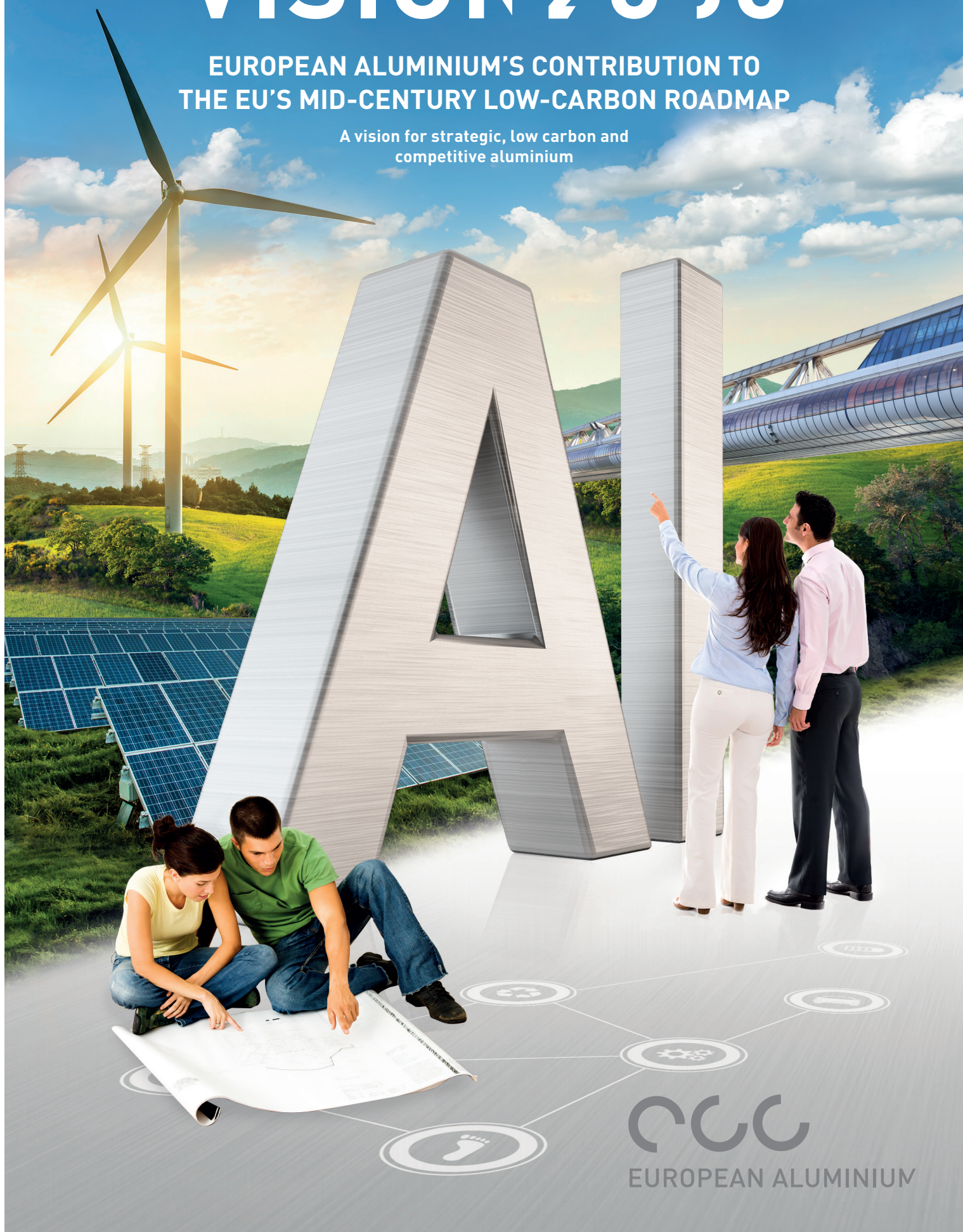


VISION 2050

EUROPEAN ALUMINIUM'S CONTRIBUTION TO THE EU'S MID-CENTURY LOW-CARBON ROADMAP

A vision for strategic, low carbon and
competitive aluminium



EUROPEAN ALUMINIUM

Note from the authors

This report has been drafted and coordinated by European Aluminium. Several departments were involved, including public affairs, sustainability, statistics and innovation. All data, estimates and projections are the property of European Aluminium.

CRU Group and PricewaterhouseCoopers GmbH (PwC) were contracted exclusively to provide statistical modelling support and reliable estimates for chapters 2, 3 and 4. Sources are provided for each chart.

Credits

European Aluminium expert members have contributed to all the sections of the report with data, expertise and examples, to ensure the most accurate insights. Interviews were conducted with several experts from the membership to shed light on the specifics of the aluminium industry. Without their expertise, this report could never have been written.

European Aluminium would like to thank all contributors for their efforts, which are designed to help policy makers and other stakeholders re-think our future for a better and more sustainable society.

EXECUTIVE SUMMARY

This document sheds a light on the enormous contribution that the entire aluminium industry can make to Europe's efforts to decarbonise the economy. It demonstrates aluminium's strategic role in helping achieve lower carbon targets in Europe, both through technology applied to production processes and also its unique properties of durability, recyclability and light weight. Aluminium features as a leading sector for boosting circular economy and new business models in Europe.

The introduction highlights the value of the programmes that European Aluminium implemented since the 1990s in reducing CO₂ emissions and perfluorocarbons (PFCs). Since 1990, European primary aluminium production has delivered a massive 55 percent reduction in total direct CO₂ emissions per tonne. In 2015, European Aluminium launched its Sustainability Roadmap 2025, which pursues multiple targets in key areas, including environment, energy and social areas with positive results for the entire value chain and society.

Chapter 2 reflects the main sustainability-related benefits of aluminium use in key markets, providing solid data on the growing demand for aluminium in Europe and globally. Worldwide, demand for primary aluminium is expected to grow by a further 50 percent by 2050, approaching 110 million tonnes. This is driven by key markets including automotive, building and packaging. Data confirms that China is expected to continue to increase its existing massive capacity up to the early 2030s. In addition, this chapter features the importance of aluminium for lightweight cars and the increasing innovation across the downstream sector by embracing the Industry 4.0 paradigm.

Chapter 3 is dedicated to understanding the prominent role that recycling aluminium will play in ensuring the circularity of the European Union's economy. This includes fundamental definitions and elements to enhance the potential of this industry to continue 'closing the loop'.

A main finding in chapter 4 is the dramatic reduction in overall primary emissions through the decarbonisation of the power sector in Europe. Based on the International Energy Agency's (IEA) 2°C scenario (2DS) for the European power sector, total CO₂e emissions for primary aluminium smelting in the EU and EFTA is likely to fall by 58 percent by 2050 compared to 2014. This will reduce total primary aluminium's smelting carbon intensity from 4.46 tCO₂e in 2014 to 1.73 tCO₂e per tonne of primary aluminium produced in Europe in 2050.

The report also shows how aluminium companies are leading the trend for using so-called long-term renewable Power Purchase Agreements (PPAs). This is creating opportunities for more stable sourcing of electricity as well as helping develop a renewable electricity base in Europe. The challenges posed by the more extensive use of green electricity in aluminium smelters are also outlined, with an emphasis on effectively addressing indirect costs in the coming decade.

In addition, this chapter highlights two incremental technology projects. The Karmøy Technology Pilot is demonstrating a 15 percent improvement in electrolysis energy efficiency (compared to the global average) and a substantial reduction in indirect emissions from the power system. It also describes the 'Virtual Battery' project, which provides systemic contributions to electricity grid management. Recommendations for policy makers include tailor-made funding, ETS-state aid related policies for adjusting to the global market, in-house expertise and partnerships.

Chapter 4 sets out the current landscape in a range of technologies for reducing direct emissions. It presents existing technologies and those under development, such as CCS (carbon capture and storage), CCU (carbon capture and utilisation) and inert anodes. It also explores what would be needed for Europe to advance a more effective innovation policy approach and replicate other success stories from regions outside Europe.

The report concludes with a conservative scenario of the gradual adoption of new technologies to mitigate/avoid CO₂ emissions in the smelting process in Europe by 2030. Assuming the potential and gradual introduction of several technologies, the results indicate the hypothetical potential for reducing direct emissions between 2030 and 2050. Based on this simple modelling, which includes the International Energy Agency (IEA) 2°C scenario (2DS), European smelters would decrease direct CO₂e emissions between 2030 and 2050 by 17 percent and 67 percent overall, if indirect emissions reductions through decarbonisation of the grid are included¹.

¹ Given the current maturity (the test phase is ongoing until 2024) of the technology the findings are generic estimates, without targeted goals and disconnected from any current technology in development.

CONTENTS

01 INTRODUCTION.....	6
a. Objectives of the report	6
b. Before and after the Paris Agreement (COP21).....	7
c. Aluminium industry efforts to reduce greenhouse gas emissions since 1990	8
d. Industry work for a balanced and effective European Emission Trading System (Phase IV).....	10
e. Current commitments: the European aluminium industry's Sustainability Roadmap towards 2025 in practice	11
02 ALUMINIUM: UNIQUE MATERIAL PROPERTIES IN GROWING DEMAND SCENARIOS	12
a. Aluminium as the key enabler for modern society.....	12
b. The primary sector in numbers.....	13
c. Three scenarios for primary and recycling aluminium demand and CO ₂ emissions projections by 2050.....	14
d. Aluminium: A perfect partner for a more-decarbonised and safer transport sector.....	21
e. Downstream research and innovation embracing the Industry 4.0 paradigm	23
03 RECYCLING ALUMINIUM: THE NATURAL DRIVER OF CIRCULAR ECONOMY IN EUROPE	25
a. Building the circular economy of the future	25
b. The importance of collection scrap.....	28
c. Sorting and treatment: The recycling loop	30
d. Policy recommendations	31
04 DECARBONISATION THROUGH GREENING OF THE EUROPEAN POWER MIX AND EFFICIENCY TECHNOLOGY	32
a. Decarbonisation of EU and EFTA power mix by 2050.....	32
b. The increasing support of PPAs by the Aluminium industry in Europe and the importance of regulation.....	34
c. Existing technologies and enabling conditions.....	36
a. Karmøy Technology Plant.....	36
b. Trimet Virtual Battery.....	37
d. Enabling conditions: Commonalities and insights from successful incremental projects.....	38
05 OPTIONS AND CHALLENGES FOR DIRECT EMISSIONS REDUCTION	40
a. Example of breakthrough technology: The recent Elysis Joint Venture in Canada	41
b. Carbon Capture Storage (CCS): A real opportunity for aluminium smelting?	43
c. A scenario for lower CO ₂ direct emissions reductions.....	44
06 CONCLUSIONS	46
Conclusions: Aluminium to become a strategic industry of the EU	46

a. Objectives of the report

The European aluminium value chain can be an accelerator for the transition to a low-carbon economy. Clearly, recycling aluminium already offers considerable potential for saving energy and enhancing circular economy models². However, the dynamics and role of primary production are also critical in meeting increasing demand and ensuring an operational value chain in Europe. The primary aim of this report is to aid understanding of the existing and future potential of the primary and recycling aluminium industry (EU+EFTA) for decarbonising the European economy, as well providing robust supporting arguments.

This report does not intend to set new long-term targets or collective commitments to replace our [Sustainability Roadmap 2025](#). Rather, it frames current and future scenarios for improving understanding of specific aluminium decarbonisation pathways. This should initiate a better, evidence-based debate on a strategic material for a low-carbon society.

Another goal of this Vision 2050 is to provide policy makers with the latest data and projections to support them when rethinking long-term approaches in Brussels and national capitals. As set out in our [European Aluminium Manifesto Industry Plus](#) initiative, ensuring coherence between industrial, energy, climate and trade policies remain a core precondition for ensuring effective long-term policies for the aluminium industry.

Given the continuous evolution and complexity of the industry, the report chapters cover the following topics:

1. Aluminium properties, demand forecasts and global trends (Chapter 2):

This provides a short introduction to the unique properties of the material and the evolution of primary and recycling aluminium production globally. It also introduces multiple forecasts³ for the main markets of steadily-increasing aluminium demand in Europe and beyond.

2. Reducing indirect carbon emissions (Chapter 3):

This discusses the emission reductions that will occur in the primary aluminium production as the European power mix is decarbonised in the coming decades. Using the IEA 2DS model⁴, the forecasts⁵ highlight the crucial role of indirect emissions reduction in the overall share of primary aluminium emissions. The chapter provides important insights into current primary aluminium technologies, the trend towards PPAs for securing long-term electricity from renewable power developers as well as some reflections on enabling conditions to foster incremental technology (i.e. efficiency saving and systemic gains).

² See more: [The Circular Economy: A powerful force for climate mitigation by Material Economics 2018](#)

³ Forecasts have been developed by [CRU Group](#).

⁴ The 2°C IEA model refers to the 2DS scenario of IEA's 2017 Energy Technology Perspectives model.

⁵ CO₂ emissions projections have been developed by PwC's expert team and integrated into the report.

3. Options and pathways for reducing direct emissions (Chapter 4):

This examines the basics of potentially game-changing technologies for primary production, such as CCS, CCU and new technologies to replace the current carbon anode. This chapter also reflects on the fundamental challenges of accelerating breakthrough innovations with high upfront capital risks in Europe.

b. Before and after the Paris Agreement (COP21)

European Aluminium's commitment to fighting climate change started long in advance of the negotiations that led to the Paris Agreement in COP21. Data collection started in 1990, a first roadmap was published in 2012 and our Sustainability Roadmap 2025 - with commitments - was unveiled in 2015. The industry endorses sustainability as core values of business and societal impact; the Roadmap 2025 integrates both climate change measures and societal challenges as described in the United Nations Sustainable Development Goals.

The long-awaited success of COP21 has opened a new era of commitments for all its signatories, including the European Union. There has been a shift in perception on how industry can partner effectively with the public sector and NGOs in future to act as an engine for progress and change.

The Paris Agreement incorporates a review mechanism to accelerate its pledges every five years, in order to allow them to remain sufficiently effective to keep below 2°C. This presents an opportunity for all stakeholders to continue working together to address climate change. We know that our industry alone cannot make the difference, but the entire value chain - interlinked through clusters in Europe and internationally - can make a wider impact.

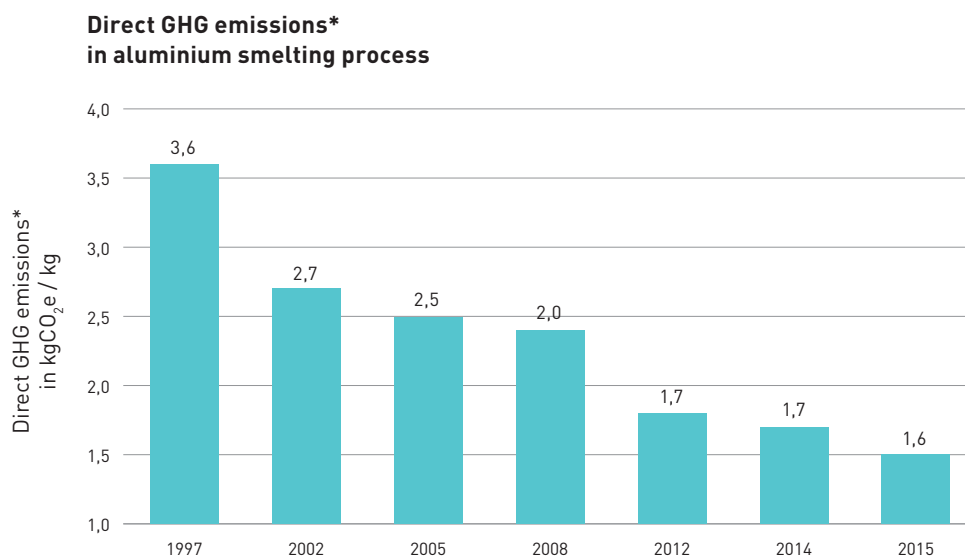
With its Sustainability Roadmap 2025, the European aluminium industry has made a core commitment to contributing to the global goals against climate change. The Roadmap sets out a long-term vision for the aluminium value chain and defines a clear agenda, via shared commitments, for fostering responsible production of aluminium, innovation in using aluminium and further improving the socio-economic contribution of aluminium and its wider impact of our industry on society.

