	423.68	2.11	0.06	33.52
Argentina	2.71	193.28	0.99	0.02	8.27
Venezuela	1.04	73.93	0.38	0.01	3.16
Bahrain	0.48	36.04	0.18	0.01	2.85
Brazil	0.41	29.09	0.15	0.00	1.25
Rest of World	2.75	253.14	1.35	0.04	16.08
Total	**135.69**	**8514.52**	**38.62**	**0.88**	**326.17**

Table 0-2: Cradle-to-gate LCIA results for the consumption mix of 1,000 kg of primary aluminum in North America.

RESULTS

Assessment Parameter	Unit	Scrap Processing, Melting and Casting	Dross & Salt Cake Recycling	Primary Ingot	Total
Primary energy demand	GJ	9.14	0.04	0.00	9.18
Global warming potential	kg CO2e	524.59	2.13	0.00	526.71
Acidification potential	kg SO2e	0.86	0.00	0.00	0.87
Eutrophication potential	kg Ne	0.04	0.00	0.00	0.04
Smog formation potential	kg O3e	15.56	0.08	0.00	15.64

Table 0-3: Cradle-to-gate LCIA results for aluminum recycling, representing 1,000 kg of recovered aluminum from scrap in North America

Assessment Parameter	Extrusion	Sheet	Foil	Die Cast	Automotive Extrusion	Automotive Sheet
Primary energy demand (GJ)	102.38	66.72	78.87	48.76	78.97	126.14
Global warming potential (kg CO2 e.)	6213.22	3978.32	4653.41	2898.98	4739.43	7744.79
Acidification potential (kg SO2 e.)	23.77	13.81	15.39	9.66	17.04	31.68
Eutrophication potential (kg N e.)	0.64	0.39	0.46	0.28	0.49	0.79
Smog formation potential (kg O3 e.)	225.73	140.21	159.59	96.23	169.01	287.04

Table 0-4: Cradle-to-gate LCIA results of semi-fabricated aluminum products, representing 1,000 kg of products

Assessment Parameter	Extrusion	Sheet	Foil	Die Cast	Automotive Extrusion	Automotive Sheet
Primary energy demand (GJ)	46.28	49.79	57.30	29.25	45.93	35.96
Global warming potential (kg CO2 e.)	2667.42	2903.98	3286.18	1666.76	2649.77	2044.85
Acidification potential (kg SO2 e.)	6.99	8.74	8.94	3.82	7.16	4.69
Eutrophication potential (kg N e.)	0.27	0.28	0.32	0.16	0.27	0.19
Smog formation potential (kg O3 e.)	88.04	98.75	106.75	48.38	87.98	65.54

Table 0-5: Cradle-to-grave LCIA results of semi-fabricated aluminum products, representing 1,000 kg of products, assuming a 95 percent EOL recycling rate

CRADLE-TO-GATE

Energy Demand Key Driver of Environmental Footprint

From a cradle-to-gate perspective, most of the environmental footprint of the examined product systems is energy related. The generation of electricity, particularly from fossil fuel fired power plants, contributes the largest share of the total footprint.

The attribution of electricity to the overall footprint is directly related to the use of primary aluminum as a feedstock. Although primary aluminum is only a small share of the raw material input in many of the examined semi-fabricated product systems, it nevertheless accounts for more than 40 percent of the environmental impact for most products (Figure 0-1 and Figure 0-2). The remelting & casting process, which melts scrap and raw metal to produce fabrication ingots, is the next resource and emission intensive process, followed by semi-fabrication such as rolling and extrusion.

