Steel

The world's consumption of iron and steel drives around 6% of global GHG emissions. New consumption-based approaches are required to help ensure an anticipated doubling in consumption by 2050 is compatible with tackling climate change.

Key facts

- **Large global flows in embodied emissions**
  Over one third of global emissions associated with steel production are embodied in international trade, with many developed economies being net importers of emissions embodied in steel. Thirteen per cent of global steel emissions are embodied in the trade of commodity steel, with a further 23% of embodied in traded final goods.

- **Significant regional differences in both production cost and emissions intensity**
  Steel production costs vary significantly between regions, with the EU being a high cost production region (irrespective of carbon pricing). Differences in the carbon intensity of production are driven by the production technology mix in different regions.

- **The EU steel sector**
  Steel consumption emissions are almost double the emissions produced by the steel sector in the EU. Despite the positive effects of the EU ETS, total emissions associated with steel consumption are likely to grow over the period from 2010 to 2020. Carbon leakage accounts for around half of the additional flow of imported emissions embodied in steel, and a much smaller proportion of the total increase in consumption of steel.

- **A growing sector, with significant emission reduction opportunities**
  To achieve a forecasted doubling of global steel 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 steel production by around 90% using a range of radical new technologies.

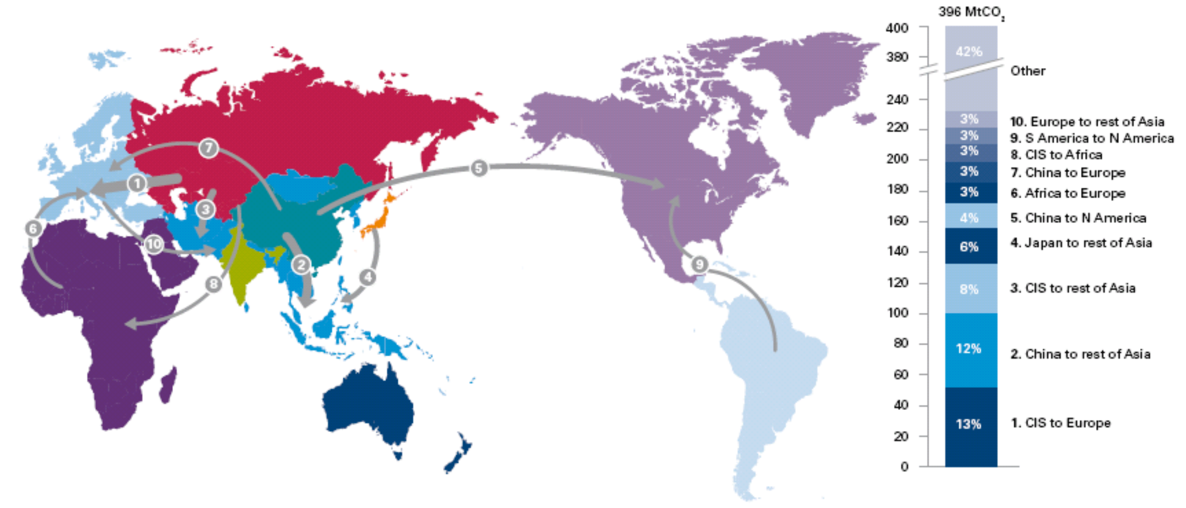
Implications for business

- **Producers of steel**
  The steel 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 of steel should continue to invest in the Research, Development, & Deployment of technologies that will decarbonise production over the long term, including top gas recycling, carbon capture & storage, bio-coke substitution, and alternative processes such as electrolysis. Producers should seek to leverage their combined knowledge, finance and experience to overcome the barriers that make RD&D breakthroughs economically prohibitive for a single player. Collaboration with government may further accelerate RD&D activities and innovation.

