Aluminium

The world's consumption of aluminium drives around 1% of global emissions. New consumption-based approaches are required to help ensure an anticipated quadrupling in consumption by 2050 is compatible with tackling climate change.

Key facts

- **Large global flows in embodied emissions**
  The production of aluminium is an energy intensive process, responsible for around 1% of global GHG emissions. Over 50% of these emissions are embodied in aluminium traded internationally, either as commodity aluminium (28% of total emissions) or incorporated in final goods (24%). Developed countries are the major net importers of emissions embodied in aluminium.

- **Costs and carbon intensity vary by region**
  Aluminium production costs vary significantly between regions, with current carbon pricing having little effect on relative cost rankings. At the same time, the carbon intensity of aluminium production varies widely, from around 1tCO_2/ t for recyclate, to 3tCO_2/ t for best available technology smelters using hydro-powered electricity, and up to 20tCO_2/t for less modern technology powered by coal-based electricity.

- **The UK and EU aluminium sectors**
  Overseas emissions resulting from demand for aluminium in the UK are around three times higher than domestic UK aluminium production emissions, while only 35% of the aluminium consumed in Europe is actually produced within the EU ETS zone. Emissions embodied in EU aluminium consumption are expected to grow through to 2020, despite the positive effects of the EU ETS.

- **Significant, and growing, global emissions**
  To achieve a forecasted quadrupling of global aluminium consumption by 2050, whilst meeting climate change targets, the industry must deliver significant decarbonisation. Short term options to increase recycle rates exist, while medium term options are available to reduce the carbon intensity of aluminium production by around 90% using a range of radical new technologies.

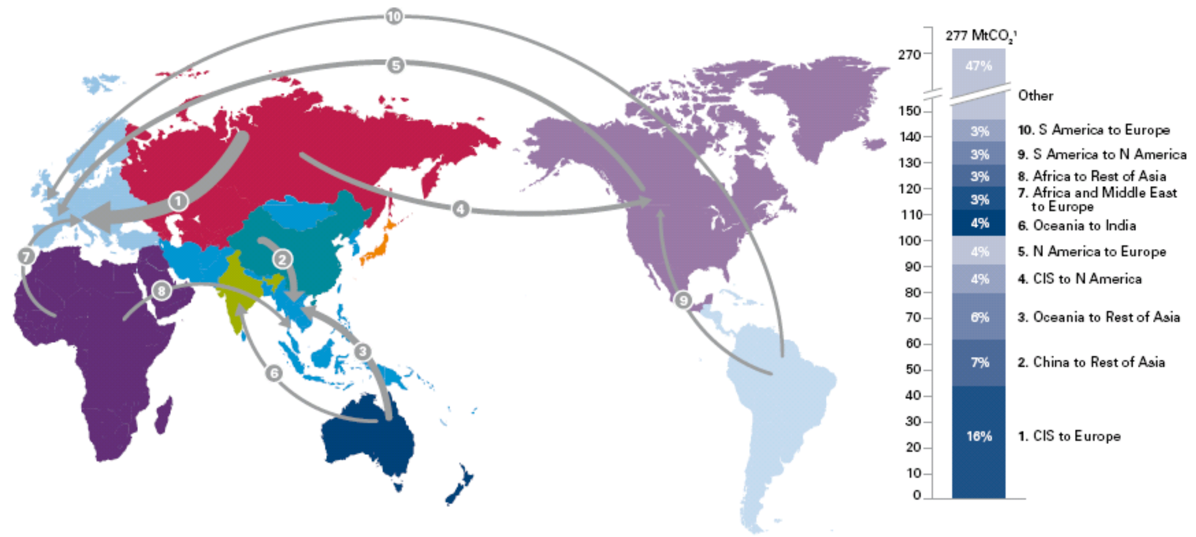
Implications for business

- **Producers of aluminium**
  The aluminium sector will increasingly be exposed to policies that seek to impose a cost of carbon on production emissions, through the development of new pricing mechanisms over time. As a result, producers should continue to invest in the Research, Development & Demonstration that will deliver, over the long term, the technologies that will meet global long-term climate change objectives. This includes wetted drained cathodes, inert anodes, and more speculatively, alternatives to electrolysis such as carbothermic reduction. To support these changes, aluminium producers should seek to work together to develop more collaborative RD&D programmes, especially for high-risk demonstration projects. Collaboration with government may further accelerate RD&D activities and innovation.

- **Consumers of aluminium**
  Consumers of commodity aluminium can drive action through practicing 'green demand' (i.e. purchasing lower carbon intensity aluminium) as a way of motivating abatement by the aluminium sector. Such a move would reward lower carbon producers, and incentivise action amongst higher carbon intensity producers. Green demand could be catalysed by more widespread adoption of product carbon footprinting in end-use products. While some green demand could be met by the reshuffling of existing lower carbon production, over the long term this demand would drive increased investment in lower carbon retro-fit and new build.

Global demand for aluminium drives significant inter-regional flows of carbon embodied in aluminium

The 10 largest regional flows of CO_2 emissions relating to trade of non-ferrous metals



Note 1: Includes Scope 1 emissions (direct), Scope 2 emissions (allocated electricity) and Scope 3 emissions (inputs to aluminium and non-ferrous metal production).
Note 2: Includes Scope 1- Scope 3 emissions generated within the country of non-ferrous metal production only (ie, excludes flows between countries of inputs to non-ferrous metal production).
Note 3: Excludes intra-regional flows.
Source: Carbon Trust Analysis; CICERO, SEI and CMU – GTAP7 EEBT (2004) model.

