KN04 - The Decarbonisation of the Aluminium Industry Between Promises and Reality

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Abstract

Climate change is the 21st century's biggest ticking timebomb.
Things have to change — quickly.

The aluminium sector and companies need to rethink and transform their models, brands and services to survive and become future-proof.

This paper will help business leaders answer fundamental questions when it comes to change and investing in decarbonisation: why is there urgency to act for business in the aluminium sector? What are the solutions? How the net-zero transformation will reshape the aluminium supply chains, and what is the status of progress?

Keywords: Climate change, Net-zero carbon transformation, Aluminium industry, Sustainability, Circularity

1. Introduction: Things Have to Change — Quickly

Too many scientific reports have been published, words written, conferences held, and videos made on climate change, biodiversity loss, pollution and other pressures on the limits of the planet. The alarming consequences of not making dramatic changes to our lives and businesses are well known.

Things have to change — quickly.
Why is it also so important for businesses, and especially the aluminium sector?

Profound transformations are at stake: governments, regulations, investors, businesses, people's mindsets, values, societal narratives — all these need to change.

Most of the largest aluminium producers have already developed a decarbonisation strategy and the sector is equipped with a transformational vision with pathways to net-zero carbon. This paper provides a holistic view of the challenges and their solutions, with updates and insights. It will help readers better understand the challenges and the solutions, and how far companies have progressed in the decarbonisation of the aluminium sector.

2. The Problem: at Global Level the Aluminium Sector Should Abate 1.1 Billion Tonnes of CO_2 per Annum

We are facing a double-level challenge: aluminium demand is expected to grow significantly, and global emissions should decrease in absolute volumes to align with a net-zero carbon world by 2050.

Aluminium demand is expected to grow and reach 174 Mt of aluminium in 2050 (86 Mt for primary aluminium production, 88 Mt for recycled aluminium production), from current levels at 100 million tonnes (65 for primary and 35 for recycled aluminium).

Aluminium is the second most-used metal in the world by tonne produced after iron, hence the most used non-ferrous metal worldwide. Aluminium needs are growing, especially in the context of the energy transition thanks to its qualities (lightness, strength, durability, electrical and thermal conductivity, formability and recyclability). Aluminium is needed for lightweight vehicles, solar energy (solar energy systems use aluminium for various components, including for mounting and framing solar photovoltaic (PV) panels and for reflectors in concentrating solar power systems), and in the electric power grid electrical cables (along with copper).

The aluminium industry is currently responsible for 2 % of global greenhouse gases (GHG) emissions and generates about 1.1 billion tonnes of CO_2-eq annually. Primary aluminium production is highly energy-intensive, with electricity making up a large share of the energy consumed. Figure 1 below presents the breakdown of total aluminium emissions by process in the value chain. Clearly, the smelter stage accounts for most of the total emissions, with 78 % of sectoral emissions. Of this 78 %, 60 % comes from energy generation (electricity) and 18 % come from process direct emissions.

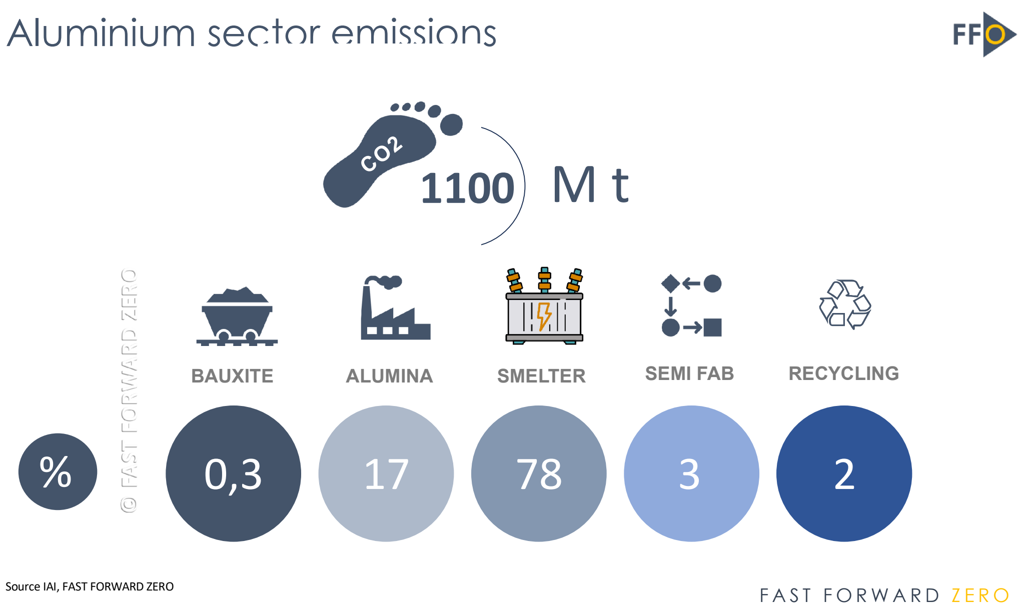

Figure 1. Breakdown of total aluminium emissions by process.

In January 2020, the International Aluminium Institute (IAI) created a GHG working group to understand what a Paris-aligned 2050 aluminium footprint would look like, what the pathways to get there would be, and what challenges can be expected along the way. The reports were finalised in 2021 [1].

In summary three broad areas of emissions reduction have been identified and developed, each with distinct innovation, policy and financial drivers, barriers, costs and materiality:

1. Electricity decarbonisation
2. Direct emissions reduction
3. Recycling and resource efficiency

In 2022, the Mission Possible Partnership [2] developed further a sectoral vision with more details for the different technological pathways and the enabling conditions for producers to effectively transform and invest. Figure 2 below provides a good summary of the challenges. 75 % of the problem is about energy decarbonisation, including 60 % which is linked to decarbonising the electricity used for the smelters.

