Sustainability of the Indian Aluminium Industry: Challenges and Opportunities

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Abstract

Sustainability is at the core of economic viability of global aluminium industry today. The sustainability model being discussed, is based on a three pronged approach of Responsible Stewardship, Stakeholder Engagement and Future Proofing. The key emphasis is on balanced business performance on 3Ps - People, Planet and Profit, through adoption of sustainable business practices. Primary aluminium production processes are energy intensive and usually associated with high level of fossil fuel consumption and thereby, high greenhouse gas emissions. An improved energy efficiency is essential for the aluminium industry, both from an economic and environmental point of view. Production of this metal is also associated with consumption of large volume of natural resources, bauxite ore and coal and generation of large quantities of solid wastes. In India, about 5 - 6 tonnes of bauxite ore and 10 - 14 tonnes of coal are consumed for production of 1 tonne of aluminium. Also, the process is associated with generation of about 2 - 3 tonnes of bauxite residue and 2 - 5 tonnes of coal ash per tonne of aluminium production. The other solid wastes generated are spent pot liners, aluminium dross etc. Conservation of these natural resources and safe disposal and management of such large volume of wastes are the major challenges to the industry. At the same time, the industry should seriously explore converting these challenges into opportunities through creation of wealth from the wastes. Other sustainability challenges include land management, community service, biodiversity, water conservation and new product and application developments. As a part of future proofing exercise, Hindalco has identified “Energy & Emissions” and “Value from Wastes” as the two major thrust areas. In this paper, some of the technology initiatives undertaken at Hindalco for addressing these issues will also be discussed.

Keywords: Sustainability, primary aluminium, energy and emissions, solid wastes, value from wastes.

1. Introduction

The Indian Aluminium industry is rapidly expanding in both primary metal and downstream sectors. With the continuing trend of economic growth, the demand and consumption of aluminium is expected to increase. Higher consumption levels are expected from building and infrastructure, transportation, automotive and roadways, railways, energy, defence and aerospace, packaging; and consumable durables. Unlike other metals, aluminium has high strength to weight ratio and density, which is $1/3^{rd}$ that of steel. It is resistant to weather, atmospheric gases and liquids; its impact absorption and high elasticity is an added advantage in structures; is highly durable; is non-combustible and is a good thermal conductor. Further, 100 % recyclability of the metal makes it one of the most sustainable material for the future. India’s per capita consumption of aluminium per year is too low at 1.8 kg when compared with the developed nations in North America & Europe (25 kg to 30 kg); Japan (15 kg); Taiwan (10 kg) and China (17 kg) while the world average is 8 kg. India with large deposits of high quality bauxite ore (primary source for aluminium), amounting to almost 5 per cent of the world’s reserves, totaling about 3 billion tons, has therefore, enormous growth opportunities.

The future world is strained with many challenges – the burgeoning population, climate change and threats to water and food security. With India poised to be the most populous country by 2030, the strain of increasing demands is being felt in the country with increased pollution due to rapid urbanization and industrialization, loss of biodiversity, growing water stress and demand for more electricity. This is very much applicable to the aluminium industry which heavily depends on exploitation of natural resources including bauxite ores, coal and water, affects the environment with disposal of large volume of solid wastes and effluents generated and various emissions, including greenhouse gases (GHG) and finally demands long-term engagement and commitment with most of its stakeholders. Thus, it is imperative to adopt sustainable solutions and development by the industry not just for the planet, but also businesses as they cannot survive without the planet.

2. Sustainability Framework

Sustainability is an ability or capacity of something to be maintained or to sustain itself. It is about taking what we need to live now, without jeopardising the potential for people in the future to meet their needs. A robust Framework is essential for ensuring sustainability of any business. The Aditya Birla Group (ABG) sustainability model discussed in this paper focuses on three cores, namely, Responsible Stewardship, Stakeholder Engagement and Future Proofing (Figure 1).

Responsible Stewardship is to create a Framework to promote sound practices, encourage transparency and accountability, and contribute to positive development impacts. The Responsible Stewardship encompasses aspects of environment, health, safety, security, human rights, product stewardship and sustainable infrastructure. The Framework comprises of Code of Global Business Ethics & Compliance Standards, Sustainability Statement and Policies, Management Standards, Technical Standards, Guidance Notes and IT system for data management.

Stakeholder Engagement is needed not only to inform the stakeholders the various things happening in and around the business but also to be engaged with them in the entire business process for capturing their current as well as future needs and to gather knowledge to understand how fast things will change and where disruptions will occur.

Future Proofing is to deal with the externalities that can pose a threat to our existence. It is to plan and initiate actions proactively so as to create and share stakeholder value for staying ahead of the Major Trend Curves – Roadmaps for Products, Energy and Climate Change, Water,

Waste, Human Rights, Health & Safety, Biodiversity, Supply-Chain, New Businesses etc.
Sustainability performance could be measured in terms of business impacts on three well established parameters – People, Planet and Profit. While the impacts on profit or economy and to some extent on People or society is easily visible, the same on Planet or Environment is not easily measurable, at least on short time horizons. This factor is therefore become very critical, especially for manufacturing industry like aluminium which is established with a long term strategy. A systematic study is therefore essential to identify the critical impacts the industry create on environment and develop an action plan to mitigate these effect well in time.