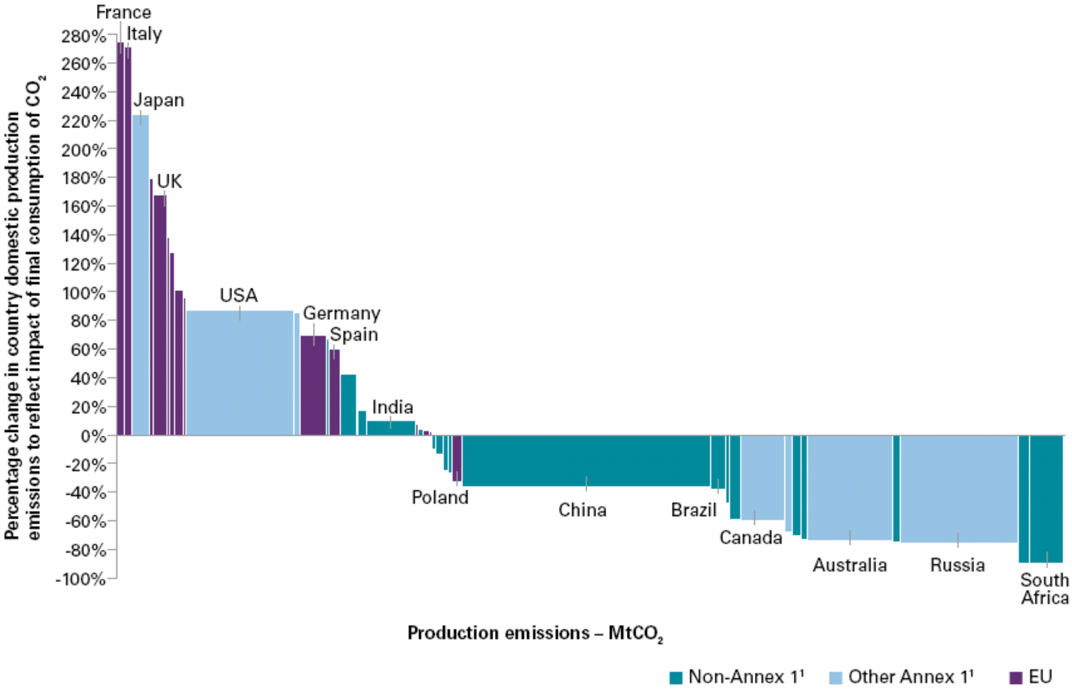
Approximately one third (28%) of aluminium emissions cross a border embodied in commodity aluminium. Half of this trade is contained within regions, and the other half between regions.

The ten largest inter-regional flows of carbon embodied in traded aluminium and other non-ferrous metals are illustrated above, with the most significant being from the CIS (ex-Soviet Union Commonwealth of Independent States) to Europe, China to the rest of Asia and Australia to Asia. This flow reflects both the volume of metal shipped and the relative carbon intensity of the country of origin, with both China and Australia being heavy users of coal in their aluminium and other non-ferrous metal production.

Within these regions, there are also significant embodied emissions flows between countries, such as from Canada to the USA.

Net imports of emissions embodied in aluminium are significant for many developed countries; net exports are dominated by a small number of major producers

The impact of a consumption perspective on non-ferrous metal emissions by country

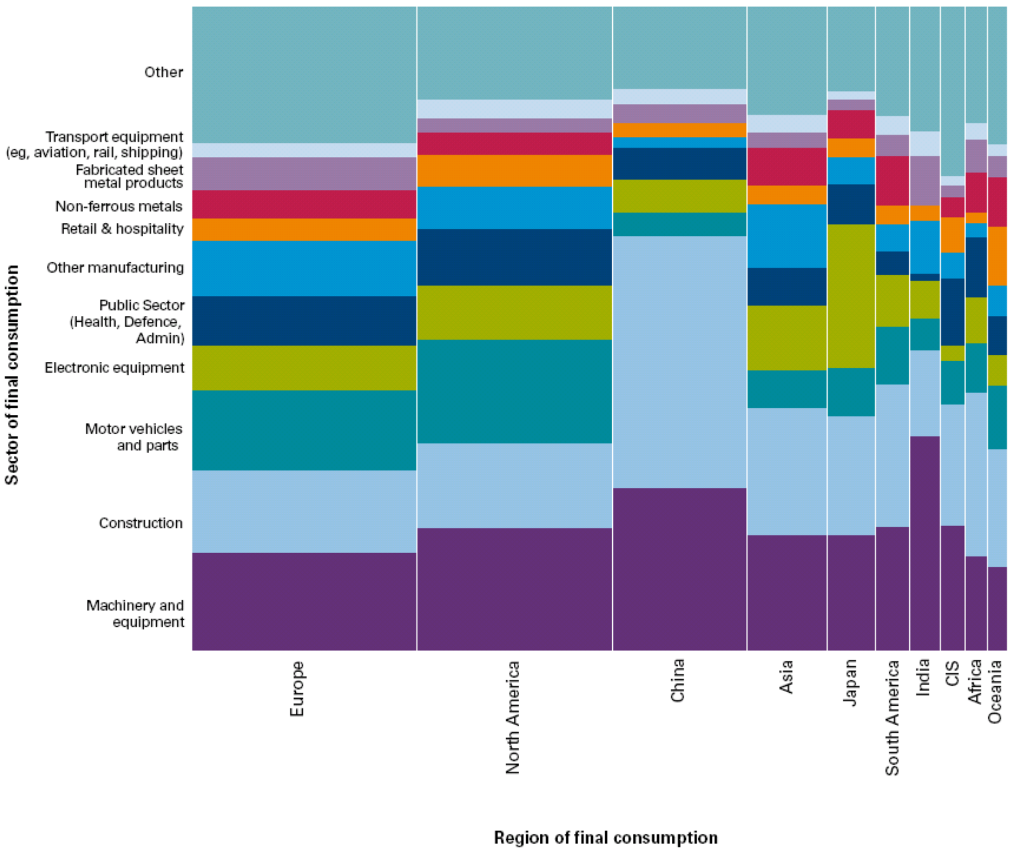


Note 1: Top 40 non-ferrous metal producing countries only.
Note 2: Includes Scope 1 (direct) emissions and Scope 2 emissions (allocated electricity)
1. Defined as Annex 1 / Non Annex 1 to UNFCCC.
Source: Carbon Trust Analysis; CICERO / SEI / CMU GTAP7 MRIO Model (2004).

These 'carbon flows' of aluminium, both as a commodity and as aluminium embedded within products, drive a net imbalance in the emissions associated with production and those associated with consumption in a given country. Most countries are either net importers or exporters of embodied aluminium and other non-ferrous metal emissions. For example, the UK production of non-ferrous metals in 2004 caused $9MtCO_2$ of GHG emissions (including electricity emissions), but its consumption of aluminium products caused $24MtCO_2$ of emissions. This means that while, from a production perspective, non-ferrous metal emissions are only 1% of UK emissions, they are actually approximately 3% of UK emissions from a consumption perspective. The above Figure lays out by country the percentage increase or decrease of their carbon emissions from the consumption of aluminium, compared to emissions arising on their production of aluminium.