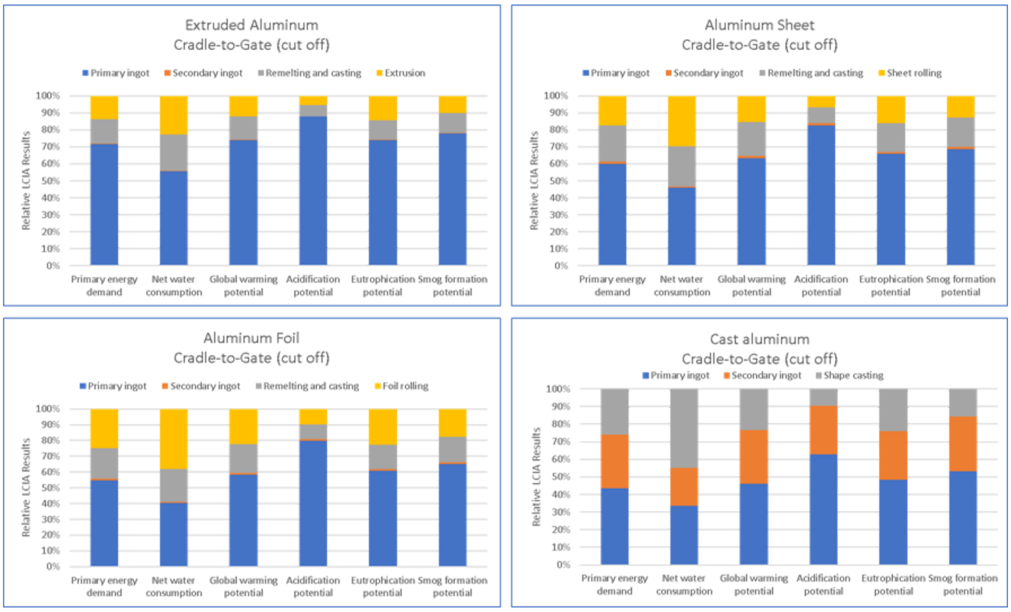

Figure 0-1: Breakdown of cradle-to-gate LCIA Results for extrusion, sheet, foil and die cast aluminum

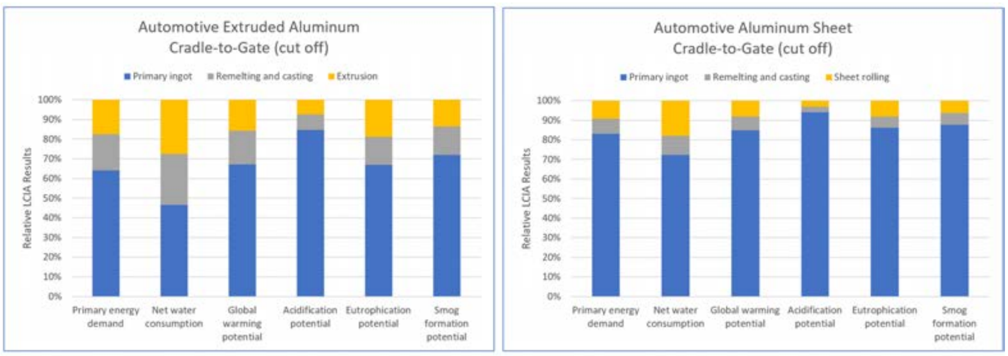

Figure 0-2: Breakdown of cradle-to-gate LCIA Results for automotive extrusion and sheet

CRADLE-TO-GATE

Recycled Metal Reduces Footprint

Given the significant influence of primary aluminum on the cradle-to-gate footprint, one way to address it is to reduce the use of primary aluminum and increase the use of recycled metal. As shown in Figure 0-3, a one percent increase in primary aluminum will increase the cradle-to-gate carbon footprint by as much as 117 kg CO2e for 1,000 kg of products. This is equal to say that a one percent increase in the use of recycled aluminum in the products will lead to a reduction of carbon footprint by the same amount.

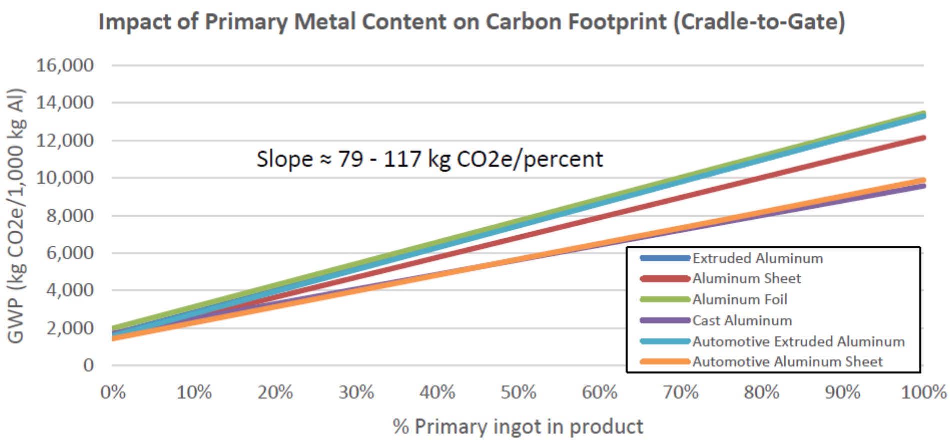

Figure 0-3: The impact of primary and recycled metal use on cradle-to-gate carbon footprint of semi-fab aluminum products.

