The Quest for Low Carbon Aluminum: Developing a Sustainability Index

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Introduction

Energy consumption and greenhouse gas (GHG) emissions remain two of the major concerns for the primary aluminum industry. The aluminum smelting process emits several GHGs, including carbon dioxide (CO_2eq) and perfluorocarbons (PFCs). While electricity consumption in smelting constitutes roughly one-third of the production costs, an average of around 12 kgs of CO_2eq is emitted per kg of aluminum smelting worldwide.[1] The aluminum production process requires 13,000–18,000 kWh/t of electric energy under the best and the worst practice scenario.[1] Significantly, as per Columbia Climate Center data, smelting primary aluminum consumes 4% of the world's electricity and emits 1% of its CO_2eq GHGs annually.[2]

Such high energy consumption and GHGs are driven by the high temperature required in the pots and large CO_2eq emissions during the production process. However, with the development in technology in the electrolytic process, the energy required to produce a ton of primary aluminum has reduced by 40% over the last 50 years.[2] Improved cell technologies that operate at higher amperage and deployment of digital technologies like automation, robotics, and machine learning in greenfield and brownfield smelters have contributed immensely towards achieving success in reducing energy consumption in smelting. However, the concern over high CO_2eq emissions looms large, compelling industry majors and R&D organizations to invest in alternative technologies, which can improve the carbon footprint and streamline the road to producing low carbon aluminum.

Emissions from Primary Production

The aluminum production process produces GHG emissions and residue at every level of manufacturing, from mining through to end of life (Figure 1). Primarily, four stages within the aluminum production process are responsible for the most GHG emissions:

- CO_2 emissions generated during electricity generation to power the aluminum production process
- Combustion of fossil fuels during alumina refining
- CO_2 emissions from carbon anode consumption during the electrolysis process
- PFCs generated during operational disruption in the electrolytic cell due to "anode effects"

The major share of CO_2eq emissions in the aluminum production process are generated during the smelting operation, representing about 80% of the total 12 tons of CO_2eq generated in the entire process from mining to casting (Table I). Thus, reducing the carbon footprint during aluminum smelting has been a major goal for aluminum producers across the world. Over the years, global aluminum players have invested generously in research and development projects towards reducing carbon emissions in smelting. This quest has given rise to the concept of low carbon or "green" aluminum.

Figure 1. Aluminum production processes and their carbon and by-product emissions.

Source of Emissions	Mining	Refining	Anode Production	Smelting	Casting	Total
Process	—	—	388	1,626	—	2,014
Electricity		58	63	5,801*	77	5,999
Fossil Fuel	16	789	135	133	155	1,228
Transport	32	61	8	4	136	241
Auxiliary	—	84	255	—	—	339
PFCs	2	—	—	2,226	—	2,226
Total	**48**	**992**	**849**	**9,790**	**368**	**12,047**

Table I. Emissions generated during primary aluminum production (kg CO_2eq/ton Al).

Low Carbon Aluminum

Concepts such as environmental sustainability and circular economy are no longer relegated to scholarly articles, but are key strategies for policymakers in all developed and emerging economies. To address the threat of climate change, the Paris Agreement has developed a strategy for keeping global warming below 2°C over the course of the 21st century. This has compelled heavy industries around the world to find a way to operate in line with the carbon emission constraints formulated by the agreement.

According to the Ellen MacArthur Foundation's 2019 report, "Completing the Picture," the implementation of circular economy strategies in the production of key materials could reduce emissions by 40% by 2050.[3] Hence, a shift to a low-carbon and green energy technology is a part of the greater goal of building a circular economy, which will lead to a series of changes in product development, new technologies, and the end-use of materials. In fact, the process has already started. Many organizations worldwide have already committed to reducing their carbon footprint and have started substituting their conventional input material with more sustainably produced material.

As per a new World Bank report,[4] the application of green energy technologies is expected to catapult demand for a

wide range of materials, such as aluminum, copper, and other metals and minerals. Aluminum, being an infinitely recyclable material and a preferred metal in many growth industries, has a lot to contribute towards this transformation process. Demand for this green metal is likely to grow manifold in the energy, automotive, and packaging industry because of the increased interest in lightweighting, fuel economy, and end-of-life recycling. Notably, increasing the production of aluminum may result in CO_2eq reaching dangerous levels by the year 2100, if no substantial action is taken to address the emissions and by-products that challenge primary production. This validates the need for sustainably produced, low carbon aluminum.

