Zeitschrift: Ferrum : Nachrichten aus der Eisenbibliothek, Stiftung der Georg Fischer AG

Herausgeber: Eisenbibliothek

Band: 93 (2024)

Artikel: Environmental regulation and corporate offshoring in the aluminium sector

Autor: Lobach, Simon

DOI: https://doi.org/10.5169/seals-1061983

Environmental regulation and corporate offshoring in the aluminium sector

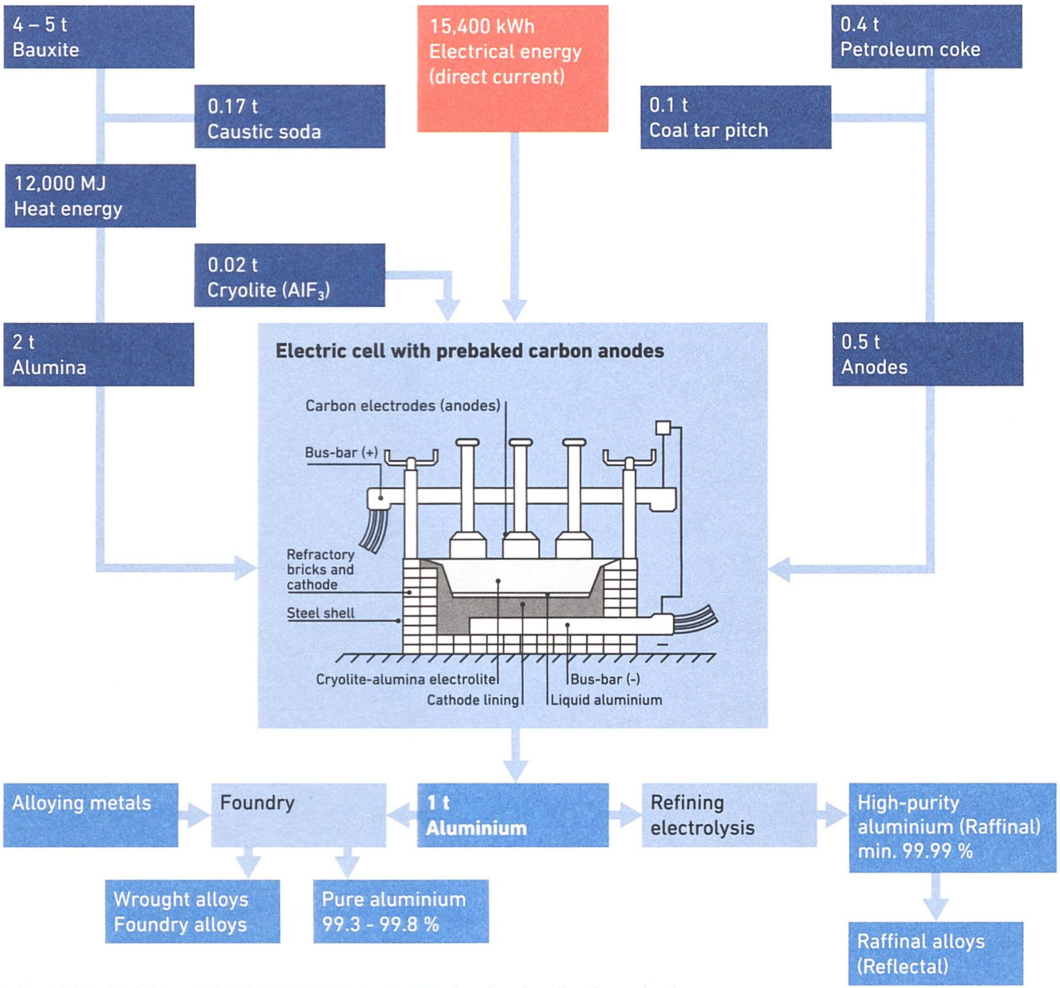
Simon Lobach

Aluminium has been produced on a large scale since the 1880s. Since the beginning, local populations have noted and protested against the environmental impacts of the processes by which bauxite is transformed into aluminium. Environmental regulation implemented to reduce such impacts often only led to aluminium companies offshoring their production to third countries. To show the underlying mechanisms, this article discusses three cases of environmental conflict involving the aluminium industry: fluoride emissions, red mud deposition, and CO_2 emissions.

Aluminium is one of the metals that has most revolutionized industrial production and modern consumption patterns over the course of the past century and a half. Two industrial processes invented in the 1880s made it possible to produce aluminium in quantities never imagined before.[1] These processes were the Bayer process (which transforms raw bauxite into an intermediate product called alumina or aluminium oxide – Al_2O_3) and the Hall-Héroult "smelting" process (which "reduces" said alumina into pure aluminium). The rise of aluminium on international markets was accompanied by a sense of optimism, as aluminium was associated with speed, flexibility and, as a result, with modernity in itself.[2] From beverage cans and chocolate wrappings to aircraft and space shuttles, "modern" life would be difficult to imagine without aluminium.[3]

Aluminium is now regarded as one of the key metals for the energy transition, given its use in the production of electric cars, solar panels and windmills.

