SIEMENS energy

Aluminum in grid technologies: enhancing transparency and leveraging decarbonization potentials

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1. Significance of aluminum in grid technologies

Unlike steel and copper, **aluminum production has the highest CO_2e emissions per ton of produced aluminum,** ranging from 6.3 [1] (European average) to 14.8 [2] (global average) tCO_2e/t aluminum, highlighting the need for sustainable practices. In 2023, the global aluminum industry accounted for 1.9 % [3, 4] of total greenhouse gas (GHG) emissions. Most of them are emitted by primary aluminum production – reaching 70.7 [5] million metric tons produced globally in the same year, mostly due to the electricity used in the smelting process. In Europe, the smelting process is already fully electrified; therefore, the carbon footprint of primary aluminum is highly dependent on the availability of decarbonized electricity.

In a previous article on recycled copper, it was outlined how the grid is expected to double in size by 2040 due to the energy transition and modernization efforts. This expansion will require hundreds of thousands of transformers and an equal number of switchgears, which is why understanding **the role of switchgear in the grid** and how to decarbonize its supply chain is essential.

Figure 1 Aluminum ingots

Put simply, switchgear cannot only turn electricity on and off, just like a light switch at home, but also prevent electricity from flowing into an area with a short circuit, equivalent to a detour in case of a traffic jam. By ensuring safety, also in terms of personnel safety, and reliability of power generation and transmission, these two main characteristics of switchgear ultimately help to protect electrical equipment, including transformers.

At **Siemens Energy Grid Technologies,** we offer gas-insulated switchgear and air-insulated switchgear for our high-voltage substations. To this day, most switchgear still uses SF_6 for insulation and even the new alternatives are still harmful to the environment. SF_6 is the most potent GHG, approximately 24,300 times more climate-hostile than CO_2. In response to these environmental concerns, we have developed our Blue switchgear portfolio using clean air and vacuum switching technology instead.

In addition to developing F-gas-free switchgear, **utilizing CO2-reduced materials** is essential. For example, over two-thirds of GHG emissions in our clean air switchgear's supply chain come from aluminum. To support the significant expansion of the grid, tens of millions of tons of aluminum will be required. Hence, it is important to **understand the emission hotspots and integrate decarbonization levers** into material selection and production.

1.1 Unveiling the decarbonization of aluminum

Considering the current European average, the aluminum industry already demonstrates lower emissions, largely due to an increased reliance on decarbonized electricity. Nevertheless, primary aluminum production accounts for about 74 %, followed by recycling at 14 % and semi-fabrication at 12 %.

Figure 2 Painting of a Blue GIS casting

As shown in figure 3, **the smelting process is responsible for the bulk of GHG emissions in primary aluminum production.** At the semi-fabrication stage, sheet production is the primary source of emissions. Meanwhile, in the secondary production of aluminum, it is the remelting process that contributes most significantly to the GHG emissions footprint.

While aluminum is one of the most commonly occurring elements on Earth, it can rarely be found in its pure form due to its high reactivity. Instead, it primarily occurs as bauxite ore, which must be extracted through mining as the start of primary aluminum production.

After extraction, bauxite is refined into aluminum oxide (alumina) using the Bayer process and then converted into molten aluminum through the Hall-Héroult process. After smelting, aluminum ingots are sold to downstream operators for further processing, one of which is the casting process, creating semi-finished products. These products are then further processed to produce finished products, which are then sold to consumers for end use.

Secondary aluminum production refers to the production of aluminum from recycled aluminum originating from different types of scrap. In recycling, aluminum scrap is collected, sorted by alloy type, melted at high temperatures, and purified before being casted into new aluminum products. This process greatly reduces reliance on primary aluminum and allows up to 95 % energy and GHG emissions savings [6].