Progress towards the voluntary targets is measured through a comprehensive set of more than 20 Sustainable Development Indicators (SDIs), collected annually.

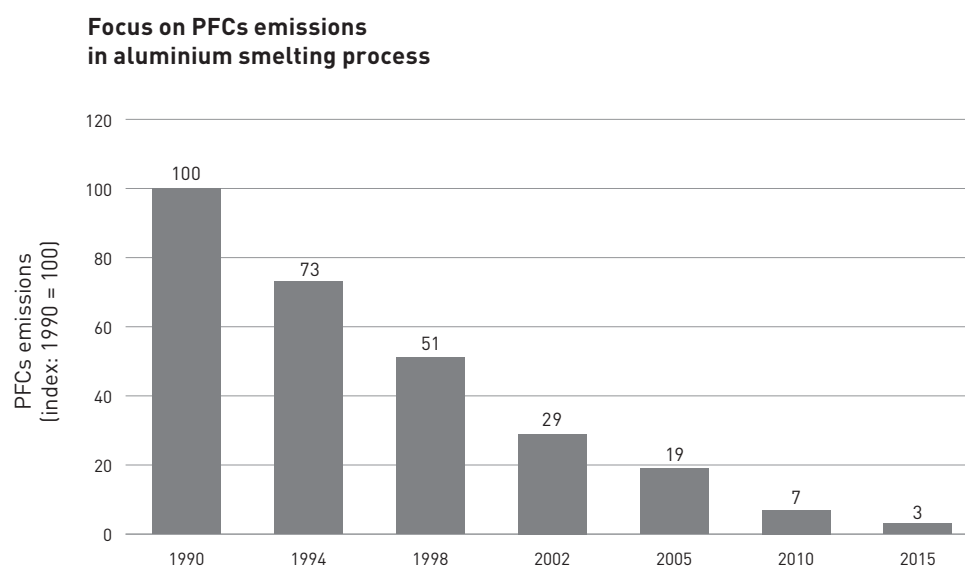
Our mid-century vision fits within this broader agenda of defining a path for realising the industry's greenhouse gas reduction potential by 2050.

c. European Aluminium industry efforts to reduce GHG (CO₂, PFCs) emissions since 1990

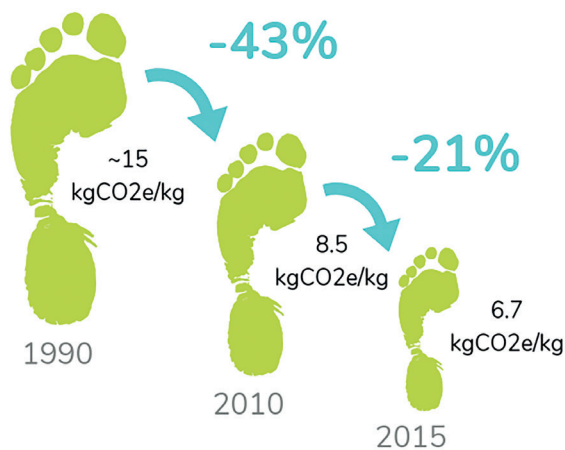
Since late nineties, primary aluminium in Europe has dramatically decreased - by 55 percent - its total direct CO₂ emissions. These emissions relate to the PFC emissions (down 97 percent) and the (carbon) anode consumption from the electrolytic process.




* PFCs and anode consumption | Source: [European Aluminium SDIs reports](#)



Source: European Aluminium




Carbon intensity of the primary aluminium production in Europe decreased by -21% vs 2010 and by -55% vs 1990

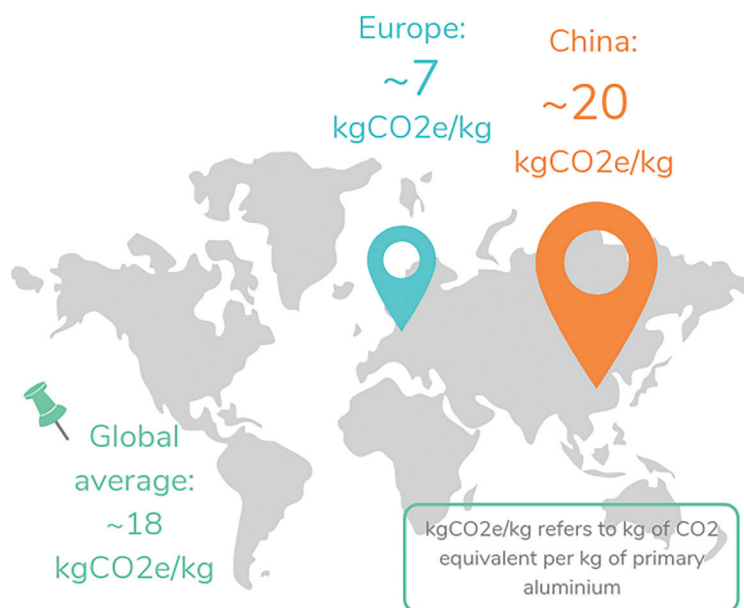

EUROPEAN ALUMINIUM

Source: [European Aluminium Environmental Profile Report⁶](#)



DID YOU KNOW...?

that European primary aluminium production⁷ is one of the world's least carbon-intensive regions? Today, primary aluminium production in Europe generates about 6.7 kg of CO₂ equiv. per kg; the carbon intensity for aluminium produced in China is three times higher.



Source: European Aluminium⁸

⁶ These figures include direct and indirect carbon CO₂ emissions from the mining process to the primary ingot.

⁷ From bauxite mining to primary ingot casting.

⁸ These figures include direct and indirect carbon CO₂ emissions from the mining process to the primary ingot.

d. Our work on a balanced and effective European Emission Trading System (Phase IV)

The introduction of the EU Emission Trading System (ETS) has had an important impact on the aluminium primary production industry.

While the ETS is a fundamental instrument for driving CO₂ emission reductions in Europe, it also is a challenge for European industry. Direct and indirect carbon costs⁹ (CO₂ prices passed on to electricity prices) represent a risk to global competitiveness compared to industries in those regions without similar CO₂ pricing.

More precisely, indirect carbon/emission costs, or so-called 'indirect' ETS costs, are significant for those power-intensive industries that rely on regional power mixes where users must bear the cost of carbon content that they themselves have not created. These indirect costs from power generators have already had a massive impact on aluminium smelters located in Europe, as they cannot pass through costs to customers¹⁰. Moreover, indirect carbon costs for aluminium can be as many as seven times those of direct carbon costs.

A report by the Centre for European Policy Studies (CEPS) in October 2013, entitled "Assessment of Cumulative Cost Impact for the Aluminium Industry"¹¹, highlighted the unsustainable regulatory costs that are damaging the global competitiveness of the industry. In short, the ETS accounted for 45 percent of all cumulative regulatory costs borne by the aluminium industry.

European Aluminium has therefore called for full compensation for indirect costs for all European smelters up to the benchmark levels. Current indirect carbon compensation policy is closely linked to national compensation mechanisms, which differ in volume, rationale and budget. The upcoming state aid reform on indirect compensation - to regulate the regime for the next phase - will be fundamental in securing the future viability of the entire European value chain operating in both the EU and EFTA.



ZOOM IN

Delivering 12 percent CO₂ reductions from 2008-2012

According to European Aluminium simulations using real-world plant data, the best-performing smelters in 2007-2008 (defined as the average of the top 10 percent, expressed in tCO₂/t of aluminium) were largely the same as in 2013-2014. This was also the case with the specific electro-intensity (MWh/t of aluminium). **The trend confirms that the current technology is reaching its theoretical limits; further improvements will only be achieved with a breakthrough technology.**

⁹ 'Indirect' greenhouse gas emissions sources are those that relate to the company's activities but that are emitted from sources owned or controlled by a third party.

¹⁰ Passing the costs to customers is not possible, as aluminium is a global commodity and its price is set by the London Metal Exchange (LME)

¹¹ See full CEPS report: https://www.ceps.eu/system/files/final-report-aluminium_en.pdf



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At the same time, the actual environmental impact of the GHG emissions has to be considered relative to the total volume of tCO₂ emitted by the entire aluminium sector. In this context, the same simulations showed that in 2008-2014, the highest-emitting facilities closed the gap on the performers. **This represented a total saving of around 800 ktCO₂ (12 percent), while the level of aluminium production remained essentially the same.**

While waiting for a breakthrough technology, significant reductions in CO₂ emissions remain possible by continuing this trend. The aim should be to improve performance of the entire production to bring all closer to the current state-of-the-art.

e. Current commitments: Sustainability Roadmap towards 2025 in practice

Through its Sustainability Roadmap 2025, the European aluminium industry has defined, together with key stakeholders, 'common goals and shared actions'. This is a programme of ambitious targets and commitments extending far beyond legislative obligations, reflecting the aluminium industry's forward-thinking approach to change and its commitment to action.

Its success relies on a collaborative and innovative approach, engaging with other stakeholders to connect industry challenges, climate change imperatives and societal impacts. This is why best practices are shared across the value chain, stimulating initiatives and encouraging their duplication and adoption.

A CLEAR VISION FOR 2025



ALUMINIUM: UNIQUE MATERIAL PROPERTIES IN GROWING DEMAND SCENARIOS

a. Aluminium as the key enabler for society

In modern society, aluminium plays a pivotal role in emerging low-carbon and energy-efficient applications. The attractive properties of the material (see box below) – light weight, formability, recyclability, conductivity – are increasing demand in strategic applications. Aluminium can actually offset its initial energy consumption by providing significant savings during its use phase.

- **Light mobility:**

Aluminium is an important enabler to reduce CO₂ emissions in the transport sector (cars, vans, trucks, public transportation and aerospace), thanks to lightweighting contributing to greater energy efficient and safer transport.

- **Low consuming buildings:**

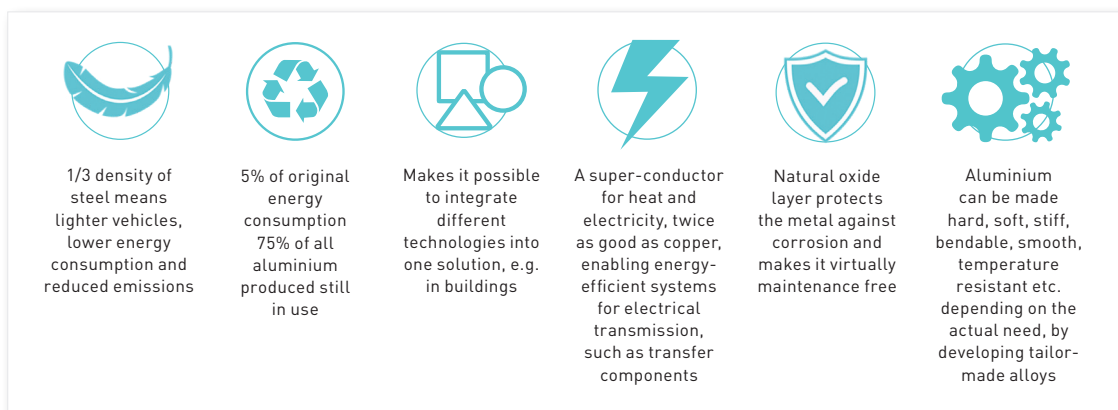
Aluminium improves the energy performance of buildings, notably via windows, curtain walls and ventilated facades.

- **Resource efficient packaging:**

Aluminium offers highly-efficient packaging that uses very little material and that often has a lower environmental footprint than its contents. In addition, it provides an efficient barrier that helps reducing food waste.

- **Recyclability:**

Aluminium can be repeatedly recycled without losing its properties, saving energy and playing a leading role in shaping a circular economy.



Source: European Aluminium 2018, unique property materials



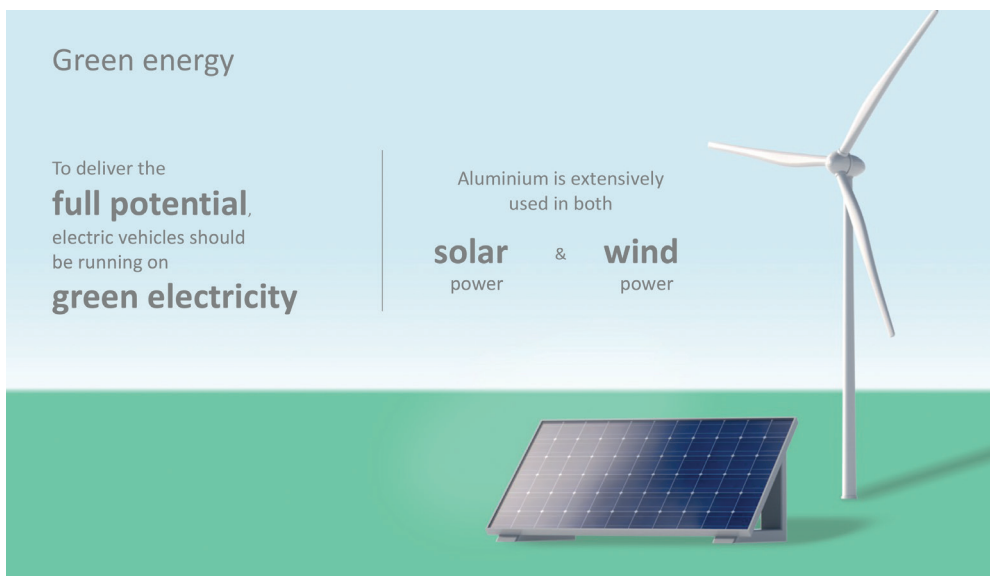
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The role of aluminium in fostering the electrification of mobility

Green energy

To deliver the **full potential**, electric vehicles should be running on **green electricity**

Aluminium is extensively used in both
solar & **wind**
power power



Charging infrastructure

Perfect material for **charging stations**

Also used in electrical **wires and cables**



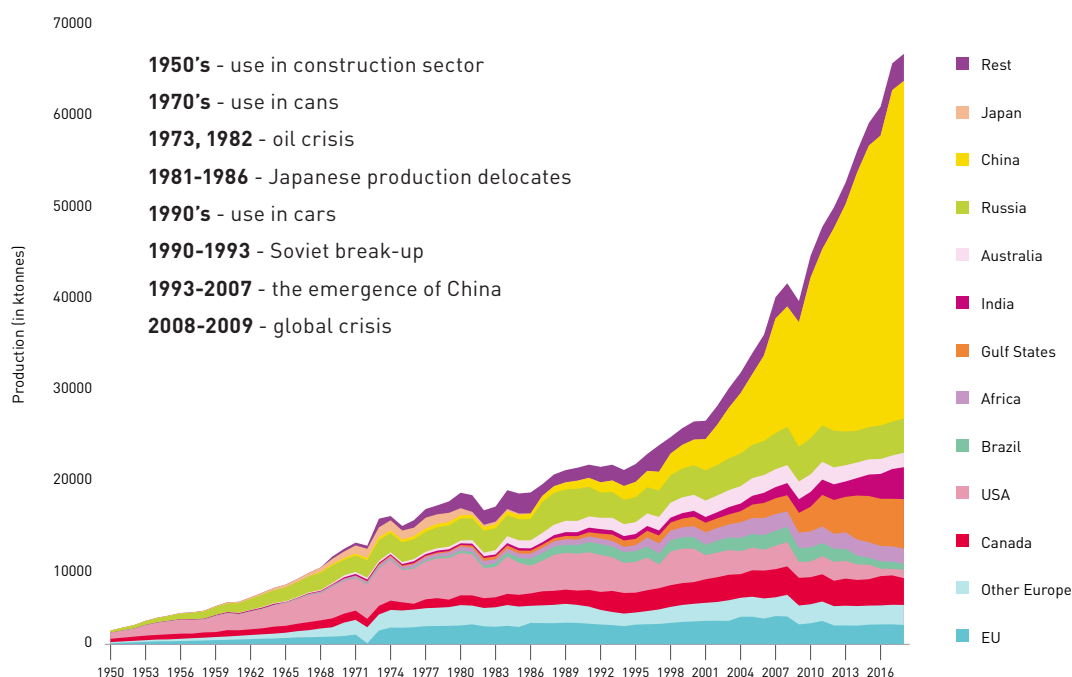
b. Primary sector in numbers

The modern global aluminium industry bears scant resemblance to its counterpart of the early 1970s. There have been important structural changes in the geographical relocation of bauxite, alumina and aluminium production centres, such as shifts in the levels of concentration and integration of companies and the emergence of new aluminium-consuming regions. There has also been the development of new end-use markets; the historic decline in real prices and the recent increases in the industry costs; the market adjustment mechanisms and more recently, the growing popularity of commodities as an asset class.