Today, this association between aluminium and modern life is perpetuated in a different form, as aluminium is now regarded as one of the key metals for the energy transition, given its use in the production of electric cars, solar panels and windmills.[4] As a result, expanding global aluminium production is now considered a necessity for "sustainable" life. This places us in front of a paradox, as aluminium production itself has numerous environmental impacts. At the planetary scale, the metal is responsible for two to three percent of greenhouse gas emissions (GHGs),[5] but aluminium production can have several other environmental im-



1 A schematic overview of the aluminium production process, centred upon the electric cells where alumina (derived from bauxite) is smelted with the help of carbon anodes to become aluminium.

pacts occurring at the local level, ranging from fluoride emissions to "red mud" deposits overflowing.

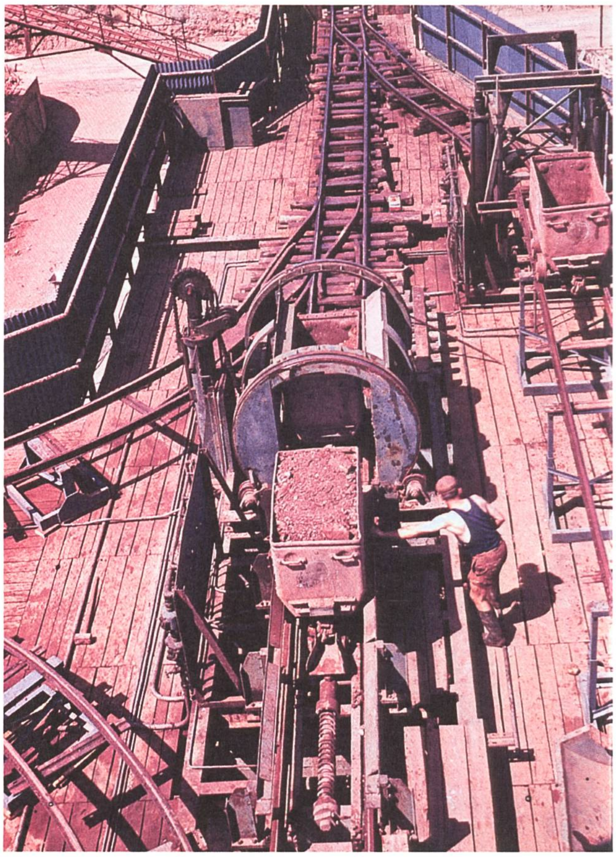
This article looks into the environmental regulations that have or have not been implemented in the global aluminium sector over time, and how such developments have influenced the current composition of this industry. Regulatory regimes are often established at the national level, which makes studying them on an international scale difficult. For this reason, the article looks at general tendencies across countries, exemplified by their results, rather than at individual regulations. It does so through three case studies, which represent key moments in which the aluminium industry was forced to reflect on its environmental impacts: the crises around fluoride emissions; incidents with "red mud" leaking and overflowing; and the current appeals to the aluminium industry to reduce greenhouse gas emissions, most notably CO_2.

The case studies are presented in the order in which they became notorious, which does not coincide with the order of the steps by which bauxite is transformed into aluminium: bauxite mining, followed by alumina refining (Bayer Process), followed by aluminium smelting (Hall-Héroult Process).

