

## Waste Management in the Indian Aluminium Industry – Key to Circular Economy

Manasa Prasad Mishra<sup>1</sup> and Subha Brata Purohit<sup>2</sup>

1. Director (Project & Technical)

2. Assistant General Manager (Corporate Planning & Strategy Management)

National Aluminium Company Limited, Bhubaneswar, India

Corresponding author: manasa.mishra@nalcoindia.co.in

### Abstract

**Aluminium** is the second most used metal in the world, after steel, with an annual consumption of about 90 million tonne (including scrap). When the world is aiming towards decarbonization and Net Zero, aluminium, with its obvious advantages, is poised to be a key enabler in achieving this goal and waste management would play a significant role in reaching this end.

India aims to become a USD 5 trillion economy in 5 years and a strong foundation is being laid to achieve this objective. The role of aluminium sector in this endeavour will be crucial. Government of India missions such as “**Make in India**” and “**Atmanirbhar Bharat**” aspire to make the country self-reliant in meeting all needs including production of high-end aluminium required for strategic sectors like defence and aerospace.

Production of primary aluminium, which is a resource intensive process, is also associated with significant amount of waste generation. While lot of focus is there on green aluminium, sustainable waste management has not received the desired attention.

Significant investment in R&D and collaborative efforts are needed to find ways to utilise the various waste generated in the aluminium value chain, i.e., from mining of bauxite ore to smelting and casting of aluminium. This paper deliberates on this issue, primarily from NALCO’s perspective, the major wastes generated, the current practices of disposal and the opportunities for better management in future, in the backdrop of the latest developments in this field.

**Keywords:** Make in India, Atmanirbhar Bharat, Waste management in aluminium industry, Circular economy.

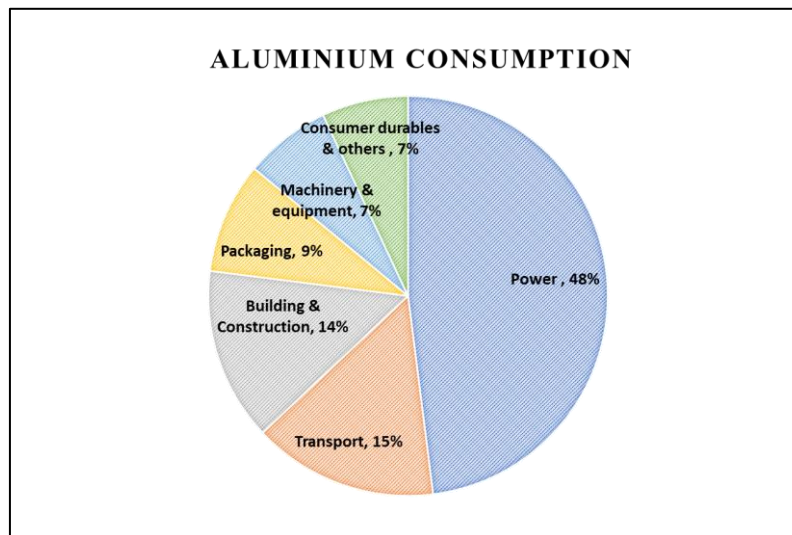
Aluminium is the second most used metal in the world after steel, with an annual consumption of about 90 million tonne (including scrap). The demand for aluminium will grow significantly in the coming days, driven by its continuous increase in its use in automotive, construction, packaging, electrical, renewable energy sectors etc. Currently, out of the total demand of 90 million tonne, about 60 to 65 million tonne is met from primary aluminium production and the rest from secondary production. The secondary/recycled aluminium presents a huge opportunity for the World as the metal is infinitely recyclable without any deterioration in quality and consumes only 5 % of the energy that is required for making primary aluminium. This makes aluminium the metal of choice for the future in the path to the decarbonization. However, the growing demand for aluminium in near future can be met partly by recycling of scrap due to its limited availability and hence significant amount of demand will still be fulfilled through production of primary aluminium.

