MASTER'S THESIS

How carbon neutrality imperatives are changing the Aluminum Industry?

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Dissertation written under the supervision of Professor Peter Rajsingh.

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Resumo

A Indústria do Alumínio está a enfrentar uma grande pressão da sociedade e dos governos para atingir a neutralidade de carbono até 2050, uma vez que é uma indústria de alta emissão de CO2. Este estudo visa determinar como os imperativos de alcançar a neutralidade de carbono até 2050 afetarão a indústria de alumínio. Examinarei como as teorias e outros estudos sobre a descarbonização da indústria se enquadram na realidade. As empresas estão realmente a realizar esforços para descarbonizar o setor ou é tudo fachada, quais serão as maiores mudanças no setor e quais estratégias que as empresas podem adotar para atingir esse objetivo?

Para explorar como as imperatividades da descarbonização irá mudar a indústria do alumínio, vários esforços de pesquisa foram realizados. Em primeiro lugar, a revisão da literatura enquadrou o problema e a investigação ajudou a compreender melhor o problema que a indústria está a enfrentar. Além disso, várias entrevistas foram realizadas com especialistas. Os resultados demonstram que as empresas, algumas mais do que outras, estão de facto a colocar em prática diferentes estratégias para atingir a neutralidade de carbono, embora ainda estejam nos processos iniciais de implementação.

Esses resultados sugerem que as empresas estão de facto cientes dos factos e estão a agir. No entanto, a indústria ainda é muito voltada para o lucro, embora as empresas afirmem que não, como mencionarei no decorrer desta tese.

Palavras-Chave: Imperatividade ; Neutralidade do Carbono; Emissões de efeito de estufa ; Tecnologia de ânodo inerte; Alumínio; CO2 ; 2ºC

Abstract

The Aluminum Industry is facing high pressure from society and governments in order to achieve carbon neutrality by 2050, since it is a high CO_2 emission industry. This study aims to determine how the imperatives of achieving carbon neutrality by 2050 will affect the aluminum industry. I will examine how theories and other studies regarding decarbonisation of the industry frame themselves in reality. Are companies really trying to make efforts to decarbonize the industry or it is all for the show, what are going to be the biggest changes in the industry, and what strategies companies can adopt in order to achieve this goal.

To explore how decarbonization imperatives will change the aluminum industry, various research efforts were undertaken. First, the literature review framed the problem and information helped better understand the problem that the industry is facing. Further, various interviews were conducted with experts. The results showed that companies, some more than others, are in fact putting in practice different strategies to achieve carbon neutrality, even though they are still in the early stages of the deployment.

These results suggest that enterprises are in fact aware of the facts and are taking action. However, the industry is still very profit driven, even though the companies claim not to be as such as I will mention in the course of this paper.

Key-Words: Imperatives ; Carbon Neutrality; Greenhouse emissions ; Inert anode technology ; Aluminum ; CO_2 ; 2ºC ;

Chapter 1: Introduction

Picture a light yet strong metal which resists corrosion, is non-toxic and long-lasting, and can be shaped into essentially any shape. This is aluminum, a resource, an instrument at the disposal of an architect that allows him or her to design structures that are impossible to develop with wood, plastic, or steel. (Aluminium Leader, s.d.).

Aluminum is the third more common chemical element on earth after oxygen and silicon and is the most abundant metal in Earth's crust (Aluminium Leader, s.d.). It has played an important role in industrial development and as a critical industrial metal, it is lightweight, has high resistance, high reflectivity, high elasticity, and is capable of conducting heat and electricity. As a consequence, aluminum usage in industrial areas has increased substantially. By 2025, global aluminum production is expected to reach 120 metric tons (MT), up from 45.3 MT in 2006, with an annual growth rate 4.1% and a total increase of 160% (Menzie, et al., 2010).

2019 was the second warmest year on record and the end of the warmest decade (2010- 2019) ever recorded (United Nations, 2020). In 2019, levels of carbon dioxide (CO2) as well as greenhouse emissions in the atmosphere reached a record highs (United nations, 2020). Countries on each and every continent are affected by climate change. It is disrupting national economies and affecting lives. Weather patterns are changing, sea levels are rising, and weather events are becoming more extreme (United Nations, s.d.). A recent series of articles examining efforts by heavy industries to decarbonize production of construction/building materials, portrays aluminum as highly relied upon in buildings all over the world and accountable for 2% of all human-caused greenhouse emissions (Cousins, 2021).

Transforming aluminum from bauxite consumes a lot of energy and also has a panoply of environmental repercussions. Mines, both open and underground, have a protracted influence on wildlife in surrounding areas and across numerous generations. Clear-cutting forests and grasslands generates biodiversity loss, habitat destruction, carbon dioxide emissions, and erosion. Mining operations have gradually caused considerable devastation, although in recent years, efforts to rehabilitate and regenerate natural ecosystems have been implemented after mining extraction is completed (Student Conservation Association, s.d.). The road to carbon neutrality will have multiple impacts on the aluminum industry, since it is a major pollutant being used more extensively in Europe and around the world.

Efforts by European Aluminum to tackle climate change started well before negotiations that culminated to the Paris Agreement at COP21 (the Paris Climate Conference is also known as the United Nations Framework Convention on Climate Change (UNFCCC)). Sustainability is recognized by the industry as a business and societal value; the roadmap 2025 incorporates both climate change policies and societal concerns as stated in the UN Sustainable Development Goals (European Aluminium, 2015).

Chapter 2: What is Aluminum and its History

Chapter 2.1: History

It may be difficult to believe but only 150 years ago aluminum was contemplated to be silver from clay and was a highly expensive metal. Nowadays, it ranks number two in consumption volume among all the metals, only being surpassed by steel. In the upcoming decades the demand for aluminum will proceed to increase. Current developments in the auto industry as well as the fast growth of cities, new likely uses of aluminum as a substitute for copper in the power industry - these and many other trends mean that the winged metal is well positioned to maintain its dominance as a fundamental structural material in the twenty-first century (UC Rusal, s.d.).

Aluminum bearing compounds were used by ancient civilizations in the form of clays containing add rated aluminum silicate, farm into pottery. The Egyptians and Babylonians used aluminum ions to make colours and medicines (Aluminium Federation, 2015). Sir Humphry Davy, a British scientist, was the first to uncover the presence of aluminum in 1807, on earth. Hans Christian Ørsted, a Danish chemist, first produced impure aluminum in 1825, using aluminum chloride to heat potassium amalgam. In 1827, Friedrich Wöhler refined this process and established the specific gravity of aluminum in 1845. During the second half of the 19th century, a number of other chemical processes were developed that resulted in aluminum being produced in small quantities as a semi-precious metal (King, 2001).

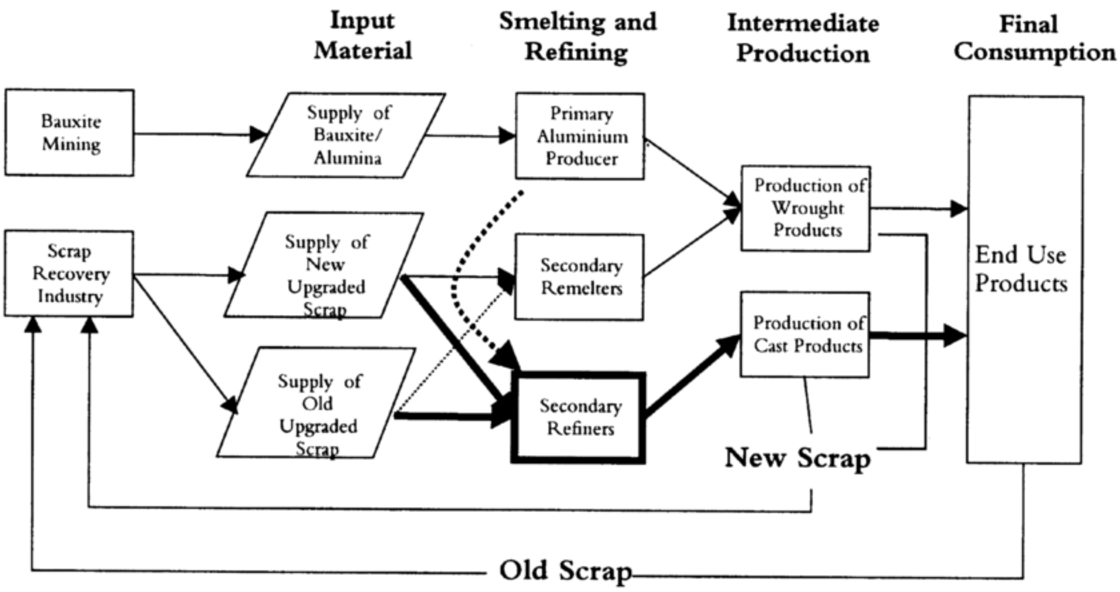
At the turn of the 20th century, aluminum was essentially not used in civil engineering, due to its prohibitively high cost and scarcity of supply. However, everything changed in the 1920s, when electrolysis brought down the cost of aluminum by 80%, making it extremely popular for roofs and domes, drainage, and wall panels, as well as for decorative purposes (Reynaers Aluminium, s.d.). The Empire State Building in 1931 pioneered wider use of aluminum as the tallest building in the world until 1970. The metal was employed in all of the building's regular structures as well as in the interiors with frescos being one of the building's "calling cards" on the lobby ceiling, as well as aluminum and 23 carat gold on the walls (Ngoc Diep Group, 2021).

Aluminum's use in construction was curtailed in the 1940s since the metal was predominantly used to construct airplanes. It even got a new nickname: "winged metal." Nevertheless, beginning of the twentieth century, high-rise skyscrapers and bridges began to use aluminum more often. Roofs, paneling, transparent panes, windows and doorframes, stairwells, air conditioning systems, and solar protection are among the applications today, heating systems, furniture, among many other things (Gulri, What Architects and Designers Say About Aluminium, 2021). Even though aluminum is an exceptional heat insulator, one of if not the most important quality of aluminum is its lightness. Aluminum plate has half the weight of steel plate with the same strength due to its low specific weight. As a consequence, aluminum structures weigh half to two-thirds as much as steel buildings and potentially to one-seventh as much as fortified concrete structures with the same bearing capability (Gulri, What Architects and Designers Say About Aluminium, 2021). This is why aluminum is employed in high-rises and skyscrapers today as a more cost-efficient alternative to steel which requires deeper foundations. Aluminum drawbridges' lightness makes their components lighter, reduces counterbalances, and offers the architect more freedom to express creative vision (Aluminium Leader, s.d.).