Since the end of the Second World War, use of primary aluminium has evolved rapidly and cyclically, responding to the emergence of new economies and new markets (cars, packaging), international crises (oil, financial) and the rise of an increasingly interconnected, global economy.

In addition, primary aluminium has entered a new era with the growth of production in China. At the beginning the 21st century, China represented around 10 percent of world production; it now produces more than 55 percent. In addition, it continues to grow significantly and beyond China's domestic demand, despite the much greater carbon intensity of their primary aluminium production, which is up to three times greater than in Europe (see Chapter 1).

History of primary aluminium production: Main producing countries and regions 1950-2016



Source: European Aluminium AA, JAA, ABAL, RTA, Metallstatistik

c. Projected scenarios in Europe (+EFTA) and the potential of aluminium by 2050

Aluminium is now a preferred material in multiple markets, including the automotive, aerospace, packaging, building, cables and electronics sectors, contributing to a steady increase in demand. According to a recent World Bank report, demand for low-carbon technology - and hence relevant minerals and metals - is increasing more rapidly the closer the world comes to achieving the COP21 commitment to limit the rise of global temperature below 2°C. The most significant example is in the field of electrical storage batteries. Demand for the metals used to manufacture these batteries - aluminium, cobalt, iron, lead, lithium, manganese and nickel - has grown by more than 1000 percent under a 2°C scenario, compared to the relatively modest levels seen for 4°C.¹²

The following sub-sections explore primary aluminium demand in Europe (including EFTA) in the global context and the drivers of future demand until 2050.

¹² "The Growing Role of Minerals and Metals for a Low Carbon Future (2017)" by the World Bank.



ZOOM IN

Future markets: Submarine cables in Europe and the key role of aluminium

According to the leading European electrical cable manufacturer's trade association, Europacable, Europe will need a further 90,000km of high and extra-high voltage cable in the coming decade alone; most of which will be submarine cable. This represents an investment of approximately €150 billion by 2030.

Submarine cables will play a significant role in connecting northern and southern Europe, ensuring a more liquid electricity market by transporting renewable energy to where it is needed. Demand for aluminium cable is expected to increase in the coming years, as it becomes the preferred material for 'connecting' European energy needs beneath the seas.

Data demonstrates aluminium is the 'metal of the future'

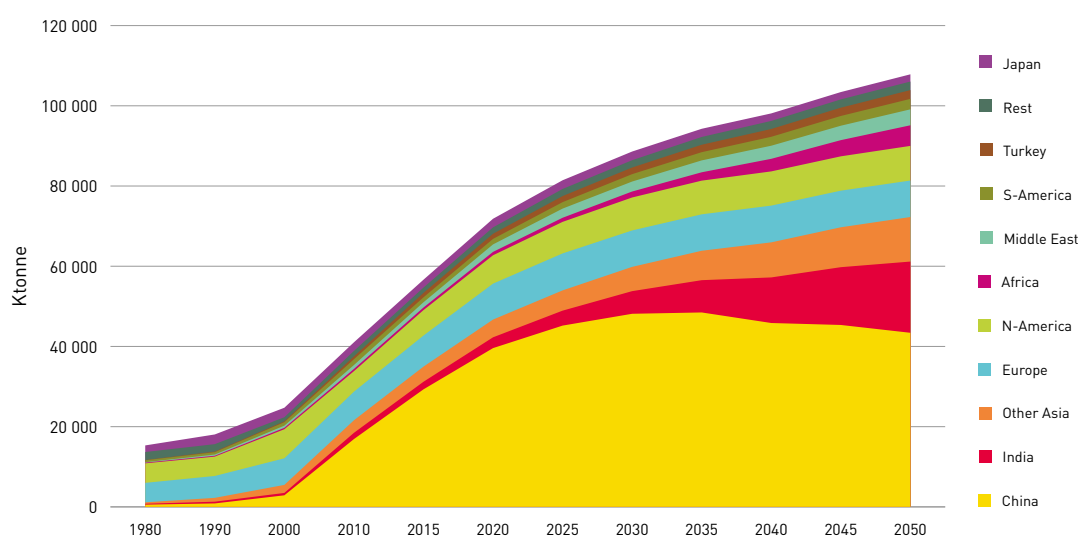
Global demand for primary aluminium is expected to grow by a further 50 percent by 2050, approaching 107.8 million tonnes¹³. The most rapid growth will be in Asian countries, although Europe is currently the second-largest user of primary aluminium and is likely to remain so until at least 2050. For the coming decades, Europe will need approximately 9 million tonnes of primary aluminium each year.

Importantly, China is responsible for more than half of all global primary aluminium demand; this is expected to peak around 2035 at almost 50 million tonnes. Subsequently, demand growth in China is expected to stabilise or possibly slightly decline. By 2050, China is expected to have 40 percent share of primary aluminium demand.

India seems likely to replace China in terms of expansion of demand for primary aluminium by the mid-2030s. It is expected to grow from 4 percent to 16 percent of global demand. In addition, other Asian countries, as well as African nations, will seek more primary aluminium by 2050.

In short, demand is forecasted to grow in virtually all countries worldwide.

Demand for primary aluminium (1980-2050)



Source: CRU 2018

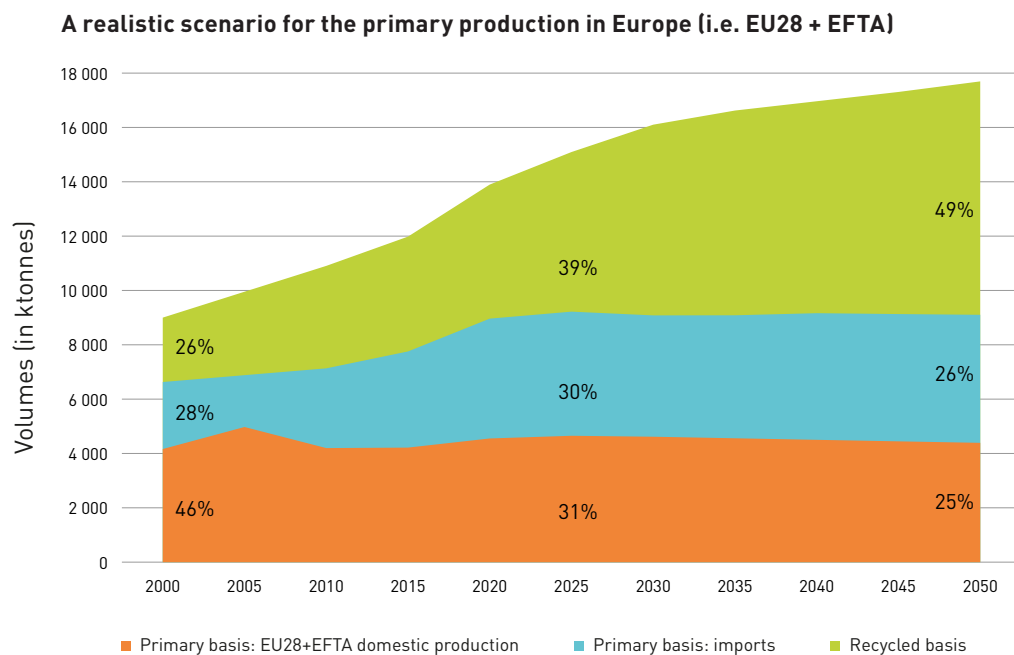
¹³ All the data provided in these sections has been developed by CRU Group.

A realistic scenario shows the importance of policy and integrated value chains

According to European Aluminium data, the share of recycled aluminium in European end-use applications was 26 percent in 2000. However, our realistic scenario - with supportive policies - for our sector by 2050, recycled and primary are expected to have almost equal shares of total European demand; this is forecast to reach around 18 million tonnes.

Regarding the GHG emissions, the continuous increase of the recycled production to meet the European demand during the period 2020 - 2050 would avoid between 880 and 1500 million tonnes of CO₂ equivalent emissions during this period. This is in comparison to a scenario where the recycled production would remain constant (i.e. at current level) until 2050 and the additional demand for metal would be supplied by imports of primary aluminium from third countries. **Thanks to the recycling industry, the potential GHG emissions savings for the period 2020-2050 are equivalent to about 20 to 35 percent of the total EU28 annual GHG emissions or the overall fossil fuel CO₂ emissions-related coming from Germany alone¹⁴. The CO₂ emissions avoided would be between 29 and 51 million tonnes of CO₂ equivalent per year,** echoing Material Economics data¹⁵, which estimates a fall of around 300 million tonnes of CO₂ equivalent per year from heavy industry in total.

The aluminium recycling industry infrastructure is already well-distributed across Europe, with around 220 plants. There is the capacity to produce more as long as sufficient aluminium scrap is available. This trend should reconfirm Europe as the global leader in aluminium recycling.



Source: European Aluminium based on CRU 2018 datasets

¹⁴ EU28 total GHG emissions in 2016 are equal to 4293 Mio tonnes of CO₂ equivalent (excl. LULUCF).

Source: European Environmental Agency 2018 Annual EU GHG inventory report. As per Germany, the source is EDGAR database created by European Commission and the Netherlands Environmental Assessment Agency in 2015.

¹⁵ The report stresses that a more circular economy can make deep cuts to emissions from heavy industry: in an ambitious scenario, as much as 296 million tonnes CO₂ per year in the EU by 2050, out of 530 in total – and some 3.6 billion tonnes per year globally.

Decreasing production scenario with poor or inadequate policy support

A decreasing production scenario, with no predictable and supportive regulation (i.e. state aid and indirect carbon costs compensation, continuous internal market barriers, inadequate fiscal conditions, no equivalent EHS conditions vis-à-vis third countries, etc.) will see domestic primary production in Europe fall by 14 percent in 2050 and increasing CO₂ emissions via the need to import from third countries.

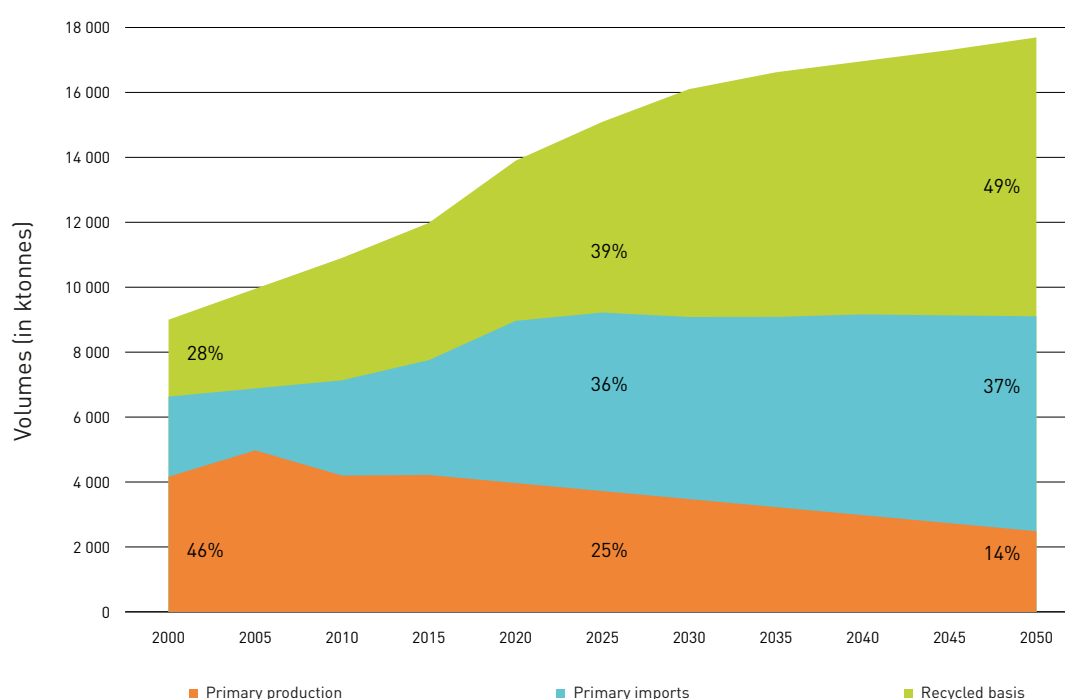
In this scenario, primary production in Europe would be limited to Norway and Iceland, as EU production will cease. In addition, the European domestic production will be around 2.5 million tonnes, i.e. a drop of 43 percent compared to the current situation. Over the same time, imports will increase by around 6.6 million tonnes, i.e. an increase of 74 percent.

Regarding the GHG emissions, the additional emissions relating to the additional imports of primary from third countries required during 2020-2050, in comparison with the baseline scenario, are estimated between 158 and 529 million tonnes of CO₂ equivalent. **These additional GHG emissions for 2020-2050 are equivalent to about 4 to 12 percent of the annual EU28 total¹⁶.**

The CO₂ emissions avoided thanks to the domestic primary aluminium industry, in comparison to the primary imports from third countries, would be between 5 and 17 million tonnes of CO₂ equivalent per year. As highlighted above, Europe has one of the lowest carbon footprints in the world related to its primary aluminium production (see Chapter 1.c).

European aluminium demand for aluminium ingot (2000 - 2050)

Decreasing production scenario for primary production in Europe (i.e. EU28 + EFTA)



Source: European Aluminium based on CRU 2018 datasets

¹⁶ EU28 total GHG emissions in 2016 are equal to 4 293 Mio tonnes of CO₂ equivalent (excl. LULUCF).