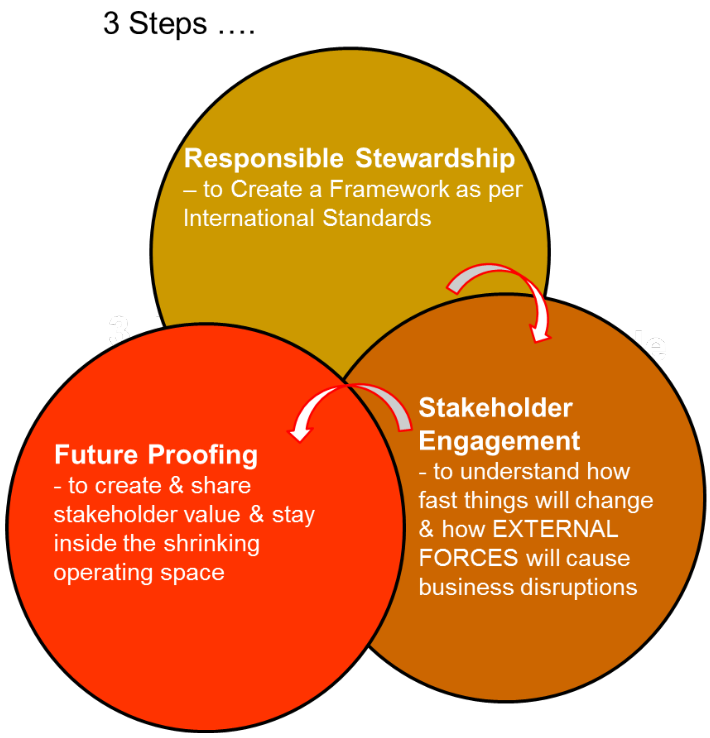

Figure 1. Sustainability Model – 3 steps approach.

3. Responsible Stewardship – Environmental Impacts of a Typical Indian Aluminium Plant (LCA Study)

Life Cycle Assessment (LCA) study was undertaken to quantify the life cycle environmental impacts for producing one tonne of primary aluminium ingot and one tonne of aluminium cold rolled strip product [1]. One of the plants of Hindalco Industries limited, India, having the oldest technology of aluminium production, was selected for the study. The objective was to understand the extreme case of environmental impact from aluminium making in India. Thinkstep Sustainability Solutions Pvt Limited, a subsidiary of Thinkstep AG, Germany had been entrusted to carry out the LCA study for the two aluminium products using GaBi software and ISO 14040/44 standards. The system boundary and geographical scope covering Cradle to Gate included bauxite mining, transport of bauxite by truck/rail, alumina refining by the Bayer process, production of pre-baked anodes, aluminium smelting by the Hall-Héroult process, aluminium casting, scalping, hot rolling, cold rolling, cogeneration plant, effluent / sewage / waste treatment plants at site and coal based electricity generation at captive power plant. Environmental impacts were assessed in terms of global warming potential (GWP), acidification potential (AP), primary energy demand (PED), photochemical ozone creation potential (POCP), abiotic resource depletion (ADP) and ozone depletion potential (ODP).

Figure 2 summarises the impacts of the various processes on the environmental indicators. The results of the study indicated that contribution of mining stage relative to other two stages alumina refining and smelting are negligible. The contribution of aluminium smelting or the electrolysis process to various environmental impact indicators was the highest, varied from 6 – 74 %. Alumina production was the next in terms of its impact on environment. During electrolysis process, electricity played predominant role with contribution of 24 % - 100 % for all the indicators. Some of the hot spots in the alumina refining were combustion of coal and heavy fuel oil (HFO), electricity consumption and sodium hydroxide consumption. The total global warming potential for 1 t of cold rolled strip was 25.25 t CO_2 equivalent, with major contribution shared by electricity consumption in refining and smelting, process emission due to perfluorocarbons CF_4 and C_2F_6 caused by anode effects, anode production and combustion of fuels such as coal and HFO. Primary energy demand was 249 563 MJ with major contribution from consumption of electricity and fossil fuels. Total acidification potential was 42.1 kg SO_2 equivalent which is mostly contributed by electricity production and SO_2 and NO_x emissions during alumina refining, anode production and electrolysis process. Eutrophication potential was 4.01 kg-phosphate equivalent, wherein major contributor is electricity production. Photochemical ozone creation potential is 3.89 kg-ethene equivalent, wherein major contribution caused by NO_x emission during electricity production and during electrolysis process.

The key environmental concerns emerged from the LCA study were:

- High energy consumption (as high as 250 GJ/t cold rolled strip)
- High GHG Emissions (as high as 25.25 t CO_2equivalent / t cold rolled strip)
- Large raw material requirement (~ 5.5 t bauxite ore and ~ 12 t coal)
- Large solid waste/by-products generated: ~ 3.5 t bauxite residue, ~ 4 t fly ash and aluminium dross, Spent Pot Liner (SPL), etc.
- Large fresh water requirement (as high as 17 m^3/t cold rolled strip)

To address these issues various improvement scenarios were conceptualized and scenario analysis was carried using the LCA tool to quantify the potential benefits from these ideas:

- Moving towards Greener Energy Mix - Comparison with average European aluminium smelter performance using data from the European Aluminium Association (EAA) – If the electricity and fuel mix are maintained the same (like 50 % of electricity from hydro-power), the total normalized GWP for 1 t cold rolled strip for Hindalco was 8.68 t in comparison to 8.75 t CO_2 equivalent for average EAA condition [2 – 3].
- In the electricity mix, substitution of captive coal based electricity with 10 % renewable energy (5 % solar and 5 % wind) resulted in reduction of environmental impacts to the tune of 2 - 8 %. The highest saving was observed in the acidification potential and global warming potential reduced from 25 250 kg to 23 335 kg CO_2 per t of aluminium cold rolled strip.
- Reduction of Electricity consumption in smelting operation from 14.5 MWh/t liquid metal to 13.5 MWh/t leads to substantial reduction of all the impact categories in the range of 4 – 6 %. The global warming potential reduced from 25 250 kg CO_2 to 24 065 kg CO_2 per tonne of aluminium cold rolled strip.
- If the extractable alumina content in Bauxite ore is increased from 38 to 43 %, environmental impacts could be reduced to the tune of 5 – 8 % with highest savings on abiotic resource depletion potential.
- Utilization of red mud by 50 % as substitute for clinker in cement kiln results in reduction of environmental impacts to the tune of 0.5 – 2 %. The highest savings was observed in the acidification potential and ozone layer depletion potential. The global warming potential reduced to 25 225 kg CO_2 from 25 250 kg CO_2 per tonne of aluminium cold rolled strip.
- Similar environmental benefits (0.5 - 2.0 %) are expected when 70 % of the fly ash generated is utilized as alternative raw material in cement kiln substituting clinker. The highest savings was observed in the acidification potential and ozone layer depletion potential. The global warming potential reduced to 25 197 kg CO_2 from 25 250 kg CO_2 per tonne of aluminium cold rolled strip.

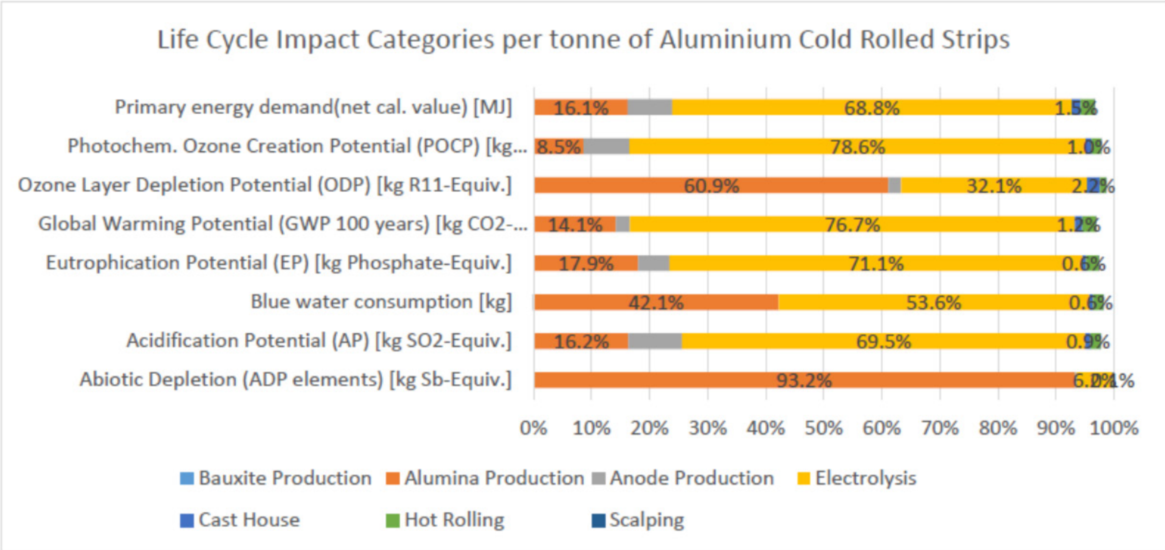

Figure 2. Life cycle impact categories per tonne of aluminium cold rolled strip.

4. Future Proofing: Hindalco Experience on Mitigating Environmental Challenges

The LCA study clearly established the major environmental issues associated with Indian Aluminium Industry:

- High energy consumption with associated high global warming potential
- Handling and disposal of huge quantity of solid wastes generated
- Consumption of large volume of raw materials (bauxite ore, coal etc)
- Requirement of large quantity of fresh water.

Technology could play an important role in mitigating some of these areas. Based on detailed background study and inputs received from all stakeholders, two Technology Thrust Areas were identified for future proofing of business at Hindalco These thrust areas are (a) Energy and Emissions and (b) Value from Wastes and being discussed in detail in the following sections.

4.1. Reduce Energy Consumption and GHG Emissions

4.1.1. Challenges in India

Energy consumption in Indian aluminium industry has following unique attributes, as compared to other energy-intensive manufacturing industries like iron & steel; cement etc.: (a) about 8 0-90 % of energy is used in form of electricity (b) about 80 % of energy consumption in an integrated aluminium company is in the aluminium smelters including its captive power generation plant (c) electricity consumed by the aluminium plants in India is fossil fuel based and captive generation [4]. Since the operation of aluminium smelters needs steady and stable supply of electricity, potential of captive power plant based on renewable energy (solar/wind) is very limited.
India's move towards low carbon economy through National Action Plan on Climate Change and its various missions, is impacting the energy sourcing and cost for aluminum industry, through:

a. Energy efficiency enhancement measures under Perform Achieve and Trade (PAT) scheme;

b. Procuring renewable power or renewable energy certificates (REC) under Renewable Power Purchase Obligation (RPO),
c. Increase clean coal cess from Rs 200 / t to Rs 400 / t.