However, the ability for manufacturers to increase the use of recycled aluminum is constrained by both resource availability and certain technical hurdles. Aluminum scrap as a resource is limited by its availability since most scrap is from post-consumer products. Most aluminum products have a very long lifetime in use, particularly those in buildings, infrastructure facilities, transportation equipment and vehicles, and durable goods. Scrap can only be made available when a product is taken out of service and gets collected and recycled.

In addition to availability, scrap is often “contaminated” when it is collected and recycled in a mixed-material and mixed-alloy environment. In order for aluminum scrap to be effectively used to make a new product, the contamination must be removed by sorting, segregation and cleaning. Current infrastructure in the recycling system is not good enough to efficiently and effectively segregate different materials and sort different alloys. These technical hurdles need to be solved to achieve a true closed-loop recycling system for aluminum and other metal materials.

CRADLE-TO-GATE

Not All Primary Aluminum Is Created Equal

Another way to achieve environmental impact reduction for manufacturers is to source cleaner primary aluminum. Figure 0-4 shows the effects of primary aluminum sourcing on carbon footprint (cradle-to-gate), assuming the same level of primary and recycled metal contents in the products. The regions and countries included in the sourcing analysis are:

- RNA represents the weighted average of the primary aluminum consumption mix in North America, which is the baseline case;
- CA represents Canada where primary aluminum is exclusively smelted with hydropower electricity;
- CN represents China where primary aluminum is mainly smelted with coal-fired electricity;
- RME represents the Middle East where primary aluminum is mainly smelted with natural gas fired electricity.

The scale of difference is dependent both on impact category (e.g., PED, GWP, etc.) and on how much primary/recycled aluminum content is in the products. The more primary aluminum is in the product, the more striking the difference between hydropower smelted aluminum and coal-power smelted aluminum. For instance, the cradle-to-gate carbon footprint of automotive aluminum sheet made of Chinese primary aluminum would be 3.2 times higher than it is made of Canadian primary aluminum when assuming the same primary aluminum content.

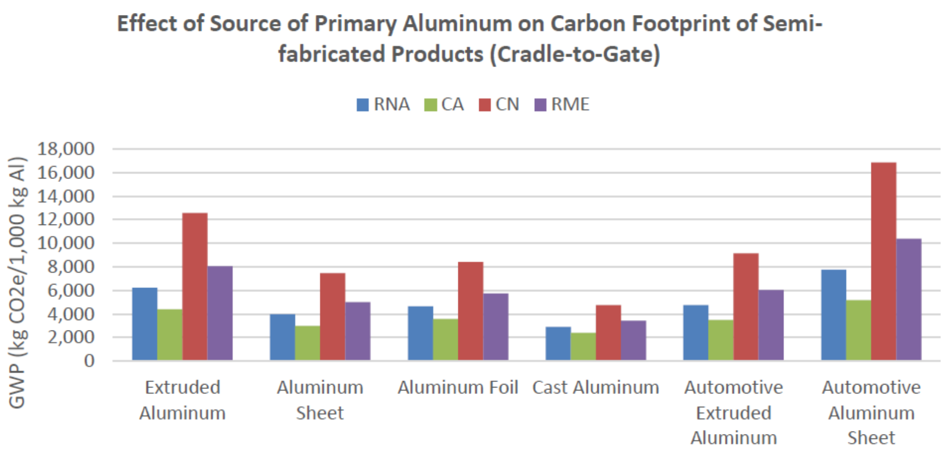

Figure 0-4: Effect of source of primary aluminum on cradle-to-gate carbon footprint. RNA: North America; CA: Canada; CN: China; RME: Middle East

CRADLE-TO-GRAVE

EOL Recycling Helps Significantly Reduce Footprints

From a cradle-to-grave perspective, the recycling of aluminum at the end of its useful life can significantly reduce the potential environmental impacts. The effect of increasing EOL recycling rates can be seen from Figure 0-5. The figure shows that a one percent increase in EOL recycling can reduce the overall carbon footprint by 80 kg CO2e for 1,000 kg of products (or 0.08 kg CO2e/kg Al) for all examined product systems. Similar effects can also be observed regarding to other impact indicators.