Chapter 2.2: Production

There are two primary sources of raw material from which aluminum is produced: bauxite ore and scrap aluminum metal. Before being sent to a primary aluminum smelting plant, bauxite ore is refined into aluminum oxide (alumina) through the Bayer process at an alumina refinery. In the primary aluminum smelter, the alumina is further refined using the Hall-Héroult electrolytic process of which there are two varieties, the Soderberg- and the Prebake processes. Primary aluminum production plants, ingot products such as slabs, billets, casting alloys and remelt ingots, are used by intermediate producers of various cast and wrought products (The Aluminum Association, s.d.) (How products are made, s.d.). The other source of raw material

- scrap metal - comes in two general varieties, old and new scrap. Old scrap arises when products containing aluminum metal worn out and in due course discarded. New scrap is generated throughout all stages in the manufacturing process itself; Drill holes, clips, and trims, as example, are returned into the manufacturing process and remelted into marketable aluminum properties (Bloomberg, 2007).

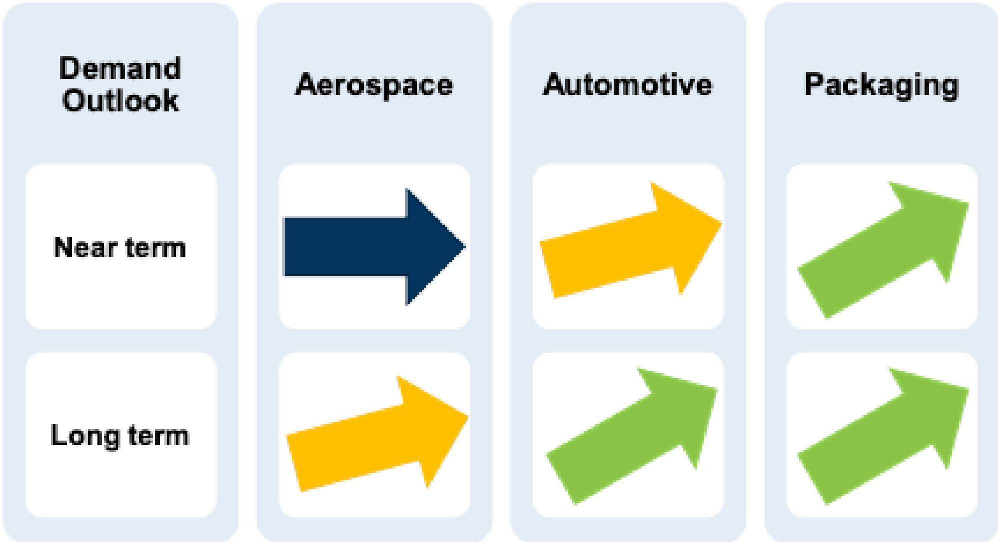


Source: Google Images

Chapter 3: The vast uses of Aluminum

Nowadays, aluminum uses include the automotive sector, aerospace, packaging, construction, cables, and electronics with steadily increase in demand (European Aluminium, 2019). Per a recent World Bank study, development and demand for low-carbon advanced technologies - and thus minerals and metals - is growing in order to try to achieve the COP21 commitment towards preventing temperatures from rising more than 2°C. A notable case is electrical storage batteries which use aluminum, iron, manganese, cobalt, lead, nickel, and lithium. Demand for these metals has surged by more than 1,000% under a 2ºC scenario (World Bank, 2017).

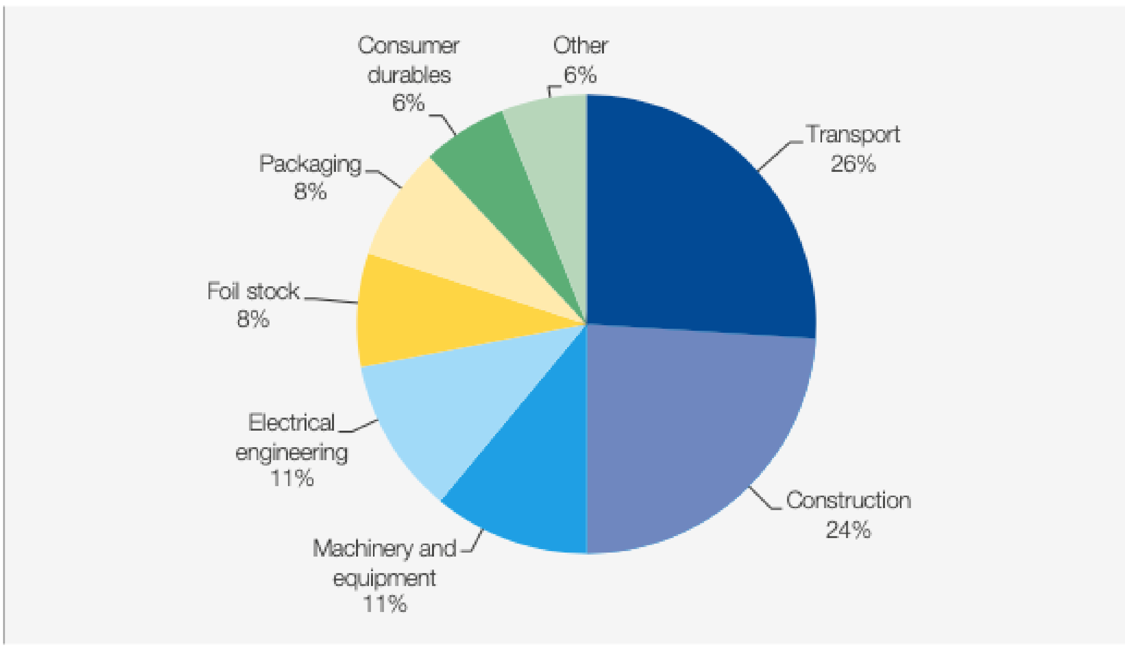
Near-term and long-term demand outlook for various end markets



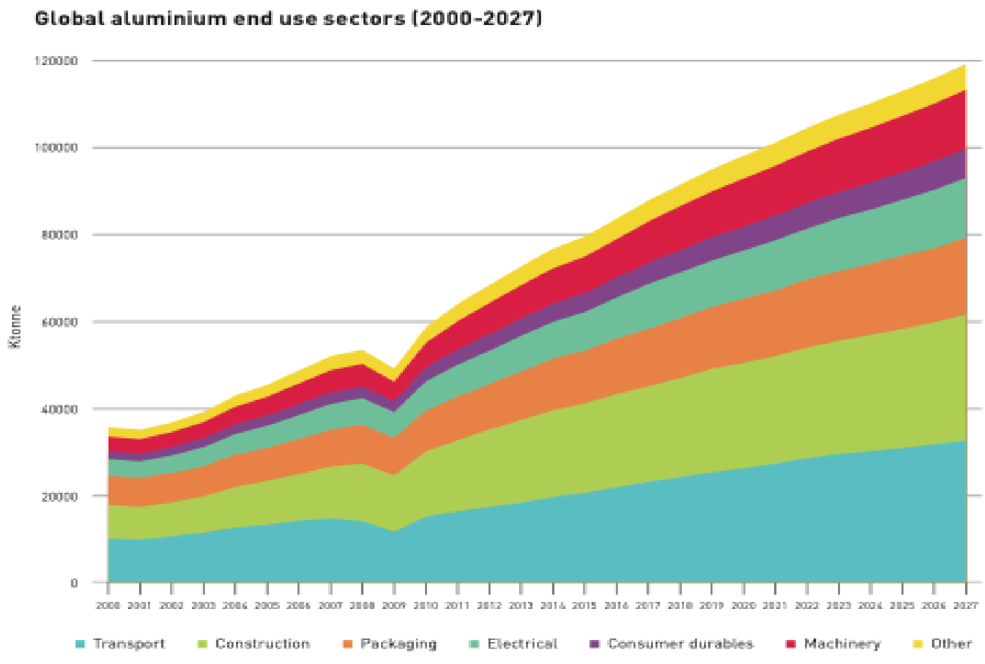
Source: Goldman Sachs Investment Research

The graph above shows that packaging is the most attractive market for aluminum products, both near and long term.

Global end use of aluminium (2019)[29]



Source: (Statista, 2020)



Source: CRU 2018

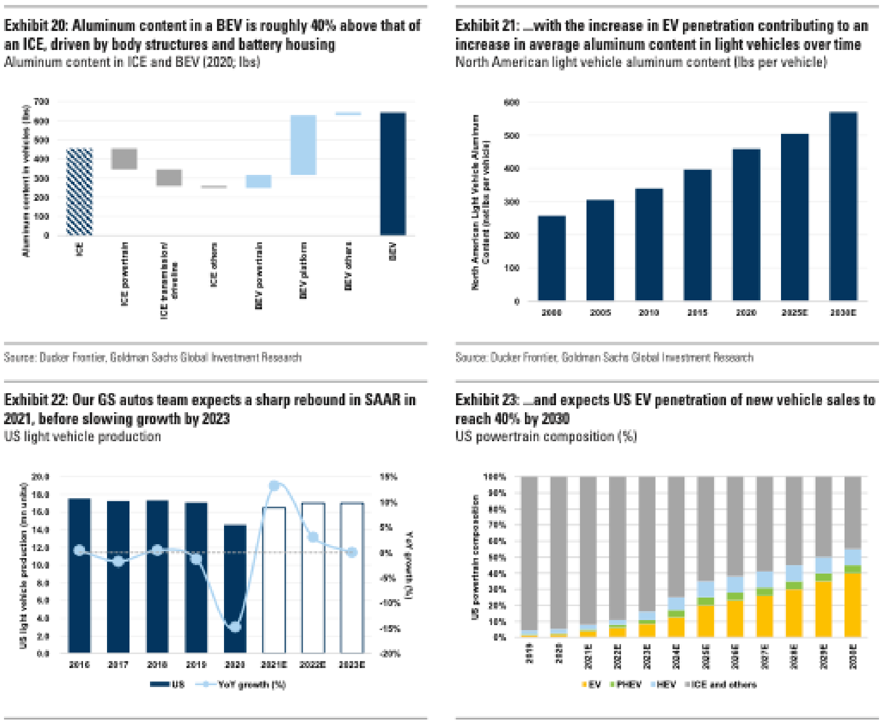
Chapter 3.1: Use by Industries

3.1.1 Automotive

While steel makes up the largest proportion of a vehicle, there has been a shift towards increasing aluminum use, particularly in the body-in-white (BiW) segment. We see further use cases in hoods, doors, fenders, crash management systems and battery enclosures - all with the purpose of reducing emissions and increasing fuel efficiency in light-weight cars. Further, aluminum has the added benefit of superior energy absorption, reducing the force on occupants in a crash. Due to the fact that aluminum is lighter than steel, it allows automotive manufacturers to enhance damage resistance. This way body panels can be thicker while still lowering the weight that creates better acceleration, better braking and handling. In addition, lighter vehicles can haul and tow more because the engine isn't carrying unneeded weight (Goldman Sachs , 2021).