- **Consumers of steel**
  Consumers of steel can help drive action through practicing green demand (i.e. preferring to buy steel made at a site with lower emissions), motivating abatement by the steel sector. Such a signal would reward lower carbon producers, and incentivise action amongst those with more carbon intensive production. Green demand could be catalysed by more widespread adoption of product carbon footprinting in end-use products. This would ensure that final consumers reward producers for the actions taken in decarbonising their products. While some green demand could be met by the reshuffling of recycled and lower carbon steel, over the longer term green demand will only be met by increased investment in more carbon efficient production capacity.

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

The 10 largest regional flows of CO_2 emissions relating to the trade of iron and steel

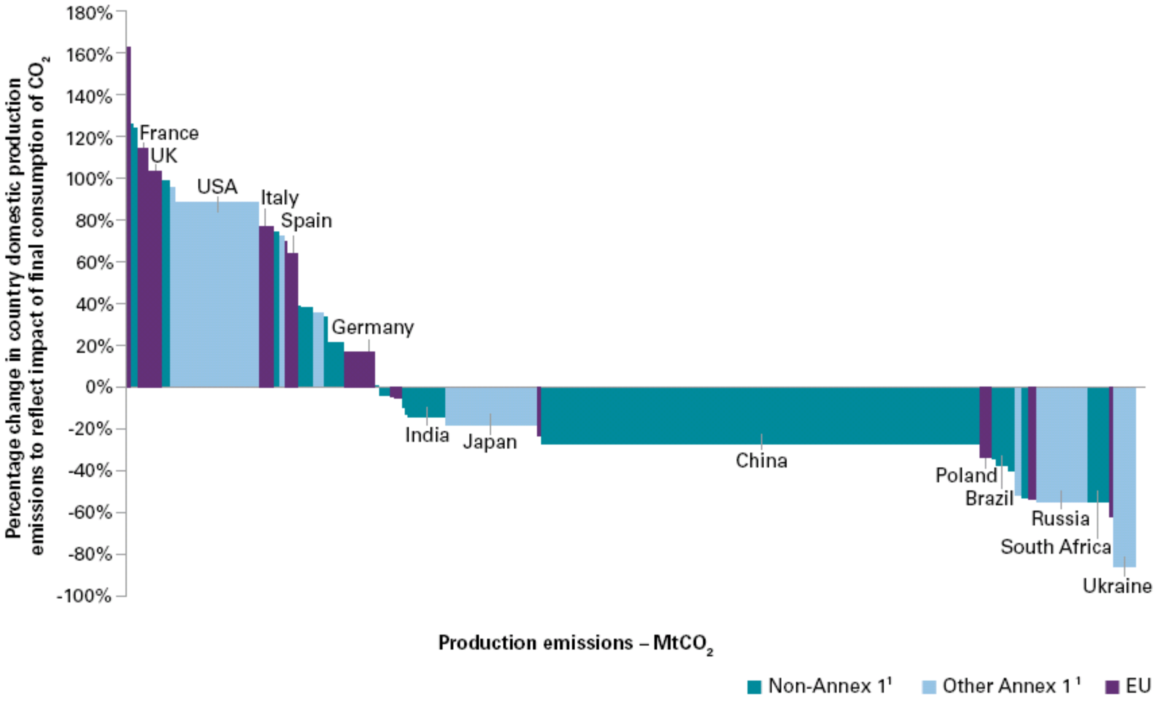


Note 1: Includes Scope 1 emissions (direct), Scope 2 emissions (allocated electricity) and Scope 3 emissions (inputs to iron and steel production).
Note 2: Includes Scope 1 – Scope 3 emissions generated within the country of steel production only (ie, excludes flows between countries of inputs to iron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

The trade in steel gives rise to the flow of 'embodied' carbon in steel that moves from exporting to importing countries. Over 20% of emissions associated with the production of commodity steel are associated with commodity steel that crosses a national border, of which approximately 70% are flows between regions (i.e. 13% of emissions flow between regions). The 10 largest bilateral inter-regional flows are illustrated in the above Figure. The embodied carbon associated with inter-regional trade in iron and steel is dominated by flows from the CIS to Europe, and China to the rest of Asia.