Production of primary aluminium is a resource intensive process with about 22 tonne of input materials required to produce one tonne of metal. The process also generates huge amount of waste across its value chain starting with mining of bauxite to ending with production of aluminium metal. In recent times, a lot of emphasis is being given on reducing the use of fossil

fuels for primary aluminium electrolysis process and a gradual shift to production of ‘Green Aluminium’. However, the waste generated in the process has not yet received its due attention. Useful resources available in the wastes, if extracted in a commercially viable scale, will lead to a reasonable benefit for the companies and the nation apart from addressing environmental concerns.

## 1. Introduction

India is a rapidly developing country and the role of aluminium sector will be critical as the country advances to meet its economic growth goals. Aluminium consumption in India has witnessed a strong growth over the last 5 years - from 2.36 million tonne in financial year 2016 to 3.7 million tonne in financial year 2020 i.e. at a CAGR (compound annual growth rate) of ~11.84 %. At present, power (48 %), transport (15 %), building & construction (14 %), packaging (9 %), machinery and equipment (7 %), consumer durables and others (7 %) sectors as depicted in Figure 1, are key demand drivers of aluminium in the country.



**Figure 1. Sector wise Aluminium consumption in India.**

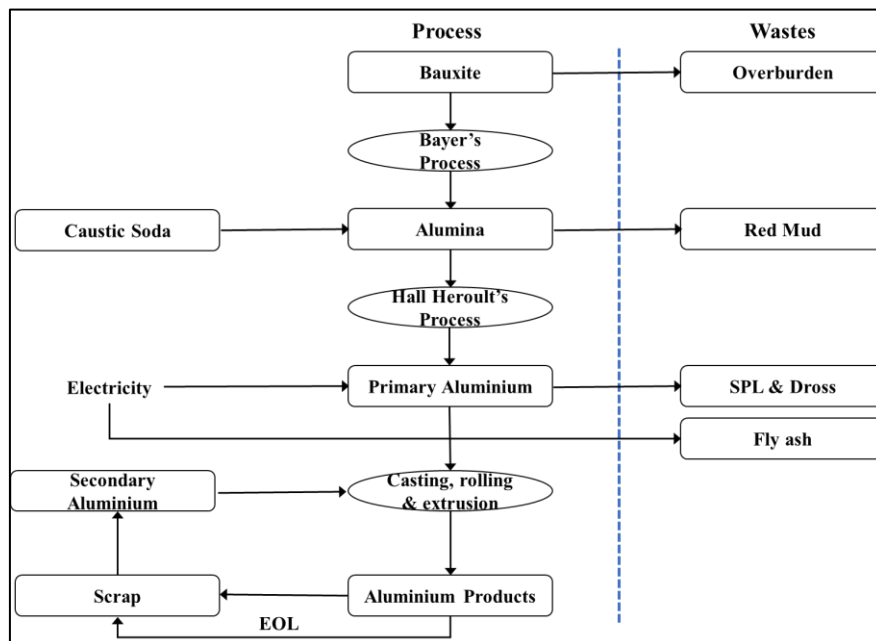
However, the per capita Consumption in India is very low at about 2.5 kg to 2.8 kg compared to the global average of 11 kg. Per capita consumption of aluminium is closely related to Gross Domestic Product (GDP) of a country. India is aiming to become a USD 5 trillion economy by 2024-25 and a strong foundation is being laid to achieve this objective. The ambitious national projects like: Make in India, 100 % rural electrification, FAME (Faster adoption and manufacturing of hybrid and electric vehicle) scheme for switching to electric vehicles, renewable energy, National Infrastructure Pipeline (NIP) along with growth in urbanization will increase the demand for aluminium significantly in the coming years. It is projected that, the demand for aluminium in India will grow to about 7 million tonnes by FY 2030 from the current level of 3.7 million tonnes.