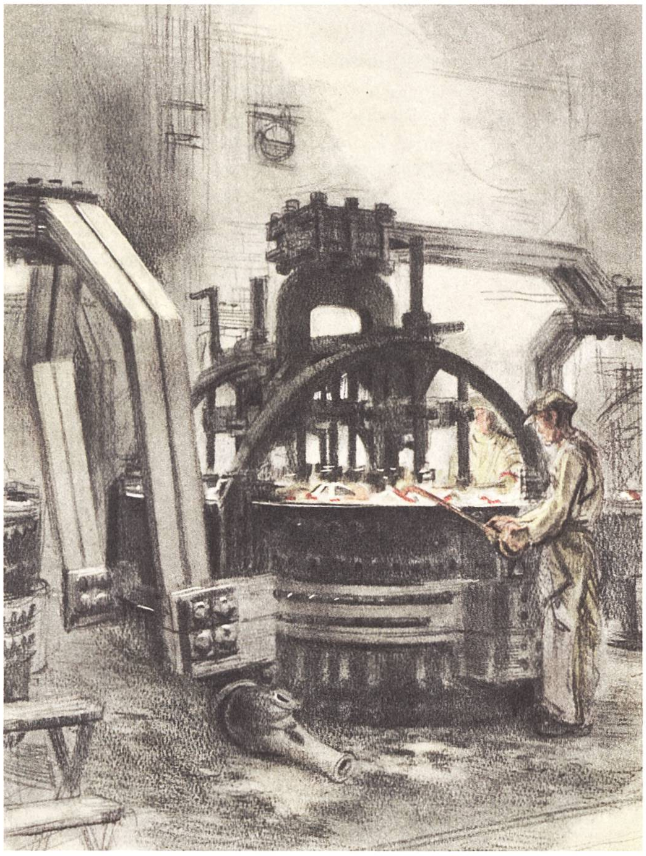
Fluoride emissions

The methods to produce aluminium resulted from a combination of discoveries, not only technological but also geological, that occurred in the 19th century. In terms of the raw materials, two minerals were essential: bauxite and cryolite.

Bauxite is a red rock, or a clay, from which alumina (Al_2O_3) can be refined. It was discovered in 1821 in Les-Baux-de-Provence (hence *baux*ite) but is present in many locations around the globe (especially concentrated in hot and humid regions), and became the main source material for aluminium.[6] Cryolite, on the other hand, is a rock mainly found in a single deposit site – in Ivittuut, on the west coast of Greenland – although it is currently mostly produced synthetically.[7] Cryolite molecules (Na_3AlF_6) contain aluminium, but aluminium cannot be easily isolated from the mineral itself. The aluminium industry became interested in cryolite because of another feature: its relatively low melting temperature. The process of de-oxidizing alumina through electrolysis consisted of melting cryolite in a pot, after which alumina was fed into these cryolite baths. Carbon was introduced into the same pot, after which a very potent electric current was sent through the molten minerals, separating the ties between the aluminium and



2 Carts being loaded with bauxite at a mine in Villeveyrac, France.



3 Early (pre-Söderberg) round electrolysis cell with several vertical prebaked anodes at an Alusuisse aluminium smelter, painted by Otto Baumberger, around 1938.

oxygen atoms in the alumina. This caused the oxygen to react with the carbon to form CO_2 ($2\,Al_2O_3 + 3\,C \rightarrow 4\,Al + 3\,CO_2$), while almost pure aluminium would sink to the bottom of the pot, where it could be obtained for industrial uses. After the invention of this process in 1886, the first aluminium smelters emerged in the USA, Switzerland, Canada and France.

In principle, cryolite is supposed to be an inert participant in the process, as it only serves to convey the electrical current but does not itself take part in the chemical reaction. However, as an unintended side effect, amounts of cryolite constantly decompose as a result of the conditions inside the pot. This decomposition caused fluoride-containing fumes to escape from the pots and make their way into local environments. The effects were not lost to farmers around the smelters. In the 1920s, farmers around the aluminium smelter in the Swiss town of Chippis (Valais) complained about damage caused to vines, forests, fruit trees and cattle.[8] Similarly, French farmers in the Alpine Maurienne valley complained about a "noxious stench", the landscape around the smelter changing into a "desert, a void", while damage done to forests was causing erosion and avalanches.[9]

The issue of fluoride emissions could become so problematic because of the rapid expansion of aluminium production, which was mostly fuelled by the construction of airplanes in the context of the First World War. This development would only get worse during the Interbellum, as the build-up for yet another conflict initiated a global run to produce the largest possible amounts of aluminium. Eventually, over a million aircraft would be produced during the Second World War. In the post-war period, the aluminium sector would do everything to keep its output levels up, and started producing a wide range of new consumer goods.[10]

One of the technologies that had enabled this rapid expansion of aluminium output had been presented in 1918 by Swedish chemist Carl Wilhelm Söderberg. According to him, the carbon blocks that were introduced into the cryolite pots did not need to be baked separately, as the heat of the electrolysis process in the pots could itself be used for this effect. The Söderberg technology was quickly taken up by aluminium smelters throughout the sector, which greatly improved efficiency and allowed for more flexibility to adjust output to changing demand. At the same time, the Söderberg technology had a downside as well, as Söderberg pots emit much larger amounts of fluoride-containing gases.[11]

From the 1950s to the 70s, during the so-called "fluor wars" in Switzerland, Valaisan farmers clashed with Alusuisse. Public opinion increasingly sided with the farmers, and so did judges in the courtroom battles that ensued. New Alusuisse investments were directed at outsourcing large segments of its production capacity to third countries, including places with low population densities and high hydropower potential, such as Norway. Switzerland, due to expanding environmental regulation in favour of local communities and ecosystems, had become an increasingly difficult place for such a polluting industry.[12] When this author visited the aluminium smelter in Sunndalsøra (Norway), he met an informant who visited the smelter some 40 to 50 years ago as a child and who remembered that the tour guide, back then, had made a remark that children in Sunndalsøra did not need to see a dentist given the atmospheric fluoride concentrations in the village.

