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An LCA study of a primary aluminum supply chain

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Abstract

The production of aluminum billets—starting from the conversion of bauxite to alumina, the processing of alumina to aluminum, and the final cast product—is studied using a Life Cycle Assessment (LCA) approach. The aluminum supply chain consists of a refinery, a smelter, and a casting plant. In the LCA model, the environmental loads of four different case scenarios were investigated. The scenarios included various approaches employed for improving the environmental performance of the system for the production of 1 ton of aluminum metal.

The final impact assessment results for the overall environmental loads of the supply chain showed cumulative decreases of 2.2% and 3.8% for Scenarios 2 and 3, respectively. In Scenario 2, scrap metal was reduced from the casting plant. For Scenario 3, the reduction of scrap metal from casting was accompanied by improvements of both energy efficiency and reject rates at the smelter. A significant cumulative decrease of 32.8% was obtained in Scenario 4, which was mainly due to the reduction of red mud from the refinery by about 50%.

Keywords: Life Cycle Assessment; Primary aluminum production; Supply chain

1. Introduction

Primary aluminum production plays a major role in the Australian economy. Aluminum's lightweight, corrosion resistance, formability, and high strength-to-weight ratio are attractive properties to many industries, namely in aerospace applications, automobiles, beverage containers and in the electronics sector [1]. Aluminum oxide, or alumina as it is known, is the raw material from which aluminum metal is produced. Alumina, on the other hand, is produced from bauxite ore. Australia is the world's largest producer and exporter of bauxite and alumina. In 1999, Australia produced 37% of world bauxite and almost 30% of world alumina. And in 1999–2000, the total value of exports by the Australian aluminum industry was close to AUD 7200 million [2].

The conversion of bauxite to alumina and the processing of alumina into aluminum are both energy intensive processes. This gives rise to the growing concern of atmospheric emissions from the power plant, which supplies energy to these processes, as well as the high consumption of coal. Also, wastes such as red mud and high levels of emissions such as carbon dioxide are inevitable by-products during the production of primary aluminum. Therefore, various measures have been taken to achieve better use of resources and energy as well as implement more sustainable practices in the production system (e.g., [3,4]). This paper looks at an aluminum supply chain by employing a Life Cycle Assessment (LCA) approach. The case study involves a refinery, a smelter, and a casting plant.

1.1. Life Cycle Assessment

LCA is a systematic method for evaluating the environmental burdens associated with a product, process or activity, by identifying and quantifying energy and materials consumed and wastes released to the environment [5]. It is concerned with the environmental impact or loads of a series of industrial operations or a system. A full LCA study involves four stages: goal and scope definition; life cycle inventory (data gathering); environmental

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impact assessment and, finally, interpretation (including recommendations).

Various recent LCA studies have been performed relating to aluminum production. Norgate and Rankin [6] performed an LCA of aluminum smelting which investigated the results of various processing routes for aluminum production as well as the levels of greenhouse emissions due to various forms of energy used—black coal, natural gas, and hydroelectricity. Other LCA studies focused on the levels of perfluorocarbons (PFCs) that were released by the aluminum industry under certain operating conditions [7]. It was concluded in both studies that the life cycle approach is important in managing environmental issues and in ensuring environmental and business sustainability.

This paper offers a new LCA study of a primary aluminum production from the perspective of a supply chain. The supply chain involves three consecutive plants, which are combined to form a single integrated system.

2. The case study

The primary aluminum production chain involves a refinery, a smelter, and a casting plant, all based in Australia. The refinery accepts bauxite as raw material and converts it into alumina. The alumina is sent to the smelter to be processed into large-sized aluminum slabs. Finally, the casting plant converts the aluminum slabs into small-sized billets. The electrical energy for the refinery, smelter, and casting plant is supplied by a coal-fired power plant nearby.

2.1. Bauxite mining and the refinery

Bauxite is basically aluminum ore, which consists of approximately 50% aluminum oxide, 10–20% water, and various other impurities. Bauxite is typically mined in open-pits and is usually processed into alumina by a nearby refinery. Australia's annual production rate of bauxite has reached 29.5 million tons.

At the refinery, bauxite is accepted as raw material and is converted into alumina by a process called the Bayer process [8]. This includes the digestion of bauxite with caustic soda, clarification of the liquor stream, precipitation of alumina hydrate and, finally, the calcination of alumina. The main processes of the refinery are displayed in Fig. 1.

Red mud, which is a by-product from the refinery process, is an environmental load from the alumina industry. Typically, over 2 tons of residues are produced for each ton of alumina. In the year 2000, Australia produced 15 million tons of alumina. It was projected that the world's future demands for alumina and aluminum will continue to increase [9]. As the demand for primary aluminum grows, the huge tonnage of red mud will continue to represent an increasing potential threat to the environment in terms of solid waste management.

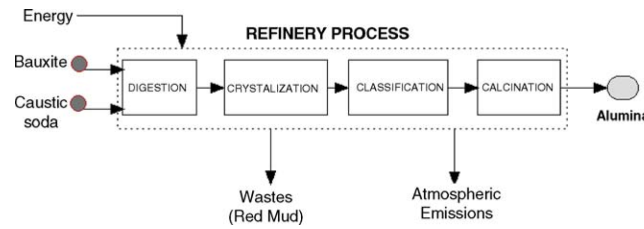

Fig. 1. The Aluminum Refinery Process.

2.2. The smelter

The smelter receives alumina from the refinery and converts it into large-sized aluminum slabs. The smelter consists of two main plants, the carbon and reduction plant.

At the carbon plant, sacrificial carbon anodes are produced for the aluminum smelting operations. It is a stand-alone facility with a capital replacement value of approximately AUD 350 million. Raw materials consisting of pitch, coke and crushed spent anodes are sized, mixed, vibration-formed, baked and cast to form anodes, which are then sent to the reduction plant. At the reduction plant, the carbon anodes are mixed with alumina to cause a reaction that produces aluminum. This reaction is known as the Hall–Héroult process. The overall processes of the smelter are depicted in Fig. 2.

2.3. Casting plant

The final plant accepts aluminum slabs as raw material and converts it into small-sized aluminum billets. In the casting plant, molten aluminum metal is first alloyed in the furnace and then injected to the casting machine where it is processed into small-sized aluminum billets. These products are made to fill

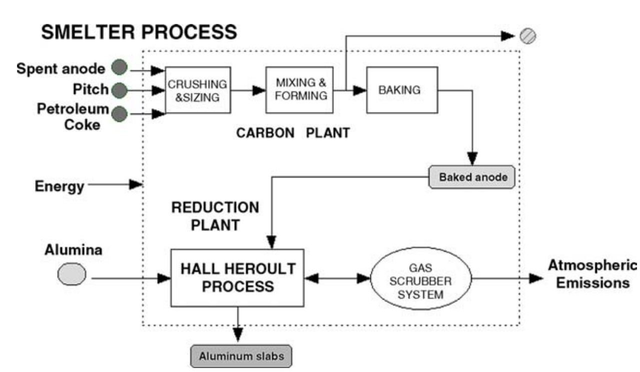

Fig. 2. The smelter processes.