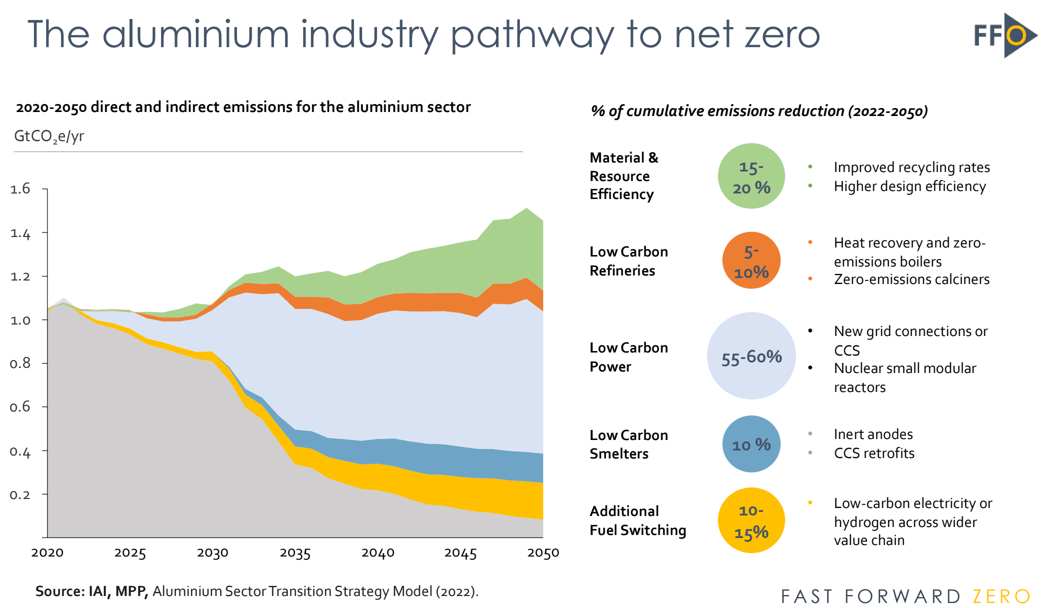

Figure 2. Summary of the challenges for the different technological pathways.

3. The Business Case for Decarbonisation is Now

The overarching reason is fairly obvious; solving the climate crisis is not an option for humanity.

However, in our fundamentally egotistical societies, many feel that the problem is the responsibility of others who should act first. I strongly urge anyone in this category to change lenses and look at the global picture.

Any business operating in the global aluminium value chain is part of a local and global ecosystem that is under huge pressure and already in movement to decarbonise. This is what customers want, what competitors are doing, and regulators are developing carbon tax schemes either at the source of emissions (country of origin) or through carbon import tax mechanisms (Figure 3). Organisations around the world have made tackling climate change a global priority. Reputation is also playing a big part as it drives a company's attractiveness to investors, customers, and has an impact on employee loyalty and talent acquisition.

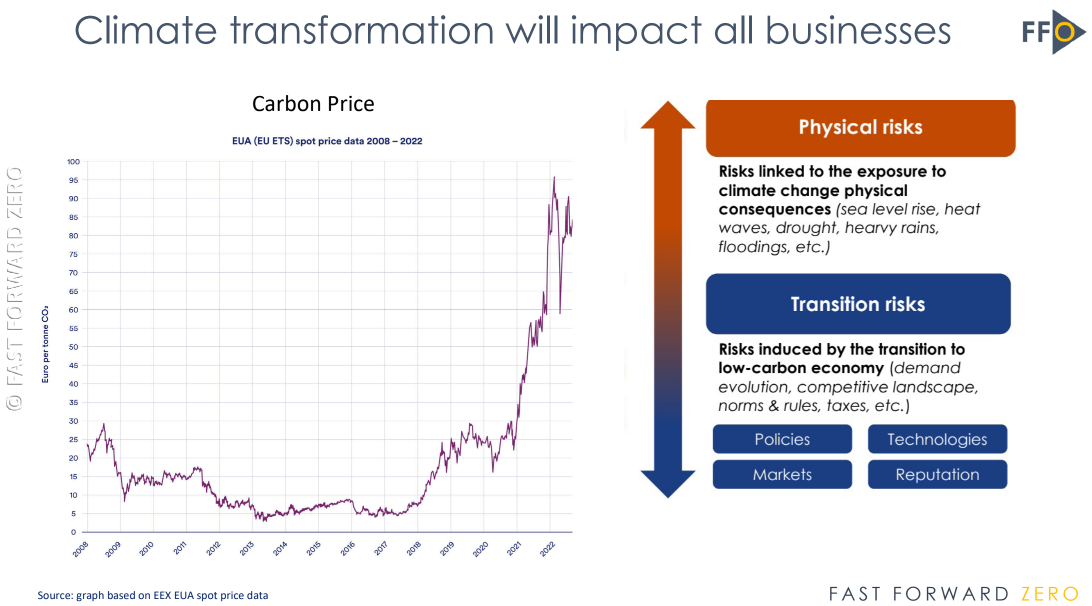

Figure 3. European Union carbon tax.

The aluminium sector has collectively understood the business case for decarbonisation, and a few leading companies have been pioneers in this space. The aluminium sector was the first industrial sector to publish a collective decarbonisation roadmap, through the collective work orchestrated by the Mission Possible Partnership, with the contribution of IAI, the World Economic Forum (WEF) and leading producers.

On the producer side, Rio Tinto (as early as February 2020) and EN+ Group/RUSAL were the first two global companies to make net-zero carbon pledges in the aluminium sector.
Since, most of the other leading producers have announced their net zero carbon commitments.

On the other side of the value chain, aluminium consumers are also engaging in a net-zero carbon journey. The most dynamic pressure comes from large consumer brands, especially from automotive OEMs, as well as the food and beverage sector. In the automotive sector, while OEMs are busy adapting their operations to switch their product portfolio to electric vehicles, they are developing strategies to reduce their scope 3 emissions. For example, Mercedes-Benz, require their suppliers to sign an "Ambition Letter" for any new contract, with a pledge to supply carbon-neutral products by 2039.