History of Low Carbon Aluminum: Over the last 25 years, there has been a continuous growth in total CO_2eq emissions in line with growing aluminum production. Nevertheless, one positive indicator of the aluminum industry's implementation of sustainability measures is that its share in total global emissions has remained steady at 1%. Further, the total CO_2eq per ton of aluminum has significantly dropped over the years. In 1995, the aluminum industry emitted 364 million tons of CO_2eq, with a rate of around 16.5 t CO_2eq/t Al (total aluminum production of 22 million tons).[1] Whereas in 2018, emissions stood at 773 million tons, with a production of 64.4 million tons of aluminum and about 12 t CO_2eq/t Al.

North American primary producers have successfully reduced CO_2eq emissions by 85% after closing older, inefficient smelters aging back to the 1940-1960s that generated a high rate of PFCs. Deployment of best practices in pot technology and better control of the anode effect, as well as the introduction of new technologies, have been able to bring down direct emissions significantly over the years (Table II). A substantial reduction in CO_2eq emissions has been achieved by shifting to hydropower electricity, which emits no CO_2eq. This brings down indirect emissions to almost zero, resulting in a considerable change in total carbon emissions.

Process	CO_2eq (t/t Al)	Change
Average Hall-Héroult (H-H)	12	Base
Best Practice H-H	10	15%
Wetted Cathode	9	25%
Inert Anode	8	33%
Carbothermic Electric Furnace	8	33%
Clay Carbochlorination & Chloride Electrolysis	8	33%

Table II. Alternative aluminum production processes (current and in development) and their impact on emissions.

Definition and Methodology: The industry has not been able to set up an exact definition or benchmark for low carbon aluminum as a product. According to Carbon Trust's Methodology statement,[5] a "lower carbon primary aluminum" label should be defined by the current benchmark of 4 t CO_2eq/t Al for the process emissions from aluminum electrolysis, anode production, and aluminum casting. Despite the efforts towards standardization, there is still a lack of consistency on the threshold level or even the scope of the footprint being measured.

The Aluminium Stewardship Initiative (ASI) is working towards setting up a sustainable standard for aluminum production. By introducing international standards with an entire value chain approach, the aim of the global non-profit is to encourage responsible production, sourcing, and stewardship of aluminum. As per the benchmark set by the ASI, aluminum products from smelters that meet the 2030 ASI Performance Standard of 8 t CO_2eq/t Al (Scope 1 and 2) are certified as low carbon aluminum.[5] This, however, is considered by experts as too inclusive a benchmark for low carbon aluminum. In 2020, the ASI initiated a revision of its standards and documents in order to clarify and improve its standards (see article on page 30).

The International Aluminium Institute (IAI) has proposed three levels of disclosure of carbon footprints to reduce the workload of data collection and calculation, while maintaining consistency and transparency regarding the carbon footprint of the aluminum industry.[6] These levels are indicated as follows:

- Level 1: Emissions from aluminum electrolysis, ingot casting, and anode/paste production, as well as emissions from electricity generation and heat production associated with these processes. (The ASI and other standards are broadly aligned with Level 1.)
- Level 2: In addition to Level 1 emissions, direct emissions from bauxite mining and alumina refining, as well as emissions from electricity, heat production, and fuel combustion from these two processes, are measured.
- Level 3: A complete cradle-to-gate carbon footprint of aluminum ingot including all GHG emissions from bauxite mining, alumina production, carbon anode production, electrolysis and ingot casting processes, raw materials transport, electricity and heat generation, and aluminum dross processing. It also includes the production of ancillary materials and fuels required for primary aluminum production.

Broadly speaking, the IAI's Level 1 emissions cover the Scope 1 and 2 emission standards set by the GHG Protocol's Corporate Accounting and Reporting Standard. According to the GHG Protocol, Scope 1 emissions are direct emissions from owned or controlled sources, whereas Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 1 and 2 emissions (GHG Protocol) or Level 1 emissions (IAI methodology) are currently the most commonly used measurement indicators for defining low carbon aluminum. For the bigger picture, the full scope carbon footprint of an aluminum ingot or Level 3 should be considered. Nevertheless, in the future, the footprint scope is expected to expand from IAI's Level 1 or GHG's Scope 1 and 2 to cover the full cradle-to-gate emissions.