Source: European Environmental Agency [2018 Annual EU GHG inventory report](#)



ZOOM IN

Additional European aluminium available by further improving the existing collection and sorting infrastructure

Our present recycling rates vary from 90-95 percent for automotive and building end-use applications, 74 percent for beverage cans and an estimated 60 percent for all aluminium packaging. The recycling performance of aluminium in other end-use markets (e.g. engineered products, electric and electronic applications) is more complicated, as aluminium is usually a small part of the end-use product in these sectors.

This means that there is a significant remaining potential for retrieving more aluminium from recycled sources, providing that a few extra conditions are met within the near future. One of the most important conditions for generating more end-of-life scrap will be the increasing availability of well-performing collection and sorting schemes across Europe, to be based on the Extended Producer Responsibility principle. All end-use sectors should be obliged to take care of their used products, combined with tougher European recycling rates per material and the phasing out of landfill.

This could potentially generate growth in aluminium scrap, replacing the need for primary aluminium. However, these scrap flows need to be better-sorted, preferably by specific product and by alloy family in order to satisfy future demands. It is expected that today's demand for ingots of casting alloys may not remain constant, mainly due to the introduction of electric vehicles. In addition, there will be greater demand for product-to-product recycling. Extra investment in innovative sorting technologies (x-ray, laser, robot, etc.,) is essential.

A combination of policy and fiscal instruments are needed in order to convince European Member States and industries to invest more in creating a true European circular economy:

- EU Funds for regions and industries, which are willing to invest in a better collection and sorting infrastructure;
- Removal of the remaining Internal Market (EU+EFTA) trade barriers for shipping waste and scrap flows to the best-equipped facilities;
- Restrictive aluminium scrap export and aluminium primary and semifabricated products import policies for third countries that do not apply the same EHS conditions as in the European Union.

Ideal growing scenario with tailor-made supportive policy

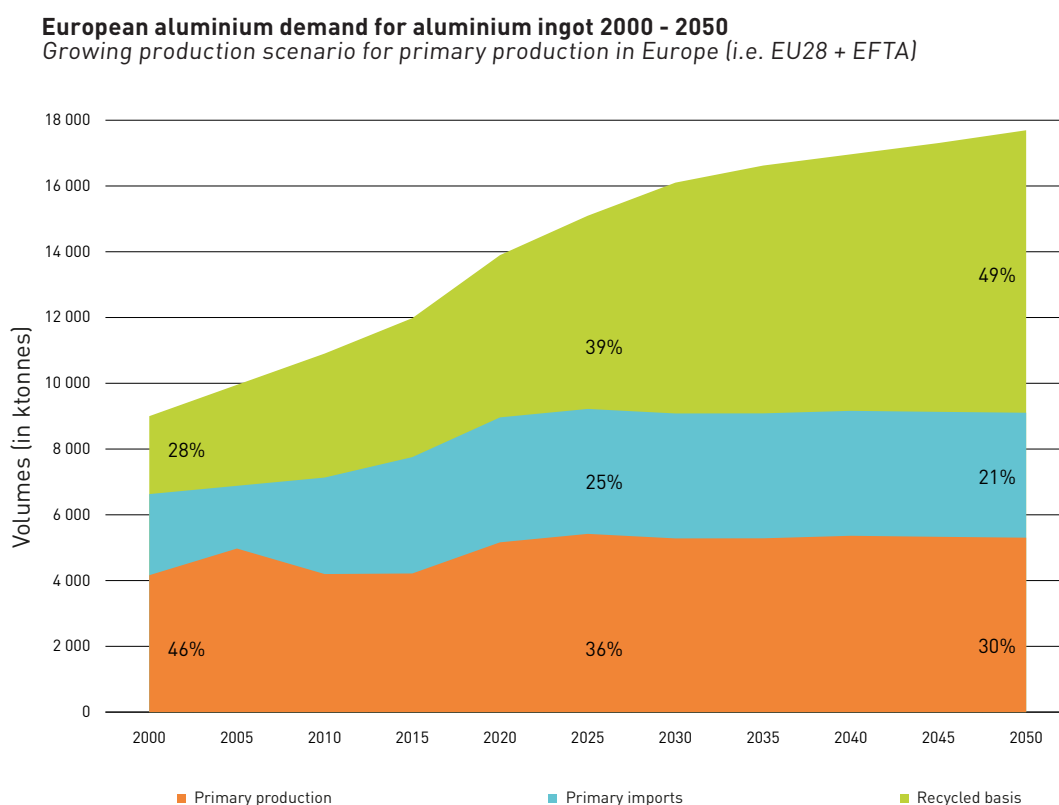
An ideal scenario is also possible in which 'creeping' projects¹⁷ for smelters will be supported by EU policy, with indirect carbon costs covered 100 percent in the transition to a decarbonised grid. This could create an opportunity for domestic production growth by 30 percent in 2050 and limit imports from third countries.

From this extremely positive scenario, primary production in Europe (EU+EFTA) would reach around 5.3 million tonnes, i.e. an increase of 22 percent in comparison to current levels. In this scenario, imports remain stable.

Regarding GHG, in this extremely positive scenario, the emissions avoided during the period 2020-2050 (due to the increase of the European domestic primary production replacing the imports from third countries) to feed the demand are estimated between 94 and 314 million tonnes of CO₂ equivalent.

These additional GHG emissions for the period 2020-2050 are equivalent to about 2-7 percent of the total EU28 annual GHG emissions¹⁸.

The CO₂ emissions avoided related to the increase of the domestic primary aluminium industry instead of the imports from third countries would be between 3 and 10 million tonnes of CO₂ equivalent per year. As previously highlighted, Europe has one of the lowest carbon footprints in the world for primary aluminium production (see Chapter 1.c).



Source: European Aluminium based on CRU 2018 datasets

¹⁷ Creeping means increasing the amperage of the aluminium primary pots in order to increase primary aluminium production. This process requires an investment.

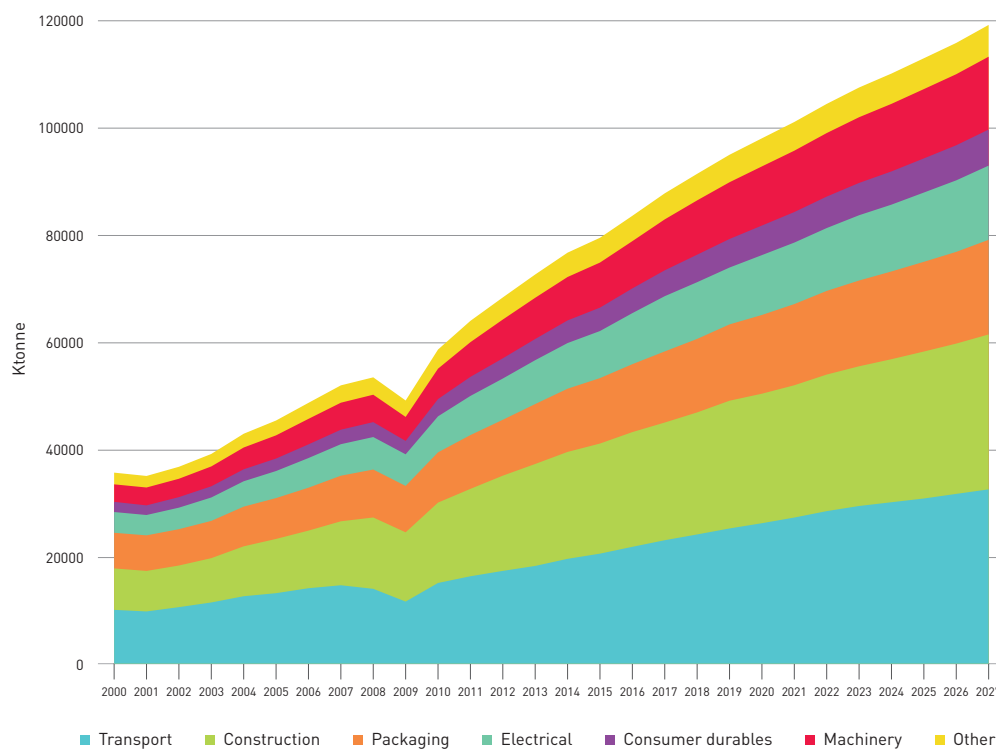
¹⁸ EU28 total GHG emissions in 2016 are equal to 4 293 Mio tonnes of CO₂ equivalent (excl. LULUCF).

Source: European Environmental Agency [2018 Annual EU GHG inventory report](#)

Aluminium semifabricated consumption by end use

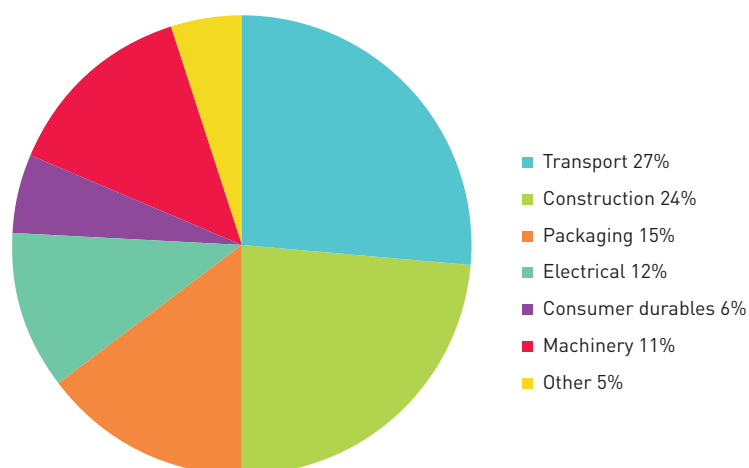
For the foreseeable future - until 2027 - aluminium use in all main sectors will increase steadily. An annual growth of 3-4 percent is expected worldwide in most sectors.

Global aluminium end use sectors (2000-2027)



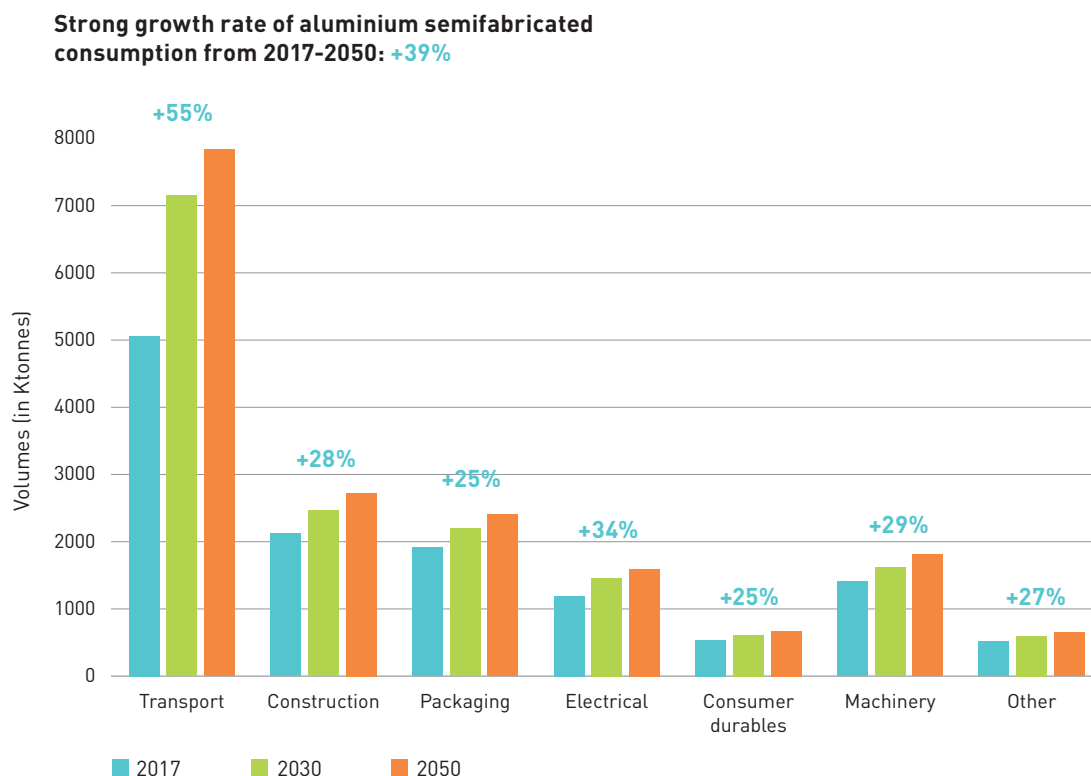
Source: CRU 2018

Worldwide end use applications of aluminium (2027)



Source: CRU 2018

In the European market, a strong growth in aluminium consumption is expected for semi-fabricated products by 2050. Transport, construction and packaging should grow by 55 percent, 28 percent and 25 percent respectively, compared to 2017 demand. The chart below depicts the trend in all relevant markets.



Source: European Aluminium based on CRU Group datasets (2018)

d. Aluminium: A perfect partner for a more decarbonised and safer transport sector

Transport is one of the largest sectors for aluminium products in Europe. Its lightweight characteristics reduce the weight of a range of vehicles, from passenger aircraft to cars, increasing fuel efficiency and reducing CO₂ emissions. Aluminium's lightweighting properties mean it already makes a substantial contribution to reducing emissions and improving fuel efficiency, preventing 70 million tons of unwanted CO₂ in vehicle emissions from reaching the atmosphere. This makes a substantial contribution to reducing climate change. Innovative car manufacturers such as Tesla, Jaguar Land Rover, Audi, BMW and Daimler increasingly recognise that well-engineered aluminium car parts are as safe and strong as steel while up to 40 percent lighter. This delivers significant enhancements in performance and agility and improves fuel economy and CO₂ emissions.

The aluminium industry has invested more than **€ 1.1 bn in auto body sheet capacity over the last decade**. If European legislation does not encourage innovation also on the material side, European manufacturers risk losing their competitive advantage on lightweight materials and subsequently CO₂ reductions for cars, vans and heavy vehicles.

As well as cars, aluminium is now widely used in trucks, particularly those carrying freight and therefore approaching the maximum permitted vehicle weight. Reducing the dead weight of the vehicle allows it to carry a greater payload. With the maximum weight of trucks in Europe being regulated by law, each kg of weight saved on the truck or the trailer allows an extra kg of valuable load. This means fewer journeys and lower overall CO₂ emissions.

This aluminium lightweighting is now extensively used in city buses. Given their frequent start-stop cycles, lightweighting makes a rapid contribution to reducing CO₂ emissions and improving air quality.

Aluminium also offers the opportunity to make trucks safer in the future. In 2015, the EU decided to allow truck cabins to be longer, increasing their safety and aerodynamics. The aluminium industry has shown how to use this extra space to improve passive safety by introducing an energy-absorbing crash management system. More than 90 percent of aluminium from trucks is recycled, another good example of circular economy.



ZOOM IN

Ducker Study¹⁹ confirms great potential for aluminium in cars

In September 2016, a Ducker Worldwide study forecasts the aluminium content in cars to increase by up to 30 percent over the next ten years. This surge is mainly driven by rolled and extruded products, where auto body sheet leads the growth with an expected increase of 110 percent over the same period. This is largely attributed to aluminium's role in lightweighting cars, thereby contributing to low-emission mobility.

The study predicts that the aluminium content of cars produced in Europe could reach nearly 200 kg per vehicle by 2025, up from 150 kg today.