1. **Decarbonized electricity:** Transitioning to lower-carbon electricity will significantly reduce indirect GHG emissions, which account for about 50 % of primary aluminum's carbon footprint. This shift will benefit both current electrified segments, such as primary smelting, and those transitioning to electrified processes.
2. **Investing in R&D:** To meet 2050 climate targets, technological innovations, such as inert anodes in primary smelters, are essential for eliminating direct emissions. A gradual adoption of this technology is expected to begin in the second half of the 2030s.
3. **Supporting lower-carbon and circular production:** Given the substantial financial investments required for the transition and the growth opportunities from increased demand, initiatives should be implemented to strengthen investor confidence and create incentives for decarbonization.
4. **Improving scrap recovery and recycling:** Since aluminum recycling consumes only 5 % of the energy needed for primary production, it is crucial for reducing CO_2 emissions. However, it will require the expansion of producer responsibility schemes as well as incentives for aluminum alloy users to choose alloys that incorporate a higher percentage of scrap is necessary.

1.2 Deep dive: taking a look at recycling as a decarbonization lever

Aluminum recycling rates are among the highest compared to other materials. In 2023, recycled aluminum accounted for 30 % of global aluminum production [8, 9], while in Europe, it is expected to reach 39 % in 2025 [10], underscoring the important role of recycling in the aluminum sector.

Figure 4 illustrates the trends in ingot demand in the EU, categorized by primary aluminum, primary imports, and recycled sources. As primary production in Europe is expected to decline over time, there is substantial potential for improving recycling to also reduce dependence on imports.

Recycled aluminum accounted for 26 % of enduse-applications in Europe in 2000. By 2050, with supportive policies, recycled and primary aluminum are expected to have equal shares in meeting Europe's aluminum demand, projected at 18 million tons. From the GHG emissions perspective, increasing recycled aluminum production between 2020 and 2050 could prevent 880 to 1,500 million tons of CO_2 emissions [11].

To increase recycling rates, several key improvements are necessary. These include