Low Carbon Products

A number of aluminum producers have already launched so-called "low carbon primary aluminum" products. On the whole, all the current green aluminum brands marketed by various aluminum producers tend to range around 4 tons of direct and indirect CO_2eq emissions.

Alcoa Corporation: Alcoa introduced a product line called Sustana™, which includes three products: Ecolum™, EcoDura™, and EcoSource™.[7] Ecolum is a primary aluminum brand produced at Alcoa in its largely hydropowered smelters. The product's total carbon footprint for Ecolum, including emissions from bauxite mining and refining, is less than 4 t CO_2eq/t Al, which makes it one of the top contenders for low carbon aluminum products. The product comes with certification of origin, confirming sustainability metrics of the product line. The Environmental Product Declaration (EPD) is also verified by a third party.

The EcoDura aluminum is made with a minimum of 50% recycled content, which can be extremely beneficial for building and construction customers with regard to LEED certification. It has a footprint of no more than 2.5 t CO_2eq/t Al (including both direct and indirect emissions), around 75% better than the industry average.

In September 2020, Alcoa expanded its Sustana line with the introduction of EcoSource,[8] the industry's first low-carbon, smelter-grade alumina brand. EcoSource is produced with about 0.6 t CO_2eq/t alumina—two times better than the industry's average of 1.2 tons. Alcoa's measurement methodology takes into account the emissions in the bauxite mining and alumina refining processes and indirect emissions from the energy consumed in those processes. Significantly, Alcoa's alumina refining system has the lowest carbon footprint in the industry globally.

Arctus Metals: Arctus Metals Ltd., a small company in Reykjavik, Iceland, developed a turnkey modular aluminum smelter that runs on a cheaper and less energy intensive carbon free chemical process. The proprietary technology is based on the Beck electrolysis cell, exploiting vertical inert electrodes at a lower temperature of 750°C.[9] The firm recently produced its first batch of low carbon aluminum—a one-pound ingot—from its lab. The company is currently expanding its demo unit from a 500 A electric current capacity to 10,000 A. According to a company spokesperson, if Iceland's three aluminum smelters, which use geothermal and hydropower, adopt their technology, this would eliminate about one-third of the country's total emissions.

Century Aluminum: Aligning itself towards the cause of green aluminum, Century announced the launch of its Natur-Al™ low-carbon aluminum products in February 2020. Natur-Al products are processed at the company's ASI-certified Norðurál Grundartangi aluminum plant in Iceland, fuelled by renewable energy sources. The company confirms the aluminum as having 4 t CO_2eq/t Al, less than one-fourth of the industry average. The emissions are verified by independent third parties, which facilitate life cycle assessments for customers. With this product addition, Century intends to respond to growing customer demand for responsible aluminum production and help its customers significantly reduce or fully offset the carbon footprint of their products.

Elysis: A joint venture between Alcoa and Rio Tinto, Elysis is touted as being a producer of zero-carbon aluminum (in the smelting process).[10] The company produced its first commercial batch in 2019 at the Alcoa Technical Center in Pittsburgh, PA, and sold the supply to Apple. Elysis recently completed construction on its US$37 million research facility in Saguenay, Quebec, Canada. The ambitious project is expected to start commercializing the technology by 2024.

The zero-carbon concept of Elysis is primarily based on the use of a substitute material for carbon blocks, which can separate aluminum without causing a chemical reaction and carbon emission. Elysis hasn't officially shared exactly which materials it uses in its process, but it essentially uses an inert anode and cathode in the smelting process, which produces oxygen rather than any level of GHG emissions. Presently, several smelters in China, Norway, Russia, and Iceland are using inert anodes to process aluminum in lower-temperature conditions. However, the technology comes with its own set of challenges as the metal purity gets impacted due to gradual contamination from the inert anodes.

Although the aluminum is claimed to be zero carbon aluminum, it is pointed out by experts that the prototype aluminum is not totally GHG-free. Although Elysis claims that its aluminum is produced without "any direct carbon dioxide emissions." This does not include carbon emissions from alumina and fossil fuels. However, in the long run, the technology is expected to establish carbon neutrality across the value chain. Once Elysis starts producing its green aluminum with hydropower in Quebec commercially by 2024, it is expected to have "the potential to reduce annual GHG emissions by 7 million tons, equivalent to removing 1.8 million cars from the roads."