Aluminium is consumed across a wide range of sectors

Global consumption of embodied non-ferrous metal emissions, by region and sector of final consumption (global emissions total 632MtCO$_2$)



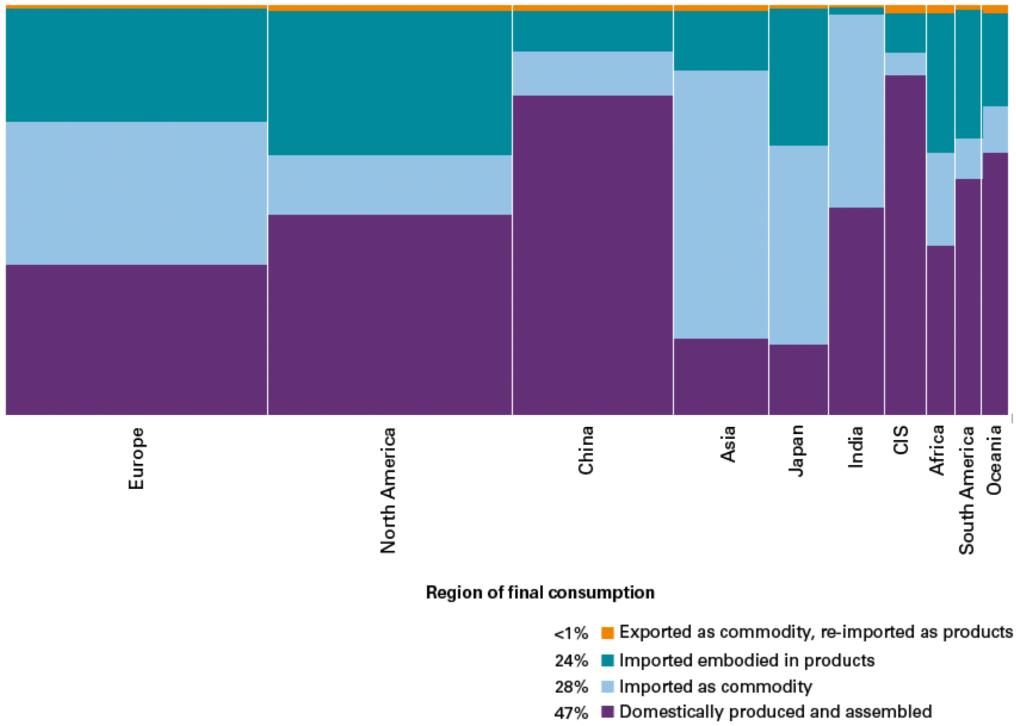
Note 1: Includes Scope 1 (direct emissions) only.
Source: Carbon Trust Analysis; CICERO, SEI and CMU – GTAP7 MRIO (2004) model.

Emissions arising from the production of aluminium (together with other non-ferrous metals) were around 630MtCO$_2$ in 2004 (including Scope 1(direct) and Scope 2 (indirect from electricity generation)). This aluminium, and hence the emissions from aluminium production, were consumed across a wide range of sectors, with machinery, construction and motor vehicles being the largest sectors of final consumption.

While the distribution of aluminium consumption between sectors is relatively constant across regions, there are some outliers. A high proportion of China's aluminium consumption emissions occur in the construction sector, reflecting high levels of infrastructure development occurring in China; at the same time, Europe and North America have the lowest proportion of aluminium consumption emissions occurring in the construction sector, reflecting the earlier investment in infrastructure in these regions. India has the largest proportion of aluminium consumption emissions occurring in the machinery sector (possibly reflecting a focus on improved manufacturing capacity), while Japan's consumption of aluminium emissions is biased towards those embodied in electronics.

Reliance on embodied emissions flows to support domestic consumption of aluminium varies widely by region

Domestic versus imported non-ferrous metal emissions by category of consumption (global emissions total 632MtCO_2)

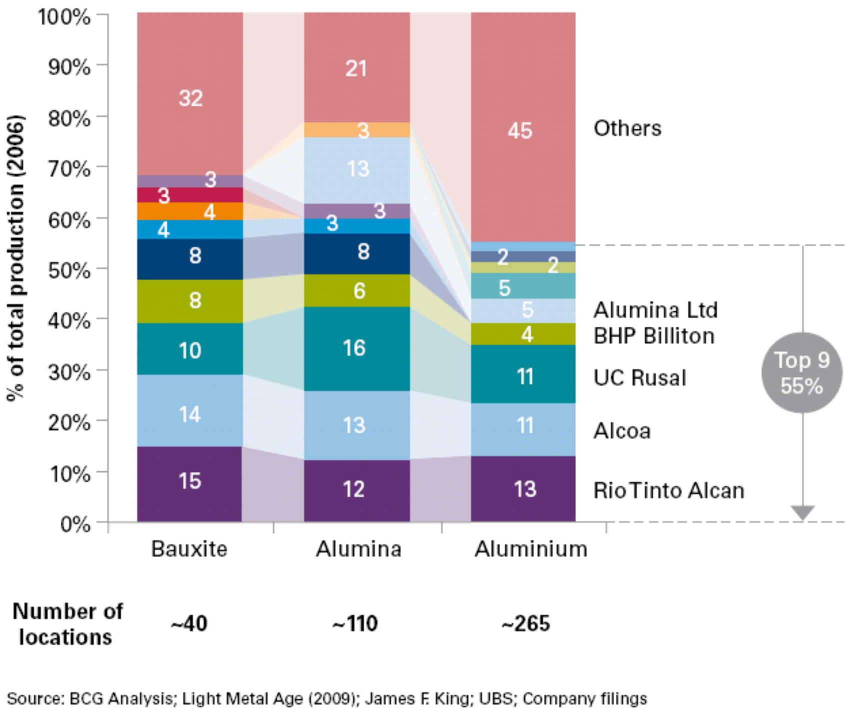


Note 1: Includes Scope 1 (direct) and Scope 2 emissions (indirect, allocated electricity).
Source: Carbon Trust Analysis; CICERO, SEI and CMU – GTAP7 EEBT & MRIO model.

In addition to the movement of 'raw' or commodity metals, emissions embodied in aluminium and other non-ferrous metals also flow between regions due to the trade in complex products that contain these metals, such as cars or machinery. As illustrated above, on average an additional 24% of non-ferrous metal emissions flow between regions as complex products. These flows can often be complex, as the embodied emissions are transferred from sector to sector and region to region.

The global aluminium industry is highly consolidated

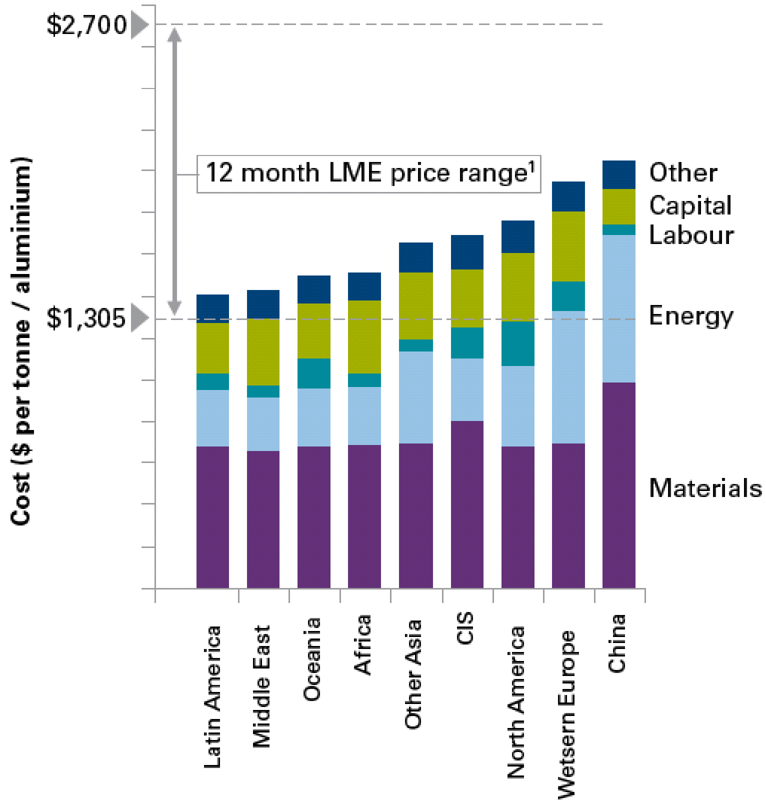
Market share of the top nine aluminium producers, 2006