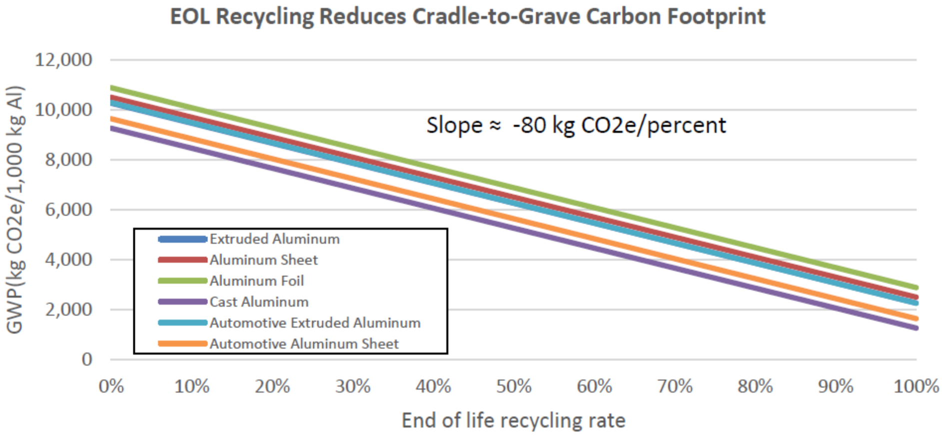

Figure 0-5: The impact of recycling on cradle-to-grave global warming potential of semi-fabricated aluminum products.

The generic environmental benefit of recycling can be quantitatively calculated by comparing the cradle-to-gate primary energy demand and carbon footprint associated with primary metal production and the recycled metal production. Figure 0-6 shows the results of such comparison. Clearly, recycling aluminum saves 93 percent of energy and reduces 94 percent of carbon footprint compared to producing the metal from bauxite ore.

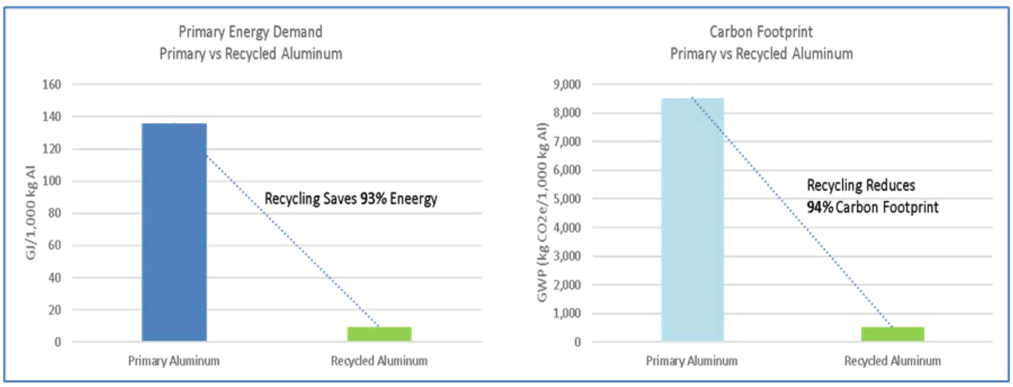

Figure 0-6: Energy savings and carbon footprint reduction associated with aluminum recycling.

SIGNIFICANT FOOTPRINT REDUCTIONS ACHIEVED

Progress can be measured by benchmarking with historical studies. During the past three decades, the Aluminum Association has sponsored numerous LCA studies. Many of them were either concentrated on assessing a particular product (1993, 2010 and 2014 studies) or product shipped to a particular market sector (1998 study), while others were focused on assessing generic semi-fabricated aluminum (2013 study). While the goal and scope of these studies have been somewhat different, it is still possible to extract information to document progress. For instance, all studies have covered primary aluminum and aluminum recycling in similar system boundary. This enables comparisons to identify trends for raw material production. In addition, the 2013 study is similar in scope and thus enables comparisons for some generic semi-fabricated products.