Emirates Global Aluminium (EGA): In January 2021, EGA announced that through its work with the Dubai Electricity and Water Authority (DEWA), it is now able to produce aluminum using solar power. This is made possible through DEWA's massive new solar farm in the UAE, which is supplying 560,000 MW hours of solar power. EGA will supply solar aluminum to global customers under the new product name CelestiAL (see article on page 32).

Hydro: Hydro launched two green aluminum brands Hydro CIRCAL 75R and Hydro REDUXA 4.0 in 2018 and 2019 respectively.[11] REDUXA 4.0 is a primary aluminum brand fueled by hydropower. This product is a series of certified, low carbon aluminum with a maximum carbon footprint of 4 t CO_2eq/t Al. The 4.0 product line is verified by a third party covering all carbon emissions from bauxite mining and alumina refining to the production of aluminum in electrolysis and casting.

CIRCAL is a range of prime quality aluminum made from a minimum of 75% recycled, post-consumer scrap and a certified carbon footprint below 2.3 t CO_2eq/t Al. The percentage share of scrap is specified based on conditions from the client. The higher the recycled content of post-consumer scrap, the lower the carbon footprint.

Rio Tinto: Rio Tinto produces some of the lowest carbon aluminum in the world at its Canadian smelters. The aluminum producer launched the industry's first certified low carbon aluminum, RenewAl, in 2016.[12] This is achieved through the use of the company's advanced AP Technology™ and carbon free, hydropowered energy. RenewAl is certified to produce 4 CO_2eq/t Al or below.

In February 2021, Rio Tinto introduced START, a "nutrition label" for responsibly produced aluminum. Using blockchain technology, the label will provide key information about the site where the aluminum was responsibly produced, covering ten criteria: carbon footprint, water use, recycled content, energy sources, community investment, safety performance, diversity in leadership, business integrity, regulatory compliance, and transparency. The aim of START is to help customers meet the demand from consumers for transparency on where and how the products they purchase are made.

UC Rusal: UC Rusal launched Allow, a new low carbon aluminum brand, in 2017.[13] The product features a carbon footprint of 4 t CO_2eq/t Al, including smelter direct and indirect emissions. The full scope carbon footprint from ore to casting for all ALLOW branded aluminum stands at less than 8 t CO_2eq /t Al. The brand is certified by the British Standards Institution and Quantis, a Swiss-based environmental research group.

Rusal is also planning to commercially launch a carbon-free version of aluminum by 2021, which will be produced using inert anode technology. The technology and the launch timeline put Rusal in direct competition with Elysis, which is also working on producing zero carbon aluminum. In June 2020, the company announced that it had started testing operations for a pilot electrolytic cell with inert anodes using an improved design. This new pilot is an improvement over the inert anode electrolytic cell already being tested by Rusal as a carbon-free aluminum cell technology. The technology

is expected to reduce aluminum's carbon footprint to a record low level of 2 t CO_2eq /t Al, as well as significantly reducing production costs.

Other Developments: The trend of low carbon aluminum is also compelling conventional aluminum producers to recalibrate their strategies and invest in low carbon technology and green fuel. China Hongqiao Group Limited, one of the largest aluminum producers globally, moved about one-third of its aluminum capacity out of Shandong province to the hydropower-rich Yunnan province to produce greener aluminum. The new aluminum plant, located in Wenshan province, with an annual capacity of 2.03 million tons, started the first phase of production in September 2020.

Responding to the need to use renewable fuel for electricity, India's Hindalco Industries is planning to set up a 24 MW solar power plant at its aluminum smelter in Odissa, India, with an investment of about US$20.5 million. The power produced will be used as a renewable purchase obligation (RPO) determined by the government. Hindalco's smelter is currently supported by a 900 MW (6 x 150) coal-based captive power plant.

Further, Alvance, the aluminum business of London based business tycoon Sanjeev Gupta, is on an acquisition spree and bought two low-carbon smelters, including Lochaber in Scotland (hydropower) and Dunkerque in France (nuclear power). The company is planning to invest more in this segment.