Automotive Original Equipment Manufacturer's (OEMs) have joined resources with Novelis, to develop novel high strength components which will allow aluminum intensive automobiles to exceed previous generations (Huetter, 2018). Novelis is also helping manufacturers to completely remodel their Body in White (BiW) design to reduce weight and maximize fuel efficiency. Novelis Advanz™ s615 is a brand-new aluminum alloy designed and developed by the company (Novelis).

EVs are a growth opportunity with expected demand for aluminum rolled and extruded products to grow in automotive production. Aluminum content in EVs is currently around 640 lbs., ~40% above that of an ICE. Ducker Frontier expects that average aluminum content, which currently represents ~12% of vehicle weight in 2020, could increase from 459 lbs. to 505 lbs. per vehicle by 2025, a CAGR of 2% (Ducker Frontier, 2020). This will be underpinned by more aluminum intensive EVs, as opposed to ICE vehicles. Given this, aluminum demand in the automotive sector will likely exceed supply given the increasing numbers of EVs (Goldman Sachs, 2021).



Source: (Ducker Frontier, Goldman Sachs Global Investment Research, 2021) (Autodata, Goldman Sachs Global Investment Research, 2021) (Goldman Sachs Global Investment Research, 2021)

3.1.2. Aerospace

Aluminum comprises about 80% of the weight of a typical commercial aircraft, encompassing heat treated sheet and plate products for structural components, wing skins, and fuselage (body) sheet. The metal's light weight, high strength and corrosion resistance make it a material of choice for the industry (Metal Supermarkets, 2016). Demand for aluminum in the aerospace industry is driven by the build rate of commercial aircraft, which should inflect as global passenger air traffic recovers (Goldman Sachs , 2021).

3.1.3 Packaging

Aluminum's ability to form any shape and its shielding qualities have made it the most versatile packaging material in the world. In addition, a key benefit is that aluminum foil, aluminum cans and other aluminum packaging materials can be entirely recycled and reused an infinite number of times (UC Rusal, s.d.).

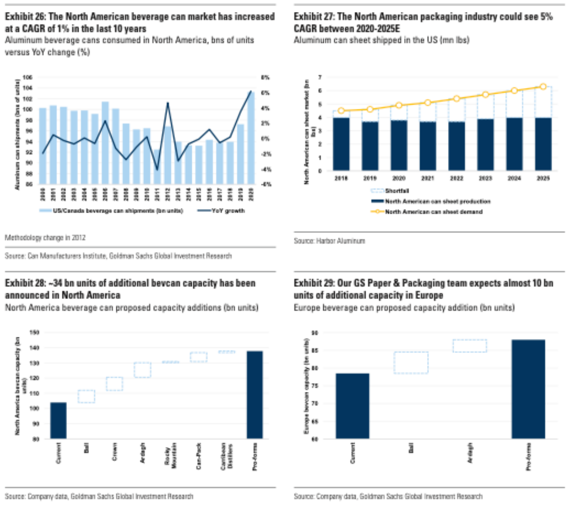
The aluminum packaging market encompasses can stock for the food and beverage industry and foil stock for flexible packaging. A shift from single-use plastics in the beverage industry and an increase in the consumption of craft beers, seltzers and energy drinks has underpinned a return to growth for aluminum in the packaging industry, following a period of decline led by a decrease in consumption of carbonated beverages in the early 2010s. Historically, the packaging industry has been viewed as relatively stable and recession-resilient; however, it is now seeing signs of growing demand (Goldman Sachs , 2021).

Eric Favre graduated in 1975 and joined Nestlé in 1976. Later, in 1991, he came up with and patented aluminum coffee capsules, outside of Nestlé, that are now in common use. Ordinary coffee bags lose their scent after being opened, whereas single serving coffee capsules do not lose their aroma since they are only opened immediately before use.

The most common application of aluminum foil packaging is in the food industry. Groceries are frequently damaged by sunlight causing them to deteriorate in appearance and taste. Aluminum foil, in particular, handles this problem. It is non-toxic and does not influence or damage the food (Aluminium Leader, s.d.). Aluminum cans are the world's greatest ecologically friendly and recyclable container, enabling liquids to keep their flavor while also protecting them from the environment.. Furthermore, the can does not rust or lose any of its characteristics in any manner. More than half of all aluminum produced to date will be recycled. In certain nations, the proportion of aluminum cans in circulation is substantially higher than in others; for example, in Germany, aluminum cans contain 95% of all drinks (IEA, 2020). Medicines are also packed with aluminum foil (Aluminium Leader, s.d.). And winemakers are increasingly adopting metal stoppers in their bottles. Since 1926, the British have used aluminum stoppers in whiskey bottles, but the wine business has been slow to adopt the technology over the traditional cork (Aluminium Leader, s.d.).

An aluminum container may be recycled an unlimited number of times without the purity of the can, made from recycled aluminum, deteriorating. Recycling drastically reduces overall energy usage, lowering CO2 emissions launched in the environment. Cans made from recycled aluminum consume 95% less energy than those made from primary aluminum (IEA, 2020).

Global aluminum can manufacturing is at 250 billion cans per year. The United States accounts for 40% of this capacity, followed by Japan, Brazil, and China. More than half of all aluminum cans are recycled throughout the world, which means that more than 113,000 cans are recycled every minute. It is estimated that recycling a single aluminum container will save enough energy to operate a 100-watt light bulb for nearly four hours. As a consequence, recycling aluminum cans saves enough energy to equal 20 million barrels of oil or 12 billion kWh of electricity per year (Aluminium Leader, s.d.).



3.1.4. Construction

"Aluminum has enabled countless conceptual structures to be realized, giving the architects more flexibility in design exploration and innovation. The possible applications for aluminum structures include windows, facades, roofing, cladding, curtain walling and structural glazing, prefabricated buildings, architectural hardware, H&V, shop fitting and partitions. Aluminum is also used extensively in industrial construction, ladders, scaffolding, thermal insulation, soundproofing, air-conditioning and solar heating," (Kalra, 2021).

Aluminum skeletons support entertainment, trade, and world fair facilities as well as other forms of construction. And for the reasons stated above, aluminum has become a preferred material among architects, constructors, and designers (Aluminium Leader, s.d.).

Chapter 4: Roadmap to Carbon Neutral 2050

Chapter 4.1: Paris Agreement

At COP 21 in Paris, on 12 December 2015, parties to the UNFCCC agreed to battle environmental change and speed up activities required to achieve a sustainable low carbon future. Similarly, the European Green Deal proposes a blueprint for making the European Union's economies more sustainable (Rowan & Galanakis, 2020). As consumers, governments and investors anticipate and expect action, organizations face expanding strain to restrict the effect on the climate or risk confronting the court of public opinion and face harsh and legitimate consequences (World Economic Forum, 2020).

"Materials such as aluminum are critical to achieving a sustainable economy. Substantial progress has been made, but more is needed. As Climate Action Champions we support this journey towards a net-zero industry by working with our allies in all continents and by supporting the establishment of closer interlinkage points with key customer industries and policy-makers." (Topping, 2020).

As a substantial emitter of greenhouse gases, the aluminum sector is positioned to help the road to decarbonization. Although some aluminum companies have announced public decarbonization goals, many have yet to begin. The industry needs to raise the degree of collective desire to drive a significant change (World Economic Forum, 2020).

4.1.1 Examples of aluminum players public climate ambitions

ALCOA → Reduce greenhouse gas emission by 30% until 2025 from a 2015 standard (Alcoa, s.d.)

EN+ Group/RUSAL → Maximum warning to 1.5ºC. Emissions reduction thorugh science (En+ Group, 2019)

GFG Alliance/Alvance → Reach carbon neutrality in 2030 (GFG Alliance, s.d.)

Norsk Hydro → Lower greenhouse gas emissions by 30% until 2030 (Norsk Hydro, 2021)

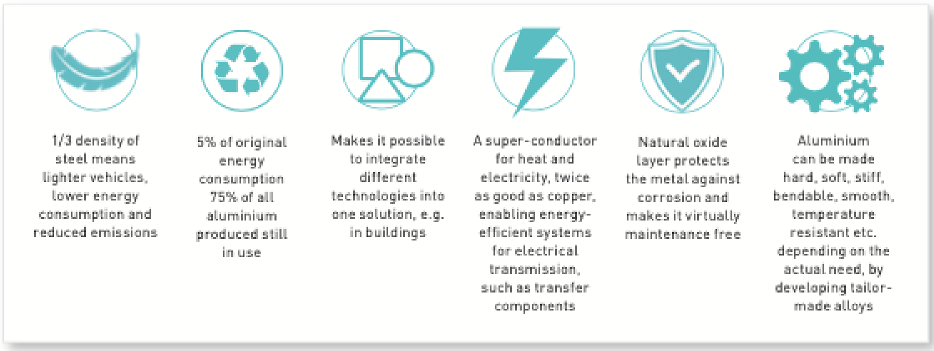
Rio Tinto → Lower carbon intensity by 30% and absolute emissions by 15% by 2030 and reach net-zero emissions by 2050 (Rio Tinto, 2019)

With the 2025 Roadmap, the European aluminum sector has committed to contributing to the global sustainable objectives in order to fight climate change. The Sustainability Blueprint establishes a long-term strategy for the aluminum value chain and a common defined goal, by means of divided responsibilities, for cultivating responsible production and use of aluminum (European Aluminium, 2019). Progress is measured through a set of more than 20 Sustainable Development Indicators (SDIs) (World Economic Forum, 2020).

Source: AER

4.1.2. Aluminum as the key enabler for society

Aluminum is becoming increasingly important in new low carbon and energy efficient uses today. The metal's characteristics allows high recyclability that is driving demand. Aluminum helps reduce CO2 emissions in the transport sector, due to its lightweight, making vehicles more efficient. Furthermore, as mentioned above, aluminum provides efficient packaging that has a low environmental footprint, while also keeping the goods inside fresher for longer periods of time, minimizing food waste. We can say that Aluminum will have a major role in the circular economy (European Aluminium, 2019).