Fluoride emissions did not only affect local environments, but also human bodies. Fluoride poisoning, or fluorosis, had already been identified as a cause for skeletal problems in Valais during the First World War, and was later observed in other countries as well, while other health issues, including certain cancers, seemed to be disproportionately found among aluminium workers. Fluorosis was recognized as an occupational disease by the International Labour Union in 1955. The aluminium sector reacted by slowly increasing safety measures meant to protect workers in the smelters, such as the use of suitable aprons and gloves, rather than limiting the fumes escaping the pots. This policy shows that even when fluoride emissions were recognized as a health and safety issue for smelter employees, this did not lead to the realization that it was also an environmental issue affecting humans, animals and plants outside the smelters. Amidst increased activism by environmental groups in different European countries, the major French producer Pechiney in 1975 reluctantly recognized the controversies around the environmental impacts of fluoride emissions, but then proceeded to downplay its significance. It argued that farmers were exaggerating the impacts of fluoride emissions, and that, moreover, the company was doing all it could to further reduce these emissions.[13]

Fluoride emissions did not only affect local environments, but also human bodies.

Clear policies to regulate fluoride emissions in aluminium smelters, with a view to protecting surrounding populations and environments, were never adopted, as a result of the behaviour of the industry described above. However, it was clear that it would not be able to maintain that strategy as evidence became ever more conclusive, and industry players could not outsource its production to third countries forever. In order to avoid reaching a point of collision with increasingly vocal environmentalists, the sector over many decades retrofitted its smelters from Söderberg technology into smelters with separate anode baking rooms. This allowed them to build cryolite pots that emitted less fumes, equipped with “sniffers” that allowed fluoride fumes to be captured.[14] Progressively, Söderberg technology was phased out across continents. Today, Söderberg technology is responsible for 4.6 percent of all aluminium produced worldwide, and for 12.5 percent of all fluoride emissions caused by aluminium production.[15]

Alumina refining and red mud deposition

Another process that attracted criticism to the aluminium supply chain was the refinement of bauxite into alumina following the so-called Bayer Process, which had been invented in 1888 by Austrian chemist Carl Joseph Bayer. The process serves to isolate the alumina from the raw bauxite, as bauxite contains several other elements that are of no interest to the industry. A crucial element in the Bayer Process is caustic soda, which first reacts with the alumina present in the bauxite, so that it can be easily isolated, after which the opposite reaction is provoked to separate the alumina from the soda again. As a result, anything in the bauxite that is not useful to the industry can be discarded, pure alumina is obtained (for subsequent use in the Hall-Héroult process – see above), and the caustic soda is recovered so that it can be refed into the process. That is the theory, at least. In practice, certain amounts of caustic soda are not recovered. Caustic soda typically makes up four percent of the "Bauxite residue" (more commonly known as "red mud": the discarded residue) typically still contains rest products like caustic soda. As a result, red mud is highly alkaline.

Early storage practices typically included no measures to seal off the deposition site from the underlying soil and groundwater.

For each tonne of alumina produced (and therefore, for every half tonne of primary aluminium), 1.5 tonnes of bauxite residue is deposited in the proximity of the refinery.[16] This red mud was sometimes deposited in old mines, but more often it was stored behind seawalls or in walled-off valleys. These early storage practices typically included no measures to seal off the deposition site from the underlying soil and groundwater, so that leakage could easily take place.[17]

Quickly after the first alumina refineries using the Bayer Process were built, neighbours realized that something was off. As of 1898, people around the alumina refineries operated by the Société électrométallurgique française (SEMF) in southern France started complaining about the clearly noticeable deterioration of their water sources, which “burns our hands when we try to use it”. The SEMF was well aware of this problem, but claimed “that there is no reason to worry about the water quality”. If there is any issue with the water, a SEMF “expert” con-

4 Fluor War in the Fricktal: demonstration with cows against fluoride damage, in front of the administration building of Alusuisse Zurich.

cluded in 1910, this must be due to substances used in the growing of vegetables in the region. All the while, the SEMF proceeded in buying up the properties located nearest to its refineries, while attempting to improve soda recovery from the process and to find new uses for the bauxite residue, like baking it for bricks and other construction materials. It was also proposed that bauxite residue could be mined to extract other minerals that may be present in the mix.[18]

As demand for alumina and aluminium kept increasing, the policy of depositing bauxite residue on land became untenable at various sites. In the post-war period, companies in several countries proceeded to dump bauxite residue immediately onto the seabed, either transported to the open sea in vessels, or through slurry pipelines, several kilometres long, built for that effect.[19] These "creative" ways of dealing with bauxite residue led to new controversies. At the shores of the Mediterranean, fisherfolk, the tourism sector and other stakeholders feared that red mud dumping on the seabed would negatively impact their businesses. Like in the previous conflicts, Pechiney (the successor of the SEMF) made small compensation payments to affected fisherfolk and people living right next to the slurry pipeline, but all the while it maintained its claim that red mud had no negative impacts whatsoever. At the same time, it made frequent reference to the employment generated by the alumina refinery, and to the loss of economic activity if the refinery were to be closed. It is because of such arguments that the company, like companies in other European countries, continued receiving the necessary government permits for red mud dumping in the sea.[20]

In the post-war period, companies in several countries proceeded to dump bauxite residue immediately onto the seabed.