In the consumer goods segment, decarbonisation is also not an option.
All major business-to-consumer (B2C) brands pledge to have net zero value chains by 2040 (ABinbev, Carlsberg, Coca Cola, Pepsico, Henkel, P&G, Unilever) or 2050 (Molson Coors, L'Oréal). Ball Corporation, the largest single corporate user of aluminium, has developed a very comprehensive net zero strategy that incorporates all key drivers of their full value chain decarbonisation. They set very clear ambitions with medium- and long-term targets (2030-2050) for their operations and across their value chain, both upstream and downstream.
The demand for green aluminium is growing, driven by consumers trends and by a growing demand for aluminium for low-carbon technologies (EVs, renewable grid electrification).

While big producers have committed to net zero carbon plans, why should smaller producers care? The wave of commitment to decarbonisation has yet to reach medium- and small-sized companies. Even if smaller business mean fewer GHG impacts, every business has a role to play, from the smallest SME to the largest corporation. The one who makes the first move is the one who takes advantage of maintaining or developing business with the most climate demanding customers.

4. What is Needed at Company Level: to Start and Run a Net Zero Carbon Strategy

First, the challenge at global level is gigantic and extremely complex. Responding to the climate crisis and to the other pressures on the limits of the planet is probably the biggest challenge since the beginning of humanity.

It will require systemic changes at a global level, business level (sectors, companies, across supply-chains and finance) as well an individual level. All levels are interlinked and there will be resistance to transformation throughout the overall network. Think of the policy changes, public incentives, private financing and investment risks required to decarbonise an aluminium smelter powered by fossil fuels. Not to mention that any decision is in competition with other priorities for other climate solutions or other different problems entirely. Overall systemic change is slow to come.

At company level, each case is different, and we see many different approaches to climate change mitigation, depending on company size and geographical location.
Clearly it moves faster where regulators have put in place incentives for change with carbon tax (sticks) or tax rebates and public fundings (carrots). This is why we see most of the significant early investments and pilot projects in the EU, Norway, Canada, Australia, and UAE.

Large companies and medium-sized companies have yet to start. From experience, common patterns are relevant for any company wanting to start and run a net zero carbon strategy. I have developed a net zero transformation framework, summarised in Figure 4 below.

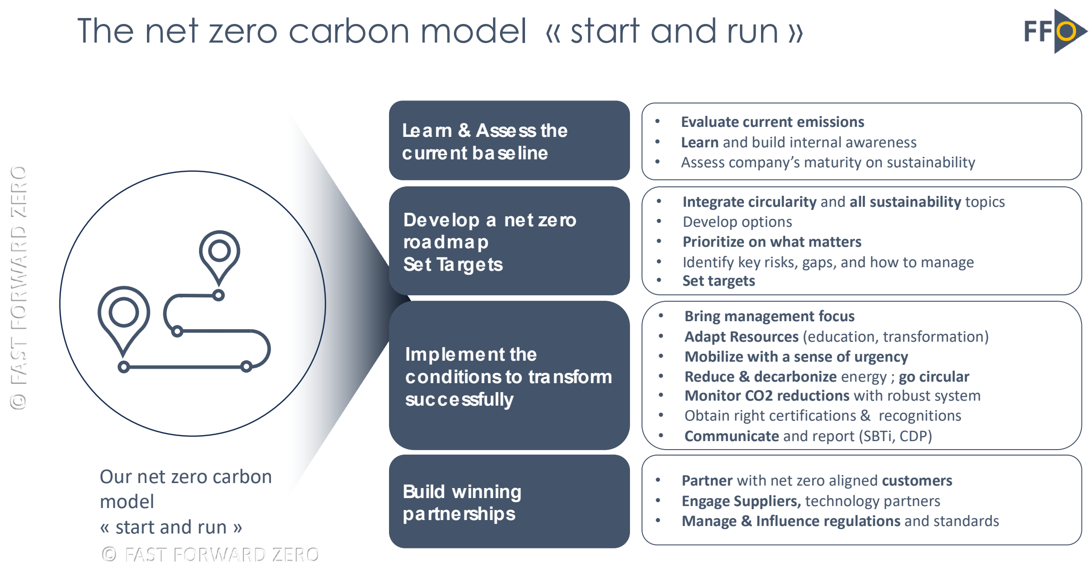

Figure 4. Net zero transformation framework.

5. The Promises and the Reality

5.1 Material Efficiency and Circularity Have the Potential to Make up 20 % of the Global Solution

Even if circularity is set to account for 20 % of the global solution it is a good starting point; it reminds us that the best energy and emissions savings come from prevention of use.

The secondary sector has the potential to grow its supply of aluminium from 36 Mt in 2022 to 81 Mt by 2050, and therefore secondary aluminium production can address the growth in demand expected over the coming 30 years, avoiding the need for additional capacity of carbon-intensive primary production. It is widely understood that remelting aluminium consumes 5 % of the energy required to produce primary aluminium. Therefore, avoiding the use of primary aluminium and maximising recycling routes are major drivers for material efficiency and GHG emissions reductions.

Globally the industry produces 103 million tonnes of semi-finished products (2022), of which 2/3 is from primary aluminium and 1/3 from recycled sources (of which 60 % are post-consumer sources and 40 % are pre-consumer scrap) (Figure 5).

