Net-zero Emissions from Primary Aluminium Production - Is it Technologically and Economically Possible by 2050?

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Abstract

Reducing greenhouse gas emissions and combating climate change have become a priority for nations and businesses, and that includes also the aluminium industry. 2050 has been chosen as the target year when the global primary aluminium industry will have reached net-zero greenhouse gas emissions. There is a clear path to decarbonization for the aluminium industry, and many aluminium producers have now developed their own low-carbon roadmaps. However, reaching the goal of net-zero emissions will require significant decarbonization of the electric energy mix, the alumina and anode production and supply chains, the aluminium electrolysis process, and also the downstream recycling. Is it technologically and economically possible for the global aluminium industry to reach net-zero emissions, and which new technologies are required to achieve this? The present paper gives an overview and discussion of the main processes that have been suggested in the open literature to reach net-zero emissions from the primary aluminium industry.

Keywords: Primary aluminium production, Greenhouse gas emissions, Decarbonisation, Net-zero emissions.

1. Introduction

The process of reducing carbon dioxide emissions from industrial processes through various strategies is called decarbonization, which implies removing carbon from the system. Leading companies in the aluminium sector have endorsed a new strategy for action to decarbonize the sector in this decade [1]. With the present extensive use of carbon-containing raw materials for electricity and other energy sources for the aluminium industry this is a formidable task.

2. What Do We Mean by Net-zero Emissions?

Natural ecosystems like wetlands and forests absorb carbon dioxide from the air and turn it into biomass, which is a part of earth's natural carbon cycle. Forestation means to plant, manage and grow forests and is a low-tech way to remove and store carbon in the biosphere, and this works also on a large scale.

The industry is now using the expression net-zero greenhouse gas (GHG) emissions. Net-zero does not necessarily mean that all greenhouse gas emissions are eliminated. At net-zero, emissions are still generated, but an equal amount of CO_2 is removed from the atmosphere as we release into it. Thus, net-zero means that emissions from human activity must be balanced by absorbing an equal amount of greenhouse gases, primarily CO_2, through climate projects.
CO_2 emissions cannot be avoided completely, so when are they "close enough to zero" to be called net-zero? The International Aluminium Institute (IAI) [2] has modelled a 1.5 Degree Scenario for global warming and the result is a low total emission of 0.5 tonne of CO_2 equivalent per tonne of aluminium (t CO_2e/t Al). So this may be low enough to be called net-zero. However, it means that the aluminium producers presently operating with a low total emission of

4.0 t CO_2e/t Al must reduce their emissions by 88 % and the total global emissions from primary aluminium production must be reduced by 97 %.

3. The Emission Target for 2050 - Net-Zero Emissions from Primary Aluminium Production

The time horizon for net-zero targets - 2050 - feels distant and the target sounds simple and plausible. The year 2050 is probably chosen because it is just a round number and halfway into the 21st century. For comparison, let us go 27 years back in time and take a look at the situation in 1996. Some global average data are compared in Table 1.

Table 1. Comparison of some global average data from 27 years ago with present data [3], and IAI data for business as usual (BAU) and net-zero target by 2050 [2]. The data for 2023 is from 2021 and 2022 [3].

Process/Year	1996	2023	2050 (business as usual)	2050 (net-zero target)
Global production of Al (Mt/year)	20.9	68.5	88	68
Energy consumption (kWh/kg Al)	14.5	13.2	12	~ 10 (?)
Percentage of electric power from coal and natural gas (%)	43	67	61	19
GHG emission (t CO_2e/t Al)	16.9	16.6	15.8	0.5

The annual global primary aluminium production has increased by almost 50 million tonnes since 1996, but the IAI modelling does not include any large increase up to 2050. The energy consumption has shown a nice reduction and this will surely continue. The amount of electric power from fossil sources has increased considerably, and the GHG emissions are the same now as in 1996. So it is obvious that the electric power mix must change and the emissions must be reduced dramatically in the next 27 years to reach the net-zero target.