In addition to the above, cost of captive power generation is further increased due to: (i) stringent air emission norms (SO_x, NO_x, mercury); and (ii) increased electricity duty for captive power plants in some of the states. This necessitates the need for more energy savings initiatives and innovations for increased use of renewable energy in the aluminium plants in India.

4.1.2 Hindalco Strategy on Energy and Emissions

Hindalco Industries Ltd, is the metals flagship company of the Indian conglomerate Aditya Birla Group (ABG), and an industry leader in aluminium and copper. Hindalco's Indian operation has an installed capacity of about 3 mtpa alumina, 1.33 mtpa primary aluminium metal and 0.38 mtpa flat rolled products with more than 3000 MW coal based power generation. The Technology adopted at Hindalco is more or less similar to the other aluminium companies in India. The company has achieved significant growth in recent years. Figures 3 - 4 show the gross energy and GHG emission trends for the company. On an average, about 210 GJ energy is consumed per tonne of hot metal produced at Hindalco. The corresponding GHG emission is about 22 tonnes per tonne of hot metal. On cost front, more than 30 % of the cost of aluminium is energy cost.

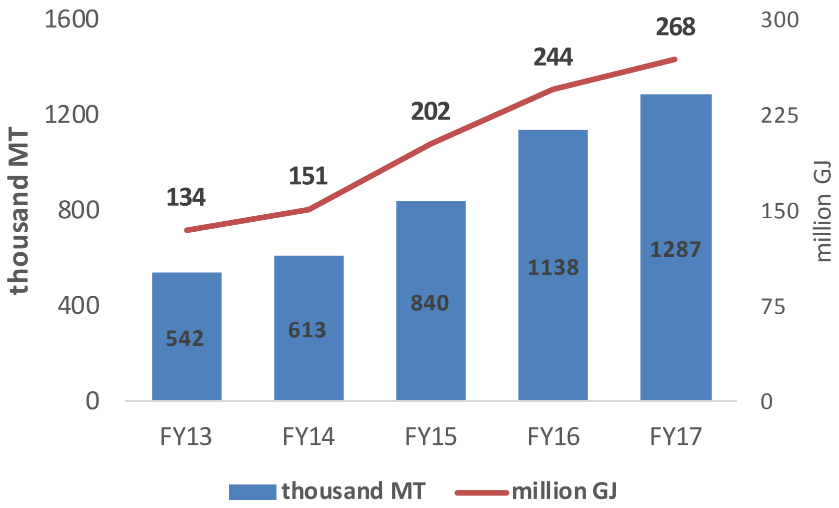

Figure 3. Hindalco's hot metal production and total energy consumption trend.

Hindalco long-term strategy for addressing the Energy & Emission challenges are:

- Adapt energy-efficient technologies for growth
- Breakthrough improvement of existing processes
- Accelerate pace on continuous improvement projects on energy saving
- Explore use of renewable energy in the plants.

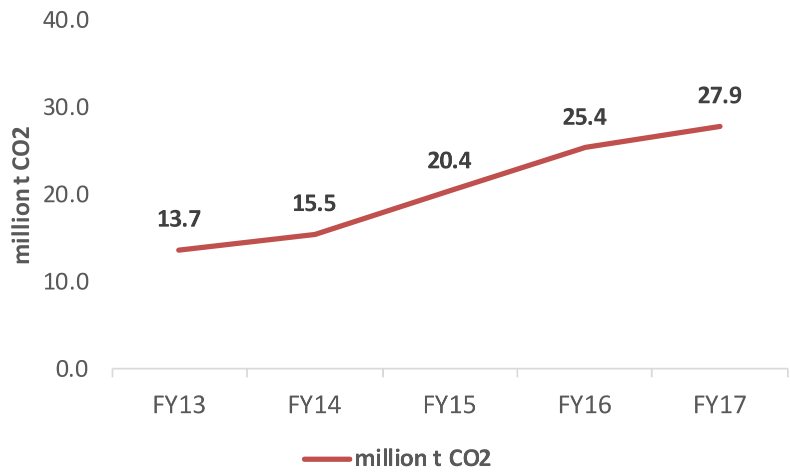

Figure 4. GHG Emission trend in Hindalco.

4.1.2.1. Growth with Energy-Efficient Technologies

Figures 5 – 6 show the smelting and refining technologies adopted over time. AP 36 smelting technology has been implemented in the new plants at Aditya and Mahan along with power plant with larger capacity boilers (150 MW). Also, the new bauxite refinery at Utkal has implemented the latest Rio-Tinto Alcan Bayer's Process technology. This has resulted a significant drop in specific energy consumption compared to the older technologies, as shown in the Figures.

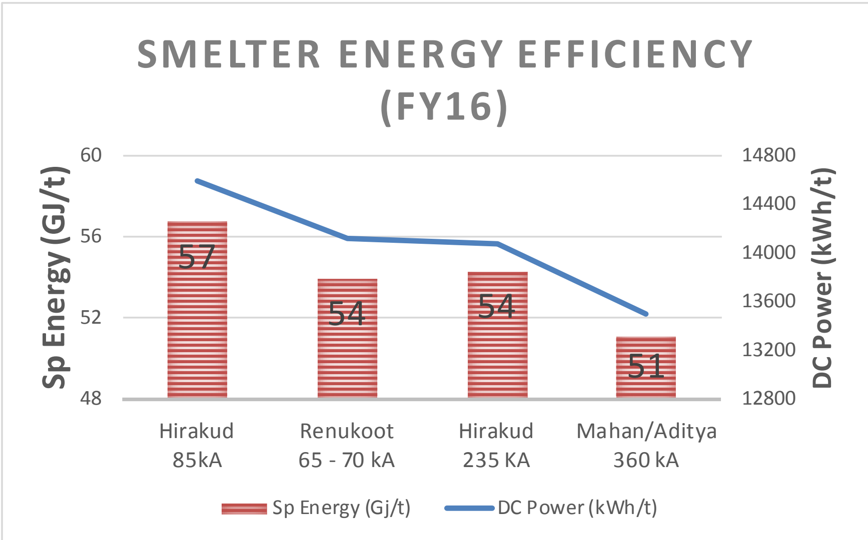

Figure 5. Energy efficiency for diffrent smelter technologies.