The aluminium industry is very consolidated. There are less than 300 aluminium production sites globally supplied by around 40 bauxite mines. As illustrated in the Figure above, the top nine companies control half the market, led by Rio Tinto Alcan who control 13% and Alcoa and UC Rusal who control 11% each. The top firms tend to control their own bauxite mines and alumina processors.

Significant variation in global aluminium production costs

The cost of aluminium production within and across regions and across technologies



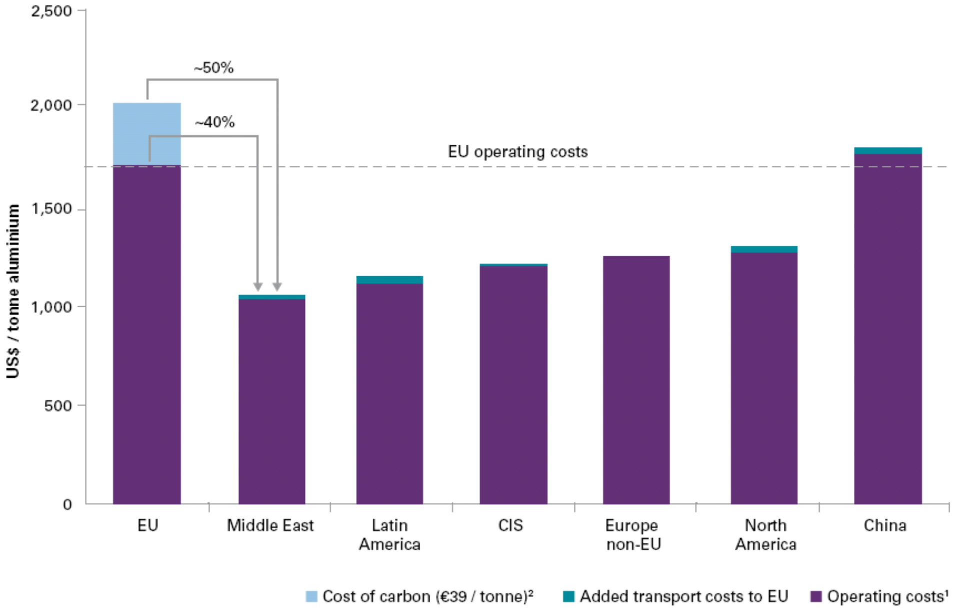
[1] LME (London Metal Exchange) price range is over period 25/7/08 to 21/7/09.
Source: BCG Analysis of data provided by James F. King (2008).

About 40 million tonnes of aluminium are consumed each year and this figure is expected to triple or even quadruple by 2050. The main consumer regions are in China (32%), other countries in Asia (20%), the EU (18%) and North America (15%). China has the fastest growing consumption, averaging 10% growth a year between 1980 and 2007.

Virgin aluminium costs $1,000-$2,000/t to produce. The variation of costs across regions is illustrated in the above Figure and is broadly linked to the availability of cheap, high grade bauxite and cheap energy. Latin America benefits from both. China suffers because its domestic bauxite is lower grade and although coal is generally cheap, China's growth rate is placing considerable strain on electricity generation. Bauxite mining is frequently the bottleneck in aluminium production, and therefore owners of bauxite mines can earn greater profits than the sector as a whole (for example more than 20% return on assets compared to 10% for smelting and perhaps only 5% for finishing products).

Aluminium production costs vary widely between regions

The cost of producing aluminium in the EU compared with other regions. Indicative figures for comparison only.

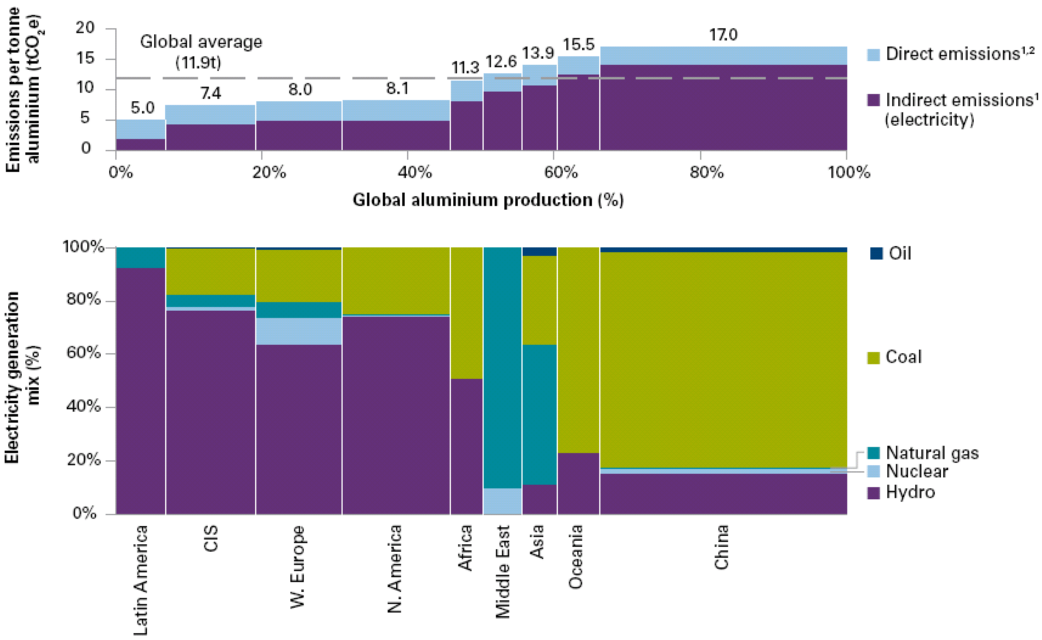


[1] Operating costs are a weighted average for region.
[2] European Commission estimate of required carbon price to achieve 2020 targets.
Note 1: The operating costs of any region could vary significantly based on changes to input costs eg, electricity prices.
Source: BCG Analysis; James F. King, industry interviews.