Source: European Aluminium 2018, unique property materials

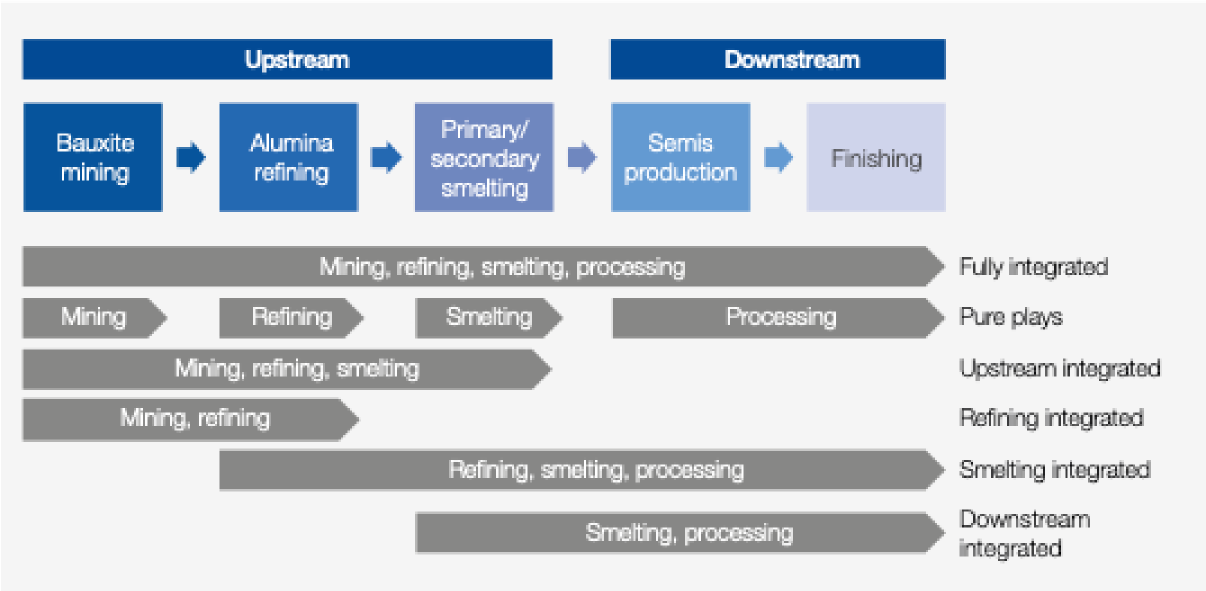
Chapter 4.2: Decabornization → Paths and Challenges to Decarbonization

Solid growth projections and continuous demand make decarbonization of the aluminum industry particularly urgent and challenging (World Economic Forum, 2020).

4.2.1 Industry-specific challenges

In an energy intensive industry, the most considerable and feasible opportunity to minimize CO2 emissions is through renewable sources of energy, either solar, wind, and or hydro power. Even though all power supplies must attain carbon neutrality by 2050 to meet a 1.5º/2ºC scenario, regional disparities make conversion to a renewable power source more costly since the aluminum sector overall operates on rather low profit margins. Consequently, companies must be able to use the most economical power sources (CSI Market, 2021). Electrical power represents one third of operating expenditures for aluminum smelters, with $/kWh oscillating based on local power costs (Butler, 2019). This by default lowers margins, making it difficult to finance any substantial investments required to switch power sources (World Economic Forum, 2020). Thus, there are substantial discrepancies in the early stages of decarbonization for aluminum companies throughout the value chain, and this, as a consequence, prevents a coordinated response from stakeholders (CSI Market, 2021).

Companies that participate in different components of the value chain have different characteristics, making it virtually impossible to compare decarbonization efforts. Firm idiosyncrasies dictate how far the organization can impact the carbon intensity of the finished product. Value-chain stakeholders must collaborate to achieve and develop a process, from mining to the end product, to make carbon neutrality a reality.



Source: (World Economic Forum, 2020)

4.2.2. Pathways to Decarbonization

The sector must begin working on three major areas to achieve targets:

1. Decarbonization of power generation
2. Decarbonization of process emissions
3. Growth of scrap usage and recycling

1. Decarbonizing the Power Supply

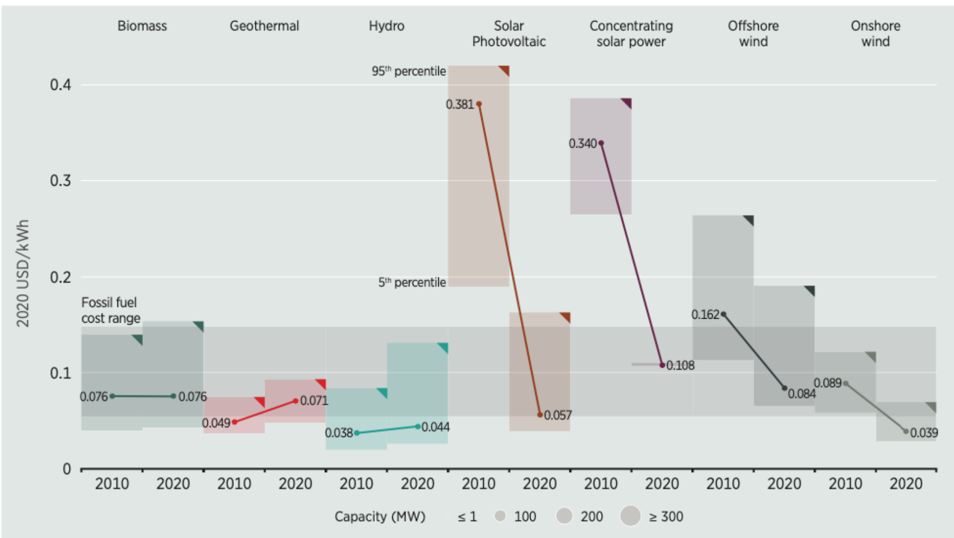
As previously mentioned, the power supply is where companies must focus to achieve carbon neutrality by 2050. Considering that more than 60% of the sector's greenhouse emissions are a derivative from electricity, it becomes imperative to act (International Aluminium Institute, 2020) (Butler, 2019). The industry's power supply can be approached in two ways:

1) the transition to renewable energy.
2) "Carbon capture, utilization and storage (CCUS)" technologies to lessen emissions place (World Economic Forum, 2020).

Since 2000, renewable power generation around the world rose 3.7-fold, from 754 GW to 799 GW, as costs have substantially decreased owing to steady developments of tech, scale economies, competitive supply chains and superior developer expertise. Furthermore, in the last 10 years, costs for electricity from utility-scale photovoltaics have decreased, as shown by the graph below where costs fell 85% (Irena, 2020). The levelized cost of energy (LCOE) from renewable sources supply has become a viable price competitor with fossil energy solutions (United Nations Environment Programme, 2019). This is true for most nations, even in a non-subsidized context. Renewable generation costs are "entirely below the range of LCOE for new coal-fired power plants" and "in the same range" as the operating cost of existing coal plants in China and India (Evans, 2020).

Lazard states that onshore wind and solar are approaching a point where it is more cost effective to develop and invest in new renewable sources than to continue running existing ones (Lazard, 2019). However, this raises a problem that operators will need to take into account, that is the fluctuation of both wind and solar power. Therefore, storage solutions are needed along with purchase agreements to balance supply and demand (World Economic Forum, 2020).

Figure ES.2 Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020



Source: IRENA Renewable Cost Database

Through their capacity to provide power 24/7, hydro and geothermal power provide aluminum manufacturers with a more reliable renewable energy solution. Expanding renewable power in aluminum manufacturing will require the integration of alternative renewable sources into power portfolios.

Scalable CCUS technologies are currently in early development and not yet widely available, however, there is no doubt that these will play a major role. Furthermore, in the short term, CCUS alongside the shift to renewable sources will be an imperative to allow decarbonization of the industry (Irena, 2020).

1.1 Challenges to Implementation

Coal-fired power factories are still active today, built in areas with a lack of reliable alternative sources, or where there are only more expensive alternatives. As mentioned above, smelters need access to energy sources 24/7, and so there is a need to store. In the short to medium-term, investing in carbon capture, utilization, and storage technologies would appear the norm, until decarbonization of power sources becomes possible (World Economic Forum, 2020).

China accounts for 58% of the sector's greenhouse emissions in 2019 with its largely coal-based energy. China needs vast changes to mitigate the sector's carbon footprint (CM Group, 2020) (Jones, 2020), and recently pledged to achieve carbon neutrality by 2060. Nonetheless, even if action is taken to decrease CO2 emissions in other regions, the industry-wide reliance on nonrenewable energy will likely persist if no endeavors are made to minimize greenhouse emissions from electricity.

2. Decarbonizing Process Emissions

Direct emissions associated with the production of aluminum represent another high-impact domain for decarbonization, in addition to addressing the carbon footprint of energy consumption. In 2018, anode consumption represented 10% of the industry carbon emissions, furthermore fuel combustion represented 15% to 20% of sector emissions (International Aluminium Institute, 2020).

The most effective strategies to minimize direct carbon emissions in the aluminum industry are: 1) the development of a non-carbon anode; and 2) transitioning to technologies that can provide heat and steam without the use of fossil fuels.

Carbon anodes relate to the electrolytic process separating pure aluminum from alumina which generates CO_2 as a consequence. They are a vital component in this process due to the fact that they are major conductors of electricity and are cheap (Harvey, 2018). Furthermore, operating expenses of inert anodes, that are already in development which produce O_2 rather than CO_2, are expected to be 10% to 30% less than carbon based anodes (Kvande, 2014). Considering the financial and environmental advantages of anode technology, it could be effectively promoted to further lessen energy demand and corresponding emissions (Fischedick, et al., 2014).

Aluminum processing requires large amounts of heat and steam during refining, currently primarily generated using fossil fuels. Alternatives for heat production incorporate solar water heaters, biomass, geothermal, green hydrogen, or concentrated solar power (CSP) which are largely dependent on geography.

Small-scale CCUS could promote decarbonization, having the capability to reduce greenhouse emissions by 35% throughout the industry (Instituto Affari Internazionali, s.d.). CCUS offers a realistic transition solution to minimize greenhouse emissions while other low-carbon technologies are still being developed.