Carmakers' preference for aluminium is largely linked to its lightweight nature, contributing to CO₂ reduction. Due to aluminium's inherent strength and its excellent ability to absorb crash energy, well-engineered aluminium car parts can be both safer than steel and up to 50 percent lighter. Lighter cars substantially contribute to reducing CO₂ emissions and improving fuel efficiency. In fact, using 200 kg of aluminium in a car could reduce CO₂ emissions by up to 16 grams per kilometre travelled. With the 2014 average at 123g/km, increasing the aluminium content of cars could play a significant role in enabling the EU to achieve its target of 95g/km by 2021.

¹⁹ Ducker Worldwide Study summary report can be found here: https://european-aluminium.eu/media/1721/european-aluminium-ducker-study-summary-report_sept.pdf

Aluminium: Delivering lighter and fuel efficient planes

In 1903, the Wright Brothers chose an aluminium engine for their first aeroplane, because of the weight it saved. Since then, the phenomenal growth of the aerospace industry has been built on its widespread adoption of aluminium. **In the Airbus A380, aluminium accounts for 61 percent of the structural weight.** Aluminium is the metal that has allowed mankind to travel; even into space. Since the launch of Sputnik almost 60 years ago, aluminium has been the material of choice for all types of space structures. Its high strength-to-weight ratio, and its ability to withstand the stresses of launch and space operation, has led to aluminium being used in the Apollo missions, Skylab, the Space Shuttle and the International Space Station. Aluminium alloys consistently surpass other metals for their mechanical stability, dampening, thermal management and reduced weight. The continuous innovation and development on new alloys, such as aluminium-lithium alloys, is delivering ever-lighter and stronger solutions, enabling further fuel-efficiency improvements in the aviation sector.

e. Downstream research and innovation embracing the Industry 4.0 paradigm

European Aluminium's downstream members are constantly assessing opportunities for future production processes including digital manufacturing, cloud computing, big data, automation.

Following the Industry 4.0 approach and principles (interconnection, information transparency, technical assistance and decentralised decisions), our industry is convinced that we are entering into a new paradigm with substantial opportunities to optimise the performance of aluminium applications and decarbonise our entire value chain. For example, advanced data analytics can help identify the most effective manufacturing process windows or predict maintenance needs. New sensor technologies will improve our products and processes. Augmented reality could help to train the next generation of plant personnel and leverage expertise across the whole organisation. Productivity improvements will be driven by automating repetitive or dangerous manual tasks with collaborative robots and automating repetitive intellectual tasks through machine learning.

Currently, there are four main areas in which our members are working:

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



ZOOM IN

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

FAST by Constellium and partners: Together with STELLIA Aerospace, a world major player in the design and production of aircraft equipped fuselages and CT INGENIERIE, a leading engineering company in technological innovation throughout the product lifecycle, Constellium launched FAST. This project focuses on topological optimisation of aero structures and additive manufacturing, also known as 3D printing. The FAST project is an innovative solution using optimised design and technologies to make large aerospace structures and parts more efficient, cost-effective and inventive than ever before. 3D printing offers alternatives for designing and producing large aerospace components, such as the fuselage. With the existing available technology, the design of large-scale modules is currently restricted by cost, size and efficiency constraints. 3D fuselage printing has the potential to transform the aerospace industry, allowing for easy design modification, duplication and customisation at a lower cost.

Micromill by Arconic: Arconic has developed the so-called Micromill technology, which turns aluminium from liquid to solid in seconds. While traditional rolling mills take approximately 20 days to turn molten metal into coil, Micromill does the job in 20 minutes - using one-quarter of the floor space and with half the energy. With Micromill technology, it is possible to produce an aluminium alloy that is more formable and stronger than average. Improving formability means greater design flexibility and vehicle performance.

Novelis Advanz s615 alloy: For aluminium-intensive vehicles to outperform previous generation body styles, carmakers have collaborated with Novelis to produce innovative high-strength products. Novelis partnered with all major OEMs to help completely redesign their Body in White (BiW) concepts in order to reduce the vehicles' weight and increase their fuel efficiency. A brand-new aluminium alloy, Novelis Advanz™ s615, was developed by Novelis researchers, metallurgists, engineers and technologists. This innovative alloy is flexible enough to withstand high-volume part stamping and assembly, yet strong enough to meet rigorous durability and safety requirements. Today, Novelis Advanz™ s615 is setting the standards for vehicle strength and toughness in the automotive industry.

RECYCLING ALUMINIUM: THE NATURAL DRIVER OF CIRCULAR ECONOMY IN EUROPE

In a growing market like Europe, demand for aluminium can mainly be fulfilled through primary aluminium production. However, use of end-of-life scrap is steadily increasing, thanks to aluminium's excellent recyclability properties. This means that in future (as shown in the previous chapter), a greater proportion of European demand will be met from recycled aluminium.

Aluminium is by definition circular. It is a permanent material, one that keeps its original properties irrespective of how many times it is processed and used²⁰.

a. Building the circular economy of the future

Among other uses, aluminium components make buildings more energy-efficient, while aluminium packaging keeps food and drink fresh. When these products reach the end of their life cycle, be it after sixty days (in the case of beverage cans) or after several decades (in buildings), the material can be easily recycled and give life to a new product. Given those qualities, 75 percent of all aluminium ever produced remains in use today.

Europe is already the world's greatest per-capita recycler. Over half of all the aluminium currently produced in the European Union originates from recycled aluminium put on the market by refiners and remelters, a trend that is on the increase. Yet there is more that can be done to build the circular economy of the future.

The goal for Europe must be to increase the aluminium recycling rates wherever it can. This requires innovation in the collecting and sorting of used aluminium, to ensure that every last piece of metal is recovered. It also means ensuring that valuable aluminium scrap remains available for European recyclers, serving as a perpetual resource for Europe's business community.

²⁰ <https://european-aluminium.eu/media/1644/recycled-content-vs-end-of-life-recycling-rate-may-2016.pdf>



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Recycling and its benefits

Aluminium is durable and endlessly recyclable without losing its properties:
75 percent of all aluminium ever produced remains in use today.

Increasing recycling contributes to reducing Europe's energy consumption and greenhouse gas emissions. **Recycling aluminium saves 95 percent of the energy required and the GHG emitted for the primary production.**

Europe enjoys high end-of-life aluminium recycling rates: **over 90 percent in the construction and automotive sectors and 60 percent in the packaging sector.**

A SME-driven industry

One of the most important characteristics of the recycling sector is the entrepreneurial nature of the businesses within it. Economic growth is driven by ambitious and imaginative SMEs and family-owned businesses building their companies and employing increasing numbers of people. These engines of prosperity make up the majority of aluminium recyclers. They are found all across Europe, frequently in companies which are the heartbeat of their local communities.

Europe's recycling rates are high. Some 90 percent of the aluminium used in the construction and automotive sectors, with about 60 percent of that used in packaging being recycled. Despite this impressive record, the amount of aluminium collected and sorted needs to be increased. Growing demand for scrap makes it challenging for the European industry to access this valuable raw material.

The Aluminium Effect

In Europe aluminium enjoys high recycling rates:

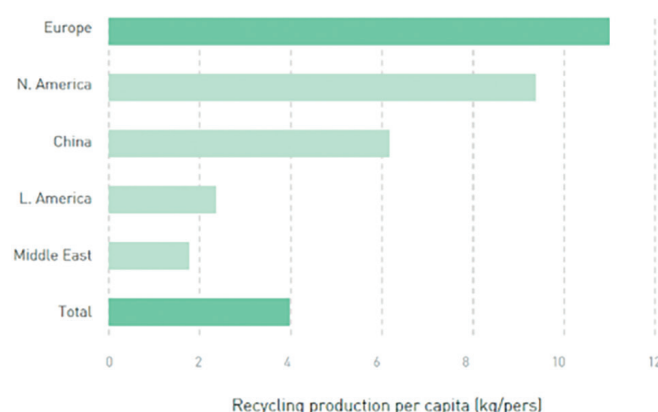


Packaging



Construction and automotive

Europe is number 1 in recycling



Source: European Aluminium, 2015

This chart shows the community of interdependent businesses that have carved out technical specialisations throughout the recycling value chain. From the skimmings that result from primary production, all the way through to products at the end of their life, specialist skills and dedicated operations optimise Europe's yield of recycled aluminium. Refiners and remelters are producing new material for manufacturers and finishers such as foundries, rolling mills and extruders.

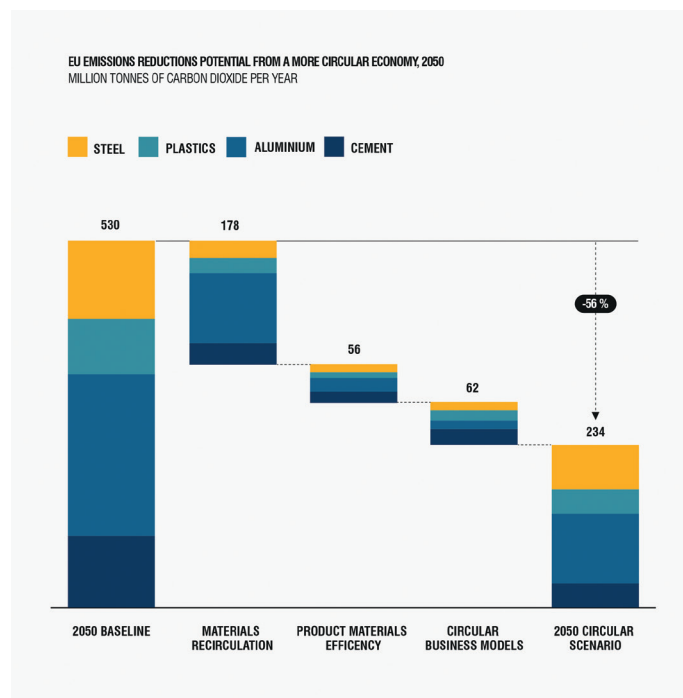


Source: "The Recycling Process", European Aluminium 2015

Material Economics study proves the enormous opportunities of aluminium

An external study by Material Economics²¹ shows that opportunities for more productive use of materials has a role to play in the overall decarbonisation challenge, through reducing emission and energy savings. According to the optimistic recycling scenario of the study, 50 percent of the demand could be covered by recycling. This is what we discovered in one of our projected scenarios (see previous chapter).

In addition, additional benefits may arise from increased product materials efficiency and new circular business models.



Source: Material Economics 2018

²¹ The Circular Economy: A powerful force for climate mitigation by Material Economics 2018



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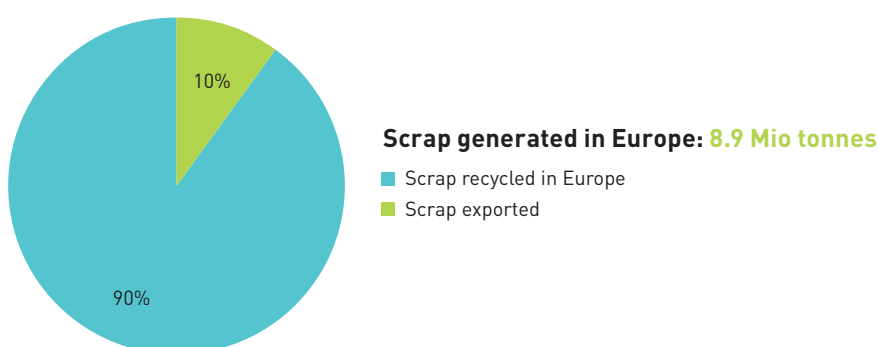
What makes a permanent material like aluminium perfectly suited to a circular economy?

While the Circular Economy package proposed by the European Commission is a clear step towards a true resource-efficient and circular economy, European Aluminium believes this can be further stimulated by introducing an additional focus on materials. Aluminium can claim to be a permanent material, one for which the inherent properties do not change during use and following repeated recycling into new products. It is essential to make a clear distinction between recycling that leads to the gradual degradation of the material and recycling that keeps the material in the loop without losing its intrinsic material characteristics.

b. The importance of scrap collection

While the term 'scrap' can imply something of little value, to aluminium recyclers it is the exact opposite. It represents the vital raw material of their thriving and growing industry. The scrap value of used aluminium is normally high enough to compensate for the investments made in modern waste collection and sorting equipment.

Scrap comes from two sources. First, there is the metal harvested during either the primary aluminium production or at any of the processes leading to final fabrication. Second, there is the scrap recovered from products containing aluminium that have reached the end of their service life.



Source: European Aluminium 2017 data

While this is an encouraging picture, issues become more challenging once products are either discarded or reach the end of their lifecycle. This aspect of the yield is highly-dependent on initial product design concepts that embed recycling principles for end-of-life. Yet it also relies on initiatives to collect aluminium for recycling. This means that citizens, industry, municipal and national authorities all play a part in efficient and innovative collection systems.

For example, local schemes to collect used beverage cans play an important role. By releasing the high scrap value of aluminium, they can generate substantial income for municipalities, waste management companies and even individual collectors.



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What is the difference between post- and pre-consumer scrap?

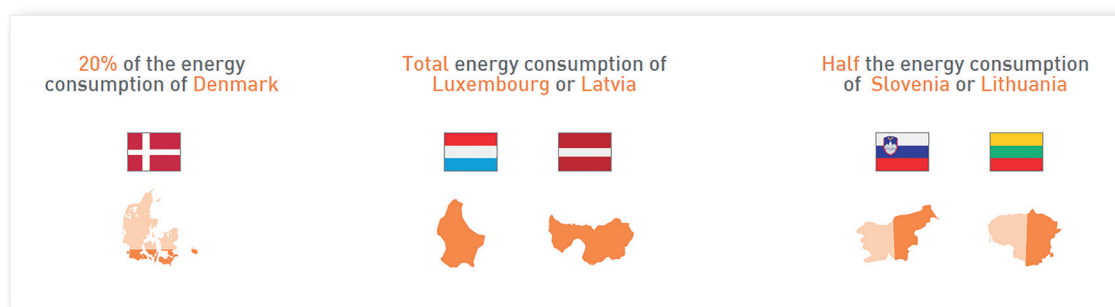
Post-consumer scrap is what we commonly associate with used aluminium, such as beverage cans, old cars or broken window frames. This type of scrap has to be collected and sorted before it can be recycled.

Pre-consumer scrap arises during the manufacturing process. This can be the end of a rolled product or clippings that were produced in a factory. This type of scrap returns directly to the recycling plant, where it is remelted.

The challenge of aluminium scrap exports and its embedded energy

Since 2002, the European Union has been a net exporter of aluminium scrap. In 2017, around 900 thousand tonnes of scrap were exported. About 80 percent of these exports go to Asia (mainly China, India and Pakistan).

To provide a sense of scale, the energy contained in the exported scrap is approximately equivalent to²²:



Source: European Aluminium, European Environmental Agency

Moreover, domestic recycling of all the aluminium scrap currently exported would allow recycled production in Europe to increase by about 20 percent over current levels. This would reduce Europe's dependency on imports, lowering the current volume of primary imports in Europe by about 24 percent. Based on current sourcing of European imports of primary from third countries, this would also avoid import of about 9 million tonnes of CO₂ equivalent per year. It means that exported EU waste to non-EU countries has a negative impact on competitiveness of the European aluminium industry, due to the shortage of scrap availability, an increased dependency on raw materials and higher operation costs.

To prevent this phenomenon, a mandatory EU certification scheme should be created where third-party verification should apply. This would lead to effective compliance with current EU environmental standards, fairer competition rules with third countries and greater control over scrap exports. In addition, this would help secure EHS standards and shape equivalent conditions vis-a-vis third countries.