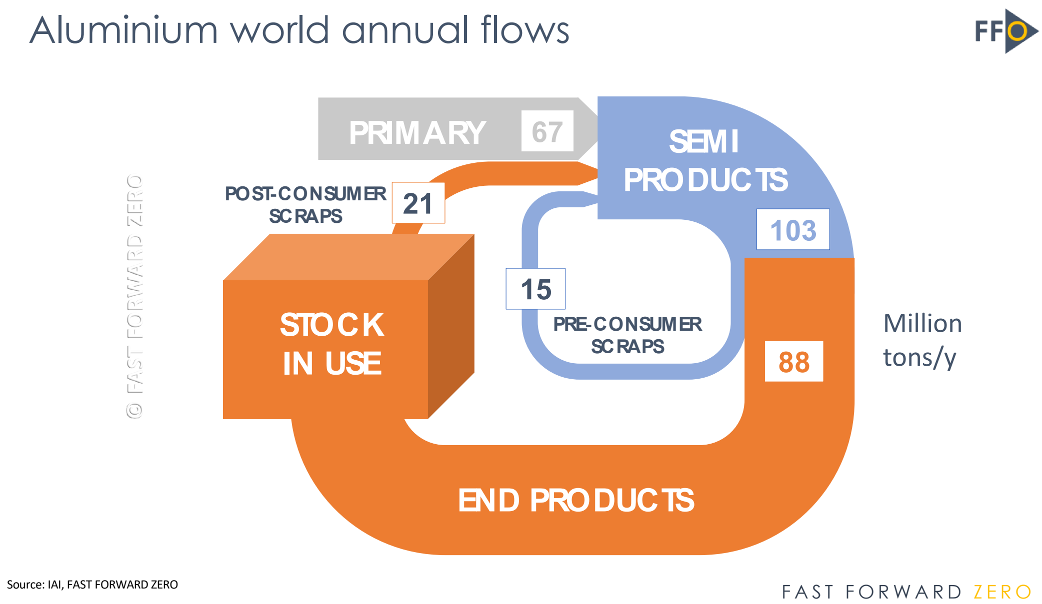

Figure 5. Annual production of semi-finished and end products.

We cannot produce all our aluminium products from scrap. This is because most of aluminium is kept in use in long-lasting applications (like building and construction, automotive, airplanes). There is not enough scrap available to cover global demand. However, absolute volumes of aluminium scraps will grow over time especially in regions where the use of aluminium is still relatively young (like in China). In addition, there is huge potential to increase the level of post-consumer scraps through better collection and avoiding landfills.

Globally 70 % of all aluminium contained in products at end-of-life is effectively collected and recycled back in the industrial loop. This makes aluminium one of the most recycled materials. However, there remains 30 % of aluminium waste that is lost and goes to landfill.

As shown in Figure 6 below, current post-consumer scrap collection rates vary widely across geographies and sectors. The aluminium can collection rate is above 95 % in Brazil but only approximately 50 % in North America.

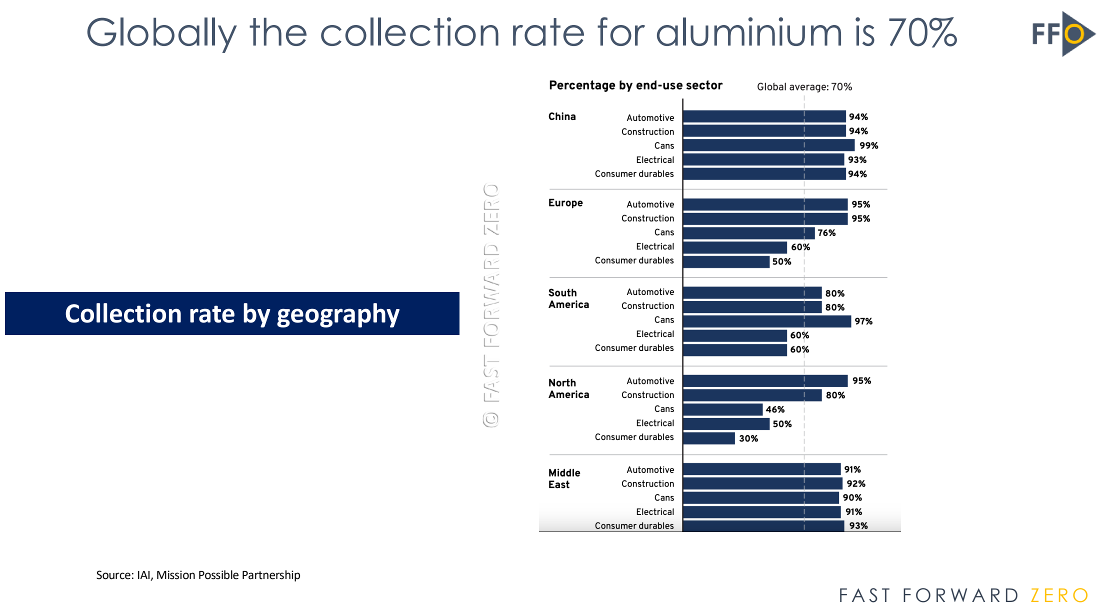

Figure 6. Post-consumer scrap collection rates.

Globally, average scrap collection rates for all end-use sectors will need to move from about 70 % today to more than 90 % by 2050 to maximise circularity in the sector.

Key solutions and measures to improve material efficiency and collection of aluminium scrap are well known, (but not always easy to implement):

- Regulating and normalising scrap collection (like deposit return schemes). Such systems have demonstrated their efficiency. Germany has achieved high can collection rates (over 98 %). The challenge is how this success can be replicated in more complex situations, such as extracting scrap aluminium from buildings, where it is likely to be mixed with other material.
- Circular design or eco-design, whereby the design of products and buildings incorporates end-of-life planning to ease the reuse, repair, dismantling and sorting of materials after the end of the use phase.
- Alloy separation, sorting, and purification methods, which involve a mix of managerial, logistics and technological solutions. As they develop, they will maximise the volumes, quality and chemistry consistency of post-consumer scrap.

5.2 Electricity Decarbonisation of the Smelters is 60 % of the Problem

Here we are touching on the elephant in the room of aluminium sector decarbonisation.

Globally, the industry needs to decarbonise 80 GW of constant electricity capacity, as about 50 million tonnes of primary aluminium production (75 % of the world production) is operated with electricity based on fossil fuels. 80 GW is huge; it represents more than 5 times the total installed electricity capacity of a country like France. An average smelter of 500 kt/year needs 800 MW of power, constantly delivered 24 hours a day, 365 days a year.