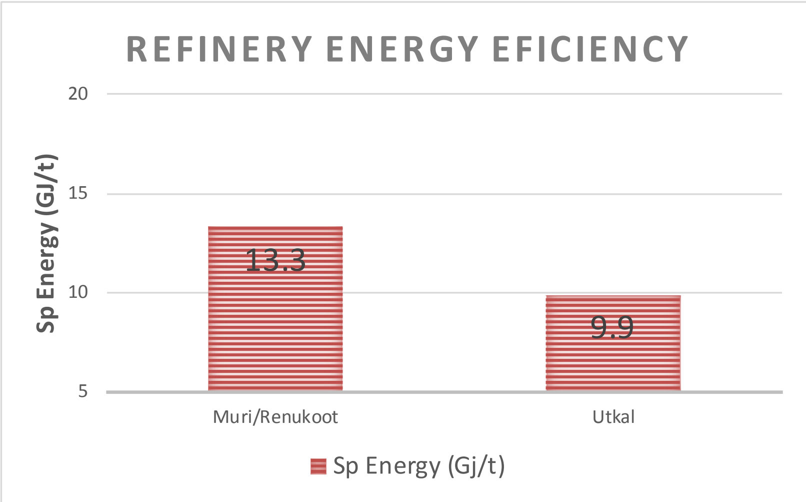

Figure 6. Energy efficiency for different bauxite ore refining technologies.

4.1.2.2. Breakthrough Improvement of Existing Processes

The key focus is to develop technologies for up-gradation of the existing smelter technologies of Renukoot and Hirakud plant. Renukoot plant is based on vintage Kaiser Technology of 65 - 70 kA smelter pots. Hirakud has 85 kA pots based on old GAMI technology. The power consumption in these plants are in the range of 14 200 - 14 600 kWh/t. Studies were conducted to modify the Renukoot pots for reducing the power consumption by 1000 kWh/t. Based on a collaborative work with KAN-NAK, a new technology called Gemini was developed to up-grade the pots to 75 - 80 kA capacity with target power consumption of about 13 200 kWh/t. A schematic of the improvement initiatives is shown in Figure 7.

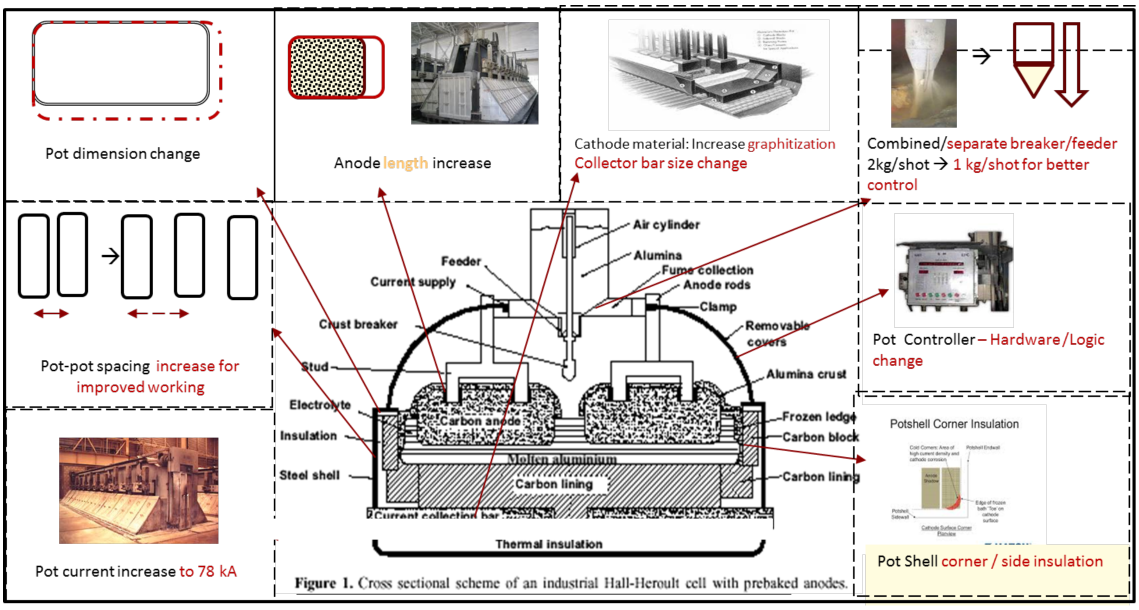

Figure 7. Schematic of Gemini Smelter Pot developed at Hindalco.