²² The "gross inland energy consumption" of Slovenia is about 6.8 Million tonnes of oil equivalent (Mtoe) _

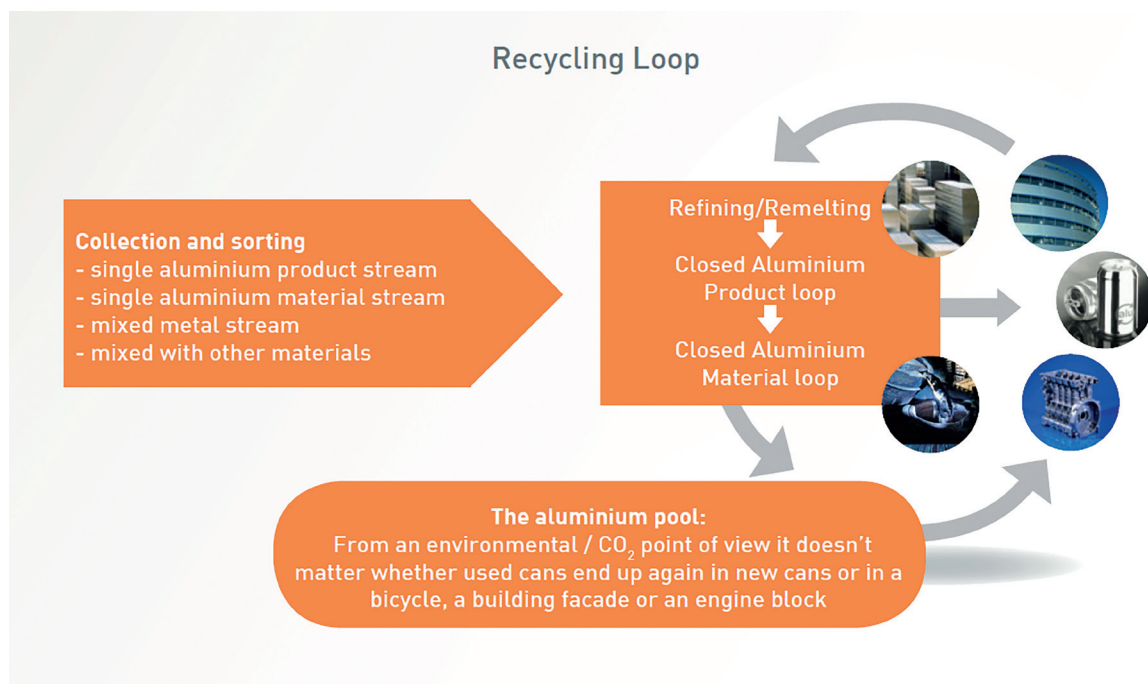
Source: European Environmental Agency, 2016 data

The total energy embedded in the aluminium scrap (from bauxite mining to primary ingot) exported outside EU is about 3.2 Mtoe _ Source: European Aluminium Environmental Profile Report.

c. Sorting and treatment: The recycling loop

Once scrap has been collected, the process of preparing it for recycling can begin. Scrap is treated according to its origin or previous use, a highly technical part of the process. The versatility of aluminium means there are a vast array of different applications, each with its own physical properties and alloys that demand specific treatment. Whether a window frame, the engine block of a car or an electrical component, it needs to be processed into its various constituent parts so that the aluminium elements can be separated.

The core properties of aluminium are preserved through infinite cycles of use. It can be recycled ready for fabrication, either into the same product as before without any loss of quality ('closed aluminium product loop') or into something completely new.



Source: European Aluminium 2015

d. Policy recommendations: The need to increase scrap availability and further innovation on collection and treatment of scrap

Europe's recycling industry is the world leader. With lucrative export markets available to businesses that collect and treat scrap, this leadership is now under pressure. The current picture is clear; with exports of aluminium scrap increasing, there is a pressing need to safeguard scrap availability within Europe.

If the industry had access to all the aluminium scrap in the EU, recycling within Europe could be about 20 percent higher than current levels. In addition, when scrap is exported from Europe, the energy locked within the material is also exported. At a time when energy security is a concern, the aluminium recycling industry's efficient use of power should not be overlooked.

Safeguarding scrap availability within EU will both further enhance the potential for greater recycling and foster a European circular economy that retains as much of its precious resources as possible. Furthermore, there is a lack of a level playing field for EHS standards, which undermines European industry's competitiveness and circularity of the metal and thus increases Europe's dependency on imports. The current waste legislation outlines EHS standards to be broadly equivalent to non-EU standards for aluminium scrap exports. Such rules are insufficiently clear when it comes to national level implementation; Member States adopt diverging approaches to validating these so called 'broadly equivalent' conditions. A mandatory EU scheme would represent the best option to secure implementation of those rules.

An improved alignment on the interpretation of waste codes and classification system (hazardous/non-hazardous waste) between Member States and the international community should be undertaken to ensure the continuing viability of business operations.

Research and development, which is both expensive and complex, is beyond the reach of many smaller businesses in the sector, a reality made more acute by a competitive marketplace and tight margins. Effective partnerships, supported by EU financial assistance, could open the pathway to ever-more effective techniques that ensure that as much quality scrap as possible is used in increasingly cost- and energy-efficient ways. New technologies, such as x-ray, sensor-based, laser/induced and artificial intelligence robot sorting should be explored and supported financially to improve collecting and sorting of the smallest particles.

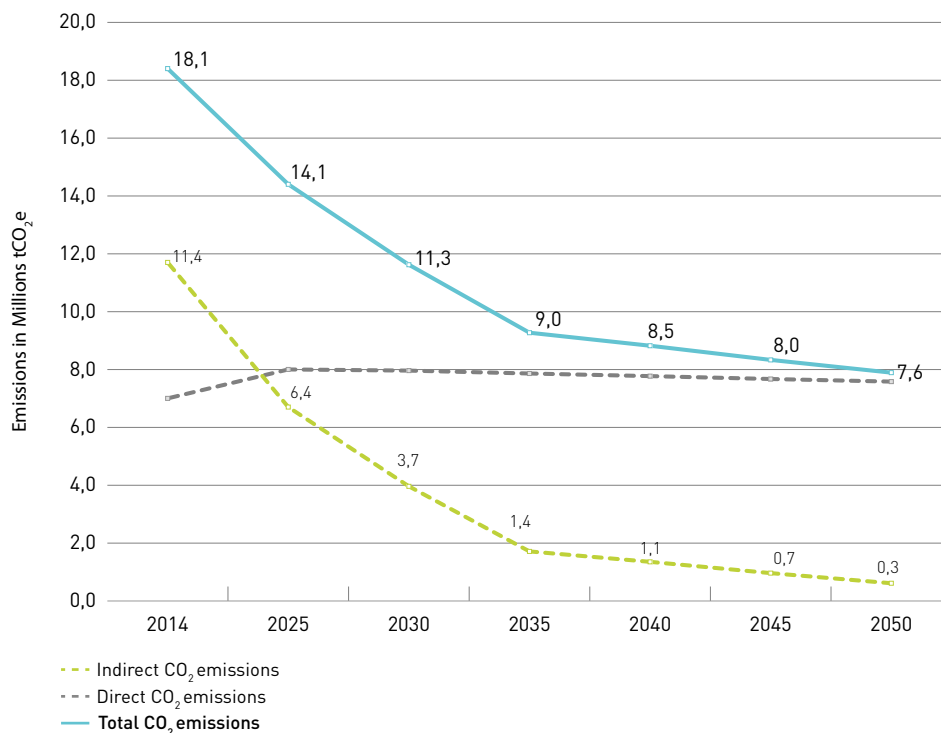
Creating this virtuous circle will require multilevel cooperation, particularly at EU and Member States levels.

DECARBONISATION THROUGH GREENING OF EUROPEAN POWER MIX AND EFFICIENCY TECHNOLOGY

a. Decarbonisation of EU and EFTA power mix by 2050

According to the PwC projections undertaken for this study (see chart below), decarbonisation of the power sector will drive a major decrease in total CO₂ emissions from primary aluminium smelting in EU and EFTA countries.

Direct, indirect and total CO₂ emissions evolution 2014-2050 from primary aluminium smelting in EU28+EFTA



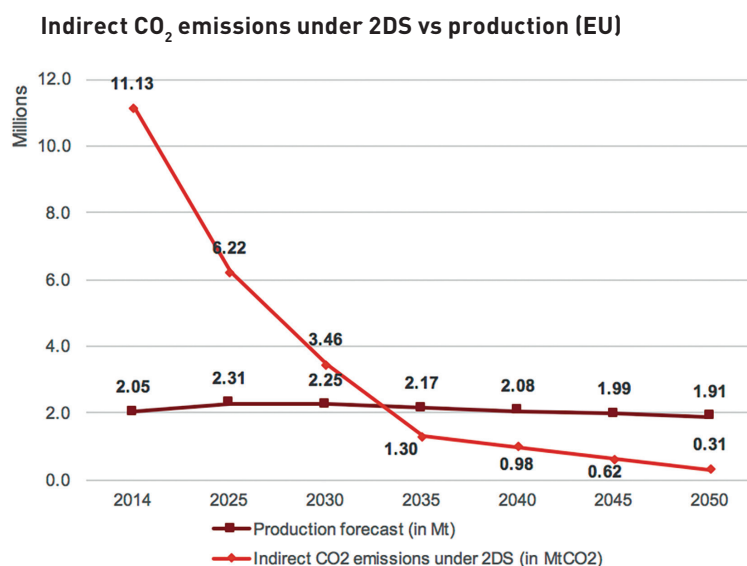
Source: PwC data 2018. Graph developed by European Aluminium, based on primary smelting process

More precisely, decarbonisation of the power sector will **see total CO₂e emissions for primary aluminium smelting in the EU and EFTA fall by 58 percent by 2050** from 2014 levels (blue curve). This should reduce the carbon intensity of primary aluminium smelting from **4.46 tCO₂e per tonne of primary aluminium in 2014 to 1.73 tCO₂e in 2050²³**.

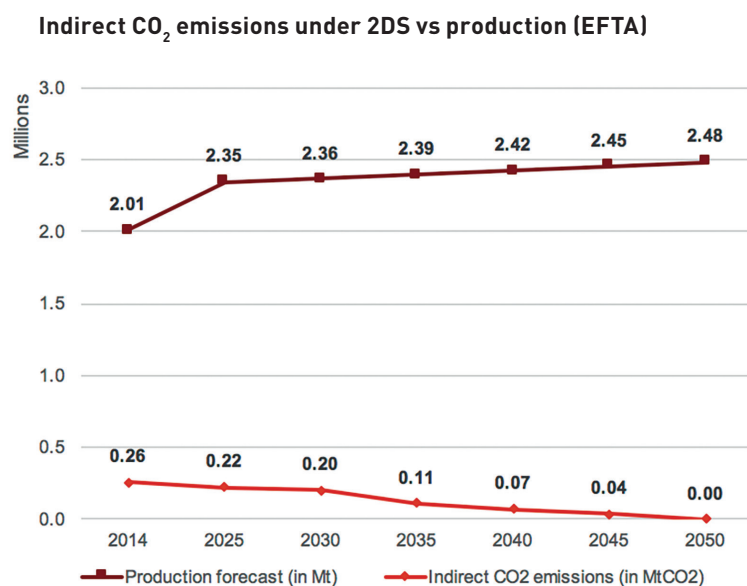
²³ This model is based on the IEA's 2DS scenario for indirect CO₂ emissions and constant 2014 carbon intensity for direct emissions which is very conservative compared to the data collected in the last 20 years.

The main driver will be the decrease in **indirect CO₂ emissions in the primary aluminium smelting sector by 97 percent by 2050 compared to 2014**. This will reduce carbon intensity for primary aluminium smelting of 2.73 tCO₂ per tonne of primary aluminium produced²⁴.

As expected, separate projections for EU and EFTA show critical reductions in indirect CO₂ emissions in the EU's power sector, as EFTA's power market has already been largely decarbonised. The following chart illustrates the different trajectories.



Source: PwC Data 2018 (based on primary smelting process)



Source: PwC Data 2018 (based on primary smelting process)

²⁴ These charts assume IEA's 2DS scenario for indirect CO₂ emissions and production forecasts by business analysts CRU Group.



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Why does decarbonising the grid not automatically reduce CO₂-related costs for smelters?

Although decarbonising the grid will reduce indirect CO₂ emissions from European smelters, the costs linked to these emissions will not decrease at the same pace. Power markets use marginal cost-based price discovery, where the price of all the demand is set by the bid of the last producer needed in the merit order²⁵. This last producer is usually offering at least at fossil fuel running costs (i.e. coal or gas). Decarbonising the electricity system will reduce the indirect CO₂ impact on the electricity price. However, even when meeting the new target of at least 32 percent of EU's final energy consumption from renewable sources by 2030, such indirect CO₂ impact will still be meaningful. This is because there will still be a significant number of hours per day where fossil fuels are needed in the merit order.

In 2016, a leading external energy consultancy²⁶ assessed the potential impact of the regulatory changes to the European Emission Trading System Phase IV (2021-2030) on the power purchasing costs for electro-intensive industries (including aluminium), post-2020. This suggests that in the period 2021-2030, these industries will require the equivalent of approximately 2300 million allowances to be fully compensated for indirect carbon emissions costs up to the level of the current EU ETS benchmark. This study confirms the massive impact of power prices on electro-intensive industries, such as aluminium smelting, in a decarbonised future and the critical role of compensation for indirect carbon costs in the upcoming decades.

b. The increasing support of PPAs by the aluminium industry in Europe and the importance of regulation

Currently, the private sector consumes around half of Europe's electricity. Powering corporate consumers with long-term electricity sourcing helps support greater investment in renewable energy sources. Overall, the volume of corporate wind PPAs almost trebled in Europe during 2017, with over 1.3 GW of capacity contracted. European Aluminium members are becoming key industrial contributors to PPAs, enhancing the production of renewables in Europe.

With primary aluminium production an unavoidably electro-intensive process, electricity costs are a key consideration for the sector. Indeed, power represents between 30-40 percent of the overall operational costs of the sector's installations, with energy costs being major factors for investment and location.

Long-term renewable PPAs appeal to European Aluminium's producers, as the industry needs a long-term horizon for investment and an incentive to diversify the risk of volatility by achieving competitive and predictable power costs. Irrespective of the source, these long-term PPAs have been part of the industry strategy for decades, as investors and financial institutions alike seek to diversify market/price risk long term (i.e. 20 years).

²⁵ For every predefined period, the generation bids are aggregated to one supply curve ranked according to increasing price.