The Market for Low Carbon Aluminum

With growing awareness about responsibly produced and sustainable aluminum among producers and consumers worldwide, a market is being developed for low carbon aluminum. Notwithstanding the fact that there is not enough demand for green aluminum currently to generate a physical premium, policymakers and producers in the European Union (EU) and North America are working to create adequate demand for low carbon aluminum in the market. The market developments noted here highlight the fact that a green premium is being conceptualized in the financial market as a product, based on projected consumer demand.

HARBOR Green Aluminum Premium: HARBOR Aluminum announced the launch of the world's first green aluminum premium, the US MW P1020 Green Aluminum Spot Premium, in October 2019.[14] According to the organization, low carbon aluminum is produced with a emission rate of 4.5 t CO_2eq/t Al or less. HARBOR projects that worldwide (excluding China) production of low-carbon P1020 aluminum in the form of ingot, T-bar, and sow to be around 4.7 million tons by the end of 2020, which will be about 43% of total P1020 production. The firm intends to create and provide the market with tools to make informed commercial and/or hedging decisions on green aluminum. The specification for the product is described as a green aluminum daily duty-paid premium paid over the London Metal Exchange (LME) cash price. The product is specified as spot physical 99.7% high-grade aluminum with 4.5 kg or less of CO_2eq emitted per kg of aluminum produced (IAI Scope 1 and 2). Calculations of CO_2 emissions will be done as per the WRI, IAI, and/or GHG Protocols on products traceable to a single smelter.

LME Trading Platform: The LME has streamlined a sustainability agenda for metals, leveraging its position as a global platform for metal pricing and trading. The exchange has already embedded responsible sourcing standards into its brand listing requirements and is planning to incorporate broader sustainability issues facing the metals and mining industries.

As a first step, the LME plans to provide greater transparency in the definition and access to low carbon aluminum criteria. The LME intends to leverage LMEpassport—a digital register that will record electronic certificates of analysis and other value-add information—to store carbon-related metrics for specific batches of aluminum.[15] Through the voluntary register, producers or metal owners could choose to input the relevant data on their green aluminum. This would be the first step towards labeling green aluminum in an LME-approved market.

Additionally, the LME is investigating the creation of a trading platform for end-consumers from the transportation or packaging industries, which are specifically interested in sourcing low carbon aluminum. "We also acknowledge that there are different views on exactly how to manage the transition to a low carbon economy, which is why we are committed to providing a range of tools and services to facilitate different approaches—while also maintaining optionality," said Georgina Hallett, LME chief sustainability officer. Both LME- and non-LME-listed brands will be given access to LMEpassport and the spot trading platform, which are expected to launch in Q1 2021.

The decition to launch a spot trading platform for low-carbon aluminum has been faced with criticism from major aluminum companies, including Hydro and Hindalco. Hydro believes that a separate contract for low-carbon aluminum is self-contradictory and may actually weaken the LME's efforts towards de-carbonization of the metal sector. The trading platform is likely to commoditize a specialized product. Further, the company is concerned about the fact that there is no standard calculation method for measuring carbon content in different green metal products.

Hindalco is of the view that an exclusive focus on the energy source used to produce aluminum could end up overshadowing other serious sustainability issues in the value chain, including bauxite mining and residues. In addition, only a handful of aluminum producers use renewable power sources, which helps them produce aluminum with a minimum CO_2eq, providing an unfair advantage over the lion's share of aluminum producers.

Fastmarkets Low Carbon Aluminum Pricing: In October 2020, Fastmarkets, a global commodity pricing and intelligence service, proposed to launch a differential for low-carbon aluminum.[16] This would be priced as either an upcharge or a discount over its current P1020 aluminum and value-added product premiums. The organization made the decision based on the feedback it had received from customers. A separate differential, according to them, will not split the liquidity on current premium offerings. The proposed offering will allow market participants to hedge existing underlying legacy premiums simultaneously. Fastmarkets has yet to decide whether its pricing mechanism will be based on 4 t CO_2eq/t Al or 8 t CO_2eq/t Al. The third option of a brand distinction, which would list green aluminum as a separate brand, has not received much support from market participants.