From a cradle-to-gate perspective, significant progress has been made in the North American aluminum industry in improving energy efficiency and reducing emissions:

- For primary aluminum, energy demand and carbon footprint have been reduced 27 percent and 49 percent since 1991, respectively (Figure 0-7);
- For recycled aluminum, energy demand and carbon footprint have been reduced 49 percent and 60 percent since 1991, respectively (Figure 0-8)
- For generic semi-fabricated products, a similar downward trend can be seen regarding to energy demand and carbon footprint since 2010 (Figure 0-9)

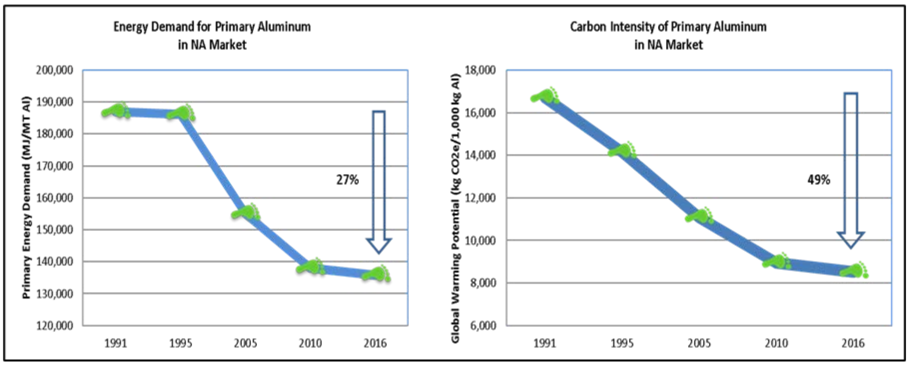

Figure 0-7: Trend of primary energy demand and carbon footprint associated with primary aluminum production.

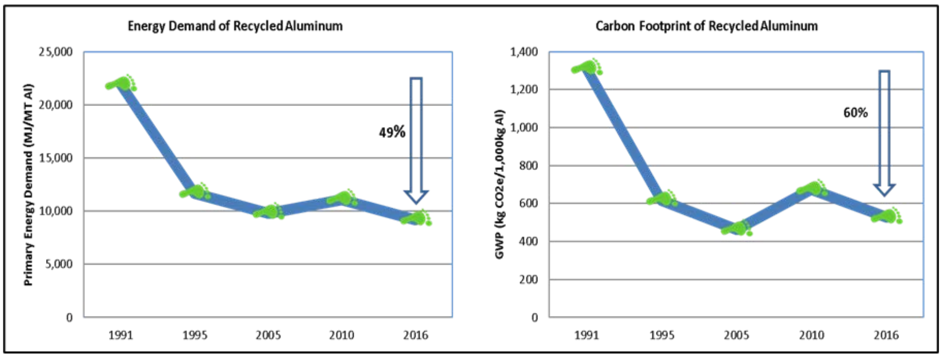

Figure 0-8: Trend of primary energy demand and carbon footprint associated with recycled aluminum.

SIGNIFICANT FOOTPRINT REDUCTIONS ACHIEVED

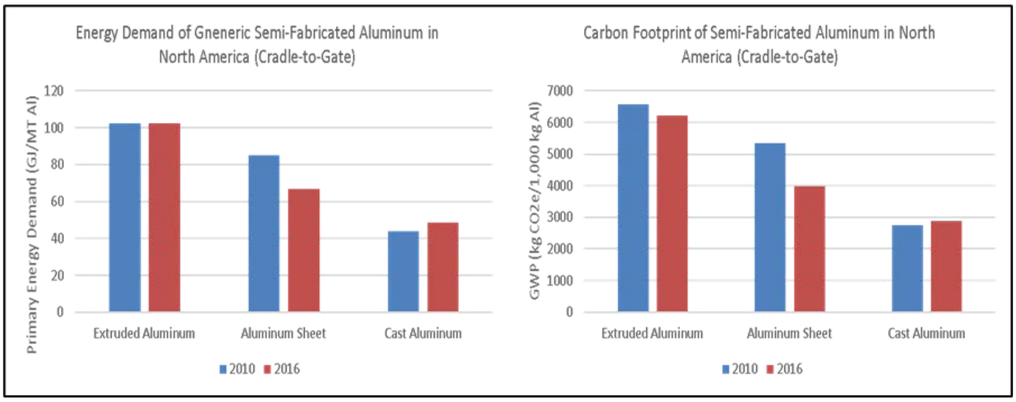

Figure 0-9: Trend of primary energy demand and carbon footprint associated with generic semi-fabricated aluminum (cradle-to-gate)

For primary aluminum, the improvement in energy efficiency and carbon footprint is partly attributed to technological progress in which computerized process controls have enabled less electric power consumption during the electrolysis process (Figure 0-10) and reduced greenhouse gas emissions such as CO2 and perfluorocarbons (PFCs) (Figure 0-11).