The idea that bauxite residue was a non-hazardous waste when deposited into the sea was reflected in international regulation as well. Even though a German review in 1973 already concluded that red mud deposition in the North Sea "proved to be harmful to a variety of organisms",[21] red mud or its constituents were never added to the list of substances banned by the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter that entered into force in 1975. Global North countries only started banning red mud deposition at sea as of 2006, when the London Protocol replaced the London Convention for some signatories. Departing from

5 The dyke around a red mud basin in Ajka, Hungary, collapsed in 2010, causing the toxic sludge to flood an extensive area, killing 10 people.

the "precautionary principle", the London Protocol had turned the Convention upside down: instead of including a list of hazardous substances to be banned, the Protocol includes a list of substances that are known to be non-hazardous, with all others being automatically banned.[22] Bauxite residue ("red mud") is not on the list and its deposition at sea has therefore been gradually halted.[23]

While red mud dumping at sea thus became banned, the keeping of red mud in on-land basins ("lagooning") continued in the Global North, until it received a considerable blow in 2010. The particularly rainy summer augmented the pressure on the containment dykes of a red mud basin in Ajka, Hungary, belonging to MAL Hungarian Aluminium. After the dyke collapsed, one million cubic metres of red mud spilled into the surrounding environment, killing ten people, injuring 150, and severely affecting wildlife in the entire water catchment area. While organizations like Greenpeace voiced concerns over the alleged heavy metal concentrations and radioactivity of the red mud, these fears were quickly dismissed by Hungarian government scientists, who confirmed that the burn-like wounds on humans and animals that occurred after contact with the red mud resulted from the substance's high alkalinity, and nothing else[24] – as if that wasn't bad enough.

Industry representatives have long minimized the potential impacts of red mud. It is true that the concentration of heavy metals, including radioactive ones, in red mud is higher than in bauxite, but it may also be true in most cases that these remain within thresholds that are considered safe. Red mud's alkalinity, however, is a problem to which the sector is slow to respond. A technology to stop the dispersal of caustic soda (so-called "press filters") is available, but costly. Some European refineries took the necessary measures, but many others could no longer compete and closed down after the Ajka accident.[25] While alumina production has steeply increased worldwide over the past decades, European alumina output has, as a result, remained remarkably stable.[26] The bulk of alumina production today takes place in increasingly large-scale facilities in countries like China, Australia, Brazil and India.[27]

While alumina production has steeply increased worldwide over the past decades, European alumina output has remained remarkably stable.

Incidents involving red mud are still occurring regularly. The most infamous incident occured in Brazil, in 2018, when red mud spilled into local water streams from the red mud dumping sites of the gigantic Alunorte refinery in the Amazonian town of Barcarena. The Norwegian company Norsk Hydro, operating the refinery, denied that it happened.[28] The Brazilian authorities partially suspended activities at the refinery, which were only resumed after Norsk Hydro retrofitted its refinery to install press filters to avoid these accidents from happening again. A similar incident occurred in Muri (Jharkhand, India) with a Hindalco-operated plant, but this one received hardly any attention outside India.[29] In China, environmental authorities discovered that a series of alumina refineries were regularly dumping red mud into a river, and announced more thorough inspections.[30]

Regulation of red mud management is a country-level affair, but not all countries are equally stringent in applying and enforcing regulation to prevent red mud leakage into local environments. The overall landscape of alumina production seems to suggest that flight may be taking place to locations where no appropriate regulatory mechanism is in place. Only environmental disasters seem to be able to convince local authorities to regulate red mud deposition.

The instalment of a press filter in Barcarena (Brazil) should be interpreted against the backdrop of the public outcry against the incident (a Norwegian company polluting an Amazonian ecosystem), and the company's explicit intention to become the "greenest" player in the industry. Companies from countries with less press freedom, with less environmentally minded customers, or operating in less iconic environments, may not take the same decision. Meanwhile, new investments follow the path of least resistance.