The challenges are multiple and complex:

- Renewable energy is intrinsically variable. Aluminium smelters need constant and stable energy,

- A typical nominal power of 1 MW requires two to four times more nominal capacity of renewable energy, to compensate for the intermittent production of solar or wind energy. The actual ratio depends on the type of renewable, storage, grid stability, and demand flexibility solutions available,
- Securing renewable Power Purchase Agreements (PPAs) is difficult because demand typically outweighs supply, and many geographies have yet to mature a merchant power market,
- Depending on geographies, there is significant variation in availability of local low-carbon power and in how quickly the local grids can decarbonise,
- the cost of transformation is enormous and many businesses cannot justify the business case.

Emirates Global aluminium was a first mover in 2021. They built a plan to source part of their electricity with renewable energy. It started with a renewable energy PPA for the equivalent of 40 000 t of aluminium production. Since then, they have developed a strategy to completely free up their production from gas powered electricity, including the divestment of their existing gas power plants.

As of September 2023, many cases of electricity switch and power purchase agreements have been announced. To mention a few recent ones:

- Alcoa announced wind power purchase agreement to support future restart of San Ciprián smelter in Spain. The agreement with Endesa would include up to 131 MW beginning in the second half of 2025 and through 2033, representing slightly more than 30 % of the smelter's energy requirements at maximum capacity.
- In June 2022, Rio Tinto issued a call for proposals to develop four gigawatts (4 000 MW) of large-scale wind and solar power, alongside "firming solutions" such as battery storage, to power two aluminium refineries (Yarwun Alumina Refinery, and Queensland Alumina refinery) and one smelter in Queensland's Gladstone region (Boyne). The three assets require 1 140 MW of reliable power to operate, which it says equates to at least 4 000 MW (4 gigawatts).
- In 2023, Vedanta announced an ambition to achieve 2.5 GW renewable power capacity by 2030. The company has entered into long-term power delivery agreements to source over 1 335 MW of renewable energy (through a mix of solar and wind energy across Odisha and Chhattisgarh's operations).

Figure 7 shows the electricity consumption for primary aluminium by region.

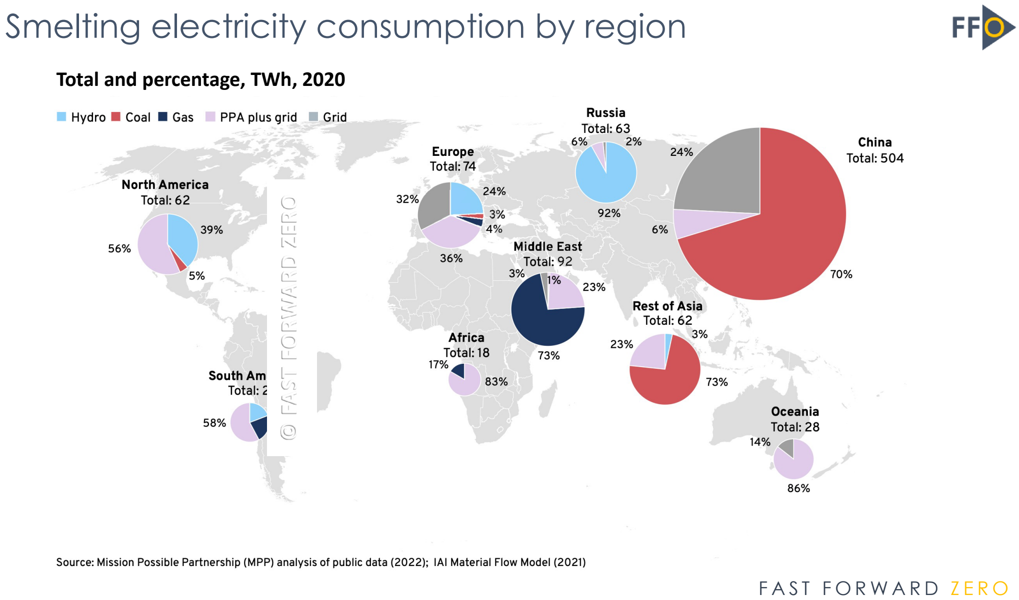

Figure 7. Aluminium smelters electricity consumption by region.

The move to renewable energy is difficult and the road to carbon free electricity in the aluminium sector is a long one.

Rio Tinto is committed to a multibillion-dollar plan to halve its carbon footprint by 2030 and reach net zero by 2050. Recently, Rio Tinto's CEO, Jakob Stausholm, highlighted the immense challenge such ambitions represent in terms of investment and time pressure. In Australia, their renewable energy plan faces multiple challenges, including the negotiation of land deals with traditional landowners and the time required to execute projects. Jakob Stausholm said at the annual general meeting: "Our coal-fired energy contracts are running out in 2028/29, so right now is the time to work towards finding renewable energy sources. Obviously, we cannot burn your money, shareholders' money, so we need to find a way where we can get competitively priced renewable energy. It takes time to get these things done, and that means that it's urgent because 2030 is really tomorrow."

5.3 What is The Future for Carbon Capture in the Aluminium Sector?

Carbon Capture Use and Storage (CCUS) technologies have the potential to address the big part of the aluminium decarbonisation challenge, because it can be applied for the coal and gas power plants. Carbon capture technologies encompass a series of technological solutions, some are mature for many years and other are still in developments. The International Energy Agency (IEA) evaluates that 45 million tonnes of CO_2 are captured annually, and it will grow to 380 million tonnes of CO_2 by 2030. Figure 8 below presents the wide range of technological options for CCUS [3].