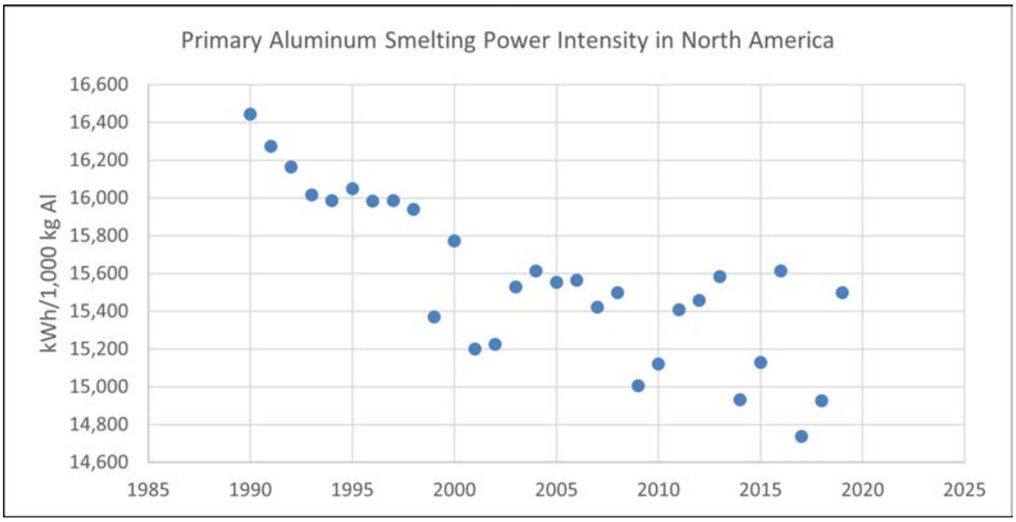

Figure 0-10: Trend of electric power consumption of primary aluminum smelting.

SIGNIFICANT FOOTPRINT REDUCTIONS ACHIEVED

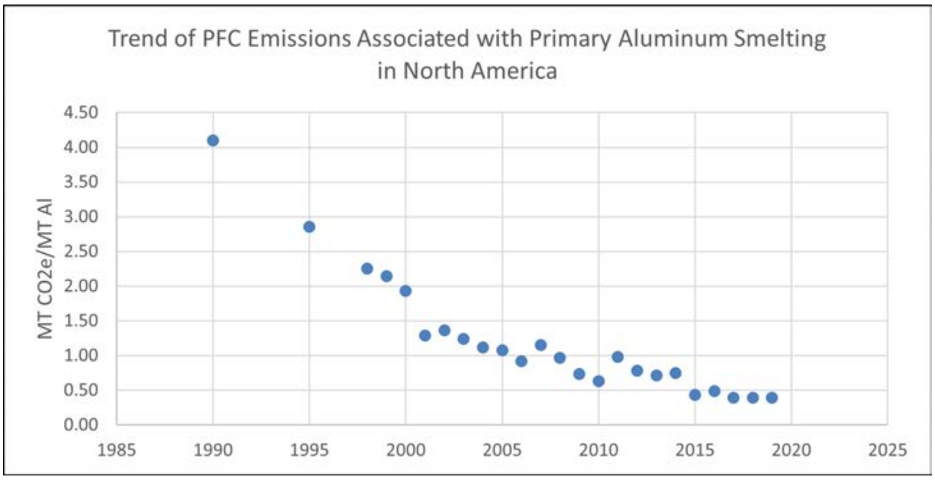

Figure 0-11: PFC emissions intensity reductions.

The improvement for primary aluminum is also attributed to the gradual phase out of old smelting technology – the Söderberg technology. Compared to the pre-bake technology, the Söderberg technology is less energy efficient and releases more emissions. During the past 30 years, Söderberg facilities have been gradually closed and more pre-bake facilities have been built.