Similar actions have also been initiated for developing a technology ”Galaxy” for improving the performnace of the 85 kA pots of Hirakud. The key focus areas are: (a) Busbar configuration/Design modification for improving electromagnetics and magnetohydrodynamics of cell and reducing external voltage drop (b) Improve anode assembly, like, joints, yoke and stub design, alignment etc (c) Improve cell lining including better cathode material and copper-insert collector bar for reducing voltage drop across cathode and anode-cathode distance. All these initiatives are expected to reduce the power consumption in the cell by about 1 000 kWh/t Al. Actions have also been initiated to improve the energy efficiency of the new process at Mahan and Aditya

4.1.2.3. Continuous Improvement Projects on Energy Saving

PAT scheme in India is to promote energy conservation and Incentive for good performance. Under this scheme, aluminium industry was included in the list of 8 energy intensive sectors identified under PAT Cycle-1 (2014 - 2015). Hindalco was given with a target of achieving 5.7 % improvement in specific energy consumption from its baseline performance. To achieve this, each Unit had identified energy savings opportunities and initiated projects not only to achieve the PAT target but also to exceed the same. Some of the improvement areas looked into are listed below:

- FRP blades in Cooling Tower
- Rationalization of motor, pump and fan capacities
- Line/transformer loss reduction by power factor improvement
- Translucent roofing sheet/sun pipe light, energy efficient LED lights, etc.
- Optimizing pot voltage in smelter
- Combustion efficiency improvement and loss reduction in Furnaces
- Compressed Air system efficiency improvement
- Efficiency improvement in Boilers
- Auxiliary power reduction through automation.

All these efforts led to a decrease in specific energy consumption by 7 % which helped not only in meeting the PAT Cycle 1 target but also earned e-certificate credit worth Rs 420 million for the company. To maintain the momentum, PAT cycle 2 has been initiated which has set a target of 4.7 % decrease in specific energy consumption for the company in 2018 - 2019 taking 2014 - 2015 performance as the base.

4.1.2.4. Green Energy – Renewable Energy Projects

Other than energy saving initiatives, the key driver for reducing GHG emissions is the use of renewable energy in the energy mix. To accelerate this, RPO scheme has been implemented by Government of India. While the idea is in the right direction, producing and utilizing renewable energy at the rate of 7 – 10 % of total energy consumption in the Indian aluminium smelters, is difficult. Aluminium smelter requires continuous and steady supply of power. Renewable energy is infirm in nature and its presence beyond a certain limit makes the power system unstable and unreliable. Neither the grid nor the captive power plants can sustain or support excursions due to natural phenomenon. Any power black-out beyond four hours leads to solidification of hot metal and damage of the pot lines. There are constraints in country's power transmission and distribution network and inter-state transmission of high quantum of renewable power is not yet favorable. To accommodate solar or wind energy in the existing plants, the thermal generation has to be brought down during the day and also varied continuously with the change in intensity of sun shine or wind flow. This will lead to drop in power plant efficiency due to continuous change in the plant load factor (PLF) and idle asset due less capacity utilization.

In spite of these challenges, renewable energy will play an important role in addressing the global warming potential associated with the industry. Hindalco has adopted a strategy in utilizing renewable energy for meeting the energy needs of the auxiliary units and other units which are not so critical from operational safety point of view. The first project for Hindalco was 1 MW solar plant at Alupuram, Cochin, commissioned in March 2016 (Figure 8). Suvas 4 MW Hydel project is in progress. A 30 MW solar plant is being built at Aditya, Odisha. At the same time feasibility of a number of renewable projects (Solar and wind) at Mahan, Dahej, Belgaum, Utkal, Mines, Hirakud is being studied. Considering the total amount of electricity consumed in the plant and the RE capacity needed for meeting RPO obligations, these efforts still may not be adequate. The applicability of RPO scheme for Indian aluminum industry, therefore, needs further consideration for the sustainability of the industry.

Figure 8. Solar PV Power Plant of 1.15 MW capacity at Alupuram, Kerala.

4.1.3 Energy Trend at Hindalco

Considering the importance of energy consumption and emissions, the company had taken an aspiring target for reduction of specific energy consumption and emissions by 35 % by 2030 (2005 as base). As shown in Figure 9, about 21.5 % reduction in the specific energy consumption could be achieved till date. Also, the ideas generated today may lead to a reduction up to 27 % by 2025. More ideas are being generated to achieve the target of 35 % by 2035.

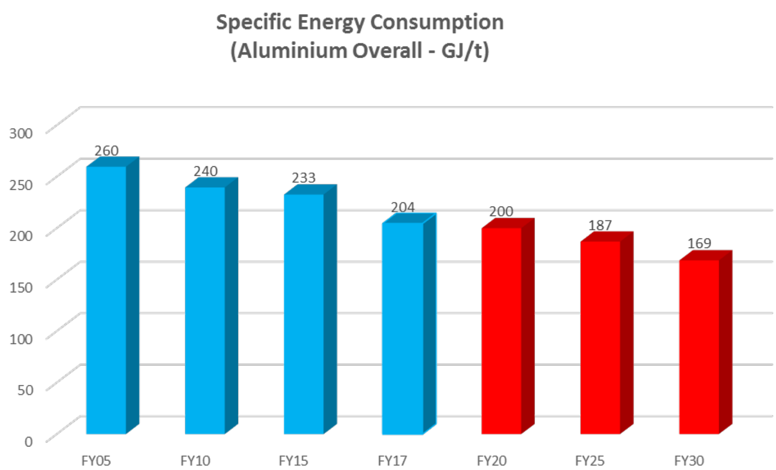

Figure 9. Long-term plan for reduction of specific energy consumption at Hindalco.