To get to net-zero emission is a big and challenging task, and the way to achieve it is partly unknown at present. We know that this is not possible with the process technologies we have and use today. Genuinely new and yet-to-be-developed technologies are needed. If and when these new technologies are available, the commercial adoption will require a significant investment across the aluminium industry.

4. What will the Aluminium Industry Need to Reach Net-zero Emissions with the Present Electrolysis Cell Technology?

With the main raw materials (electricity, alumina, and carbon anodes) and the electrolysis cell technology we have in 2023, the industry will need the following improvements before 2050:

4.1 Electric Energy Mix Decarbonization

In 2021, 67 % of the electric power used to produce aluminium originated from fossil fuel sources; mainly coal (57 %) but also natural gas (10 %) [3]. Globally there has been an increase in the specific CO_2 emissions from the energy used for aluminium electrolysis from 6 to 10 t CO_2e/t Al since 1990, and there has been only a small reduction since 2015, as shown in Figure 1. It is obvious that this trend must change, and change rapidly now.

Switching to decarbonized power generation offers the most significant opportunity of emissions reduction and is critical to the transition. It means using “clean” energy from renewable sources

10. Secondary Aluminium from Post-Consumer Scrap

The production of recycled aluminium will be more important in the coming years. This development will continue in parallel with the necessary improvements of the primary aluminium industry. Aluminium recycling is the process by which post-consumer aluminum scrap can be reused in products after its initial (primary) production. According to IAI statistics [3] the average process emissions from recycling of post-consumer scrap is 0.6 t CO_2e/t Al. Norsk Hydro [22] reports that their post-consumer scrap has a carbon footprint of about 0.5 t CO_2e/t Al. This results from post-consumer scrap collection, transport, sorting, and remelting. In June 2023 Norsk Hydro reported that the company had been melting aluminium scrap using green hydrogen instead of natural gas as fuel for the burners powering the remelt furnace [23]. This shows that zero emissions are possible from secondary aluminium production from post-consumer scrap.

11. Summary

To reach net-zero GHG emissions when using the existing electrolysis cell technology the main ways are a combination of the following requirements:

- Renewable electric power
- Emission-free alumina and anode production
- All material transportation, including alumina, by electric ships, railways and vehicles
- Carbon capture, utilization and storage (CCUS)
- Recycling of post-consumer scrap

However, one can also use new cells with inert anodes, or alternatively a new process for production of aluminium. Examples here are:

- A new and different process for aluminium production (CCR and HalZero), where the processes are based on carbochlorination of alumina to produce aluminium chloride, which is then electrolyzed to aluminium.

With the target of net-zero GHG emissions by 2050 it is possible that a new and emission-free process may be the main solution for the aluminium industry.

12. References

1. International Aluminium Institute, Aluminium industry backs action this decade for net zero by 2050, GHG, *Global Industry, News*, September 21, 2022, https://international-aluminium.org/aluminium-industry-backs-action-this-decade-for-net-zero-by-2050/ (Accessed on 11 July 2023).
2. International Aluminium Institute, 1.5 Degrees Scenario: A model to drive emissions reduction, October 2021, https://international-aluminium.org/resource/1-5-degrees-scenario-a-_model-to-drive-emissions-reduction/ (Accessed on 11 July 2023).
3. www.world-aluminium.org, Greenhouse gas emissions - Primary aluminium, Date of Issue: 5 October 2022, https://international-aluminium.org/statistics/primary-aluminium-production/ (Accessed on 11 July 2023).
4. Guðrún Saevarsdottir et al., The way towards zero carbon emissions in aluminium electrolysis, *Light Metals 2023*, 637-645.
5. Dominic Davis et al., Solar-driven alumina calcination for CO_2 mitigation and improved product quality, *Green Chem.*, Vol. 19, (2017), 2992-3005.
6. Rusal - En+ Group, Pathway to net zero 2021, issued 20 September 2021, p. 13 and p. 35, https://enplusgroup.com/upload/iblock/c20/EN_-Pathway-to-net-zero.pdf (Accessed on 11 July, 2023).
7. Halvor Kvande, Guðrún Saevarsdottir and Barry Welch, Decarbonizing the primary aluminum industry - Opportunities and challenges, *Light Metal Age*, Vol. 81, No. 1, (2023), 38-45.