A third factor for the improvement for primary aluminum is attributed to the gradually increased share of renewable electricity and decreased share of coal fired electricity as an energy feedstock for smelting (Figure 0-12). This phenomenon is related in part to the phase out of Söderberg facilities which tend coincidentally to be facilities powered by coal fired electricity. On the other hand, most of the newly built pre-bake facilities are powered by hydro and other renewable electricity.

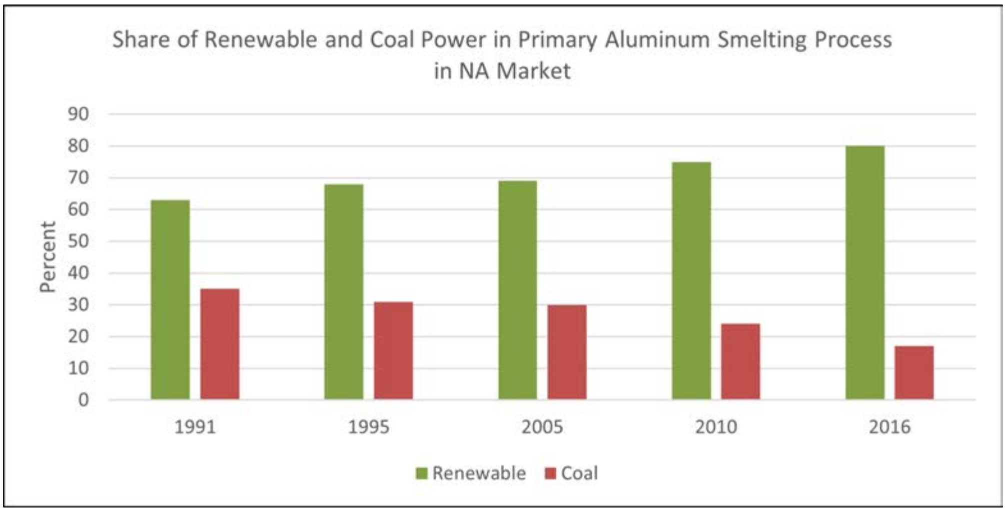

Figure 0-12: Relative shares of renewable (hydro and other renewable) and coal fired power for primary aluminum smelting in North America

SIGNIFICANT FOOTPRINT REDUCTIONS ACHIEVED

For recycled aluminum, progress over the years can be mostly attributed to process efficiency improvement. Furnaces are more efficient today than 30 years ago. In addition, several other factors are likely contributing to the reductions in energy and carbon footprint as well. These include economies of scale (today's recycling facilities are larger than 30 years ago), scrap feedstock quality improvement (e.g., better sorting and better pre-treatment of scrap), variation in product forms for delivery (e.g., molten metal versus ingots), among others.

Improvement for semi-fabricated products is more complex since the cradle-to-gate footprint is not only related to production efficiency of the semi-fabrication processes themselves, but also to the footprints of primary and recycled metal, as well as the relative shares of primary versus recycled content. For instance, both extrusion and sheet products have seen an improvement in energy demand and carbon footprint. This is attributed to two major factors:

- improvement in the footprint of raw materials, and
- increase of recycled metal content (or decrease of primary metal content)

On the other hand, cast products have experienced an increase in footprint. This is attributed to difference in production technologies assessed between the 2010 and 2016 productions. The ultimate cause for the increase is due to the difference in recycled metal content:

- In the 2013 study (production year of 2010), cast product was represented by sand casting technology and average recycled metal content was 85 percent;
- In this study, however, the production is represented by die casting technology and average recycled metal content is assumed to be 80 percent.

PRODUCT USE PHASE ANOTHER KEY CONSIDERATION

It is critical to note that the use phase of products, although not included in this study, could have the biggest impact on the overall life cycle environmental footprints. Users are therefore cautioned against drawing conclusions before including the use phase in their studies. Many LCA studies show that the environmental footprint of the production phase of a product is minimal compared to the use phase impacts. This is true across almost all market sectors including transportation, packaging, building & construction, and consumer durables. For example, the production phase of an automobile is as little as 10 percent of the total life cycle footprint while the rest is due to the energy consumptions during the use phase (Hottle, et al, 2017). Therefore, focusing solely on the production phase of a product like an automobile will lead to an incomplete environmental impact assessment and create unintended consequences.