4.2. Generate Value from Wastes

The Metals and Mining sector is hugely dependent on availability of raw materials which are generally finite natural resources, like ores. In terms of aluminium, the challenge of availability of raw materials is further compounded, with the increasing demand and consumption of aluminium especially as the world becomes more technology advanced. As a future-proof strategy, we are looking at moving towards a circular economy and derive optimal value from the waste generated.

The major solid wastes generated during aluminium production are bauxite residue and fly ash. In India, about 5 - 6 tonnes of bauxite ore and 10 - 14 tonnes of coal are consumed for production of 1 tonne of aluminium. Also, the process is associated with generation of about 2 - 3 tonnes of bauxite residue and 2 - 5 tonnes of coal ash per tonne of aluminium production. The other solid wastes generated are spent pot liners, aluminium dross etc. Conservation of these natural resources and safe disposal and management of such large volume of wastes are the major challenges to the industry. At the same time, the industry should seriously explore converting these challenges into opportunities through creation of wealth from the wastes [5 – 6].

4.2.1. Bauxite Residue

4.2.1.1. Characterization of Bauxite Residue and Challenges

Bauxite Residue (BR) is a byproduct generated from the Bayer process used for producing alumina hydrate from bauxites. Amount of bauxite residue generated is dependent on the quality of bauxite in terms of its alumina content and also the processing technology used along with the extraction efficiency across the refineries. The quantity of bauxite residue generated at the refineries varies from 1 - 2 t of BR / t Al_2O_3 produced.

Hindalco produces about 3.0 mtpa of alumina through its refineries at Belgaum, Muri, Renukoot and Utkal using the Bayer process. The total amount of bauxite residue generated through these refineries is about 4.5 mtpa. All the refineries in the world including those at Hindalco store the dry bauxite residue at around 65 – 70 % solid consistency in bauxite residue disposal areas (BRDA's) and the only bulk source of application being the cement industries.

The major constituents of bauxite residue are Fe_2O_3, Al_2O_3 and TiO_2 along with minor quantities of SiO_2 and Na_2O content. The Fe_2O_3 content in bauxite residue consists of Hematite and Goethite phases. The Al_2O_3 content in bauxite residue is dependent upon the overall extraction efficiency across the alumina refineries, which varies from 94 – 96 %. The Al_2O_3 content in bauxite residue is mainly present in the form of gibbsite and boehmite depending upon whether the digestion technology used is low temperature or high temperature digestion. Another important constituent of bauxite residue which has a potential impact on the use of bauxite residue in different applications is the alkali, i.e., Na_2O content. The higher the Na_2O content in bauxite residue the more difficult it is to use the residue in various applications. Hence in order to increase the use of bauxite residue in different applications it is essential to reduce the Na_2O content.

4.2.1.2. Use in Cement Plants

Chemical and mineralogical analysis of bauxite residue indicates that its composition is quite compatible with the cement matrix. The residue is, therefore, considered as a raw mix component in the manufacture of ordinary Portland cements (OPC). Bauxite residue is used in two ways, either in the production of ordinary Portland cement as a source of iron oxide or alumina, or in the raw mix of special cements.

Moisture and excess alkali content in bauxite residue is not desirable for cement application. Implementation of pressure filters has helped in reducing the moisture and alkali content. Also, a process of neutralization could reduce the pH of bauxite residue thereby enabling its safe disposal and increased usage in cement industries. A Process for neutralization of bauxite residue using a combination of CO_2 gas and H_2SO_4 has been established.

A mechano-treatment process has also been developed to reduce the alkali loss in bauxite residue. Mechanical activation is a process in which mechanical energy is utilized to increase the chemical reactivity of a system. Through this process the soda and or alumina content of BR get solubilized and removed. Studies conducted with bauxite residue at varying lime charges, attrition times and % solids show a soda recovery of about 47 % from bauxite residue after attrition.

At present, 3 - 3.5 % of bauxite residue is being used in the mix for the production of OPC. OPC prepared from this clinker conformed to the requirements of three Indian Standard Specifications for 33, 43 and 53 grade of OPC. All these efforts have led to an increase in bauxite residue utilization from around 4.2 % in full year 2016 to 8.7 % in full year 2017 at Hindalco.

4.2.2. Application of Fly Ash and Bauxite Residue as Construction Material

The acute shortage of the natural resources for infrastructure development in one hand and, the continued production of industrial by-products on the other, are of great concern to the present society. The coal ash coming out of the thermal power plants, bauxite residue from alumina industry, and different slags from metal industries have found many applications as aggregates, admixtures, pozzolanic substitute, manufacturing of bricks, tiles and ceramics, resource recovery, structural fill material in embankment and mines and environmental clean-up of industrial effluents and flue gases. Despite of these many application potential, most of the by-products are getting accumulated at various industrial premises forming 'manmade mountains'. This thought provoked the researchers to come up with more sustained strategies for bulk consumption of these materials. In collaboration with IIT Bombay, India, an attempt is being made to explore few potential applications, such as, marine clay stabilization, geopolymer road construction, mine backfilling etc., by establishing a synergy among various industrial by-products.