2.1 Challenges to Implementation

In spite of the fact that alternatives to carbon-intensive direct emissions processes are currently being explored, there are still a panoply of barriers that must be overcome for these solutions to be fully developed and adopted by the industry. Today, it is not feasible to generate high intensity heat and steam from sustainable power, which is essential to the process of manufacturing aluminum. Particular technologies have been proven at a small scale or in a pilot study, nevertheless it will be important to scale and get a move on the development and adoption of these technologies across the industry. As previously mentioned, not only the aluminum industry but all industries that by one way or another depend on nonrenewable sources of energy, have to invest in zero carbon emission solutions, as a matter of moral responsibility and for competitive advantages (World Economic Forum, 2020).

4.2.3. Recycling Aluminum: The natural driver of Circular Economy in Europe

By 2050, primary aluminum demand is anticipated to reach 108 million tons, increasing over 50% from today (Cru Group, s.d.). Instituto Affari Internazionali states that demand will be unable to be met exclusively through recycled aluminum, although this is expected to grow from 33% to almost 60%. Hence a supplementary 90 million tons of primary production will be required from now until 2050, supposing no significant increase or decrease in recycling rates. If no measures are taken, the growth in primary production will cause the sector's carbon footprint to increase 30% (Instituto Affari Internazionali, s.d.).

The aluminum industry is expected to increase due to a number of factors: 1) Global population growth; 2) Increased urbanization requiring new construction and expanded transportation; 3) Development of the electric auto industry; 4) Growth and development of the electrical grid; 5) Substitution of certain plastic containers mentioned previously. Another factor driving demand is that both conventional and renewable technologies need aluminum, especially photovoltaics systems since aluminum composes 85% or more of the components (World Bank Group, 2020). According to the World Bank Group, aluminum demand for solar PV technologies under a 2°C scenario from 2020–2050 exceeds 90 Mt. As this demand increases from the energy sector, it is crucial that the aluminum industry players make an effort to decarbonize or risk replacing renewables carbon savings with the high-carbon footprint of the materials required to manufacture those technologies.

If the industry had all of the aluminum scrap in the European Union, recycling would be roughly 20% greater than it is now. Furthermore, whenever scrap is exported from Europe, the energy contained inside the product is also exported. When it comes to energy security, the aluminum recycling industry's efficient use of electricity should not be overlooked.

Protecting and ensuring scrap availability within the European Union will increase the potential for more notable recycling while also nurturing a circular economy. *"Creating this virtuous circle will requires multilevel cooperation, particularly at EU and Member States levels"* (European Aluminium, 2019).

The current recycling range varies from 90-95 % for the auto industry and building end-use applications, to 74% for beverage cans, and 60 % for packaging recycling. However, recycling of electronic devices and applications is much more challenging since aluminum is only usually a small part of the end product (International Aluminum, s.d.)

There is significant ability to salvage aluminum from recycled sources, assuming a few additional requirements are satisfied such as access to high performance collection and sorting methods in Europe, based on the Extended Producer Responsibility (EPR).

Demand for ingots of casting alloys is projected to fluctuate in the future, owed to the increase in electric cars.

Efforts to increase scrap recovery should focus on:

– Advancing methods to divert aluminum from landfills

– Improving separation techniques to decrease the mixing of alloys

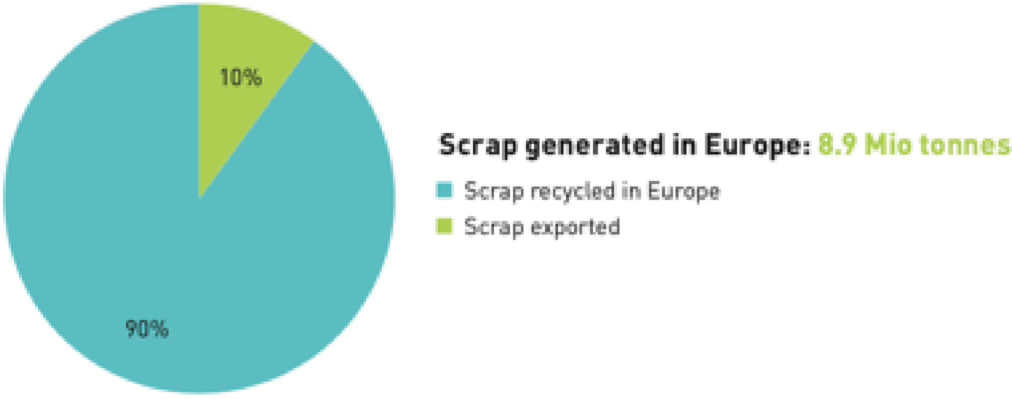
– Working with downstream partners for circular business models and closed-loop recycling

– Supporting more complex collection and separation processes with digitization to track scrap throughout its lifetime and direct it to the correct channel to retain its value

– Designing and creating products that are easily separated, collected, and recycled (Material Economics, 2020)

4.2.4. The importance of scrap collection

Scrap comes from two sources; the major source is from primary production and second is scrap recovered from the primary production and from products that have reached the end of their life cycle (European Aluminium, 2015).



Source: European Aluminium 2017 data

It has been argued that $1m of public funds spent on clean energy and energy efficiency generates 7.49 full time jobs in renewables infrastructure and 7.72 in energy efficiency, contrasted with only 2.65 for petroleum derivatives industries (Heidi, 2017).
Today, a staggering 75% of all aluminum created is being used (The Aluminum Association, s.d.). Simultaneously, the aluminum sector contributes 1.1 Gt CO_2e or 2% of worldwide emissions (International Aluminum, s.d.), as per the most recent IAI figures. The move towards a circular, low carbon economy has effectively begun. From car makers to the packaging business, numerous international companies have as of now dedicated to reducing their carbon footprint and have begun to search for all the more sustainable material. Demand for key unrefined materials (aluminum, plastic, cement, and steel), is projected to increment by a factor of two to four (Ellen Macarthur Foundation, 2019).

The sector is convinced that by embracing the principles of Industry 4.0, they will enter a new paradigm with significant opportunities for enhanced aluminum applications and for making the entire value chain CO_2 emissions free. Downstream members of European Aluminum are constantly looking for new ways to improve future production methods, such as digital manufacturing, cloud computing, big data, and automation (European Aluminium, 2019).
Currently, there are four main areas in which developments are being made:

1. New alloy development, to increase strength, crash performance and formability.
2. New joining technologies, to allow optimized hybrid structures.
3. Additive technology, to minimize the use of materials.
4. Process improvement (evolutionary/revolutionary).

Three innovative examples: 3D Printing, new alloys development and process Improvement

FAST by Constellium and partners*:* Constellium introduced FAST in collaboration with STELIA Aerospace, a global leader in the design and manufacture of aircraft equipped fuselages, and CT INGENIERIE, a leading engineering firm focused on technical innovation across the product lifecycle. The FAST venture focuses on 3D printing. Is a vanguard solution that employs optimized design and technology to develop aerospace structures more innovative, efficiently, and economical as possible. So, 3D printing has the potential to revolutionize the aerospace industry, enabling cost effective design change, repetition and customization (Constellium, 2015).

Micromill by Arconic*:* Arconic created and developed the Micromill technology, which converts aluminum from the state of liquid to solid inside a matter of a few seconds (European Aluminium, 2019). Micromill transforms molten metal into coil in 20 minutes, requiring only one-quarter of the floor area and 50% the energy used by traditional rolling mills. It is feasible to create a more weldable and stronger aluminum alloy with this technology. Greater design versatility and vehicle performance are both improved when properties of the material also improve (Djukanovic, 2016).

Novelis Advanz s615 alloy: Automotive Original Equipment Manufacturers have joined resources with Novelis to develop a novel high strength component, which will allow aluminum intensive automobiles to exceed previous generations (Huetter, 2018). Novelis is also helping these manufacturers to remodel their Body in White (BiW) design for reduced weight and maximum fuel efficiency. Novelis Advanz^{TM} s615, a brand-new aluminum alloy, was designed and developed through the collective efforts of the partnerships mentioned above. (Novelis). This novel alloy is ductile enough to sustain high stamping and assembly while also being sufficiently robust to comply with strict endurance and safety regulations. Novelis AdvanzTM s615 is the industry standard for vehicle strength and resistance (European Aluminium, 2019) (Novelis, 2019).

4.2.5. Advantages of dry machining aluminum profiles:

- No use of oil nor drinking water (lubricants are 10% oil and 90% drinking water)
- Zero environmental pollution caused by the emission of lubricants and no resource-consuming preparation of lubricants after use
- No need to extrusions to be washed: The profiles can be packaged directly after being blown with compressed air, conserving more water.
- Removing the cooling lubricant improves product quality by minimizing the risk of corrosion, reducing burr formation on the profile, and eliminating chip adhesion.
- Waste is reduced. It implies no more wasted coolant disposals, no need of cooling lubricant residues on the profile, and no residues on the packing material, allowing for the reuse of packaging materials.
- A safer working environment in production: no health impacts from lubricant-containing aerosols in the hall, and a cleaner atmosphere.

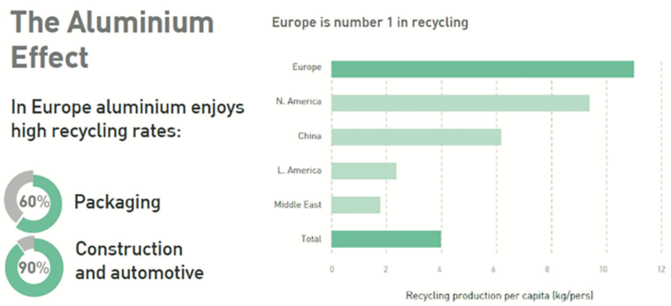
Although, Complex machining processes without lubrication are still challenging.

Low carbon Aluminum is being produced by some major companies in the industry. Hydro, a Norwegian company has two series of low carbon aluminum profiles, CIRCAL and REDUXA. CIRCAL 75R is a range of products made with at least 75% recycled, post-consumer scrap aluminum. By using recycled aluminum, Hydro is able to drastically reduce the energy use in production whilst offering high-quality aluminum. The percentage of scrap material can change depending on specifications from the client, but Hydro can always guarantee a CO2e footprint below 2.3kg of CO2e per 1kg of aluminum produced with Hydro CIRCAL 75R (Hydro, s.d.).