CO_2 emissions

The third environmental challenge to the aluminium industry discussed here is the sector's emission of GHGs, which amount to two to three percent of global GHG emissions across sectors. The two activities of the supply chain that are responsible for the bulk of the industry's GHG emissions are the energy requirements of aluminium smelters, but also the electrolysis in itself. Given the reaction $2\ Al_2O_3 + 3\ C \rightarrow 4\ Al + 3\ CO_2$, for every four aluminium molecules produced in a smelter, there are also three CO_2 molecules emitted. These emissions are called "process CO_2", to distinguish it from the CO_2 and other GHGs that result from power generation.

Today, "decarbonization" is high on the agenda of the aluminium industry. The main pathway discussed with this goal is to reduce the "process CO_2". The remaining aluminium companies in the Global North (Alcoa, Rio Tinto and Norsk Hydro – while all other top producers are Chinese, Indian or Russian) tend to regard themselves as the frontrunners in terms of environmental sustainability. It is therefore not surprising that exactly these three companies are most active in the attempts to change the Hall-Héroult process into a chemical process that does not emit CO_2. Two such technologies are under development: Elysis (by Alcoa and Rio Tinto) and HalZero (by Norsk Hydro). How these technologies would work has not been publicly disclosed yet, but it seems to rely on the chlorination of alumina with the help of carbon monoxide, after which both these substances are electrolysed, so that only aluminium and oxygen are released, while chlorine and carbon are being fed and refed into the process in a circular fashion.[31] Such a "tech fix", however, would require enormous investments, as aluminium smelters would need to undergo very significant retrofitting. This operation has not even started yet, and new smelters using the old process are still being constructed, including by the very companies involved in the development of the new technologies.[32] In parallel, Norsk Hydro is also exploring possibilities for carbon capture and storage in old gas fields,[33] with equally indecisive results.

More importantly, "process CO_2" is only a fraction of the total CO_2 emitted for aluminium production: in 2022, it only constituted 10.6 percent of total emissions.[34] The bulk of CO_2 emissions (over 70 percent) for aluminium production result from the energy requirements of aluminium smelters. Until the 1970s, the aluminium sector was often itself involved in building the necessary electricity generation capacity for its activities, but the two sectors have since been decoupled. Today, aluminium smelters buy electricity "from the grid", but that does not make them less responsible for the emissions resulting from electricity generation, especially since costly electricity generation projects have often been built with the express intent to power an aluminium smelter.[35]

> In 1980, more than 50 percent of the electricity used in aluminium smelting was hydropower; this number had decreased to 31 percent in 2021.

In spite of the sector's wide appeals for decarbonization, a look at the emissions resulting from electricity generation for aluminium smelters shows a different picture. Aluminium smelting was historically closely tied to hydropower, which constituted the most stable power supply. Whereas in 1980, more than 50 percent of the electricity used in aluminium smelting was hydropower, this number had decreased to 31 percent in 2021. The problem was not a lack of expansion in hydropower – it was that total aluminium production grew even faster, from 15 million metric tonnes in 1980 to 67 million metric tonnes in 2021. Rather than a sector decarbonizing, we are, therefore, looking at a sector that is carbonizing. Today, 57 percent of aluminium is smelted with electricity derived from coal, and 9.7 percent with electricity derived from natural gas.[36]

Some regulatory initiatives to decrease total CO_2 emissions from aluminium production are underway nonetheless. Not only do some producers of high-end consumer goods demand to be supplied "green aluminium" (hence the eagerness of some market players to demonstrate their sustainable production processes) – Global North countries also create barriers to prevent high-carbon aluminium from reaching them. An example is the EU's Carbon Border Adjustment Mechanism, which is supposed to be active as of 2026, with aluminium as one of its six target sectors. It remains to be seen how this will impact global aluminium markets, as there is currently not enough "green energy" to power all aluminium smelters in the world. It is likely that the sector will therefore split into two segments: a low-carbon segment for the Global North, and a high-carbon segment for the Global South. In terms of stopping climate change, the effect may be very limited.

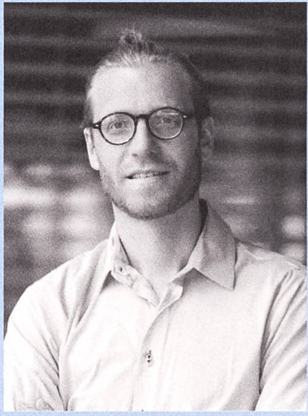
Conclusion

Each of the steps of the process by which bauxite is transformed into alumina and then into aluminium leads to significant environmental impacts, both locally and globally. When such environmental impacts came to the surface, aluminium companies have repeatedly denied or downplayed environmental problems. Only after local communities protested and gained public sympathy has the public sector (either nationally or multilaterally) implemented regulation measures. This contribution shows how this occurred for fluoride emissions, red mud dumping at sea, and red mud lagooning on land. It also shows that aluminium companies attempted to escape from more stringent regulations by moving their production capacity elsewhere, while fluoride emissions could be effectively addressed because the technology was already available.