²⁶ Ecofys study published in 2016: Impact of a "hybrid" compensation approach:
<https://www.ecofys.com/en/publications/indirect-carbon-emissions-impact-of-a-hybrid-compensation-approach/>

There are two important factors when considering long term PPAs; sourcing new capacity and upgrading capacity or maintenance projects that increase lifetime of operations:

1. Managing the costs and risks of switching to a consumption profile:

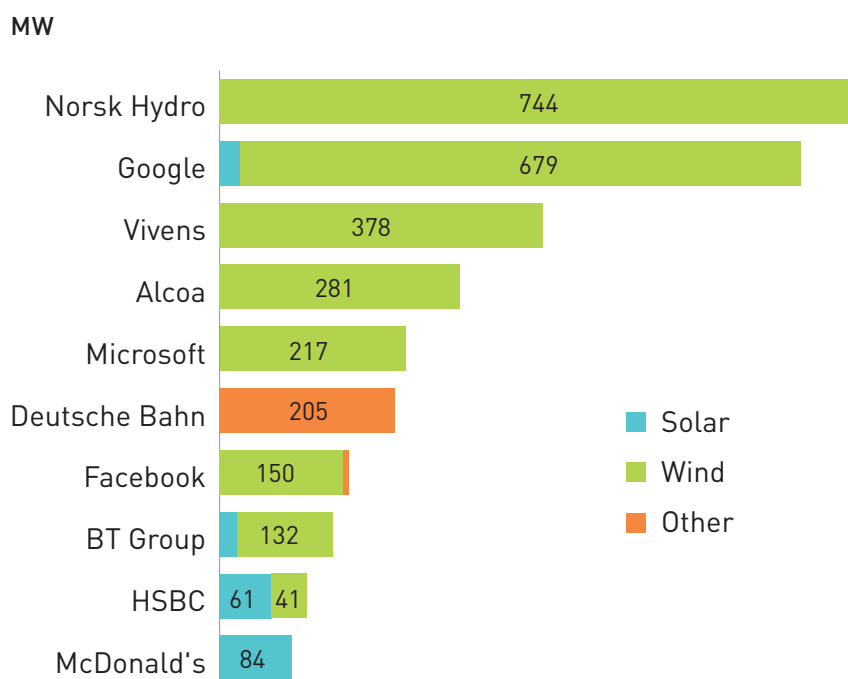
In the case of wind and solar projects, there needs to be a switch from a production to a consumption profile to match the industry's base load profile to the production profiles. The competence for this is available to the companies or in the electricity market; yet the cost and risk when entering into long-term balancing agreements can vary substantially between regions.

2. Accessing financing/guarantees:

Guarantees are also an important element for long-term renewable PPAs. It is often a prerequisite that credit support is provided by investment-grade entities throughout the contract tenor. These can be available in the financial markets in Europe, although for some industrial companies, such long-term credit support could present a barrier to adoption.

As with the main regulatory framework, the main obstacles for the primary aluminium industry to enter into a long-term PPA are uncertainties over regulatory costs. The smelter needs a corresponding long-term horizon to sufficiently safeguard it from regulatory cost exposure. Another obstacle is the lack of access (in certain countries and regions) to large-scale wind parks or hydropower production, capable of serving an aluminium smelter's electricity needs. Understandably, a smelter's carbon footprint is largely dependent on its access to carbon-free electricity. This obstacle is expected to diminish in future (post-2030), as new renewable energy schemes are developed in Europe.

A 2017 report by RE-Source, the European platform for corporate renewable energy sourcing, shows leading aluminium companies entering into renewable PPAs along with other leading brands, industries and services.



Top EMEA corporate buyers - 2017 PPAs by RE-Source (European Platform for corporate renewable energy sourcing)
Norsk Hydro and Alcoa are aluminium companies and members of European Aluminium

c. Existing technologies and enabling conditions

Karmøy Technology Plant: Pushing the borders of primary aluminium efficiency

During the last decade, researchers in Hydro's technology centres in Årdal, Porsgrunn and Neuss have developed a new generation of electrolysis technology. This aims to reduce both industry energy consumption and emissions; it is now being tested in a full-scale production plant.

The pilot was designed with an annual production capacity of approximately 75,000 tonnes. It consists of 48 cells running on the HAL4e technology (12.3 kWh/kg) and 12 cells using the HAL4e Ultra technology (11.5-11.8 kWh/kg). Total costs are estimated at €442 million, consisting of net project costs of €277 million and around €164 million in support from Norwegian government enterprise Enova²⁷.

The pilot consists of physical technology elements and an improved process control system. Several of these elements are capable of being tailored for, and used in, Hydro's existing aluminium plants. This makes the technology an advance not only for Karmøy but for all primary aluminium plants.

This **Hydro-developed technology will use 15 percent less energy for aluminium production than the global average**, providing the lowest CO₂ footprint in the world.

The pilot aims to set a new benchmark for emissions, reducing **direct CO₂ emissions to 1.40-1.45kg CO₂ equivalents per kg** aluminium, a new world low for existing technology. This new technology will mean that direct CO₂ emissions are 0.8kg per kilo of aluminium below the current world average.



Source: Hydro

²⁷ Enova SF is owned by the Norwegian Ministry of Climate and Environment and contributes to reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply. Find more information here: <https://www.enova.no/about-enova/>

The 'Virtual Battery': Flexible energy use for a reliable and stable power supply

As previously explained, primary aluminium production is a highly energy-intensive process. The massive demand offers a systemic opportunity for energy grids. TRIMET Aluminium allows one of its pot-rooms in its Essen plant to operate as an energy storage or 'virtual battery'. Its output can vary by +/- 25 percent, based on a nominal load of 90 MW, providing a virtual storage capacity of approximately 2,100 megawatt hours (MWh). This is comparable to a medium-sized pumped-storage power plant. By balancing grid fluctuations, this power-storing capability allows sporadically-produced renewable energy, including wind and solar energy, to be fed into the German power grid.

To ensure flexible control of its electrolysis cells, TRIMET Aluminium has developed a process technology that maintains a constant energy balance within the cell, even with a fluctuating energy supply. A major challenge is to sustain continuous and efficient production under these conditions, thus avoiding any interruptions in the smelting process and ensuring that delivery obligations are met. As part of this process, each aluminium electrolysis cell contains ten tonnes of liquid aluminium. Depending on the increase or decrease in production, the level of liquid can be adjusted to ensure that production fluctuations do not interfere with the continuous processing.

This new technique has huge potential. Fully implemented, the three TRIMET smelters in Germany (located in North Rhine-Westphalia and Hamburg) could increase the country's pumped storage capacity - currently 40 gigawatt hours (GWh) - by nearly 40 percent. The family-run business is investing around €36 million into this 'showcase' pilot plant. Further investments into such technology however are only justifiable, when it can become a profitable business case. This will require a stable and predictable energy-political framework, ensuring sustainable and internationally competitive power supply for aluminium smelting in Europe.



Source: Trimet. Dr Roman Düssel (Head of electrolysis plant) and Heribert Hauck (Energy Affairs) explaining the 'Virtual Battery' to Professor Pinkwart, Minister of Economic Affairs in Nordrhein-Westfalen (Germany).

c. Enabling conditions: Commonalities and insights from successful incremental projects

Further incremental primary production-related technology projects will depend on several factors. In particular, regulation plays a fundamental role in creating the right conditions to drive technology development. One element is securing a stable and predictable framework for current industrial production in Europe. Innovation, research and technology progress are interlinked and rely on stable production as the basis for new research developments. Another element is adequate regulatory frameworks to drive technology and innovation through funding and risk-sharing.

An internal survey of aluminium experts and leading companies identified four core pillars, falling into two categories:

A framework to ensure industrial production and investments in Europe:

1. Regulatory stability and predictability for long-term power sourcing for all smelters.

An EU electricity market design that ensures well-functioning markets as well as related incentives from the regional power markets. Both have an enormous impact on the capacity of the primary industry to invest in new technologies.

2. Specific EU regulation affecting power costs for industry, specifically Environmental and Energy State Aid Guidelines (EEAG) and national regimes for indirect carbon costs compensation (i.e. ETS and State aid guidelines). This could decisively impact - positively or negatively - new, incremental technology plans and pilots; it is the single most-sensitive EU and national policy area interlinking energy, climate and innovation.

From an aluminium producer's perspective, there are four fundamental policy-related factors to be considered for any type of investment:

a. Guidelines on State Aid on compensation for indirect costs of the EU ETS (post-2020):

For primary aluminium production, the indirect costs of the EU ETS are seven times greater than the direct costs. With the price of EU Allowance Units (EUAs) expected to rise significantly between 2021-2030, it is imperative that industry can access an adequate compensation system for the indirect costs of the EU ETS in Phase IV. With the exception of any contract entering into force prior to the implementation of EU ETS in 2005, any power sold has the relevant indirect CO₂ pass through in its price. This is regardless of if and how it is hedged - exchange forwards, over-the-counter bilateral contracts, longer-term renewable PPAs or any other risk-management instrument.

b. Guidelines on State aid for environmental protection and energy (post-2020):

Producers need to know whether the exemption from renewable energy surcharges will continue post-2020, and if so, to what extent.

c. Actual compensation occurring:

Once the above guidelines permit a competitive framework, the sector needs certainty that the compensations will actually be fulfilled throughout most of the PPA's tenor.

d. Electricity system costs:

Any cost increases in the electricity system stemming from the grid and balancing also need to be considered.

Framework aiming to drive technology development:

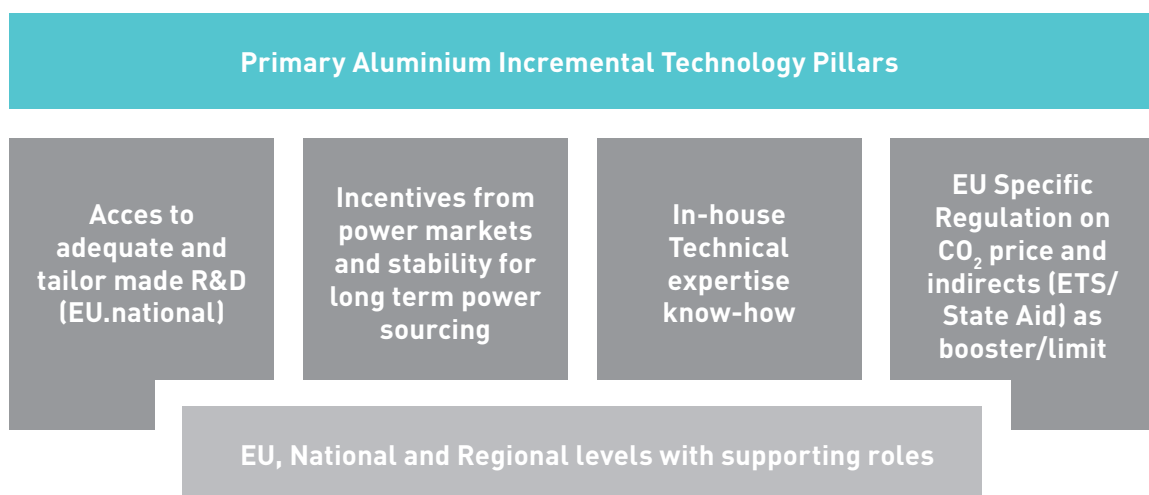
3. Access to adequate and adaptable national and/or European funding with tailor-made R&D funds. Risk capital sharing with multiple actors (i.e. private or public funds or agencies) would encourage new incremental projects in the smelting business.

4. In-house technical expertise and innovation know-how.

This is a 'must-have' for exploring and implementing technological advances. A lack of adequate highly-skilled labour poses a potential challenge for some companies when stepping up to new projects.

In addition, the experts agreed that incremental technology projects require government support at multiple levels. The notion that one, or even several, EU fund can address the entire financial demands of deploying new technologies does not bear scrutiny. In fact, national and regional governmental levels should work together to provide crucial support in several areas; financing, regulating and securing proper implementation of new incremental technology.

In addition, some companies confirmed the importance of working closely with specialised institutes and academia when planning and designing technology projects. Partnerships were also important, but not critical, for all projects assessed.



OPTIONS AND CHALLENGES FOR DIRECT EMISSIONS REDUCTION

Introduction: The quest for the technology gamechanger

Primary aluminium smelting consumes more energy than recycling, with electricity consumption constituting roughly one-third of production costs. It also emits more direct CO₂ than recycling, since about 1.6 to 1.8 kg of CO₂-equivalent is emitted per kg of aluminium for smelting compared to around 0.5 kg for recycling. Such direct CO₂ emissions from smelters is mostly related to the carbon anode consumption during the electrolysis.

Inert anode²⁸ technology represents one of the potential future options for the industry to reduce drastically direct emissions from the smelting process. With current carbon anodes, the reaction frees the oxygen present in the alumina, which immediately reacts with the anode to form CO₂. This process consumes over 400 kg of carbon anode per tonne of aluminium. However, inert anodes avoid CO₂ formation, instead generating pure oxygen as a by-product. The feasibility of this technology depends on a number of factors, many of which are R&D-related. Some of the main challenges include anode material selection and combining inert anodes with advanced electrolytic cell design.

Smelter technologies could also reduce direct CO₂ emissions by continuing to use carbon anode technology but deploying 'smart carbon sourcing and use', based on renewable bio-based carbon sourcing for their anode production. Alternatively, they could use CCU technologies, which would mitigate emissions by using it as carbon-based feedstock. Ultimately, CCS could also play a role in this quest for carbon-free smelting technologies.

In conclusion, reducing direct emissions will depend greatly on the ability of the industry to:

1. Optimise production process efficiency (i.e. Karmøy technology plant),
2. Capture the CO₂ emissions from the production process (i.e. CCU or CCS technology), and/or;
3. Replace carbon anodes with low-carbon anode technologies (see the technology chart mapping below²⁹).

This chapter explores the different options and policies, with the aim of pursuing the highest potential for sustainable aluminium production in Europe.

²⁸ An inert anode can be defined as a 'non consumable' anode. The technology is not yet at commercial stage.

²⁹ 1) Energy efficiency projects, 2) Karmøy Technology Pilot Plant, 3) CCS & CCU Technology, 4) Inert anodes

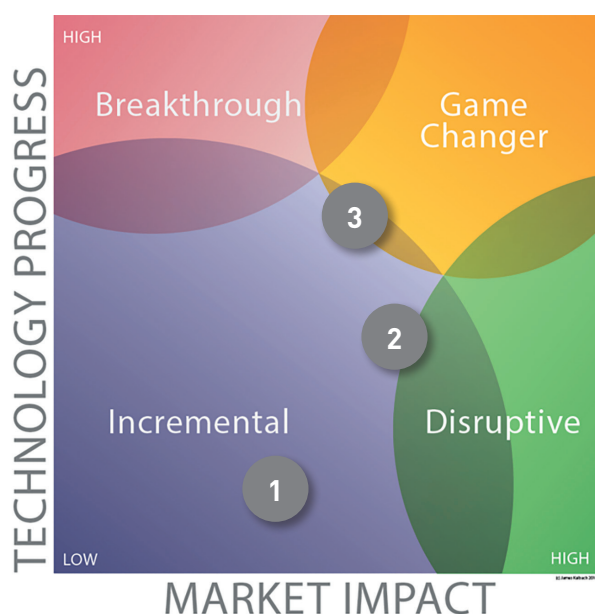


ZOOM IN

Carbon anodes and technology in Europe

Carbon anodes are the second main raw material needed for producing primary aluminium. In Europe (EU+EFTA), approximately 95 percent of primary aluminium production based on an electrolytic process relies on pre-baked carbon anodes, while the remainder is based on the so-called Söderberg process.

The main difference between the two technologies lies in how the anode is produced. In the pre-baked process technologies, the so-called green anodes - a mixture of hard-calcined petroleum coke, recycled anode butts and coal tar pitch - are baked in gas-fired ovens at 1150°C and then transferred to the cell. This is usually undertaken in an on-site anode plant, although some smelters procure carbon anodes externally. In Söderberg technologies, the mixture is baked directly in the cell by adding it to the top of the anode.