The EU is one of the higher-cost regions for production of aluminium, with the Middle East around 40% cheaper than the EU, even before a cost of carbon is applied. All else being equal and irrespective of the cost of carbon, due to lower operating costs it is generally more profitable to locate new production outside of the EU and then import the aluminium. Once outside the EU, production sites will generally face less pressure to abate. While the Clean Development Mechanism (CDM) provides an incentive to reduce emissions, it is voluntary and its rules concerning additionality limit the extent to which industry uses the mechanism. In addition, many end-products containing aluminium are imported in finished or semi-finished form, having been produced in countries which do not bear a cost of carbon.

The carbon intensity of electricity generation has a major influence on the emissions arising from aluminium production

Greenhouse gas emissions from aluminium production by region, and based on electricity supply



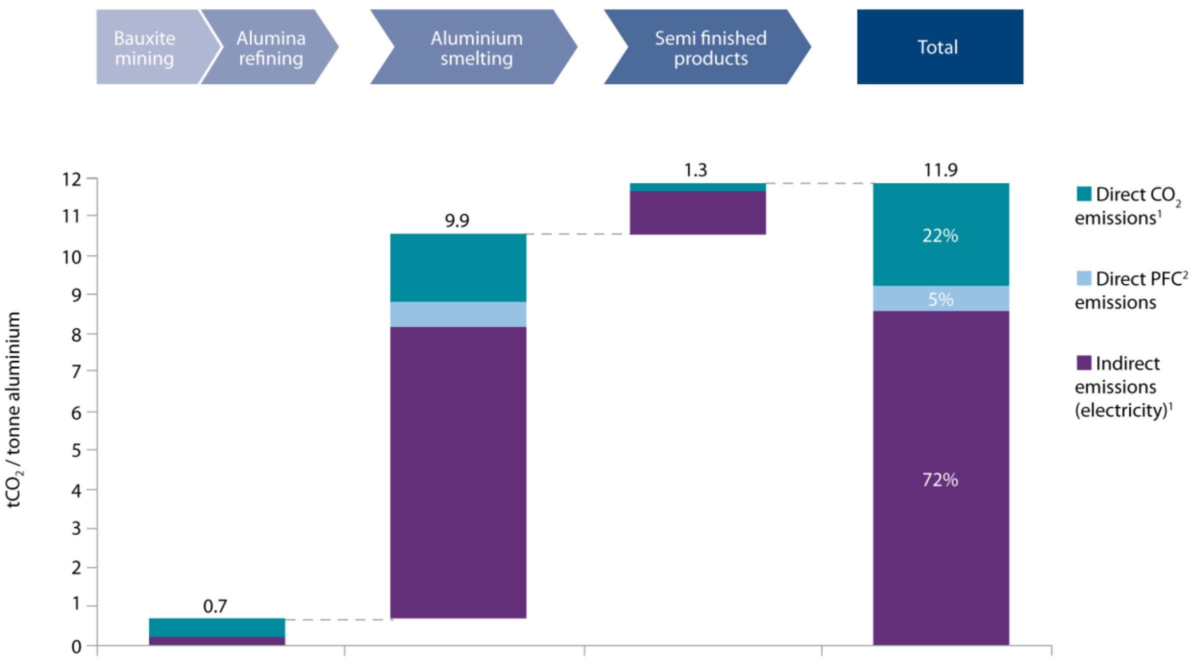
[1] Direct emissions are emissions arising from the production process (mainly anode degradation and perflourocarbon emissions), whereas indirect emissions are those associated with electricity production.
[2] Direct emissions assumed to be the same globally.
Note 1: Data based in part on interviews – approximate data only
Source: BCG analysis based on 'Production and Electricity Generation' (IAI, 2008) and industry interviews.

Approximately 30% of aluminium consumption is fulfilled by re-melting, cleaning and re-alloying scrap aluminium in reverberatory or induction furnaces. The remaining 70% is produced from bauxite, the richest aluminium ore. The ore is processed into alumina, mostly using the Bayer process. The alumina is then smelted into aluminium, almost always using the Hall-Héroult electrolysis process. It is then cast or wrought into its final form. A third of all virgin aluminium is produced in China. The next largest producers are Russia (10%), Canada (8%), the USA (7%) and Australia (5%).

The key variation in production is the technology used to produce the large amount of electricity consumed in the Hall-Héroult electrolysis process. This variation is illustrated in the above Figure, and ranges from 80% coal-based generation in China to 90% hydro-electric in Latin America. Most of the growth in production over the coming decade is expected to occur in China.

Indirect emissions from electricity used in smelting are the key driver of GHG emissions from aluminium production

Greenhouse gas emissions by step in the production of virgin aluminium



[1] Direct emissions are CO_2 emissions arising from the production process (mainly anode degreadation), whereas indirect emissions are those associated with electricity production.

[2] Perflourocarbon emissions from electroyte.

Note 1: Emissions are based on a global average. Actual emissions vary from 3-20t CO_2e per tonne of aluminium depending on electricity supply

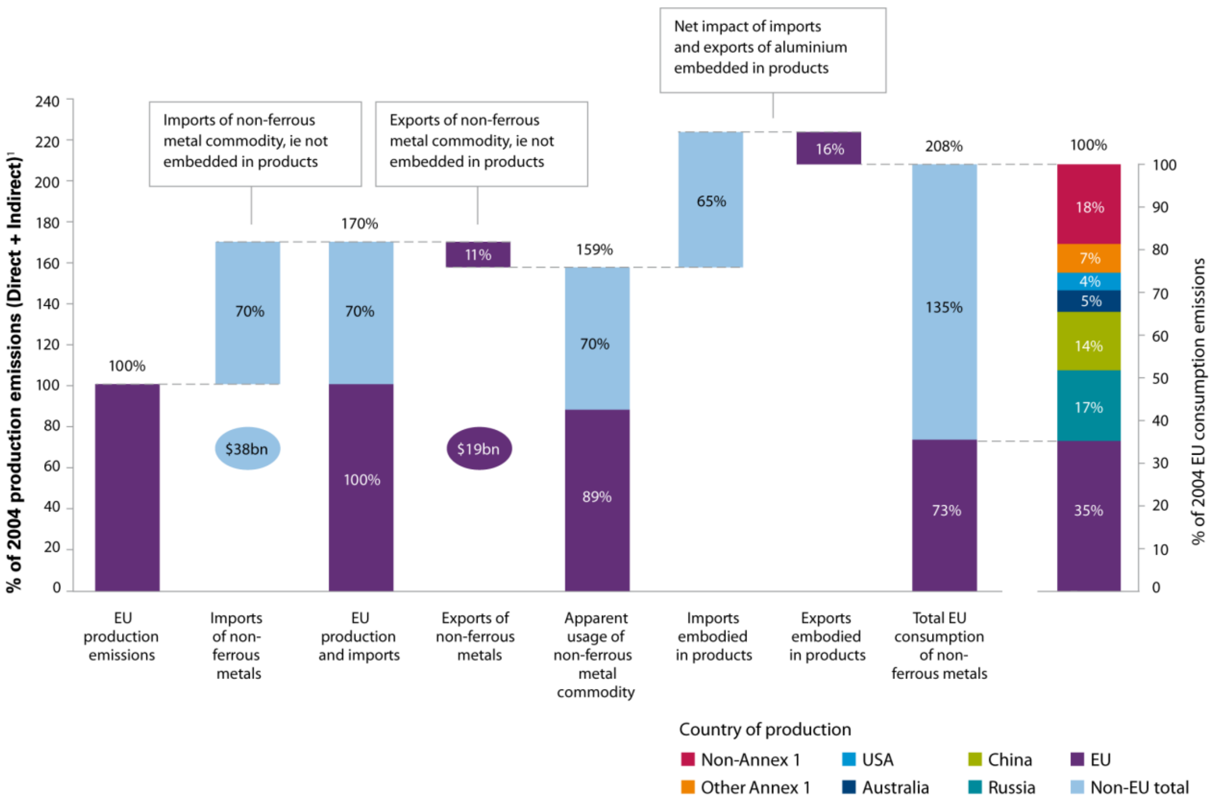
Source: BCG Analysis; Data from James F. King; Energy Report (IEA 2007); Sustainability Report (IAI, 2008).