REDUXA uses renewable sources like hydro power in production, making them able to reduce the carbon footprint per kg of aluminum to just 4kg (less than a quarter of the global average). The result is a more sustainable aluminum with one of the world's lowest carbon footprints to date (Hydro, s.d.).

4.2.6. The Circular Economy: Building the circular economy of the future

Europe is world’s greatest recycler. More than 50 percent of aluminum produced in the EU is from recycled aluminum, a trend that is growing. However, there is still work to be done in order to construct the circular economy of the future. Europe’s major target is to increase the recycling rates per capita, this requiring developments in the collection and sorting of scrap, guaranteeing that there is no waste of scrap.



Source: (European Aluminium, 2019)

But what makes a permanent material like aluminum perfectly suited to a circular economy? Aluminum is an everlasting material, meaning that the quantities we manufacture today not only meets today's needs for the material in the automobile, packaging, construction, and other sectors, but also accumulates through time to become a significant economic resource of the future. Aluminum is designed to be used for as long as feasible and to be recycled indefinitely after it has been manufactured (European Aluminium, 2020).

The circular economy presents a plan to improve Europe's competitiveness by maximizing resource efficiency, innovating business models, and providing new employment and economic prospects. This will demand both R&D and investment, establishing Europe as a leader in the fight against climate change and resource depletion. Furthermore, the information gained during this transformation may be used to other industries to help them become more circular and to encourage cooperation with other value chains.

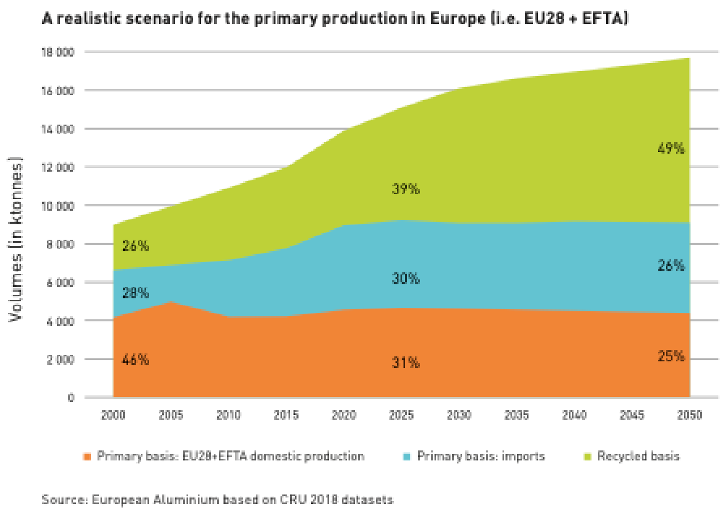
Material Economics study proves the vast opportunities of aluminum

Material economics conducted an external analysis that highlights opportunities for how a more effective use of materials can help with the overall decarbonization (Material Economics, 2018). Following the optimistic scenario of the analysis, 50 % of aluminum demand can be satisfied by recycling and, furthermore, substantial benefits from higher product material efficiency and new circular economy businesses and strategies could develop.

4.2.6.1. Integrated Value Chains

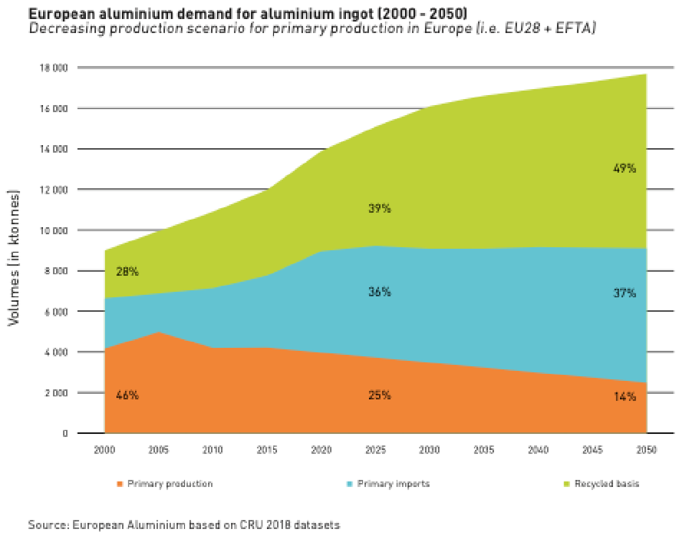
A realistic scenario shows the importance of policy and integrated value chains; If recycled production were to be increased to meet the European demand between 2020 and 2050, this would prevent around 880 and 1500 million tons of CO2. The expected and projected reductions in the aluminum industry in CO2 emissions (29-51 million tons per year) for the same period (2020-2050), correspond to all the fossil fuel emissions of Germany or 20% to a 35% of the total European Union CO2 (Mandl & Pinterits, 2018), and according to Material Economics, is projected a reduction of 300 million tons on CO2 from heavy industry.

An integrated value chain means integrations of information and knowledge, allowing for a more efficient and optimized management, traceability control and transparency among the value chain.



Decreasing production scenario with poor or inadequate policy support

In a declining production scenario, with no anticipated and supportive regulation (i.e., state aid and indirect carbon costs compensation, continuous internal market barriers, suboptimal financing conditions, no equivalent environmental, health and safety conditions vis-à-vis third countries, etc.) will see a fall in domestic primary production in Europe by 14% in 2050, resulting in increased carbon emissions due to the need to import. Primary production would be confined only to Norway and Iceland in this scenario since the members of the EU will terminate their production. Furthermore, domestic output will be roughly 2.5 tons, a reduction of 43% comparatively to the present situation., and consequently imports will then grow (European Aluminium, 2019).



Chapter 5: Managerial Recommendations

There is no silver bullet to mitigate the climate change problem, however if the aluminum industry is to play a role in fighting climate change, it must implement as many technologically and financially effective mitigation alternatives as feasible over the next decades. Setting Rand stated: "We don't know what technology will exist in ten years to help us meet our target. But now we have the incentive to find out." (Science Based Targets, 2020).

There are several ways to get to a low-carbon future. One way is to invest in breakthrough solutions and significant improvements to existing technologies via research and development; another is to manufacture materials using renewable energy sources. Both of these approaches are currently feasible, with aluminum being one of them (World Economic Forum, 2020).

Develop relevant sector-specific science based targets “roadmaps”, roadmaps that must include technological, economic and material efficiency analysis in order to come up with relevant and applicable science based targets pathway, as World Resource Institute proposes the establishment of industry-led roadmaps that spell out of the choices for individual business groups for defining and attaining SBTs, in order to simplify the development and encourage science-based commitments (Science Based Targets, 2020).

All end use sectors should be required to properly dispose their used products; however, this should not come at a high cost for companies, or if it comes, there should a reduction in the taxable income, this adding to stricter European recycling rates. Value-chain stakeholders must collaborate to achieve and develop a process, from mining to the end product, where carbon neutrality is a possibility. So, additional investment in innovating filtering technologies is mandatory in order to achieve this goal.

CCUS offers a realistic transition solution to minimize greenhouse emissions while other low-carbon technologies are still being developed. Considering the financial and environmental advantages of anode technology, it could be effectively promoted and used to further lessen energy demand and corresponding emissions (Fischedick, et al., 2014).

As previously mentioned, not only the aluminum industry but also all industries that by one way or another depend on nonrenewable sources of energy, have to invest in zero carbon emission solutions, not only in order to be morally responsible but also more cost competitive in the upcoming years as renewable energy becomes more affordable.

Producers that emphasize and value ESG principles, aluminum produced with a significantly lower level of emissions has become one of the supply chain's fundamentals. Long before COVID-19 hit the market, manufacturers of consumer goods, from automakers to the packaging industry, were exploring for ways to reduce the carbon footprint of the manufacturing process. Mercedes-Benz, in particular, announced plans in 2019 to make its new passenger vehicle fleet carbon-neutral within two decades, while Audi also aims to be carbon-neutral by 2039 (Dzikiy, 2019).

The bad news is that, despite these aspirations to make production processes more sustainable, there is currently no single unified approach to what is referred to as low carbon aluminum. Organizations such as the Aluminum Stewardship Initiative and Harbor Aluminum have established emission performance standards, but unfortunately, they are not aligned nor provide a single approach for the sector (World Economic Forum, 2020).

Study Limitations

As we know, all papers have their limitations, some more than others. I can name some limitations to this paper. And those are: Limitations due to the fact that we are still in very early stages of the decarbonization of the sector; companies are still trying to develop technologies in order to proceed with the process. There are only macro factors/studies and not micro factor/studies. The knowledge is still very much kept within the big corporations and so there is lack of flow of information throughout the sector and society. Furthermore, although the experts have considerable knowledge on the industry, a sample size of 6 experts is not relevant enough considering the size of the industry. Time was also a limitation of this study since it is a large industry and would require a lot more time to make field research. Timing was also not perfect, considering that in Q4 companies start to prepare the new year and so experts have limited to no time to answer and meet, and so therefore the interviews were kept very brief by the interviewees. Access to literature and data limitations since most of secondary data and literature exists for about 2 and more years and so it is not the most up to date information. So, for future research, there must be a further time on depth of literature and field research. Bigger sample size in order to gain more knowledge on the industry so we can make more and better assumptions and conclusions on the results. Moreover, the lack of quantitative analysis, since it is an industry and my research questions that are not of common knowledge to people that I would been able to get to answer my survey and do a quantitative analysis based on those results. So, tracking new data, new advancements and technology, new literature on the industry, bigger and better sample size will provide better knowledge on how the carbon neutrality imperatives will in fact impact the aluminum industry.

Chapter 6: Interviews

The theme of this thesis is how the goal of achieving carbon neutrality by 2050 is going to affect the aluminum industry. To understand more about the subject, I interviewed a number of experts in the industry to gain knowledge on the aluminum industry and its imperatives in order to achieve zero emissions.

The first question that was asked to the interviewees was what they thought were the imperatives to achieve carbon neutrality in the aluminum industry by 2050. All interviewees agreed about the need to ally resources with other companies, even with competitors. As ALCOA's Vice President stated, companies have joined forces with the multinational Rio Tinto in the ELYSIS Project, which is development of inert anode technology that eliminates greenhouse gas emissions from smelting. Furthermore, government plays a role in driving companies to adopt the technology to eliminate the CO2. So, key variables are technologies that are already available or that need to be developed, and the motivation to deploy those technologies. Also, there is the need to for cooperation between small and larger enterprises, since small enterprises won't stand a chance in the battle against climate regulations. Experts A and C stated that they do not believe that it is possible for the sector to achieve carbon neutrality by 2050. This is due to the sector gaining more and more traction across various industries including the automotive industry, solar industry, aviation industry, etc. With these industries growing, the demand for aluminum production will rise accordingly. There is also a paradox where companies shift their productions to countries where geothermal energy is abundant in pursuance of carbon neutrality, but at the same time, these same companies, when it is financially lucrative, proceed to reopen these same factories in countries where oil is cheaper.