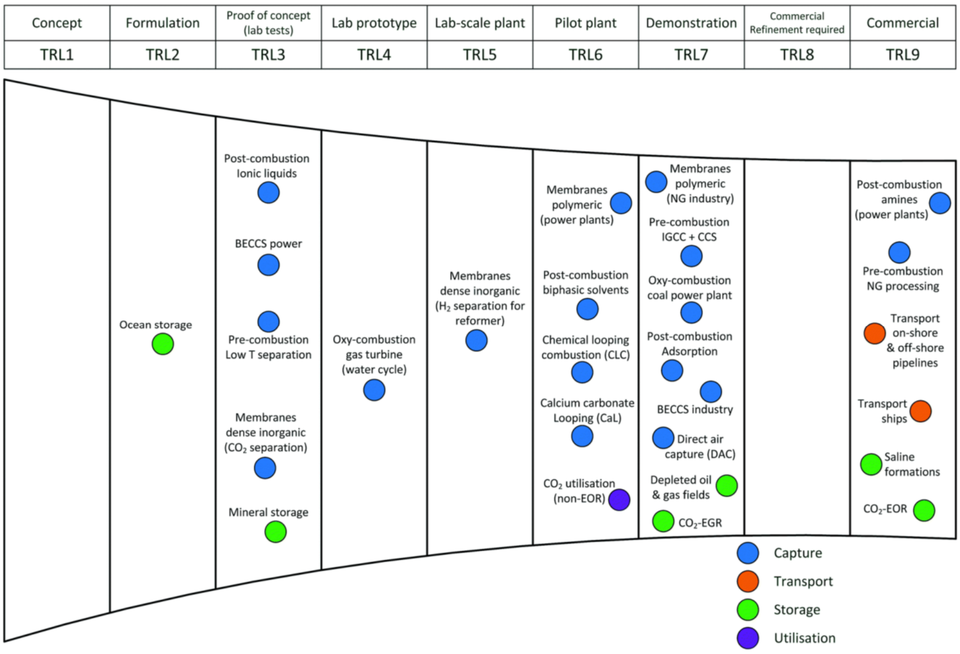

Figure 8. Range of technological options for CCUS.

Carbon capture technologies, such as amine absorption, are already commercially mature. They have been used for decades especially in the fossil fuel sector to enhance the recovery of gas and oil fields. (In these cases the impact is unfortunately an increase of CO_2 emissions for the site! Technologies often can be used for good or for bad.). The steel and cement industries are investing in industrial pilots to test different configurations and technologies of carbon capture with storage or use. When it comes to the process emissions at the smelters (CO_2 produced from the consumption of anodes), CCUS technologies can also play a role, although it is commonly said that CCUS is not a viable option. This statement needs to be moderated and may become untrue in the future.

Industry expert Stephan Broek (Kensington Technologies) predicts that the carbon capture is feasible at low concentration and can achieve very good capture efficiency (90 %).

The main problem for smelters is the low concentration of off-gases (typically 1 %) as well as pollutants (HFx and NOx) which can be detrimental to the economic viability of a Carbon capture system. The low concentration increases the size of CO_2 absorber and the electrical power consumption to push through the gas flow. Alternatives are to concentrate the effluents up to 4 %. This would imply to reduce the ventilation flow at the potlines (up to 75 % reduction), impacting then the process, and the superstructures which may need to be redesigned and replaced.

Stephan Broek's view is that dealing with 1 % volume CO_2 is probably the better option to start with, while making improvements with decreased volume of ventilation gases. A future sweet spot is probably ~2 % vol. CO_2 with 40–50 % reduced flow. That would require large heat exchangers which are being currently tested at 2 smelters in the Middle East.

There will be trade-offs to be made between low concentration/larger capture equipment and higher concentration of effluents with reduced capture installations but adaptions to the potlines. The bottom line will be higher CAPEX and OPEX costs compared to CCU installations operating with higher concentrations 5 % and above.

Real cases:
Aluminium Dunkerque applied for funding to build a CO_2 capture pilot plant using a solvent. The focus of their work will be on the concentration of effluents.

Start-ups like Verdox technology are working on promising new technology of electro-swing carbon removal. Hydro Aluminium has started a pilot project

5.4 Inert Anodes – When Will the Technology Really Be Available?

The electrolysis of aluminium with inert anode technology is addressing approximately 15 % of the global sectoral emissions.

The technology is not new. Alcoa, Rio Tinto (and formerly Alcan and Pechiney) as well as Rusal have been working on it for many decades. Despite 40 years of research, the technology is not yet proven at industrial scale. Often referred as the Holy Grail for industry, the technology makes an exceptionally attractive promise: producing oxygen as a by-product of aluminium instead of CO_2. In the absence of carbon electrodes, the emissions of PFCs (Perfluorinated compounds) will also be eliminated, and there will be no need for big anodes plants and their associated emissions and scrubbers.

So when will the dream become reality?

Let us acknowledge that the challenges are enormous, as explained very well by Donald Sadoway [4]: The process conditions of the aluminium electrolysis are extremely tough: high temperature (typically 960ºC), in a very corrosive bath of cryolite. The right material should be physically and electrochemically stable at high temperature, in presence of reactive electrolytes, resistant to attack by pure oxygen and it should be electrically conductive. Finding the right material for the inert anodes is a major step but not final. Everything else needs to be redesigned: the chemistry of the electrolytes, the size of the reduction cell, the flow of material and energy, the heat balance on the inside and outside of the pot, the design and industrialisation of the anode itself. It is not surprising that research for the inert anode has gone for so long.

The expected readiness of commercial production lines has been pushed back a few times. At the launch of the ELYSIS joint venture between Rio Tinto and Alcoa in 2018, the promise was to have a technology commercially demonstrated in 2023. As of September 2023, the pilot plant is in construction in Alma, Quebec. The technical tests and process validations may take and additional 2 to 3 years. RUSAL has been operating an industrial pilot at 140 kA for a few years, but with fundamental challenges on the core of the technology (Figure 9).

So when?
Well, Neils Bohr once said, “Prediction is very difficult, especially if it’s about the future.”
In my view, not before 2030.

The other aspect is that the changes compared to existing operations are so big that it is hopeless to count on easy retrofits of current potlines. The potential inert anode technology will be adapted for new green fields or complete reconstruction of potlines.