With the increase in demand for aluminium, there will be significant burden on the country’s natural resources. Ores and minerals are non-renewable in nature and hence, with the ever-growing demand, it is imperative to achieve resource efficiency in the processes as well as reuse and recycle the metals that are already in use to conserve natural resources. Worldwide there is a growing recognition for development based on circular economy, which is also reflected in sustainable development goal, to ensure responsible consumption and production. Adaption of the 6Rs principles of reduce, recycle, reuse, recover, redesign and remanufacture will enable the aluminium industry to achieve a robust circular economy.

## 2. Aluminium Production Process

The production of primary aluminium metal starts with bauxite ore, which is composed of hydrated aluminium oxide (40 %-60 %) mixed with silica and iron oxide. Roughly 6.5-7.0 tonne of bauxite is required to produce approximately 2 tonne of alumina and 1 tonne of aluminium. Production of primary aluminium is resource intensive. 1 tonne of aluminium requires about 22 tonne of material resources (coal 15 tonne, bauxite 6 tonne, calcined petroleum coke 0.38 tonne, fuel oil 0.24 tonne, caustic soda 0.22 tonne, coal tar pitch 0.09 tonne, aluminium fluoride 0.02 tonne etc.).

Aluminium production process generates a significant amount of waste. Figure 2 describes the various wastes generated in the aluminium value chain.



**Figure 2. Aluminium production process & Waste Generation.**

The industry produces more waste (solid) than primary metal during its making. About 8-10 tonnes of by-products/wastes [1] such as: overburden, bauxite residue (red mud), fly ash, spent pot liner (SPL), dross etc. are generated for each tonne of aluminium. All these materials have great potential in terms of value-added applications and can contribute significantly in achieving circular economy when extracted or utilized in a viable manner. These wastes not only pose a significant environmental challenge for their disposal but also lock a large amount of untapped economic wealth. At the moment, the emphasis is given on safe disposal of all these wastes. However, time has come to invest in research and development to find alternative solutions to extract valuable materials from these wastes. In short, the primary producers need to consider in finding solutions to these wastes as a part of their mandatory need.

## 3. Waste Management in Aluminium Production Process

The operations for manufacturing of aluminium start from extraction of virgin ore by mining and ends with recycling scrap generated from the end of life of the manufactured products and recycling or disposal of the waste products. Each activity generates some wastes or by-products that can be effectively utilized by the metal industry or by some other industries with active support of primary producers. For the success of circular economy and material resource

efficiency, all such wastes and by-products must find some useful and viable application so that zero waste, a basic objective of resource efficiency, can be achieved across the sector.

The waste generated in the process, current practices of disposal and opportunity for better management in future (efforts towards circular economy) are detailed below with reference to Indian context:

### **3.1 Bauxite Mining – Generation of Overburden and PLK**

During mining of bauxite, materials like overburden (a lateritic material), partially lateritic khondalite (PLK) and kaolinised khondalite rocks are excavated. These low-grade materials are discarded off due to their inferior composition and currently they are being used only for backfilling. These materials have characteristics of high silica and high iron content. Further, bauxite mines have significant quantity of PLK below the bauxite ore, which is not mined now as it is uneconomical for any commercial processing due to higher reactive silica.

However, PLK can be a rich secondary source of alumina having high percentage of alumina (35-45 %) along with  $\text{Fe}_2\text{O}_3$  (10-20 %) and Silica (25-30 %). If an economically viable process can be successfully developed, PLK can be a secondary source for all alumina producers, especially for Indian mines having large quantity of the material. Until today, very small progress has been made in this regard, due to lack of research and availability of commercially viable technology.

At NALCO, studies are in progress in collaborative mode with different institutions and organizations to develop a suitable technology to extract alumina from PLK. Alternate studies are also being carried out for utilization of PLK as a potential and value-added filler material with specific reference to white ceramics and pigments. A scale up study on development of proppant from PLK and fly ash is also under way to establish suitable use of these waste products. Commercial utilization of PLK will lead to huge increase in the resource efficiency of the process and lead to resource conservation.