Today, the aluminium sector claims to invest significantly in decarbonizing the sector, while presenting aluminium as an essential ingredient to enable the energy transition and thereby to stop global warming. A more thorough review of the available data shows, however, that the aluminium sector is not decarbonizing, but carbonizing, as it moves away from hydropower and into fossil fuel-based production processes. Again, like in the two historical cases, we can witness how the sector attempts to present itself as being "cleaner" than it actually is, while increased regulation in one set of countries risks pushing production to another set of countries ("offshoring"), which would not necessarily lead to less pollution.

About the author

Simon Lobach, PhD



Simon Lobach is an environmental historian interested in the development and functioning of extractivist networks. His PhD research, defended in 2024, was a socio-environmental history of the aluminium sector in Amazonia. In his current postdoctoral position in the project "Synthetic Lives: The Futures of Mining", he conducts research on the social and environmental implications of technological developments in mining and metallurgy. He has an academic background in history, Latin American studies and international affairs, and he has several years of professional experience in international environmental cooperation.

Geneva Graduate Institute, Geneva, Switzerland
simon.lobach@graduateinstitute.ch

Related article in the Ferrum archive:
"Von der Aluminium-Militärfeldflasche zum crashsicheren Strukturbauteil im Automobil"
by Reinhard Winkler in Ferrum 75/2003

Annotations

1 Dominique Barjot and Marco Bertilorenzi (ed.), Aluminium: Du métal de luxe au métal de masse (XIXe-XXIe siècle), Paris 2014.

2 Mimi Sheller, Aluminum Dreams: The Making of Light Modernity, Cambridge and London 2014.

3 Saleem Ali, From Soil to Foil: Aluminum and the Quest for Industrial Sustainability, New York 2023.

4 Wood Mackenzie, Aluminium under an Accelerated Energy Transition 1.5 °C Scenario, 2022. World Economic Forum and Accenture, Aluminium for Climate: Exploring Pathways to Decarbonize the Aluminium Industry: Community Report, Cologny/Geneva 2020.

5 International Aluminium, GHG Emissions Data for the Aluminium Sector (2005-2019), dataset, London n.d. https://international-aluminium.org/resource/ghg-emissions-data-for-the-aluminium-sector-2005-2019/. Cited in: World Economic Forum and Accenture (see n. 4), p. 3.

6 Fathi Habashi, A Hundred Years of the Bayer Process for Alumina Production, in: Historical Metallurgy Notes 81/909 (1988), p. 70.

7 For details about this process, see: Aluminium Limited, Aluminium Panorama, Montréal 1953, p. 30.

8 Peter Indermaur, Was andere können, können wir auch: Eine Geschichte der Alusuisse, in: Tobias Bauer, Greg Crough, Elias Davidsson, Frank Garbely, Peter Indermaur and Lukas Vogel Silbersonne am Horizont, Alusuisse, eine koloniale Geschichte, Zurich 1989, p. 46 f. Urs Gasche, Bauern, Klosterfrauen, Alusuisse, Bern 1981, p. 25–28.

9 All cited in Olivier Chatterji, Les débuts de l'aluminium en Maurienne: Conflits et mobilisations contre les "émanations délétères" (1895–1914), in: Revue française d'histoire économique 4–5 (2015), p. 218–221.

10 George Smith, From Monopoly to Competition: The Transformations of Alcoa, 1888–1986, Cambridge, Mass. 1988, p. 242–252.

11 Mike Barber and Alton Tabereaux, The Evolution of Søderberg Aluminum Cell Technology in North and South America, in: The Minerals, Metals & Materials Society 66/2 (2014), p. 223 f.

12 Adrian Knoepfli. Im Zeichen der Sonne: Licht und Schatten über der Alusuisse 1930–2010, Baden 2010, p. 48–59.

13 Florence Hachez-Leroy. Aluminium in Health and Food: A Gradual Global Approach, in: European Review of History 20/2 (2013), p. 224–226.

14 Leonard Weinstein and Alan Davison, Fluorides in the Environment: Effects on Plants and Animals, Wallingford, UK and Cambridge, Mass. 2014, p. 14 f.

15 These numbers can be calculated from the data contained in the database of the International Aluminium Institute for the year 2022: https://international-aluminium.org/statistics/fluoride-emissions/ (status 28.3.2024).

16 Mauve Carbonell, Environnement et usines d'alumine: des plaintes des riverains à la contestation globale des boues rouges, les exemples de Gardanne, France et d'Aughinish, Irlande, XXe-XXIe siècles, in: Cahiers d'Histoire de l'Aluminium, 67/2 (2021), p. 76.