Trafigura Financing Platform: Considering the growing demand for low carbon aluminum from the EU automotive and packaging industries, commodities trader Trafigura launched a US$500 million financing platform for low carbon aluminum in September 2020.[17] This was said to be the first of its kind for the company and the aluminum market. Natixis and Rabobank will fund the platform, through which Trafigura will be able to access financing at a preferential interest rate. This will be used to pay a premium to low carbon aluminum producers.

Through this new collaborative financing platform, Trafigura has developed a methodology that sets out parameters

for low carbon aluminum production, based on existing recommendations and standards endorsed by the EU Technical Expert Group on Sustainable Finance and the ASI.

Trading houses are expecting low carbon aluminum to trade with a premium in the physical market in the next one to two years. Even financial houses in Europe and North America are likely to consider the carbon performance of materials while financing a deal because of the growing pressure on carbon neutrality. The premium for low carbon aluminum is expected to standardize on its own over time. But different aluminum producing regions are moving at a different pace towards reducing carbon emissions, and the biggest aluminum producing region is still heavily under coal-powered fuel. Thus, a low carbon aluminum premium is expected to settle at the regional level rather than at a global level side by side with the standard aluminum premium.

Ongoing Challenges

Even though the developments taking place in the low carbon aluminum space are good news from the point of view of the environment and sustainability, there remain several questions that are yet to be addressed. The current definition of low carbon aluminum is primarily determined by the IAI's Level 1 emission guidelines, which are used to create a distinction between "green" (low carbon) and conventional (carbon intensive) aluminum production, with a heavy focus on the kind of power used to fuel the smelters. Therefore, a market is being created for green aluminum produced by aluminum companies with captive hydropower capacity, which are able to introduce low carbon brands. This is also creating an opportunity for the LME to introduce its new products in the commodity market and financial institutions to leverage green lending. This green and conventional aluminum divide is likely to widen over the coming years due to the push from big-ticket consumers (such as Apple and Tesla) and the growing competition among the low carbon aluminum producers over the credibility of their technology and methodology.

The dilemma that the primary aluminum industry faces can be illustrated by the distribution of power sources for smelters around the world (Figure 2). The largest portion of aluminum production (about 75%) is still fuelled by coal and natural gas, and it is not clear how coal and natural gas based producers in Asia might be able to adapt to alternative fuels for smelting. Not all aluminum producers have access to hydropower and it is not always possible build new hydro dams for fuel. All economically accessible sites for hydro dams and geothermal sources have already been utilized. It is also not possible to construct many more additional hydropower dams in a economic way without impacting the environment and local communities.

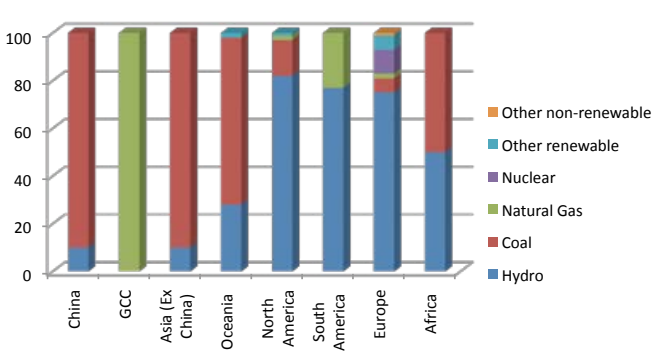

Figure 2. Power sources for aluminum smelters by region (in %).

Technological advancement must also take place in order to lower the carbon footprint at electricity producers, particularly for those that use fossil fuels. This is in addition to lowering the carbon footprint of the bauxite mining, alumina refinery, and smelting processes. All of these factors play a collaborative role in reducing the total carbon footprint of aluminum production.

Furthermore, carbon emissions are not the only factor that should be taken into consideration when considering the sustainability of aluminum. The production process also produces other dangerous by-products at various stages (Figure 1), including bauxite residue (or red mud), spent potlining (SPL), dross generation, and landfilling of scrap aluminum.

Bauxite Residue: As per recent data, globally, the aluminum industry generates more than 150 million tons of red mud annually, with an existing global inventory of more than 3 billion tons of bauxite residue. The industry has not yet been able to find an environmentally and commercially viable solution for bauxite residue disposal and reutilization. The leakage in the red mud ponds from Hydro's Alunorte refinery in Brazil, which released the slurry into the surrounding area in 2018, is an example of how red mud ponds can impact the environment. The incident led to a 50% capacity cut in the refinery and an operation embargo for almost two years.