4.2.2.1. Marine Clay Stabilization

The infrastructure development on challenging soils requires a lot of engineering skills. Under consolidated marine deposits are the one such soils that undergo excessive consolidation settlements and exhibits lower shear strength under the application of external loading. Hence, their stabilization, before infrastructure development, becomes utmost important. However, many a times the sites with such deposits are inaccessible due to soft and sensitive nature of the clays and sediments. Conventional techniques of stabilization, such as, perforated vertical drains, chemical grouting etc., find difficulty in achieving the desired objectives. A new method has, therefore, been proposed for in-situ stabilization of marine deposits. The method consist of inserting a micro pile made of industrial by-products, such as, fly ash, bauxite residue and blast furnace slag, into the marine deposits The marine sediments, considered in the present study deposited at a 'sea port' in Mumbai, India. The technique is currently being demonstrated at pilot scale in the field, as shown in Figure 10.

4.2.2.2. Mine Backfilling

Most of the Indian alumina industries practice the wet/semi dry disposal of the bauxite residue into the impoundments. However, its usage for backfilling the abandoned mines seems to be sustainable solutions to overcome two major concerns, namely, the ground subsidence and acid mine drainage (AMD). Keeping in view the stringent environmental regulations on rehabilitation of mines, it is proposed to standardize the whole process including the cost, methodology to be adopted for closure and the impact of bauxite residue disposal on the geo-environment, in particular the ground and surface water contamination due to leaching of alkali and growing vegetation on the backfilled mines. Investigations are undertaken in understanding in situ permeability and lateral permeability of the flow channels in down streams. To come up with environmental friendly solution a hydro geological study of an abandoned mine site has been undertaken.

Figure 10. Pilot trials for marine clay reclamation at sea port, Mumbai.

4.2.2.3. Road Construction

An attempt has been made to construct road layers with the help of these two industrial by-products, namely, fly ash and bauxite residue. Fly ash, an alumina-silicasious material, when activated using alkalis forms polymeric binder material termed as ‘Geo-polymer’ [7 – 9]. As bauxite residues contains residual alkalis in freely available form, the use of it as an alkali activator for fly ash, has been attempted for production of geo-polymer binder. The field study has been conducted by constructing a road at one of the bauxite refinery plants in India. The pavement layers were laid with different mix proportion with basic intension of understanding the strength properties and leaching behaviour with time. The preliminary study inferred that incorporation of the bauxite residues in lower proportion with Fly ash forms an intact layer which will have safer leaching characteristics. Although the leaching characteristics showed a reduction in release of heavy metals and sodium ions, with further increase of the residue the mix showed a tendency to crack on hardening. Further studies have been undertaken for improving the strength properties and reducing the cracking potential of the pavement layers.

4.2.2.4. Pavement Blocks and Road Surfacing

Use of Bauxite residue for the production of bricks is well established. In the conventional process, the residue is pressed into blocks and fired at high temperatures. Current research is focusing on geo-polymerization properties of the fly ash and bauxite residue mixture for the production of paver blocks. In this process the mixture of bauxite residue, fly ash and other components along with binders are pressed to form green block which gets cured in room temperature or at low temperature for attaining the required strength for various applications. A project has been initiated in collaboration with National Metallurgical Laboratory, India, for developing and implementing this application.

4.2.3. Remediation and Rehabilitation of Bauxite Residue Storage Areas

The most important barrier to remediation and rehabilitation of bauxite residue management is its high alkalinity. A systematic study was conducted at Hindalco's Belgaum plant for improving the physico-chemical characteristics of bauxite residue in order to make it suitable for rehabilitation through afforestation activities [10 – 11]. Prior to interventions, extensive experimentation on various reclamation trials involving combinations of soil amenders along with bacteria and mycorrhizae and selection of suitable tree and grass species was undertaken at the nursery stage for one year. During this period, five tree species and four grass/legume species were selected for afforestation program. Of the selected five tree species, *Prosopis juliflora, Acacia nilotica* and *Pongamia pinnata* responded well. Among the grass and legume species, all the selected four species namely: *Brachiaria mutica, Brachiaria decumbens, Stylosanthes scabra* and *Sesbania sesban* responded well at the nursery stage and thus were experimented at the research plot along with the tree plantation. Continuous monitoring on growth pattern of tree and grass species, and soil characteristics revealed remarkable changes in the physic-chemical properties of red mud. Apart, toxicity of the planted species and other naturally grown herbaceous flora on the research plot of red mud was also tested for their edibility properties and the results were found encouraging. All the efforts have led to green belt development on the bauxite residue storage area, as shown in Figure 11. Similar development in other bauxite refineries has been undertaken.

Figure 11. Plantation at Belgaum Bauxite Residue storage area.

5. Concluding Remarks

Environmental impacts associated with aluminum production are the major challenges for the sustainability of Indian Aluminium Industry. LCA study revealed that production of 1 tonne of aluminium cold rolled strip in India may lead to up to 25 t of GHG emission, 250 GJ energy consumption, 5 - 6 t of bauxite ore and 10 - 14 t of coal consumption, 2 – 3 t bauxite residue and 2 – 5 t fly ash generation and 17 m^3 fresh water requirement. To address these issues a three step sustainability model has been adopted by Hindalco Industries Limited. As a future proofing exercise, two technology thrust areas - Energy & Emissions and Value from Wastes, have been initiated. Adoption of latest technologies and breakthrough improvements of the existing smelting technologies along with building renewable energy capabilities are the key focus areas under the energy and emission thrust program. For generating value from wastes, multiple applications of bauxite residue and fly ash, such as, cement, construction material, mine backfilling, marine clay reclamation, soil amendment etc., are being explored.

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