Comparing to the production phase, the use phase is usually product specific and is not as straightforward. LCA practitioners should pay special attention in their approaches to model the use phase so that it can be scientifically sound and practically accurate. This topic, although extremely important, is out of the scope of this study. This study can be used as the foundation for data users to build their use phase upon it.

INCREASED USE AND RECYCLING CAN DRIVE FUTURE IMPROVEMENTS

Looking at the future, the aluminum industry is expected to continuously make progress in reducing product environmental footprints at the production stage. However, the extent of such improvement is often determined by the law of physics. On the other hand, significant reduction of future life cycle footprints of aluminum products can be achieved through increased beneficial use of aluminum and through improved quality of EOL recycling.

As stated previously, the use of aluminum could substantially improve the overall environmental footprint of a product:

- Aluminum as a strong and lightweight automotive material can significantly reduce the energy consumption of the vehicles compared to both conventional auto steel and advanced high strength steel (AHSS), and thus help reduce the overall life cycle footprint of the vehicles (Audi, 2005; Dubreuil et al, 2010; Das 2014; Bushi et al, 2015; Bushi 2018;). An EPA literature review shows that "most of the LCAs reviewed demonstrated that aluminum-intensive designs were able to achieve the largest reductions in life-cycle energy use and GHG impacts, specifically in the use phase" (Hottle, et al, 2017).
- A study by ICF International concludes that depending on retail location, GHG emissions associated with the transportation and refrigeration of beverages packaged in aluminum cans are 8-23% lower than plastic bottles, and 67-90% lower than glass bottles (ICF, 2016).
- Studies by the European Aluminum Foil Association conclude that aluminum foil used for food and beverage packaging plays a key role in "minimizing the overall environmental impact of the product by reducing spoilage, over consumption, and/or by facilitating more sustainable lifestyles" (EAFA, 2008, 2009, 2010, 2011, 2013).
- Aluminum helps improve energy efficiency of a building. Strong, lightweight and durable aluminum products contribute to controlled and optimized functioning of heating, cooling, lighting, and ventilation systems. The optimization is achieved through balancing the competing needs of occupants in terms of optimal indoor temperature, maximum daylight and view, and maximum fresh air (AA Green Building Guide 2015).

Aluminum is a perfect material for recycling. When properly collected, sorted, and segregated, the recycling process does not change any functionality of the metal, regardless of how many times it is recycled. While aluminum products for transportation, infrastructure, building and construction, and durable goods have been historically mostly recycled at the end of life, the recycling rates for some consumer products such as packaging are far from expectation. It is estimated that a significant amount of aluminum, more than a million metric tons, is lost in landfills each year in the North American region. The recycling of these lost metals will not only help the industry reduce its environmental footprint, but also help society save the metals and the attached energy resources for future generations, thus achieving the ultimate goal of sustainable development for humanity.

INCREASED USE AND RECYCLING CAN DRIVE FUTURE IMPROVEMENTS

Even for products with high recycling rates, the potential for improvement is still significant. The current recycling infrastructure available and technology deployed in North America do not meet the demand for increasing the quality of recycling and closed-loop recycling of aluminum. Aluminum scrap collected is often mixed with other materials, and most harmfully, mixed with different alloys. Contamination of aluminum scrap by other materials and commingling of different aluminum alloys are common. Such contamination and commingling could lead to a phenomenon called “downcycling” – where high-quality wrought aluminum alloys end up being recycled into cast alloys since cast alloys have higher tolerance for impurity. While the metal does get recycled and reused, again and again for new products, such a system is not an optimal recycling system, and it does not reuse society’s scarce resources in the most efficient way. Most importantly, it is not sustainable since the demand for cast alloy has limitations.

To address this problem, we must work together to find better solutions. Policy makers need to develop smart and effective policies to incentivize quality recycling. The scrap collection industry needs to invest in new infrastructure to meet current and future demand. And technology developers need to seize the opportunity to provide state-of-the-art technologies to improve recycling efficiency and quality. The Aluminum Association calls on all stakeholders to work together to improve our aging recycling system to meet the 21st century demand for optimal use of our planet’s scarce resources.