### **3.2 Alumina Refining – Generation of Bauxite residue**

Alumina is extracted from bauxite through the Bayer process. The aluminous minerals in bauxite are dissolved in a hot solution of caustic soda and lime. Insoluble materials are then separated from the sodium aluminate solution in thickeners and filters. Aluminium hydroxide is precipitated by cooling of the liquid and adding crystal seeds. The precipitate is filtered and washed to remove and recover entrained caustic solution. Aluminium hydroxide is calcined in kilns at temperatures in excess of 960 °C. Free water and water that is chemically combined are removed to produce commercially pure alumina. The process residue, which is otherwise termed as bauxite residue, is then washed and stored in a specially designed pond. The wash water, containing caustic soda, is recycled to the process.

Every tonne of alumina production generates about 1.2 to 1.5 tonne of bauxite residues. Disposal of bauxite residue is a major problem in alumina plants throughout the world due to its high alkalinity and is a potential pollution threat to water and land in close proximity to the alumina refinery plants. Conventional storage in ponds requires vast land, besides the risks of flooding therefrom. Aluminium industries are moving away from storage of the residue in slurry form in ponds to dry stacking, which allows the residue to be stored in higher piles, using less land and eliminating the risk of flooding in the adjacent areas. The typical composition of Bauxite residue is detailed at Table 1.

**Table 1. Typical composition of NALCO's bauxite residue.**

Element	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	CaO	SiO <sub>2</sub>	Na <sub>2</sub> O	Rare Earth Elements (REE)
Wt. %	50-55	15-20	4.3-5.4	1.2-1.6	5.5-6	4.5-4.9	222 ppm

Research for the economic recovery of the components and finding useful applications is a challenge, for which all out efforts are needed. Bauxite residue has a very wide range of applications from building and construction materials to metal recovery. The possibility of extraction of iron, titanium, rare earth elements (REE) (Lanthanides, Cerium, and Scandium, etc.) is being explored worldwide. Despite over 1 000 patents on bauxite residue utilization and many laboratory scale successes, so far industrial utilization is limited to only about 2-4 million tonne, mostly in construction sector (including in cement industry), accounting for less than 3 % of the annual bauxite residue generation.

At NALCO, various studies are in progress to utilize bauxite residue and extract the metal values trapped in it. Laboratory study was undertaken for extraction of iron from bauxite residue. From the tests carried out, it was found that the iron mineral inside bauxite residue is mostly limonite and goethite that have weak magnetic properties unlike bauxite residue of some of other plants, where it exists in the form of hematite. Using high gradient pulsating two phase magnetic separation technology, the grade of iron concentrate reaches 53-55 % Fe (from 30 % Fe<sub>2</sub>O<sub>3</sub> in bauxite residue) with a recovery of over 30% making the process viable for bauxite with diasporic alumina and using high temperature digestion. In case of NALCO bauxite residue, although the process yielded Fe of around 45%, the recovery rate was only about 20%, thus making it unviable [2].

In another pilot scale study, red mud, coal and binder (bentonite) are mixed after proportioning and the mix is converted into pellets. The pellets are directly reduced in rotary hearth furnace with additives like limestone. Metallic iron (Hot metal/Pig metal) could be obtained through smelting separation of the reduced material. From one tonne of dry Red mud, about 0.3378 tonne of iron (hot metal/pig iron) of 95.46 % (As Fe) and 0.4166 tonne of Smelting slag is obtained. It is possible to convert the smelting slag to rockwool/ceramic fibre/ceramic tiles/ceramic bricks. Significant utilization of red mud could be achieved in the pilot scale study with zero discharge. However, high amount heat energy is required in the rotary hearth furnace and thereafter during the smelter separation, which can be a deterrent in development of a commercially successful process.