The actual emissions per tonne of aluminium vary quite widely according to whether it is recycled (average of approximately 1tCO_2e/t aluminium) or virgin (average 12tCO_2e/t aluminium). Emissions from recycling are almost entirely from indirect electricity production and split equally across smelting the scrap material and forming it into a semi-finished product.

Within virgin production, the emissions vary significantly according to the source of electricity used (hydro powered aluminium production emits 3tCO_2e/t aluminium compared to 20tCO_2e/t aluminium for coal-powered production) and the age of the plant (particularly of the electrolytic cell technology where average PFC1 emissions have fallen from around 5tCO_2e/t aluminium in 1990 to under 1tCO_2e/t today). On average 70% of emissions from virgin production are from electricity; 5 – 10% are due to the PFC emissions described above and the remainder are direct CO_2 emissions for example from anode degradation. As shown above, the most significant step from an emissions perspective is smelting, which electrolyses alumina into aluminium and is responsible for 60 – 90% of emissions.

The European Union is a large net importer of emissions embodied in aluminium; these emissions are not priced under the EU ETS

Ratio of EU aluminium & non-ferrous metal production to EU consumption

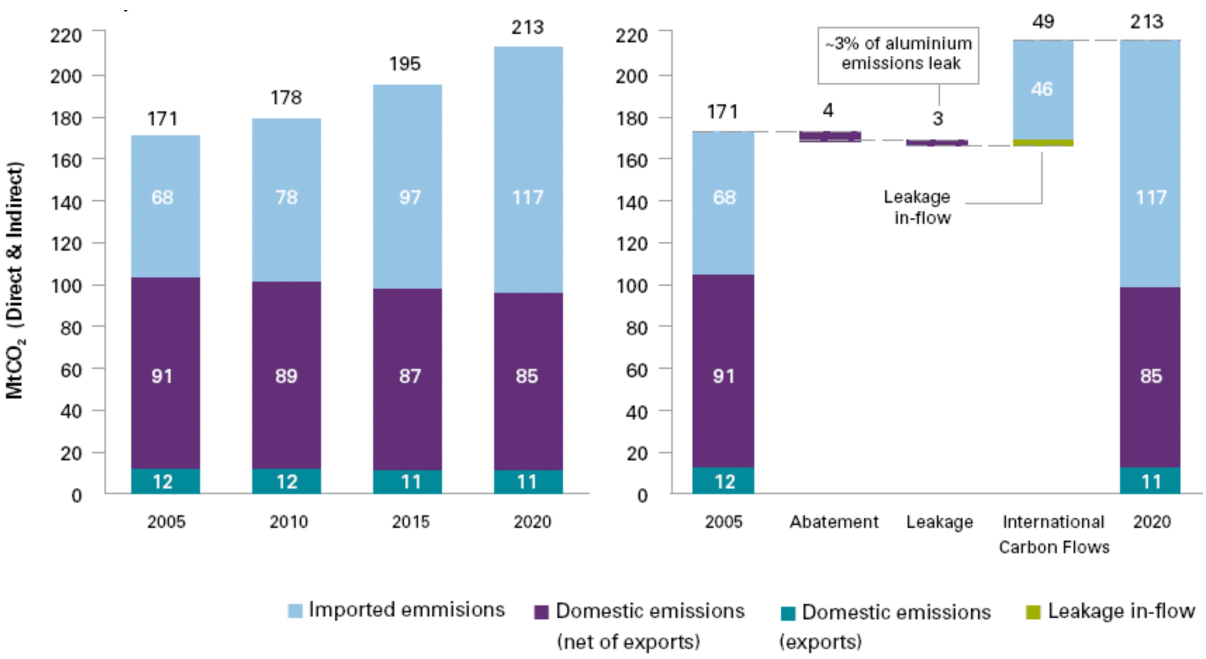


[1] Includes Scope 1 (direct) emissions and Scope 2 (allocated electricity) emissions. Indirect emissions allocated on the basis of average ratio Scope 1 to Scope 2 emissions in non-ferrous metal production in a given region.
Source: CarbonTrust Analysis; CICERO / SEI / CMU GTAP7 MRIO/EEBT Model (2004).

Imports of commodity aluminium and other non-ferrous metals into the EU increases the emissions footprint of the EU by around 70%. After accounting for exports, from an emissions perspective EU consumption of non-ferrous metal commodities are approximately 60% higher than domestic production. Once the trade in complex products is accounted for, the total emissions associated with EU consumption of non-ferrous metal is over double the emissions from production falling within the EU ETS. This means that just over a third (35%) of the EU's consumption emissions are associated with aluminium production covered by the EU ETS.

Increasing consumption, not carbon leakage, drives future increases in net EU imports of emissions embodied in aluminium

(Left) Evolution of EU non-ferrous metal production and consumption; (Right) Drivers of change between 2005 and 2020 emissions



Note 1: Assumes imports decarbonise by 9% (moving to current best practice average) and that emissions from domestic EU production decline in line with contribution expected from the sector – see Carbon Trust report 'Tackling carbon leakage in a world of unequal carbon prices'.
Note 2: Includes Scope 1 (direct) emissions and Scope 2 (allocated electricity) emissions.
Source: Carbon Trust Analysis based on data from: Addressing leakage in the EU ETS: Results from the Case II Model (Climate Strategies, 2009); CICERO / CMU / SEI GTAP 7 MRIO/ EEBT Model (2004).

