Circular Use of Aluminium as an Energy Carrier

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Abstract

Aluminium (Al) is a functional material and it has a critical importance for the sustainable transition in many sectors. Besides its use in the manufacturing Al is a dense heat and hydrogen (H_2) carrier which will create additional business cases for its use with the energy transition. In this study, a business case for the use of Al as energy carrier is introduced. An Al-based system design is introduced and its techno-economic implications are presented based on a computer model. Environmental sustainability hotspots are identified and emerging solutions are introduced. The results provide high motivation for the further research of Al as an energy carrier depending on the achieved high overall conversion efficiency, degree of flexibility, and potentially cheap Al-based H_2 price.

Keywords: Aluminium, Hydrogen, Power-to-X, Circular economy.

1. Introduction

Environmental challenges due to the climate change necessitates strict emission reduction measures and more sustainable concepts in every aspect of our daily life. In this manner, considering the contribution of the fossil fuelled energy generation and transportation sectors on the total greenhouse gas emissions (GHGs), a green transition of the energy sector with the aid of renewable energy technologies, sustainable and carbon-neutral fuels are in progress. Additionally, a major challenge is the criticality of raw materials associated with concerns regarding supply risk, scarcity, and import reliance [1]. In order to meet the growing demand, supply of metals with highly efficient, sustainable and clean processes starting from mining to delivery of the manufactured goods is inevitable to realize such a transition. The concerns regarding raw material criticality suggests the usage of application potential of abundant metals that are produced in large quantities with a long term ensured availability such as Al. Al is a functional material with its high thermal and electrical conductivity, low density, ductility, and non-ferromagnetic behaviour. Hence, Al has a wide application spectrum in manufacturing technologies and products necessary for a sustainable transition such as batteries, fuel cells, motors, wind turbines, photovoltaics, robotics, drones, 3D printing and Information and Communication Technologies (ICT) [2]. Besides manufacturing applications, the use of Al as an energy carrier is an emerging topic that is discussed in this paper. Recent studies refer to the use of Al as a renewable energy storage medium thanks to its high volumetric heat storage capacity and water-splitting behaviour due to high reactivity which produces hydrogen (H_2) [3–8]. Using Al as an energy carrier is not an entirely new concept it has been used as an additive in propellants since over 60 years [9]. But using such a dense energy carrier and vastly available metal as a renewable energy carrier is a new concept developed with the energy carrier and storage demand of evolving global energy system. Noting that, primary Al is an energy intensive metal and its production causes direct Green House Gases (GHG) emissions, and some hazardous wastes including the pre-supply chain. Advances in the technological development and implementation of sustainability measures in the Al industry brings also some opportunities creating new business cases. Nevertheless, all these advances require decarbonization of the aluminium supply chain and the establishment of a circular economy without increasing the additional demand on bauxite mines. The energy transition implies potential advantages, but also some challenges for primary Al production, which needs to be addressed. In the following, these challenges will be identified and a circular concept will be introduced for a sector-coupling case between Al smelters and energy generation sectors.

2. Use of Aluminium as an Energy Carrier

2.1 Primary Aluminium Production Process and Sustainability Hotspots

The European Al demand is showing a rapid increase due to the increasing demand in every technological field. Major Al consuming sectors are identified as transport (27 %), construction (24 %), and packaging producers (15 %) [10]. Especially, the demand of the transportation sector is forecasted to increase 55 % with respect to the 2017 [10]. Thus, it is very important to secure the supply chain, increase resource and energy efficiency, and implement decarbonization measures through the entire chain. Al appears in the nature as bauxite ore, which consists of gibbsite ($Al(OH)_3$), boehmite (ϒ-AlO(OH)), and diaspore (α-AlO(OH)) minerals. Considering the geographical distribution of high-quality bauxite mines, Europe highly depends on the imports (74 % of total consumption) from Guinea, and Brazil. Only a very small share of bauxite is mined in Greece and to lesser extent in Hungary that sums up 2.3 million tonnes (12 % of total consumption) resulting overall 87 % import reliance as reported by European Commission [11]. The most important use of bauxite is aluminium production, due to high import reliance and extraction stages, it is classified as a critical material for Europe [2]. To decrease the dependency on bauxite a higher circularity of Al in the technosphere is necessary. Consequently, mined bauxite needs to be refined. It is then transported to aluminium oxide (Al_2O_3) producers. (see Figure 1) Al_2O_3 is the parent material that Al is reduced from and it is produced via the so-called Bayer process. The Bayer process is comprised of two subprocesses where the bauxite ore is treated with caustic soda in order to extract the gibbsite and extracted gibbsite then calcined at 1 100 °C to precipitate Al_2O_3 [12]. The full process requires 412 kWh electricity and 496 Nm^3 of natural gas per tonne of Al_2O_3 in a modern state-of-the-art plant, where standard process plants consumes around 26 % more natural gas (sum of energy consumed in pressure leaching, crystallization, rotary kiln, and calcination) [13]. The process doesn't require large amount of electricity with respect to the smelting process. European production and imported (from Jamaica, Surinam, and Brazil) Al_2O_3 is then transported to smelting facility for producing primary Al. The process is an electrolytic reduction process reducing Al_2O_3 to Al. The electrolysis takes place in a cryolite (Na_3AlF_6) - Al_2O_3 mixture bath. It is an energy intensive process consuming 14.1 kWh_{AC}/kg_{Al} of electricity on global average [14].

outstanding benefits once a sustainable manufacturing chain will be established. To this aim following steps can be identified as the most critical obstacles regarding its sustainability aspects:

- Inefficient and non-green practices of bauxite mining,
- Use of fossil fuels for heat supply in all processes,
- Wasted materials within the red mud, and ecological concerns stemming from its treatment,
- Direct GHG emissions related to smelting process.

Once these problems are solved, Al could strongly contribute in the sustainability of other Al-intensive products. Even though, some actions require more efforts and depend on technological developments such as inert anodes and cathodes, some of these challenges related to the pre-chain of Al can be overcome with the circular economy approach. Simply starting with recycling of packaging materials, integrating such concepts will also create additional benefits. As an example, the introduced business case here depicts high potential on using Al as an energy carrier without increasing the mining demand of bauxite and providing a continuous use of the same amount in a closed-loop.

6. References

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