The second question was how and what is your company doing to achieve carbon neutrality. I obtained the statements from various companies. Alcoa is working closely with Rio Tinto towards the elimination of greenhouse emissions from smelting (Elysis Project). Lingote now owned by Corialis group and with the new investment is building new infrastructures from scratch where all the covered areas will have hundreds of photovoltaic panels with a view to having a higher source of renewable energy, and also for reducing costs. Furthermore, as stated in the literature review, companies must adopt more sustainable sources of power, and all the companies interviewed have photovoltaic panels installed in their respective factories, shifting from grid power only. However renewable sources of energy are not enough as the aluminum sector is very high energy intensive. There are already some companies, like Alcoa and Hydro that have moved production to countries such as Iceland that use geothermal energy. Some companies have changed one of the chemicals that they used to work with, but with Alcoa's size they managed to go further and started to eliminate diesel from transport trucks. They also launched a project called ASTRAEA which is going to be a technology applied to post

consumer recycling to improve recycling capabilities and eliminate the need for new aluminum.
Regarding the biggest changes in the industry, for the last 15 years as new capacity needs to be added to the system, China has increased their smelting capacity by adding coal powered smelters. And due to this CO_2 produced per metric ton has increased. What's changing in the industry is people starting to question capacity driven by CO_2-intensive processes. It's actually starting to affect the price of aluminum and caused the price to increase in the past 2 years. The challenge for companies is effectively roll out the existing technologies quickly and develop them and get them to scale fast and work with host governments to figure out how the companies can influence them in a way that is favorable to shareholders but also supports the CO_2 elimination goals to that country.

The fourth question is related to how the interviewees perceived the growth of aluminum. All the takes on the matter were positive for a bright future of the aluminum sector. If we believe in the need for eliminating CO_2 and the impact on global warming, electric vehicles, solar panels and lightweight more fuel efficient aircraft are all more aluminum intensive, if we think of aircrafts and engineers are trying to lightweight aircrafts to make them more fuel efficient they use aluminum and so it's a pretty good excuse to cross the border because of its light weighting and strength characteristics. So we are expecting continuous strong demand for aluminum because it supports the new economy.

Overall, the feedback regarding recycled aluminum was positive, although recycling rates right now are nowhere near 95%. However, there is increased effort to get the rates up close to the 95% mark. Corialis Portugal is now only producing aluminum profiles based on recycled aluminum billets, said Expert C. The experts are preparing for a world where post-consumer scrap has a significant market share with more limited need for primary production. However, they do not see in the near term that the sector is going to eliminate primary production, unless companies are extremely successful with projects like ASTRAEA (ALCOA). Furthermore, there are some alloys in the world that can only be successful if they have pure metal as Alcoa's CIO stated. So, the experts considered that the market will mature over the next couple decades to maximize post-consumer scrap but don't see a pathway to eliminating primary production at this point partially because they see demand for aluminum continuing to grow. So, in a nutshell, primary production will always be necessary because there is a demand as the world population grows. Also mentioned was a 5% loss in recycling, so there will be a need to also fill that gap with primary production.

As discussed by the experts and the literature review, there is need for the circular economy whereby utilizing recyclability of aluminum will be a critical step to help decarbonize the industry. It would also make aluminum available to help others decarbonize theirs as well. The use of the 3R's: Reduce, Reuse and Recycle, is applicable across the value chain of different products and industries. What the experts are looking for by 2050 in order for the 2-degree scenario to work is that the amount of post-consumer recycling has to go from 19 to 68 tonnes, based on the IAI study. The graph above in the literature review (A realistic scenario for the primary production in Europe (i.e.EU28 + EFTA)) shows that reclying is relatively flat, so recycling rates need new technical pathways.

Industry 4.0 using AI to sort of scrap is another innovation. When companies have a lot of mixed scrap and different alloys etc. they can effectively separate out one alloy from another and it makes the reuse of aluminum much easier. Some companies now are using AI to facilitate sorting along with optical and x-ray sensors used to effectively sort scrap to make it reusable.

Thank you,

Expert A → Joaquim Teixeira → CEO of Lacalfer → November 23rd

Expert B → Benjamin Kahrs → Vice President and CIO of Alcoa,US → December 14th

Expert C → José Azevedo → Previous CFO during 20 years connected to Lingote/Corialis Group → December 16th

Expert D → Sérgio Gomes → Sustainability Engineer at Fundínio, SA → December 15th

Expert E → In person visit at Corialis Portugal with Engineer António Pereira → September 9th

Expert F →In person visit at Caixiave/Tryba Group with Engineer Tiago Andrade→ September 10th

Chapter 7: Conclusions

It is evident that meeting the COP21 commitment of not exceeding 2 degrees Celsius global warming over the next 100 years will require a global reorganization of power supply and transmission infrastructures around the world. Additionally, the technologies that are expected to populate the green power transition are far more material intensive than traditional fossil fuel based energy supply systems (Vidal, Goffé, & Arndt, 2013).

The consumption of aluminum products is growing in Europe and also worldwide, due to aluminum's properties and its endless recyclability. If the current loss of competitiveness and closure of primary smelters is not reversed, Europe will become increasingly dependent on imported primary aluminum (Sevigné-Itoiz, M.vGasol, Rieradevall, & Gabarrell, 2014). This may, in the long run, also negatively affect the fabrication of semi-finished products.

Without European primary production and recycling, and based on the average worldwide energy mix, Europe would be responsible for 178% more emissions, as the imported metal would have a larger CO2 footprint than the displaced EU production. Recent developments in European and global emissions data indicated that this number will further increase. This thesis concludes that recycling is critical and imperative if we want to have a sustainable future. It allows resources to be saved and waste to be reduced. Used aluminum is valuable as it is easily and endlessly recyclable without loss of quality. Both recycled and primary metal will be needed to meet projected increased consumption of aluminum in Europe. Just as for primary aluminum smelting, the conditions must be right to facilitate the growth of recycling in Europe.

This thesis demonstrates that if companies that produce primary aluminum and recycling collaborate, they can become stronger and create synergies that enable the circular economy, since primary aluminum will remain essential in helping this cluster-based industry become more competitive, while promoting sustainability. The sector also needs new technology and groundbreaking innovation, as previously mentioned. There is a demand for creativity, proper enabling legislation, and strong political commitment.

Furthermore, the experts agreed that incremental technological initiatives require various layers of government support. The idea that a single or even multiple European Union funds can cover all of the costs of adopting new technology is inaccurate. Indeed, national and regional governments should collaborate to give key support in a number of areas, including finance, regulation, and ensuring the effective deployment of new technology. Moreover, while planning and creating technological initiatives, certain organizations affirmed the value of collaborating closely with specialized institutes and universities.

So, we come to the conclusion that the aluminum industry has a long road ahead, full of challenges and opportunities, and every one of us as users of the aluminum products will have to make efforts if we want to achieve the decarbonization of the industry by 2050.

Bibliography

Aluminium Leader. (s.d.). *Aluminium Leader*. Récupéré sur Aluminium Leader: https://www.aluminiumleader.com/application/packaging/

Aluminium Leader. (s.d.). *Aluminium Leader*. Récupéré sur Aluminium Leader: https://www.aluminiumleader.com/about_aluminium/what_is_aluminum/

Menzie, W., Barry, J., Bleiwas, D., Bray, E., Goonan, T., & Matos, G. (2010). *USGS Science for a changing world.* Récupéré sur USGS Science for a changing world: https://pubs.usgs.gov/of/2010/1256/

United Nations. (2020, March 10). *Un News*. Récupéré sur https://news.un.org/en/story/2020/03/1059061

United nations. (2020, April 22). *Un News*. Récupéré sur https://news.un.org/en/story/2020/04/1062332

United Nations. (s.d.). *United Nations*. Récupéré sur https://www.un.org/sustainabledevelopment/climate-change/

Cousins, S. (2021, August 17). *RICS*. Récupéré sur https://ww3.rics.org/uk/en/modus/natural-environment/climate-change/the-75-per-cent-problem--aluminium-s-carbon-footprint-.html

World Bank Group. (1998). *Aluminum Manufacturing.*

Student Conservation Association. (s.d.). *Student Conservation Association*. Récupéré sur Student Conservation Association: https://www.thesca.org/connect/blog/environmental-impact-aluminum

European Aluminium. (2015). *Sustainability Roadmap 2025.*

King, J. R. (2001). *The Aluminum Industry.* Cambridge: Woodhead Publishing limited.