A handful of aluminum producers are working towards a commercially viable solution for red mud reutilization. Hindalco in India became the world's first alumina producer to achieve 100% red mud utilization across three of its refineries.[18] The company has signed a MOU with UltraTech Cement Ltd. to deliver 1.2 million tons of red mud annually to UltraTech's 14 plants. The use of red mud as an input material in the cement industry is considered a significant step towards implementing a circular economy.

Spent Pot Lining: SPL is the most significant solid waste product from the aluminum smelting process and is the second largest in volume after bauxite residue. When the refractory and carbon lining of the electrolytic pot comes to the end of its life, usually after 4-7 years, it is considered to be SPL. Typically, SPL comprises approximately 55% of the first cut carbon fraction and 45% of the refractory second cut. As per the data from the IAI, in 2018, nearly 1.6 million tons of SPL were generated from primary aluminum production.[19] Based on estimates from various research reports and IAI data, more than 50% of SPL generated annually is stored indefinitely or landfilled. The other 50% is treated by the producers or supplied to other industries like cement or steel to be used as a direct feedstock material or fuel. An appropriate and sustainable management of SPL with minimum social and environmental impacts is being actively pursued by many producers within the aluminum industry (see article on page 44).

Aluminum Dross: Aluminum dross has been finding its way to landfills for years. It is only recently that the aluminum industry realized its significance as a secondary source for metal recovery. Dross can account for 5% of total production and can contain up to 80% aluminum metal.[20] Industry estimates suggest that an increase of 10 tons of aluminum dross recovery can augment aluminum production by about 3.2 tons. The Asia Pacific region accounted for 56% of the total dross generation followed by Europe, North America, the Middle East, and Africa.

One of the challenges of dross processing is that it tends to produce salt slag as a waste product, which new technologies are being developed to address. In a recent development, Ultromex, a solution provider for aluminum industry waste treatment, signed a contract with Rio Tinto to rehabilitate a salt slag landfill site in France, treating 65,000 tons of salt slag waste.

Landfilling End-of-Life Aluminum: Aluminum's recyclability at the end of a product's life is one of the metal's key advantages, especially since the recycling process requires significantly reduced energy consumption, offsetting the impact of the primary production process. However, these benefits can be lost to landfilling and downgrading if the scrapped aluminum products are not put back into a recycling loop. A planned recycling program for the industry and the implementation of close-loop recycling across the downstream value chain can save valuable amounts of metal from ending up in landfills. Thus, recycling remains a strong factor in the industry's journey towards carbon neutrality by 2050.

Sustainability Index for Aluminum

A producer cannot claim advantage or superiority based on the kind of fuel being used in producing aluminum or measure sustainability in isolation without considering the cradle-to-grave impacts. As a long term strategy, the industry needs to design a cradle-to-grave Sustainability Index for the global aluminum industry (Table III). This would require a more holistic approach to true sustainability, as opposed to focusing on just one issue—carbon intensity based on the electricity fuel source. Every aspect of aluminum production, from mining to smelting, to end-of-life must be considered, and byproducts as well as emissions must be addressed in order to make aluminum truly sustainable. The bottom line here is that even though all sustainable aluminum may be considered "green," not all green aluminum may be considered sustainable.

Sector	Impacting Factor	Severity Rating Scale* (10 = Worst)	Mitigation Strategy	Opportunity Rating Scale* (10 = Best)
Bauxite Mining	1. Bauxite Tailings	2	Reclamation	3
Alumina Refining	2. Bauxite Residue	9	Cement	1
Power Generation	3. CO_2eq Emissions	5	CCS, more Hydro	4
Anode Manufactuirng	4. POC	1	Known Technology	10
Aluminum Smelting	5. PFC Emissions	8	Anode Affect	8
	6.CO_2eq Emissions	7	Lower KWh/lb	5
	7. SPL	6	Reclamation	9
Melting & Casting	8. Dross /Salt Cake	3	Recovery	7
End-of-Life	9. Landfill	10	Behavioral	2
	10.Downgrading	4	Economic	6

*Scale is based on the author's subjective analysis of the environmental impact and importance.

Table III. Aluminum sustainability index, showing the impact and severity of various emissions and byproducts, along with their potential opportunities.

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