Concentration of the REEs varies between 200-400 ppm in the residue, where the scandium concentration is between 30-70 ppm, lanthanum and cerium are also present in the range 50-60 ppm. It is a valuable secondary resource for critical and strategic use. Appropriate leaching and suitable separation scheme are needed for selective recovery of valuable rare earths elements, which are in great demand these days. Thus, a consolidated approach is under way for complete utilization of bauxite residue with extraction of metal values including REE and address the economic challenges.

R&D studies have also been carried out for potential bulk use in construction field like use of residue in bricks, blocks and chips, light weight foamed bricks, glass ceramic tiles, geo-polymer concrete etc. Bauxite residue is also finding application in the cement industry but the economic aspect of transporting the bauxite residue to the consumers is not encouraging at the moment and policy intervention in terms of low freight is needed.

### 3.3 Aluminium Smelting – Generation of Spent Pot Lining and Dross

The Primary aluminium smelting process is based on the Hall-Héroult electrolysis process. Alumina is dissolved in an electrolytic bath of molten cryolite (sodium aluminium fluoride,  $\text{Na}_3\text{AlF}_6$ ) in a large carbon or graphite lined steel “pot” and electric current passed through the electrolyte at low voltage, but very high current - typically in the range of 200 to 500 kilo amperes in the latest generation pots. The electric current flows between the carbon anode (made of petroleum coke and pitch) and the cathode (formed by the thick carbon or graphite lining of the pot). Molten aluminium is deposited at the bottom of the pot and is siphoned off periodically, which is then cast into different semi-products. This process generates some hazardous wastes, which must be managed and disposed properly to safeguard the environment. However, these wastes also have the potential to be used as input or secondary resources in other industries.

#### 3.3.1 Spent pot lining (SPL)

During pot operation, carbon lining gradually deteriorates with slow penetration of molten melt. As the lining gets deteriorated, the continued operation of the pots/cells demands replacement of pot- lining. The pot lining, which is removed from the pots, is termed as spent pot lining. SPL is classified as hazardous waste mainly due to presence of toxic fluoride and cyanide that are leachable in water. Transportation, storage and final disposal of SPL are thus subject to tight environmental regulations. The de-lined material after the end of pot life consists of carbon portion known as first cut and refractory portion called second cut. Typical composition of Carbon portion of spent pot lining is furnished at Table 2.

**Table 2. Typical composition carbon portion of spent pot lining.**

Element	carbon	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	Na	fluoride	cyanide
Content	60-75 %	1-2 %	7-8 %	1-2 %	7-11 %	4-7 %	100-250 ppm

It is estimated that 20-40 kg SPL is generated per tonne of aluminium production (depending on the technology adopted). This translates to 1-2 million tonne of SPL generation worldwide per annum.

The utilization process as prescribed by regulatory board in India [3], involves processing of SPL for cyanide destruction in order to proceed for its further utilization. The cyanide free SPL is fed directly to the rotary hydro mist reactor along with lime and controlled water mist to convert the leachable fluoride into non-leachable  $\text{CaF}_2$ . Resultant mass from the reactor is collected and packed in bags as finished product termed as carbon mineral fuel, which can be used in cement kiln as fuel material. The carbon mineral should meet the threshold limits of toxicity characteristic prescribed by the regulatory board.

At NALCO, collaborative studies [4] are in progress to develop a process to produce carbon mineral and other value-added products from SPL meeting regulatory norms in order to use it as mineralizer for fuel materials in cement industries or recycling into production of anode or ramming paste in Smelter Plants.

#### 3.3.2 Dross

Dross is a by-product arising from oxidation of hot aluminium metal during its transportation as well as during storage in melting and holding furnaces. Dross is highly heterogeneous in terms of chemical composition and physical features. The primary dross contains alumina ( $\text{Al}_2\text{O}_3$ ), aluminium nitride (AlN) and entrapped metallic aluminium.