17 Ken Evans, The History, Challenges, and New Developments in the Management and Use of Bauxite Residue, in: Journal of Sustainable Metallurgy 2 (2016), p. 316–319.

18 Carbonell (see n. 16), p. 76–81.

19 Ibid., p. 76–82.

20 Ibid., p. 82–85.

21 Volkert Dethlefsen and Harald Rosenthal, Problems with Dumping of Red Mud in Shallow Waters: A Critical Review of Selected Literature, in: Aquaculture 2 (1973), p. 267–280.

22 International Maritime Organization, London Convention 1972: Convention on the Protection of Marine Pollution by Dumping of Wastes and Other Matter, 1972 and 1996 Protocol, London 2003.

23 Chang-Joon Kim, Chang-Soo Chung, Jun-Mo Jung, Young-Ryun Kim, Dong-Won Kang, Hye-Eun Kim, Kyung-Hoon Shin and Ki-Young Choi, Long-term Effects of Chromium from Red Mud (Bauxite Residue) Ocean Dumping on the Benthic Environment in South Korea, in: Marine Pollution Bulletin 196/115584 (2023). See also: Evans (see n. 17), p. 319 f.

24 Martin Enserink, After Red Mud Flood, Scientists Try to Halt Wave of Fear and Rumors, in: Science 330/6003 (2010), p. 432 f.

25 Evans (see n. 17), p. 319–321.

26 Valentina Dentoni, Battista Grosso and Giorgio Massacci, Environmental Sustainability of the Alumina Industry in Western Europe, in: Sustainability 6 (2014), p. 9481.

27 According to data from Statista (Leading countries based on the production of alumina worldwide in 2023, https://www.statista.com/statistics/264963/global-alumina-production-by-country/), which correspond to the general tendencies that can be found in the online database of the International Aluminium Institute (https://international-aluminium.org/statistics/; both status 15.4.2024).

28 Sabrina Mesquita do Nascimento, O licenciamento ambiental da Hydro Alunorte: O que há entre desastres, licenças e expansões produtivas?, in: Edna Castro and Eunápio do Carmo (org.), Dossiê Desastres e Crimes da Mineração em Barcarena, Mariana e Brumadinho, Belém 2019, p. 91–104.

29 Four injured, one worker missing in Jharkhand mishap: Hindalco, The Times of India, 10 April 2019. (https://timesofindia.indiatimes.com/city/ranchi/four-injured-one-worker-missing-in-jharkhand-mishap-hindalco/articleshow/68801277.cms, status 15.4.2024)

30 Andy Home, Chinese outages a reminder of aluminum's dirty secret, Reuters (https://www.reuters.com/article/idUSKCN1SM1OR/, status 16.5.2019).

31 Data on these processes, also referred to as "inert anode" technologies, are still undisclosed. The author has obtained whatever knowledge he has of these processes by attending technological conferences organized for aluminium professionals, such as the Future Aluminium Forum in Québec in May 2023, the Greener Aluminium Online Summit organized by International Aluminium Today in September 2023, and the Annual Conference of the International Committee for the Study of Bauxite, Alumina and Aluminium (ICSOBA – November 2023).

32 See, for example, the announcement on Rio Tinto's website, which mentions low-carbon aluminium, but still does not rely on Elysis technology as the company promised in 2018: Rio Tinto to expand its AP60 low-carbon aluminium smelter in Quebec (www.riotinto.com/en/news/releases/2023/rio-tinto-to-expand-its-ap60-low-carbon-aluminium-smelter-in-quebec, status 12.6.2023).

33 Norsk Hydro, Development carbon capture and storage technology for aluminium smelters (www.hydro.com/no-NO/media/pa-dagsorden/veikart-for-nullutslippsproduksjon-av-aluminium/developing-carbon-capture-and-storage-technology-for-aluminium-smelters/, status 19.1.2022).

34 For exact data, see the online database of the International Aluminium Institute (see n. 27).

35 This is, for example, the case of the Tucuruí hydroelectric plant in Brazil, the eighth-largest hydroelectric dam in the world.

36 All statistics cited here are derived from the online database of the International Aluminium Institute (see n. 27), even though some indicators have been removed since. Consulted on 9.9.2023 and 9.4.2024.

Image credits

1 Adrian Knoepfli, From Dawn to Dusk: Alusuisse – Swiss aluminium pioneer from 1930 to 2010, Baden 2010, p. 17.

2 Ibid, p. 44.

3 Geschichte der Aluminium-Industrie-Aktiengesellschaft Neuhausen 1888–1938, Bd. II, 1921–1938, Chippis 1943, plate XVII.

4 ETH-Bibliothek Zürich, Bildarchiv / Photograph: Comet Photo AG (Zürich) / Com_L12-0378-0001-0002 / CC BY-SA 4.0.

5 © Peter Somogyi-Tóth / Greenpeace.