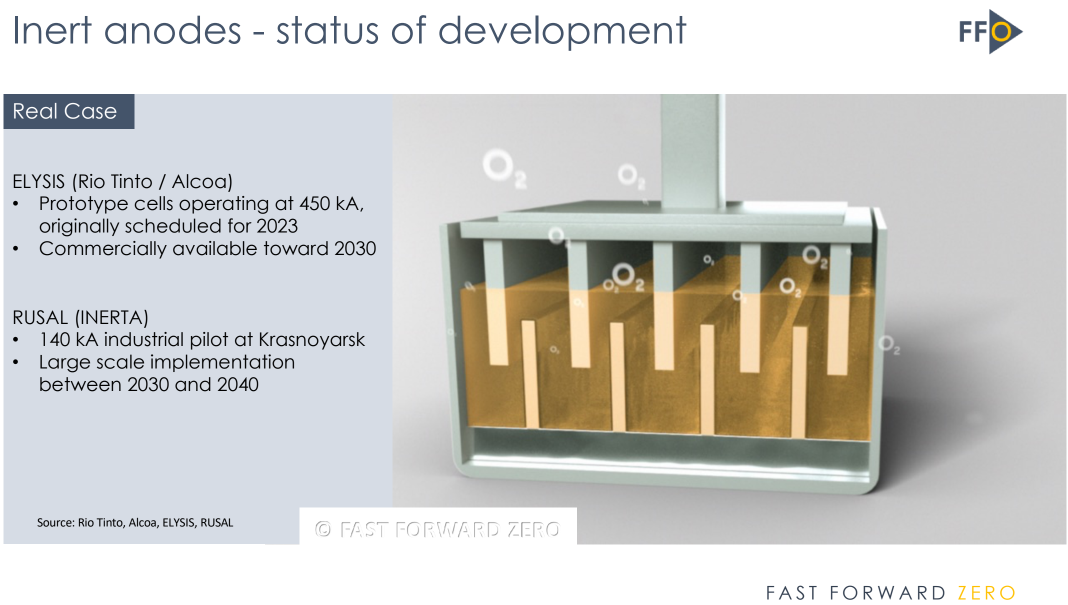

Figure 9. Status of development of inert anodes at ELYSIS and RUSAL.

5.5 The Carbochlorination with CO_2 Regeneration Can Be an Alternative Solution to the Inert Anode Technology. But the Road to Readiness Is Still Long.

Carbochlorination with CO_2 regeneration is an alternative to the inert anode technology.

Alcoa developed the carbochlorination process in the 1980s, for reasons other than CO_2 emission reductions. The motivation was to reduce energy consumption (from 14 to 8–9 MWh/t of Al), and to operate at a lower electrolyte temperature (about 720 °C). The process includes the chlorination of aluminium oxide (alumina), using CO as a reducing agent and chlorine gas (Cl_2) as a chlorination agent. The resulting aluminium chloride ($AlCl_3$) is then electrolysed using a bipolar cell. The process also produces CO_2. The new big idea is to recycle back the CO_2 and keep it in a closed loop. The CO_2 is reduced into CO and sent back to the carbochlorination process. This CO_2–CO loop would however add an extra energy consumption of 5 MWh/t Al. This process faces many challenges, especially around the handling of pure aluminium trichloride.

Norsk Hydro has launched in Porsgrunn a pilot project which aims to prove the concept by 2025 and develop an industrial scale pilot by 2030 (Figure 10).

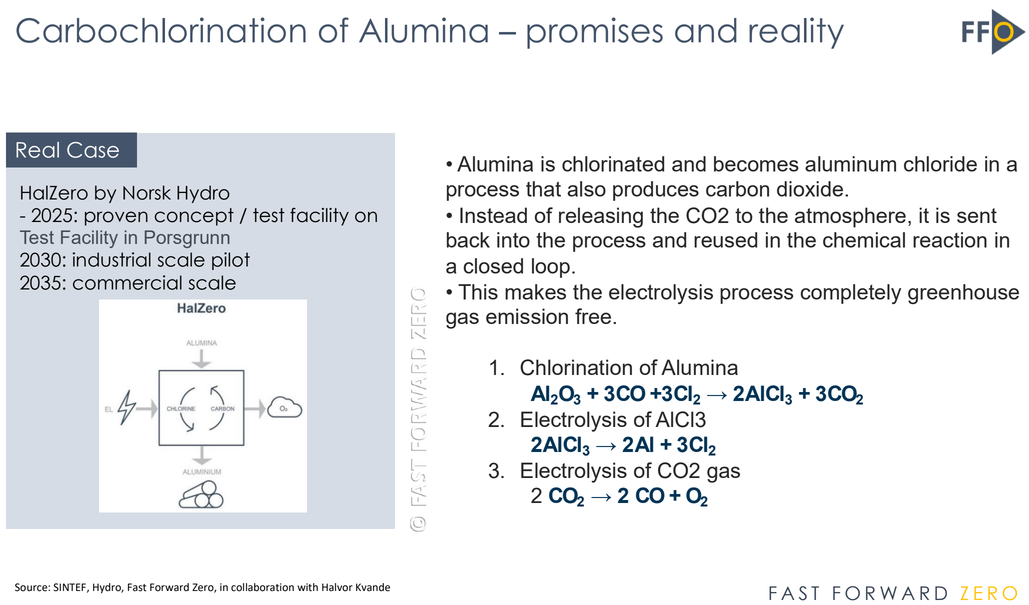

Figure 10. Carbochlorination of Alumina: Norsk Hydro HalZero project.

5.6 What Will Be the Role and Impact of Hydrogen in the Sectoral Decarbonisation?

The use of green hydrogen is a natural candidate to replace natural gas and fossil fuels everywhere we need heat, particularly at the alumina refineries (both for digestion and for the calcination), and across the downstream transformation for aluminium remelting. The implementation of a green-hydrogen-based could have the best decarbonisation potential when natural gas burners are already in place, and could be quickly retrofitted for hydrogen firing.

However the key limitation will be on availability and price.

The EU Green Deal and the US Inflation Reduction Act (IRA) have triggered a flurry of projects for green hydrogen which is often seen as a miracle solution in the hard to abate sectors. The European Union has set itself the target of producing 10 million tonnes of hydrogen a year by 2030. This level of production would require 500 terawatt-hours of renewable electricity, equivalent to France's current annual electricity consumption. By the same time (2030), the global demand for renewable electricity in Europe will represent the double of the total electricity production of today's level, because of the electrification of the other sectors: transportation electric vehicles (EVs), other industries and buildings (heat pumps replacing fossil fuels).