At NALCO, the generated unalloyed dross is almost fully utilized. It is collected and segregated to remove the metallic aluminium globules, which constitutes around 30% of the dross processed [5]. The 70 % residual dross after segregation is reused as anode covering material along with alumina and bath material in the pot line. The metallic aluminium globules is recycled into the pots to convert it into metal. The alpha alumina content in the covering material stays well within the mandated limits even after using the alumina from dross.

There is a market potential for the left-out aluminium dross as a source for refractory aggregates, production of alum etc. R&D Studies are in progress for removal of aluminium from the unutilized dross through a nano technology-based process and making composites from the residual dross.

### **3.4 Power Generation – generation of fly ash**

Most of the Aluminium Smelters have their own captive power plants (CPP) and all of them are coal-based power plants in India. Indian coal has high ash content, which results in huge generation of fly ash in the process of power generation. In fact, fly ash utilization has become an important determinant factor in the decision-making process for any brownfield/ greenfield smelter plant based on coal-based power plant in recent times.

Fly ash is a by-product from burning pulverized coal in thermal power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse, cool and solidify to form fly ash. Fly ash is pozzolanic, a substance containing aluminous and siliceous material that forms cement in the presence of water. When mixed with lime and water, it forms compound similar to Portland cement. This makes fly ash suitable as a prime material in blended cement, tiles, blocks etc. Its chemical composition shows that it contains significant amounts of alumina along with silica.

At NALCO, the coal used is of low-grade having ash content of the order of 30-45 %. Thus, large quantity of coal ash amounting to nearly 5 000 to 6 000 tonne is generated per day. As per the guidelines of the regulatory authority in the country, 100 % fly ash is required to be utilized in ecofriendly manner as prescribed by the statutory authority. The Company is working to find out alternative applications for use of fly ash. Fabrication and trial of commercial use of a highly pervious concrete material from fly ash has been completed recently [6]. Also scale-up development and production of wear resistant ceramic tiles and investigation study on recovery of alumina from fly ash [7] are in progress.

## **4. Conclusion**

The comprehensive utilization of wastes from aluminium industry is still a worldwide problem. Resource conservation, waste minimization and pollution prevention should be the guiding principles of sustainable industrial growth. Because of the limitations of viable technology, a large amount of solid waste generated from aluminium industries has not been commercially exploited effectively. Therefore, it is extremely important to develop technology for the recovery of valuables from wastes generated in aluminium industry with worldwide collaborative efforts for their utilization.

NALCO, as a responsible corporate entity, is making all efforts to manage the wastes in an effective manner so as not to sully the surrounding environment. However, the future is challenging and there is a crying need to minimize waste generation by adopting better and improved technology, promote recovery of valuable metals, optimize complex processes and develop new and viable processes to achieve and adopt circular economy and sustainable development.

## 5. References

1. Draft Strategy on Aluminium Resource Efficiency, *NITI Aayog report*, December 2018.
2. Iron extraction from bauxite residue, *NALCO collaborative study*, September 2016.
3. Utilization of Spent Pot Lining (SPL) generated from Primary Aluminium Smelting Industries (Revised), *Central Pollution Control Board (Ministry of Environment, Forest & Climate Change, Government of India)*, March 2021.
4. Bench Scale Studies for Treatment and Utilization of Carbon Portion of Aluminium Spent Pot-Liner (SPL): Recovery of Carbon- Sodium and Fluorine Values, *NALCO study with JNARDDC*, 2014.
5. Recycling of dross in Rodding shop, *NALCO Project report*, December 2018.
6. Fabrication and commercialization of a highly pervious concrete material from fly ash, *NALCO Study report*, August 2019.
7. Recovery of alumina from NALCO fly ash: modifications and validation of flow sheet, *NALCO Study report*, December 2020.