Technology Chart Mapping. Source: European Aluminium, 2018.

a. The case of Elysis: a recent multi-stakeholder joint venture in Canada

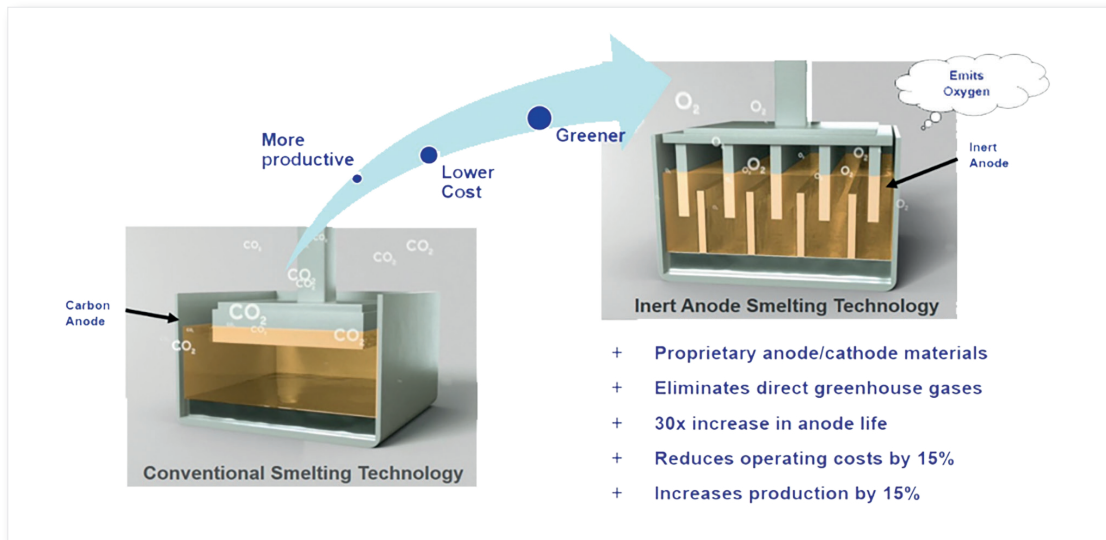
Elysis is a multi-stakeholder JV (joint venture) created by two of the world's leading aluminium companies (Rio Tinto and Alcoa) together with Investissement Quebec, which is supported by Apple Inc. and the governments³⁰ of Quebec and Canada. The final aim of the JV is to enter the commercialisation of inert anode smelter technology by 2024.

This new technology can potentially replace traditional carbon anodes with inert anodes made from proprietary materials. It is the result of more than 20 years intensive research on inert anodes made by both companies.

³⁰ Read Official Website of Canadian Prime Minister: [“Alcoa and Rio Tinto announce world’s first carbon-free aluminum smelting process”](#)

According to the JV, the main benefits of the new inert anode smelter technology would relate to eliminating direct GHG emissions linked to the electrolysis process, a massive increase of the anode life, a reduction of operating cost by 15 percent and a production increase of 15 percent (see chart below).

A breakthrough aluminium smelting technology



Source: Elysis 2018

Political and financial support from governments and customers

The financial and political support from different levels of governments and consumer brand were both essential for the creation of the joint venture (JV). The governments of Canada and Quebec have made it a clear priority to invest in innovative new technology that will provide jobs, economic growth and reduce the country's overall carbon footprint.

"Today's announcement will create and maintain thousands of jobs for Canadians, significantly reduce Canada's carbon footprint, and further strengthen the aluminum industry in North America. It is a truly historic day for the aluminum industry - and for all Canadian aluminum workers - who play such an important role in our economy and our country's future"

Justin Trudeau
Prime Minister of Canada



ZOOM IN

How do we create capital-intensive breakthrough projects in Europe?

The smelting process is not new; although the current technology has evolved over time. While there have been enormous advances in efficiency in recent years - an area that will remain a focus for R&D projects - gamechangers such as inert anodes have become a challenging mission for researchers.

- **Political support is required:** Aluminium will increasingly become a strategic and preferred material for low-carbon applications. Aluminium industrial clusters in Europe need strategic plans and specific policy actions. The value chain perspective should be the starting point.
- **Long-term European and national energy and climate policies should take a longer perspective:** A ten-year framework investment is too short for breakthrough technologies in the smelting process.
- **Funding opportunities are too broad or uncoordinated:** R&D funding should have a long-term political direction. It needs to be structured and designed for EU, national and regional funding, in order to encourage tailor-made gamechanging technologies. Protecting intellectual property when applying for funds remains critical. Aluminium low-carbon smelting should become part of Europe's industrial strategy, accompanied with a clear funding programme and goals.
- **Government structures should encourage multi-stakeholder and flexible partnerships:** Investors, producers, consumers and public authorities should identify new platforms for cooperating on breakthrough technologies.
- **Current smelting capacity remains a must-have for new potential incremental and breakthrough technologies:** "No current production - no opportunity to innovate" should be a principle for designing innovative public policy in industrial processes such as smelting.
- **Highly-skilled labour is in short supply:** Support for new programmes for materials-focused experts in European universities, as well as new traineeships for students with industry, will play a crucial role in addressing this shortfall.

b. Carbon Capture Storage: A real opportunity for aluminium smelting?

The latest Joint Research Study (JRC) has confirmed that implementing Carbon Capture Storage on exhaust gases from electrolytic cells has gathered scarce attention in the literature³¹. However, while CCS has traditionally been considered as an innovative technology for aluminium production, so far it has not been a realistic option for European smelters. Few projects were planned, and all have subsequently been cancelled.

One of the main obstacles for the technology is technical. The JRC reports confirms this. "Due to the inherent features of the effluents produced by the primary aluminium smelters, current approaches for carbon capture cannot be applied in a straightforward way."³²

³¹ Energy Efficiency and GHG Emissions: Prospective Scenarios for the Aluminium Industry (2015) by Joint Research Centre, Triple E Consulting and TNO.

³² Energy Efficiency and GHG Emissions: Prospective Scenarios for the Aluminium Industry (2015) by Joint Research Centre, Triple E Consulting and TNO. (Page 42)

Moreover, CCS technology does not currently offer a solid business case and is unlikely to generate one for aluminium smelting alone within the coming decade.

The relatively low direct emissions of overall smelting processes compared to other energy-intensive sectors (e.g. steel and power generation) make the aluminium sector less favourable for pioneering CCS development.

In short, successful deploying CCS technology would also depend on a number of factors. These include massive and short-term public funding targeted for smelting, wider public acceptance, major investments in carbon capture in other energy-intensive industries and development of storage facilities and political support in numerous Member States for testing and running demonstrations projects.



ZOOM IN

What about Carbon Capture and Use?

As part of the “smart carbon sourcing and use” approach, Carbon Capture and Use (CCU) of CO₂ from smelters could be an alternative option to CCS, given development of a feasible capture technology. Provided that CCU offers a sufficient value chain and business case for the captured carbon, this could be a more viable economic solution than CCS.

As recently highlighted by a recent report published by the European Commission³³, such technology could contribute to mitigate CO₂ emissions. In such a scenario, the CO₂ is captured and then converted – e.g. by mineralisation or chemical reaction – into a carbon-based feedstock used for materials with a long life span wherever possible, thus storing the carbon in products.

c. A scenario for lower CO₂ direct emissions reductions

Introducing **incremental and breakthrough technology are both needed to** reduce direct emissions from the smelting process. This report sets out a theoretical model that includes a constant reduction of emissions through incremental technology and a conservative introduction of any technology mentioned before (i.e. CCU, CCS, inert anodes)

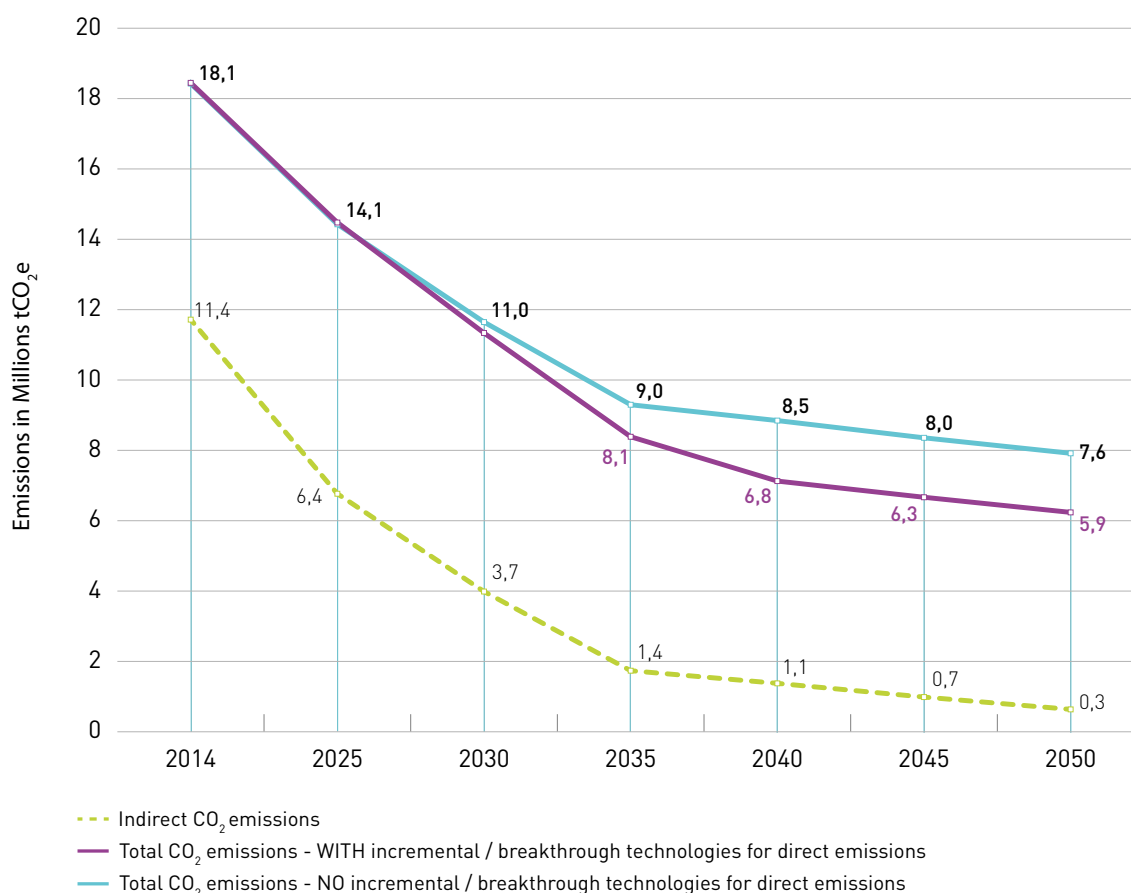
The exact timing and penetration of the different technologies is not yet known. In addition, the impact of building entirely new plants in Europe, or retrofitting the existing ones with incremental or breakthrough technologies, could alter the scenarios and consequent CO₂ emission trajectories. Therefore, the following assumptions remain highly sensitive to forecast scenarios for the next 30 years.

³³ Novel carbon capture and utilisation technologies' (CCU), Group of Chief Scientific Advisors, May 2018, ISBN 978-92-79-82006-9

In the following chart, European Aluminium has projected the potential of introduction of incremental and partial breakthrough options (violet line) assuming the following:

- **From 2030 to 2034:** approximately 4 percent of the European production (EU+EFTA) would avoid direct emissions;
- **From 2035 to 2039:** approximately 12 percent of the European production (EU+EFTA) would avoid direct emissions;
- **From 2040 to 2050:** approximately 23 percent of the European production (EU+EFTA) would avoid direct emissions.

Direct, indirect and total CO₂ emissions evolution 2014-2050 from primary aluminium smelting in EU28+EFTA - Mix of incremental and breakthrough technologies introduction as of 2030 (conservative scenario)



Source: PwC data 2018. Chart designed by European Aluminium 2018

The main findings can be summarised as:

- Total CO₂e emissions from primary aluminium in EU and EFTA falls by 67 percent by 2050 compared to 2014 figures. This includes a reduction of direct emissions by 17 percent and indirect carbon emissions by 97 percent.
- This results in a decrease of primary aluminium's carbon intensity from 4.46 tCO₂e in 2014 to 1.35 tCO₂e per tonne of primary aluminium in 2050.
- This model assumes the IEA's 2 degrees (2DS) scenario for indirect CO₂ emissions and a mix of incremental and breakthrough technologies, including increasing inert anode penetration from 2030, which partially eliminates smelters' direct CO₂ emissions (close to zero).

Aluminium to become a strategic industry of the EU

Well before the COP21 global agreement, European Aluminium embraced sustainability as one of the main drivers and core values of its entire mission. The Sustainability Roadmap 2025 that we launched in 2015 was not an aspirational document, but rather a concrete path that our 80+ members have committed to walking together. Common values, common goals and common knowledge, from small family-driven companies to multinationals, can only deliver significant changes if done together. With our Vision 2050, the core message is reinforced; sustainability is a one-way journey for our industry, with no U-turns.

This report shows that climate ambition goes hand-in-hand with the economic opportunity for Europe. Aluminium will continue to gain markets in the coming decades, as the increasing pressure for a low-carbon future will demand more-sustainable materials and more-responsible value chains. It is also about new environmental regulations intended to secure lower emissions and circular models. Whether in existing or new applications, aluminium – unlike few other materials – has the potential for growth in Europe and worldwide. The question remains over how the industry will respond to this growing demand. Will the European aluminium value chain become stronger in the next 10 years?

This report shows that there is every reason to believe that primary aluminium production and recycling can become stronger together. While both can meet the growing demand sustainably and promote economic circularity, primary aluminium will remain essential in helping this cluster-based industry become more resilient and competitive. Should crucial EU policies and legal framework fail to support European domestic production, the risk of importing higher-carbon primary aluminium will significantly increase, contradicting Europe's ambition to fight against climate change.

In this context of unique growth in demand, the expected decarbonisation of the power sector shows a substantial positive effect by reducing the overall emissions from the primary smelting process (indirect carbon emissions). As the report makes clear, total CO₂e emissions for primary aluminium smelting in the EU and EFTA will fall by 58 percent by 2050 compared to 2014. The trend in PPAs shows that our industry is constantly seeking solutions in the market. Incremental technology projects, such as Karmøy and Virtual Batteries, are only two examples of the natural instinct of this industry to become more efficient, cleaner and supportive of the entire electricity system.

This report also confirms that new technologies and breakthrough innovation will be essential for the industry. This route requires creativity from partners, adequate enabling policies and strong political support. Whichever new technology is embraced, predictable regulation and adequate policy frameworks for long-term investment will become essential. The conservative scenario explored in this report shows how applying new technology to the industry can make the difference in reducing direct emissions.

Policy makers should digest the data and proposals collected in this report and use them to define a long-term policy pathway. It is time to recognise aluminium as a strategic material and the aluminium industry as one that needs special consideration for the decarbonisation and competitiveness of the European Union.

ABOUT EUROPEAN ALUMINIUM

European Aluminium, founded in 1981 and based in Brussels, is the voice of the aluminium industry in Europe. We actively engage with decision makers and the wider stakeholder community to promote the outstanding properties of aluminium, secure growth and optimise the contribution our metal can make to meeting Europe's sustainability challenges. Through environmental and technical expertise, economic and statistical analysis, scientific research, education and sharing of best practices, public affairs and communication activities, European Aluminium promotes the use of aluminium as a material with permanent properties that is part of the solution to achieving sustainable goals, while maintaining and improving the image of the industry, of the material and of its applications among their stakeholders. Our 80+ members include primary aluminium producers; downstream manufacturers of extruded, rolled and cast aluminium; producers of recycled aluminium and national aluminium associations are representing more than 600 plants in 30 European countries. Aluminium products are used in a wide range of markets, including automotive, transport, high-tech engineering, building, construction and packaging.

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