Reynaers Aluminium. (s.d.). *Reynaers Aluminium*. Récupéré sur https://www.reynaers.com/en/how-aluminium-changed-architecture

Gulri, A. (2021, January 15). What Architects and Designers Say About Aluminium. (A. G. BHD, Intervieweur)

Aluminium Leader. (s.d.). *Construction*. Récupéré sur https://www.aluminiumleader.com/application/construction/

The Aluminum Association. (s.d.). *Primary Production*. Récupéré sur https://www.aluminum.org/industries/production/primary-production

How products are made. (s.d.). *Aluminium*. Récupéré sur How products are made: http://www.madehow.com/Volume-5/Aluminum.html

World Bank. (2017). *The World Bank.* Récupéré sur Documents World Bank: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/207371500386458722/the-growing-role-of-minerals-and-metals-for-a-low-carbon-future

Goldman Sachs . (2021). *Americas Basic Materials Initiate on Metal Processors Focus on end Markets , margins, multiples.*

Huetter, J. (2018, November 9). *Repairer Driven News*. Récupéré sur Repairer Driven News: https://www.repairerdrivennews.com/2018/11/09/announcements-show-novelis-looking-to-compete-with-steel-on-body-aluminum/

Novelis. (s.d.). *Novelis aluminium Drives Innovation.*

European Aluminium. (2019). *European's Aluminium Contribution to the EU's mid-century low-carbon roadmap .*
Ducker Frontier. (2020). *2020 North America light vehicle aluminum content and outlook.*
Goldman Sachs. (2021). *Americas Basic Materials Initiate on Metal Processors Focus on end Markets , margins, multiples.*
Ducker Frontier, Goldman Sachs Global Investment Research. (2021). *Americas Basic Materials Initiate on Metal Processors Focus on end Markets , margins, multiples.*
Autodata, Goldman Sachs Global Investment Research. (2021). *Americas Basic Materials Initiate on Metal Processors Focus on end Markets , margins, multiples.*
Goldman Sachs Global Investment Research. (2021). *Americas Basic Materials Initiate on Metal Processors Focus on end Markets , margins, multiples.*
Djukanovic, G. (2016, April 6). *Aluminium Insider*. Récupéré sur Aluminium Insider: https://aluminiuminsider.com/alcoas-micromill-technology-for-future-cars/
Metal Supermarkets. (2016, February 8). *Metal Supermarkets*. Récupéré sur https://www.metalsupermarkets.com/history-of-aluminum-in-the-aerospace-industry/
UC Rusal. (s.d.). *aluminum leader*. Récupéré sur aluminum leader: https://www.aluminiumleader.com/economics/world_market/
IEA. (2020). *Aluminium.* IEA.
Kalra, D. (2021, January 2021). What Architects and Designers Say About Aluminium. (A. G. bhd, Intervieweur)
Aluminium Leader. (s.d.). *Aluminium Leader*. Récupéré sur https://www.aluminiumleader.com/application/construction/
Aluminium Leader. (s.d.). *Aluminium Leader*. Récupéré sur https://www.aluminiumleader.com/application/construction/
Gulri, A. (s.d.).
tms.org. (s.d.). Production and Processing of Aluminum.
Aluminium Leader. (s.d.). *Aluminium Leader*. Récupéré sur Aluminium Leader: https://www.aluminiumleader.com/application/packaging/
Statista. (2020). *Global end use of aluminum products in 2020, by sector*. Récupéré sur https://www.statista.com/statistics/280983/share-of-aluminum-consumption-by-sector/
United Nations. (s.d.). *United Nations Climate Change* . Récupéré sur https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement
World Economic Forum. (2020). *Aluminium for Climate: Exploring pathways to decarbonize the aluminium industry.*
Topping, N. (2020). *WEF Aluminium for Climate 2020.*
Alcoa. (s.d.). *Alcoa*. Récupéré sur https://www.alcoa.com/global/en/who-we-are/ethics-compliance/climate-change-policy
En+ Group. (2019, September 11). *pr newswire*. Récupéré sur https://www.prnewswire.com/news-releases/en-group-commits-to-climate-targets-in-line-with-a-new-level-of-climate-ambition-led-by-the-united-nations-300915886.html
GFG Alliance. (s.d.). *GFG Alliance*. Récupéré sur https://www.gfgalliance.com/cn30/
Norsk Hydro. (2021, July 15). *Norsk Hydro*. Récupéré sur https://www.hydro.com/en-CH/sustainability/environment/climate/
Rio Tinto. (2019). *Our approach to climate change.*
CSI Market. (2021). *Aluminium Industry Profitability*. Récupéré sur Csi Market: https://csimarket.com/Industry/industry_Profitability_Ratios.php?ind=104&hist=4

Butler, B. (2019, November 1). *The Guardian*. Récupéré sur https://www.theguardian.com/australia-news/2019/nov/01/australian-aluminium-smelters-not-sustainable-due-to-high-power-costs-rio-tinto-says

Cru Group. (s.d.). *CRU Group*. Récupéré sur https://www.crugroup.com/

Instituto Affari Internazionali. (s.d.). *Instituto Affari Internazionali*. Récupéré sur https://www.iai.it/en/news/next-generation-workshop

World Bank Group. (2020). *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition.*

Material Economics. (2020). *The Circular Economy: A Powerful Force for Climate Mitigation.*

The Aluminum Association. (s.d.). *The Aluminum Association*. Récupéré sur https://www.aluminum.org/industries/production/recycling

Dzikiy, P. (2019, May 13). *Electrek*. Récupéré sur Electrek: https://electrek.co/2019/05/13/mercedes-carbon-neutral-2039/

MachineMFG. (s.d.). *MachineMFG*. Récupéré sur MachineMFG: https://www.machinemfg.com/dry-machining/

Mertens, R. (2020, November 4). *Hydro*. Récupéré sur Hydro: https://www.shapesbyhydro.com/en/manufacturing/using-dry-machining-to-reduce-aluminiums-carbon-footprint/

Hydro. (s.d.). *Hydro*. Récupéré sur Hydro: https://www.hydro.com/en/aluminium/products/low-carbon-aluminium/

Material Economics. (2018). *The Circular Economy a Powerful Force for Climate Mitigation.* Stockholm.

Mandl, N., & Pinterits, M. (2018, May 27). *European Envvironment Agency.* Récupéré sur European Envvironment Agency: https://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2018

European Environment Agency. (2020, May 27). *European Environment Agency.* Récupéré sur European Environment Agency: https://www.eea.europa.eu//publications/european-union-greenhouse-gas-inventory-2019

European Environment Agency. (2018). *Annual European Union greenhouse gas inventory 1990–2016 and inventory report 2018.* Copenhagen.

International Aluminium. (2020, May). *CM Group: An Initial Assessment of The Impact of the Covid-19 Pandemic on Global Aluminium Demand*. Récupéré sur https://international-aluminium.org/resource/cm-group-an-initial-assessment-of-the-impact-of-the-covid-19-pandemic-on-global-aluminium-demand/

Heidi, G.-P. (2017). *Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model.*

Ellen Macarthur Foundation. (2019). *Completing the Picture: How the Circular Economy Tackles Climate Change* .

International Aluminium. (s.d.). *International Aluminium*. Récupéré sur https://international-aluminium.org/

European Aluminium. (2016). *"Recycled Content" vs. "End-of-Life Recycling Rate".* Brussels. Récupéré sur European Aluminium.

Novelis. (s.d.). *Novelis Aluminium Drives Innovation.*

Constellium. (2015, July 7). *Constellium* . Récupéré sur Constellium : https://www.constellium.com/news/2015/07/07/constellium-partners-stelia-aerospace-and-ct-ingenierie-explore-3d-printing

Novelis. (2019, January 21). *Novelis*. Récupéré sur Novelis: https://www.novelis.com/product/novelis-advanz-6hs-s615/

International Aluminium Institute. (2020, September). *International Aluminium*. Récupéré sur International Aluminium: https://international-aluminium.org/resources/

United Nations Environment Programme. (2019). *Emissions Gap Report 2019.* Nairobi: United Nations.

Evans, S. (2020, October 13). *Solar is now 'cheapest electricity in history', confirms IEA*. Retrieved from Carbon Brief: https://www.carbonbrief.org/solar-is-now-cheapest-electricity-in-history-confirms-iea

Lazard. (2019). *LAZARD'S LEVELIZED COST OF ENERGY* . Lazard.

CM Group. (2020). *An initial assessement of the impact of the covid-19 pandemic on global aluminium demand.* CM Group.

Jones, D. (2020, October 6). *Coal Power plants: Aluminium's dirty little secret*. Retrieved from Ember: https://ember-climate.org/commentary/2020/10/06/aluminium/

Harvey, F. (2018, May 10). *New technology could slash carbon emissions from aluminium production*. Récupéré sur The Guardian: https://www.theguardian.com/environment/2018/may/10/new-technology-slash-aluminium-production-carbon-emissions

Kvande, H. (2014, May). *The Aluminum Smelting Process and Innovative Alternative Technologies.* Récupéré sur Journal of Occupational and Environmental Medicine: https://journals.lww.com/joem/Fulltext/2014/05001/The_Aluminum_Smelting_Process_and_Innovative.6.aspx

Fischedick, M., Roy, J., Abdel-Aziz, A., Acquaye, A., Allwood, J. M., Ceron, J.-P., . . . Tanaka, K. (2014). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* New York.

Irena. (2020). *Renewable Power Generation Costs in 2020.* Abu Dhabi: International Renewable Energy Agency.

European Aluminium. (2015). *Recycling Aluminium: A pathway to a sustainable economy.* European Aluminium.

World Economic Forum. (2020, June 30). *Aluminium can help to build the circular economy*. Récupéré sur World Economic Forum: https://www.weforum.org/agenda/2020/06/heres-how-aluminium-can-help-to-build-a-green-recovery/

Aluminium Federation. (2015). *Uk Aluminium Industry Fact Sheet.* Aluminium Federation.

Ngoc Diep Group. (2021, April 10). *Aluminium Appications: Aluminium In Construction (Part 2)*. Récupéré sur Ngoc Diep Group: https://ngocdiep.vn/en/aluminium-appications-aluminium-in-construction-part-2/

Bloomberg, J. (2007). *Essays on the Economics of the Aluminium Industry.* Luleå.

Rowan, N. J., & Galanakis, C. M. (2020). *Unlocking challenges and opportunities presented by COVID-19 pandemic for cross-cutting disruption in agri-food and green deal innovations: Quo Vadis?*

Lucci, F. (2017). *FUTURE Act to advance clean energy through Carbon Capture Utilization and Storage.* Cambridge: Cambridge University Press.

European Aluminium. (2020). *Circular Aluminum Action Plan.* Brussels : European Aluminium.

Science Based Targets. (2020). *Understanding and Addressing the Barriers for Aluminum Companies to Set Science-Based Targets.* Science Based Targets.

A, E. (2021, Novemeber 23). (A. L. Teixeira, Intervieweur)

Vidal, O., Goffé, B., & Arndt, N. (2013). *Metals for a low carbon society.*

Sevigné-Itoiz, E., M.vGasol, C., Rieradevall, J., & Gabarrell, X. (2014). *Environmental consequences of recycling aluminum old scrap in a global market.*

APPENDIX

Interview questions

1. *What do you think that are the imperatives in order to achieve carbon neutrality by 2050?*

2. *How and what Is your company, (company), doing in order to achieve carbon neutrality?*

3. *What do you think will be the biggest changes and challenges in the industry/your company, this case (company)?*

4. *Do you think that aluminum will continue to grow and become more and more used?*

5. *Do you have any prospects on the recycled aluminum and on alumina production?*

6. *Will someday primary aluminum production not be necessary? In terms of the aluminum currently circulating in the economy will be enough to satisfy the demand?*

7. *Do you think that the circular economy and integrated value chains will represent major factors in the decarbonization of the industry?*

8. *What advancements/developments in technology would you think would change the industry? The impact of the industry 4.0?*