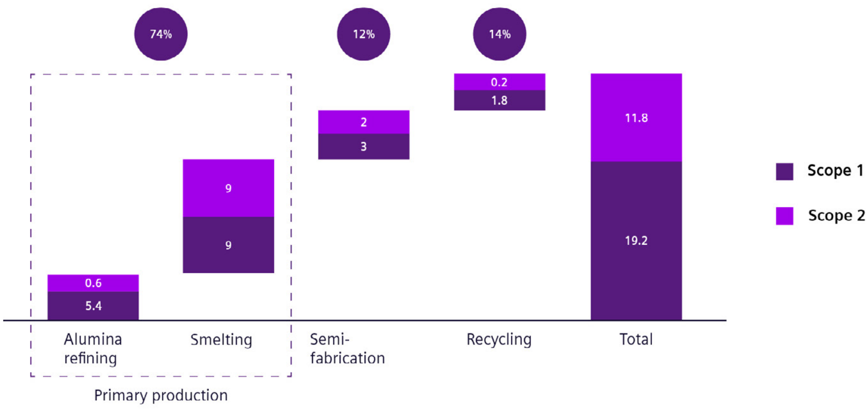

Figure 3 Scope 1 and 2 CO_2e emissions of EU aluminum industry production, 2015

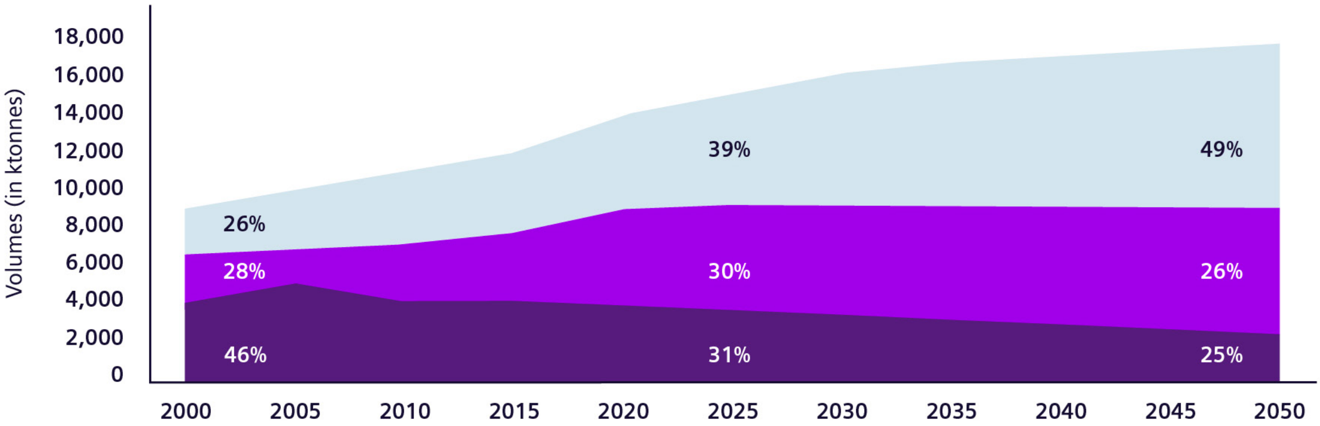

Figure 4 European aluminum demand for aluminum ingot (2000 - 2020)

designing recyclable products, implementing dedicated collection systems, advancing sorting and pre-treatment technologies, and enforcing waste legislation to reduce the volume of exported scrap and enhance local recycling efforts.

While the potential for increased recycling is promising, **challenges remain due to various aluminum alloying elements** used in production, which can be difficult to remove through conventional recycling methods. To ensure high purity in recycled aluminum and maintain the quality of the recycling process, it is essential to classify scrap into distinct alloy families and set quality requirements for separating aluminum fractions into wrought and cast alloys. These strategies will help return recycled aluminum to the market for the same applications as primary aluminum.

1.3 The status quo in the 2025 European aluminum industry

European aluminum companies are actively committed to reducing their carbon footprint by taking necessary measures and investing in innovations, even when the technology is not yet commercially available.

For instance, **Constellium** recently announced the successful completion of its first industrial-scale hydrogen casting at C-TEC, its primary R&D center [12]. Similarly, **Novelis** has successfully tested the use of hydrogen fuel to power a recycling furnace at its plant in Latchford, Warrington, UK [13]. A notable initiative is **HyInHeat** (Hydrogen Technologies for Decarbonization of Industrial Heating Processes), a European Union-funded project that explores replacing natural gas with hydrogen in aluminum and steel transformation processes [14]. In Norway, **Norsk Hydro's** Sunndal aluminum plant has announced plans to become 70 % powered by biomethane [15].

2. Collaboration as the key ingredient

At **Siemens Energy Grid Technologies,** we not only recognize potential for GHG reduction in our supply chain, but also actively promote this among our suppliers as part of our Supply Chain Decarbonization Program to meet our ambitious reduction targets, increase transparency, and develop green lead markets for low emission products.

We initiated a **cross-collaboration project** with **Thoni Alutec Sp. z o.o.,** one of our strategic key suppliers and a specialist in aluminum casting, and **We Don't Need Roads**, an external consultancy renowned for its expertise in sustainability, to ensure our suppliers are well-equipped to meaningfully drive the decarbonization in their own operations and supply chain. In the context of this project, we conducted a **comprehensive life cycle assessment (LCA)** to assess the environmental impacts of the aluminum casting parts, i.e. the different housings, that are critical components in our switching products.

As a result, key emission hotspots in Thoni Alutec's production process were highlighted, opportunities for improvements were identified, and recommendations to support further decarbonization efforts were provided. To summarize, our project highlights the potential for transformative changes in the supply chain, enabling both environmental and business benefits. However, sustainability evaluation through LCA assessments within our industry, especially for small and medium-sized manufacturers, is not yet common due to capacity and cost limitations. At **Siemens Energy Grid Technologies,** we are committed not only to the aluminum value chain, but also to **steel** and **copper,** as previous articles have already shown. And we are committed to continue creating transparency and supporting our suppliers to decarbonize the grid supply chain, step by step.

This article was written with the support and review of European Aluminium.

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Published by

Siemens Energy Global GmbH & Co. KG
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91058 Erlangen
Germany

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For the U.S. published by

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Raleigh, NC 27616
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