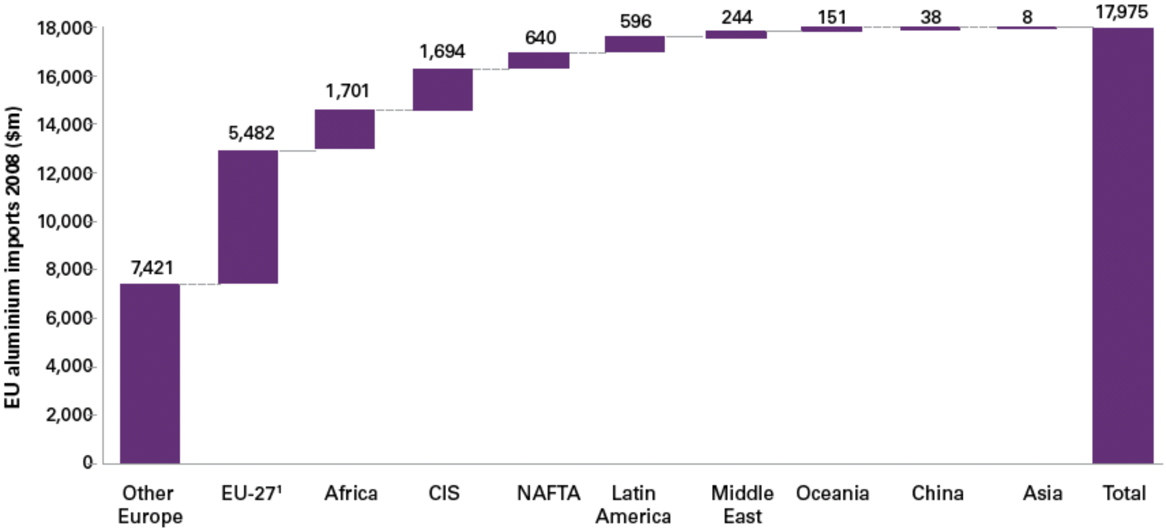
There has been much focus in recent years on estimating the extent of potential 'carbon leakage', whereby European energy intensive business may be forced out of Europe to unregulated geographies by the cost of carbon. The evidence suggests that the potential for carbon leakage is generally quite small – perhaps of the order of 2% of all EU ETS emissions up to 2020 without any mitigating actions (see *Tackling carbon leakage: Sector-specific solutions for a world of unequal carbon prices*, Carbon Trust), and approximately 3% for the aluminium sector itself.

In the context of an anticipated three or four fold increase in global aluminium production and consumption over the next 40 years, there is a strong possibility that EU aluminium production will not grow above current levels, while aluminium consumption within the EU continues to rise. This is re-enforced by anecdotal evidence within the industry that suggests that no new smelters are likely to be built in Europe. This scenario could enable the industry's emissions to remain within the overall cap, while growth continues apace outside the EU, enabling rapid growth in consumption-based emissions within Europe. One scenario for future aluminium and other non-ferrous metal emissions consumption is illustrated in the above Figures, which assumes that production emissions within the EU ETS decline by 7% (a forecast contribution from the aluminium industry to the declining EU ETS cap) while consumption increases due to growth in imported emissions by 72%.

Significantly, the majority of this growth in imports is due to the growth in 'international carbon flows' (49MtCO_2), which is many times more significant than the impact of that due to leakage in particular (only 3MtCO_2, due to the direct result of the carbon price).

Non-EU European countries are the largest producers of emissions embodied in aluminium consumed in the EU

Share of exporting countries' aluminium that is destined for the EU



	Other Europe	EU-27[1]	Africa	CIS	NAFTA	Latin America	Middle East	Oceania	China	Asia	Total
EU's proportion of exporter regions' total production	89%	80%	36%	17%	5%	8%	4%	3%	<1%	<1%	
EU's proportion of exporter regions' total exports	96%	94%	57%	21%	8%	23%	51%	3%	2%	1%	

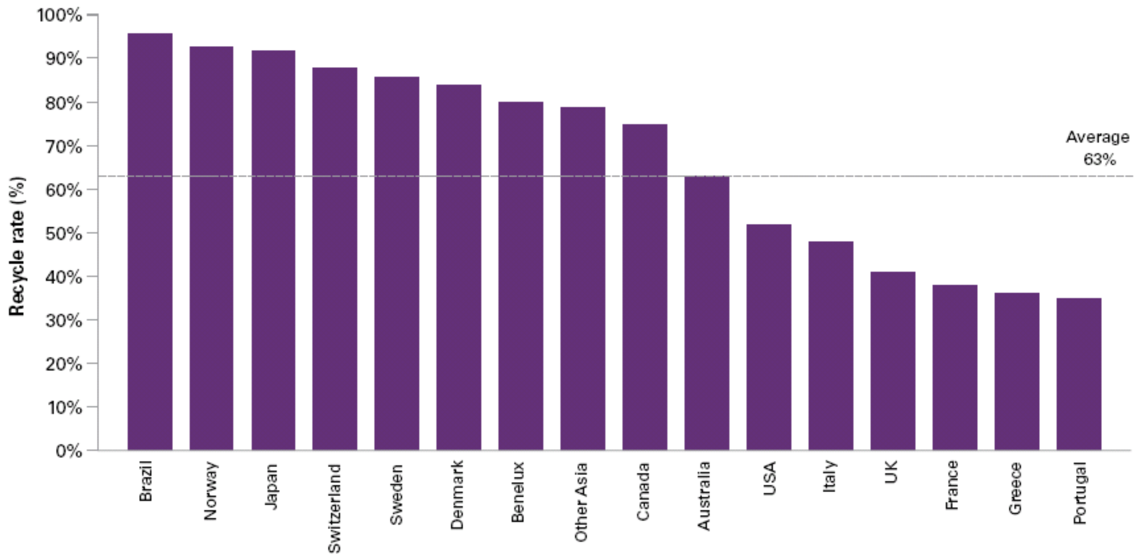
[1] Includes trade between EU-27 countries, but excludes aluminium produced for domestic consumption in same country.
Source: BCG Analysis; UN Comtrade, James F. King data.

Consumption of aluminium in final goods in the EU is supported by aluminium production activities across the world; with non-EU European states by far the dominant source of emissions embodied in aluminium that is destined for consumption in the EU. Aluminium production within EU states satisfies just under one-third of final demand for aluminium in the EU; however, aluminium production in the EU, Other European and CIS together is responsible for around 80% of the GHG emissions embodied in aluminium consumed in the EU

Measures to reduce the carbon intensity of aluminium imports are likely to help to reduce the EU's overall consumption of carbon, and therefore to reduce global emissions. However, they are likely to have only variable impact on the overall carbon intensity of production in other markets, although it would certainly provide a signal for change. For many such markets, the proportion of production destined to the EU is relatively small compared to that produced for domestic consumption or export elsewhere. However, for some countries (e.g. non-EU member state countries in eastern Europe), nearly 100% of domestic production is bound for export to the EU: as a result, measures to reduce the carbon intensity of imported aluminium would have a significant effect on all their production.