8. Les Edwards et al., Quantifying the carbon footprint of the Alouette primary aluminum smelter, *Journal of Metals (JOM),* Vol. 74, (2022), 4909-4919.
9. Sahag Voskian and T. Alan Hatton, Faradaic electro-swing reactive adsorption for CO_2 capture, *Energy & Environmental Science,* Vol. 12, No.12, (2019), 3530-3547.
10. Olivier Lassagne et al., Techno-economic study of CO_2 capture for aluminium primary production for different electrolytic cell ventilation rates, *Chemical Engineering Journal*, Vol. 230, (2013), 338-350.
11. Andrea Svendsen, Elysis moves toward commercialization of inert anodes, *Light Metal Age*, Vol. 80, No. 1, (2022), 32-33, https://elysis.com/sites/default/files/newsfiles/lmaelysisfeb2022.pdf (Accessed on 12 July 2023).
12. Production of aluminum without greenhouse gases | Installations too old for the new technology, *Actual News Magazine*, February 7, 2023, https://actualnewsmagazine.com/english/production-of-aluminum-without-greenhouse-gases-installations-too-old-for-the-new-technology/ (Accessed on 11 July 2023).
13. Jón Hjaltalín Magnússon, Breakthrough CO_2 emission free aluminium production, presentation at *20th Annual Petcoke Conference*, Anaheim, California, USA, 25 -26 February 2022.
14. Marc Dupuis, China enters the race for the development of inert anode cell technology, April 2022, https://www.linkedin.com/pulse/china-enters-race-development-inert-anode-cell-marc-dupuis/ (Accessed on 11 July 2023).
15. Caroline Reily, Introducing the age of clean aluminum technologies, Aluminum Technologies 2023, https://aluminumtechnologies.us/ (Accessed on 11 July 2023).
16. Norsk Hydro, HalZero - Zero-emission electrolysis from Hydro, January 19, 2022, https://www.hydro.com/en/media/on-the-agenda/hydros-roadmap-to-zero-emission-aluminium-production/halzero-zero-emission-electrolysis-from-hydro/ (Accessed on 11 July 2023).
17. Hans Erik Vatne, Hydro's decarbonization roadmap, PowerPoint presentation given at *Greener Aluminium Online Summit*, 24 May 2022, in association with Aluminium International Today.
18. Norsk Hydro, Hydro's HalZero technology reaches a new milestone, March 2, 2023, https://www.hydro.com/en-US/media/news/2023/hydros-halzero-technology-reaches-a-new-milestone/ (Accessed on 11 July 2023).
19. Rainer Küngas, Review - Electrochemical CO_2 reduction for CO production: Comparison of low- and high-temperature electrolysis technologies, *Journal of The Electrochemical Society*, Vol. 167, (2020), 044508.
20. Marten Ford et al., Making net-zero aluminium possible – An industry-backed, 1.5°C-aligned transition strategy, Mission Possible Partnership (MPP), Aluminium Transition Strategy, April 2023, 71 pages, https://missionpossiblepartnership.org/wp-content/uploads/2023/04/Making-1.5-Aligned-Aluminium-possible.pdf (Accessed on 11 July 2023).
21. Mission Possible Partnership (MPP), Aluminum decarbonization at a cost that makes sense, sponsored by Energy Transitions Commission in London, April 2023, https://www.mckinsey.com/industries/metals-and-mining/our-insights/aluminum-decarbonization-at-a-cost-that-makes-sense (Accessed on 11 July 2023).
22. Norsk Hydro, Carbon footprint of recycled aluminium, posted in: *Worldwide*, *Energy*, *Technology*, 20 May 2021, https://www.climateaction.org/news/carbon-footprint-of-recycled-aluminium (Accessed on 11 July 2023).
23. Aluminum companies investigate in the use of hydrogen for recycling scrap, July 6, 2023, *Light Metal Age*, https://lnkd.in/gxyVRtr3 (Accessed on 11 July 2023).