The reality will face concrete limitations in terms of global green energy availability and speed of development. Furthermore, the use case for green hydrogen is competing with many other applications. The steel industry pretends that green steel is the best use case for hydrogen. According to WV Stahl, 1 tonne of hydrogen enables 28 tonnes of CO_2 saving when replacing blast furnace with direct reduction by hydrogen. The next best alternative is transportation (using fuel cells) with 17 tonnes of CO_2 savings. In the case of the aluminium industry, the saving can be estimated at around 10 tonnes CO_2 per tonne of hydrogen when it replaces natural gas for heating (for alumina refineries) (Figure 11).

Figure 11. CO_2 savings per tonne of hydrogen for different processes.

It is very hard to predict the future price of green hydrogen. It will be linked to its availability, supply and demand dynamics. Expert projections indicate prices long term of 5 USD/kg of H_2 (2030). However, we can expect that price volatility will be the norm.

5.7 Partnerships, Public and Market Incentives, Financing Are Key to Accelerate the Transformation of the Sector

This paper has focused on the business options available at company level to globally transform the industry toward a net zero carbon future. Delivering a net zero carbon aluminium sector will require new forms of engagements and partnerships across the value chain (producers, customers, technology providers, energy producers and grids), regulators and investors. Particularly close collaboration between the aluminium sector and the electricity market is vital. Long-term investment plans need to find the right conditions between access to low-carbon electricity at the right price, long-term secure metal off takers, and financing.

The roles of market incentives are also vital.
We see a myriad of commercial partnerships with producers of low carbon aluminium and consumers which contribute to stimulate the demand for lower carbon aluminium (Norsk Hydro with Porsche, Velux, Alcoa with Audi, Rio Tinto with Anheuser-Busch InBev, EGA with BMW, NOVELIS with Volvo Cars, to mention a few).

Finally collaborative initiatives play an instrumental role to accelerate the industry transformation as they help the emergence and development of new ecosystems, common standards, tools, infrastructure and regulations.

Many initiatives should be mentioned here, but let’s mention three significant ones:

- The Aluminium Forward 2030 [5], launched by the IAI. It is a collaboration platform to structure collective actions between aluminium producers and downstream users (including big automotives OEM brands or beverage brands).
- The First Movers Coalition is gathering purchasers of aluminium making commitment to buy 10 % of all their annual primary aluminium volume below

3 t CO_2 / t Al (as per TechnipFMC definition), and to maximise the use of secondary aluminium by 2030.
- The Aluminium Stewardship Initiative (ASI) fosters responsible production, sourcing and stewardship of aluminium, through the ASI standards and collaborative initiatives.

6. In Summary, the Industry Has Started to Move, but the Real Impacts in Absolute Emission Reductions Are Still to Be Realised

It is always interesting to compare the reality with the expectations. In the decarbonisation space, there are almost no good surprises, unfortunately.

The MSCI Net-Zero Tracker published in March 2023 [6] monitors the alignment of the world's listed companies with the threshold of limiting the rise in average global temperatures to 1.5 °C above preindustrial levels as set by the Paris Agreement.
None of the hard-to-abate sectors is on a pathway to net zero, compatible to a 1.5 °C scenario.

The aluminium sector is no exception. According to IAI data, the global sectoral emissions (tracked since 1990) have not yet demonstrated the inflection point that would indicate a reverse trend of reduction. However the industry is probably ahead of all hard-to-abate sectors in terms of mobilisation, and percentage of companies committed to net zero carbon plans.
Figure 12 below summarises a research conducted by IAI in 2022 across all aluminium producers. More than 50 projects have been identified across all dimensions and solutions mentioned above. The momentum is definitely growing, everywhere in the world. This gives us a good glimpse of hope.

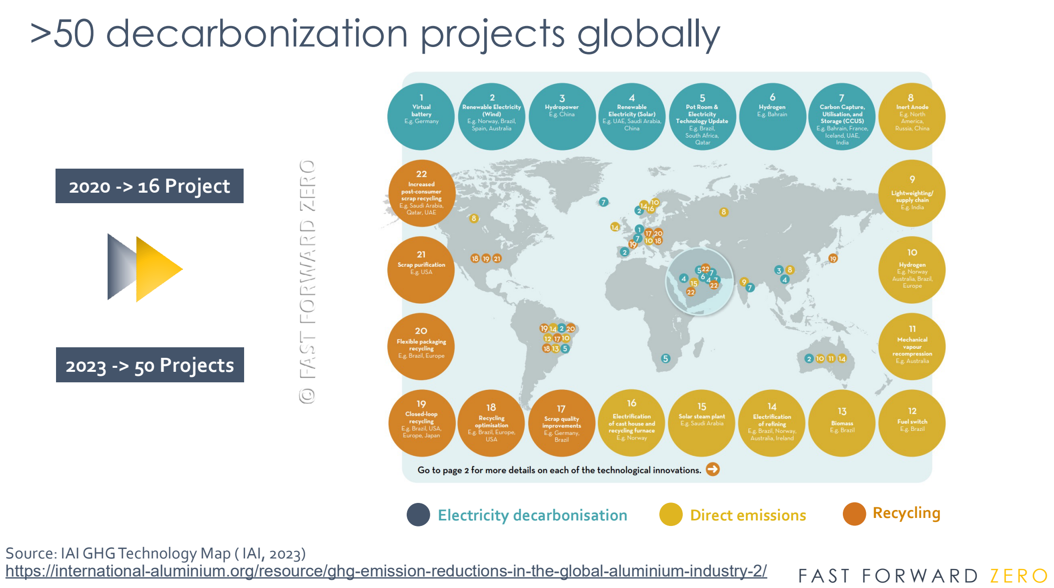

Figure 12. Fifty decarbonation projects across all aluminium producers.

7. Acknowledgement

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