Aluminium is highly recyclable; however, actual recycle rates vary significantly between countries

Beverage can recycle rates by country

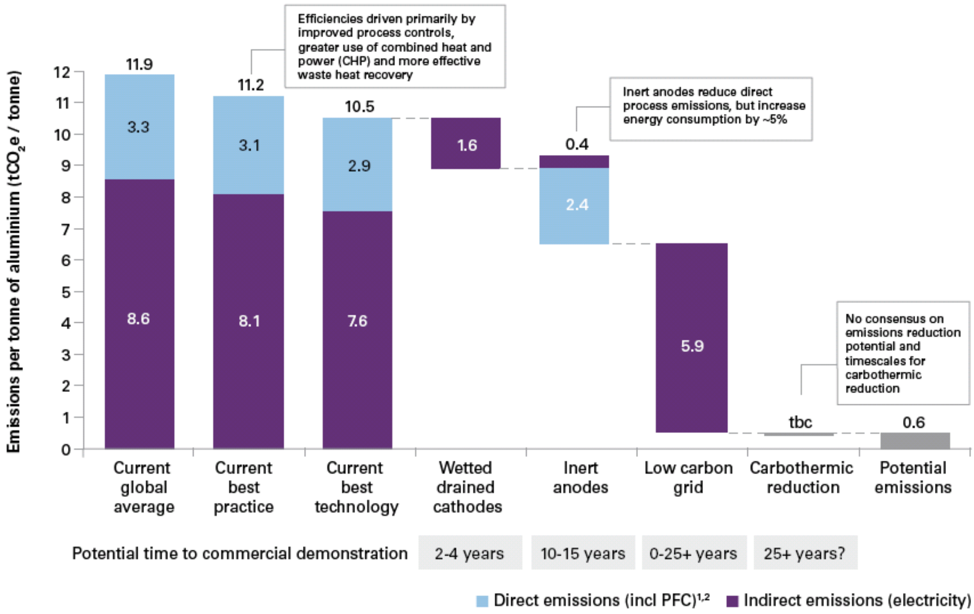


Source: International Aluminium Institute – Global Aluminium Recycling.

Aluminium (in common with steel) is already widely recycled, but scrap availability is significantly limited by the long lifetime of metals used in the transport or construction sectors. According to some estimates, up to 75% of all the aluminium ever made is still in use today, either in its original form or via recycling. However, unlike steel, there does appear to be some limited scope for increasing the use of recycled aluminium. Packaging is the single largest source of post-consumer scrap aluminium and its global recycling rate is currently only approximately 60%. Increasing this to 90%, the level already seen in countries as diverse as Japan, Norway and Brazil, would deliver an additional 2Mt of scrap aluminium into the market, cutting the sector's greenhouse gas emissions by about 5%. The above Figure shows the variation in recycling rates by country.

Deep reductions in the carbon intensity of aluminium production are possible in the medium term

Technologies that can reduce emissions per tonne of virgin aluminium



[1] Direct emissions are emissions arising from the production process (carbon anode degradation and PFC[2] emissions), whereas indirect emissions are those associated with electricity production.
[2] Perflourocarbon emissions from electroyte.
Source: Carbon Trust and BCG Analysis based on data from International Aluminium Institute (IAI); International Energy Agency (IEA); Industry reports; James F. King.

Options for reducing emissions per tonne of virgin aluminium vary in their immediate technical feasibility. Most feasible are efficiency improvements that tend to be implemented as a matter of course because they also reduce costs. Modern best practice plants use around 5% less electricity per tonne of aluminium produced than average plants, and deployment of best available technology could achieve emissions savings of up to around 12% per tonne aluminium. Wetted drained cathodes represent an opportunity to decrease indirect emissions by allowing molten aluminium in the cell to be drained away continuously, reducing energy consumption significantly. Other options also exist for reducing energy consumption in the electrolytic cell. One such technique is under development at The University of Coventry, and supported by the Carbon Trust Research Accelerator Programme (see next page).

In principle, it is possible to power aluminium smelting plants using very low carbon sources of electricity. Much aluminium production already uses hydroelectric or nuclear power sources. However, the continuous nature of production using the Hall-Héroult electrolysis process means that it is important that electricity supplies are not interrupted. This makes it challenging to power individual smelters using off-grid variable renewable energy such as wind or solar. However, both are possible sources of energy if the smelter is connected to an electricity grid.

Further reductions in direct emissions require large scale deployment of newly-developed or developing production techniques. Key improvements to the Hall-Héroult cell currently in development include wetted drained cathodes (discussed above) and inert anodes. However, these technologies appear to be at least 5 and 10 years from large scale commercial demonstration respectively. Replacing carbon anodes used in the existing process with inert anodes would help eliminate PFC and direct CO_2 emissions, although it is also likely to increase electricity consumption at least by a small amount. Outside the Hall-Héroult process, the next best option is to use an alternative reduction process such as carbothermic reduction, provided the reduction material is low carbon itself, for example sustainably sourced bio-coke. This represents the greatest opportunity to reduce energy and cost after a decarbonised electricity source, but such savings have not yet been demonstrated.

Case study: Reduction in energy use in aluminium smelting through application of an AC magnetic field

Research carried out at Coventry University, supported by the Carbon Trust Research Accelerator Programme, in collaboration with the University of Warwick and a manufacturer of smelting equipment, has recently developed a technique to reduce the energy use in aluminium smelting which could deliver energy savings of between 5-20%. The project demonstrates that collaborative research programmes such as the Carbon Trust Research Accelerator can help to deliver commercially viable innovation by combining academic and industrial capabilities, techniques and funding.

Aluminium smelting using the Hall-Héroult process takes place in an electrolytic cell where aluminium oxide, dissolved in molten electrolyte (cryolite) is electrolysed into molten aluminium and carbon dioxide. Electrolysis is sustained by the flow of electric current through the electrolyte between carbon anodes suspended in the cell and the molten aluminium products of electrolysis, which act as the cathode. For electrolysis to be sustained, the anode and cathode must remain separated by the electrolyte. During electrolysis, it is usual for electric current fluctuations to cause ripples on the surface of the molten aluminium pool. To avoid short circuiting of the cell, it is necessary to maintain a minimum distance between anode and cathode. However, the greater the electrode separation, the greater the resistance of the cell: this in turn requires more electricity to be used. Researchers at Coventry University have found that the application of a dynamic AC magnetic field significantly suppresses ripples in the molten aluminium, enabling smaller electrode separation and therefore lower electricity use. The programme’s next stage of development is to design, build and commission a commercial scale model cell, in which the smelting performance and energy consumption will be evaluated.

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