Net imports of emissions embodied in steel are significant for many developed countries; net exports are dominated by developing countries

The impact of a consumption perspective on iron and steel emissions by country

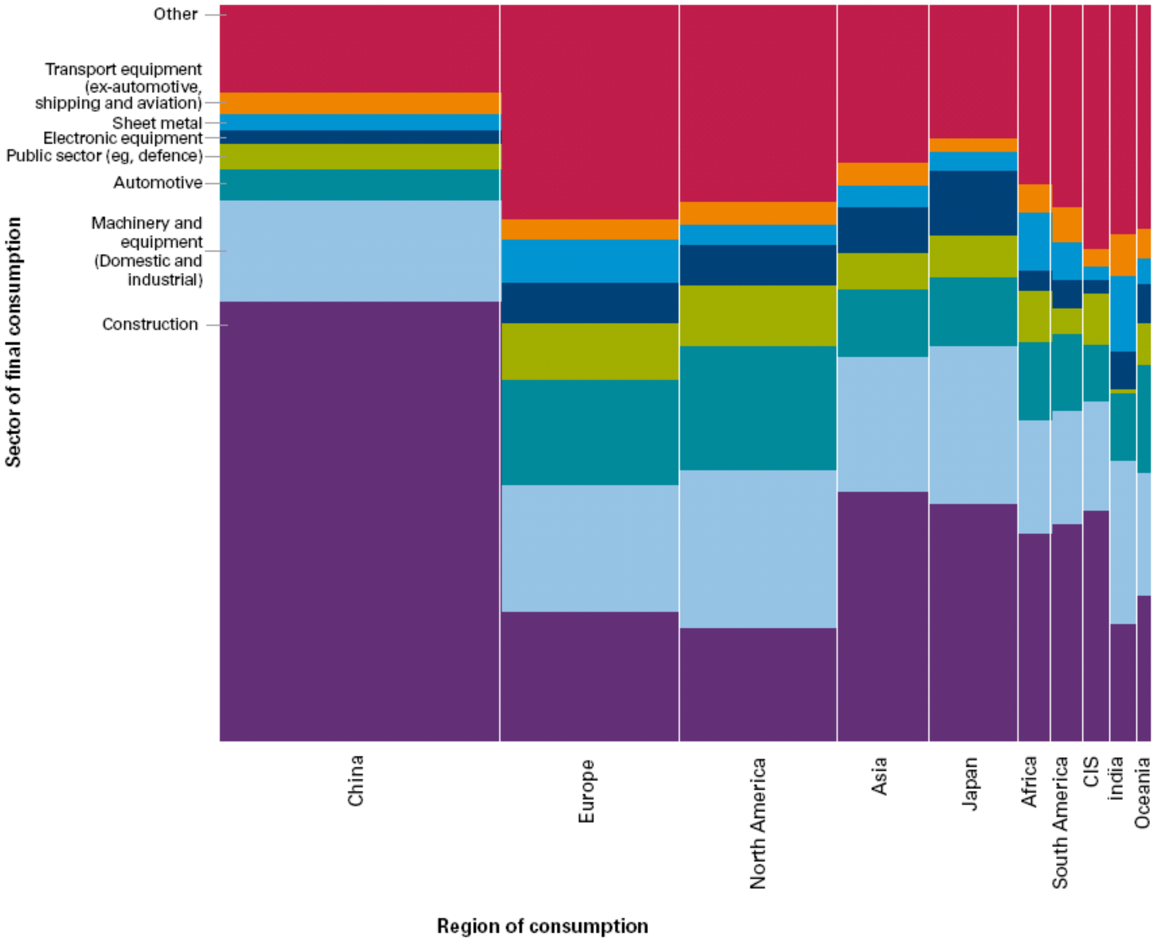


Note 1: Top 40 iron and steel producing countries only.
Note 2: Includes Scope 1 (direct) emissions and Scope 2 emissions (allocated electricity)
¹ Annex 1/Non-Annex 1 to UNFCCC.
Source: Carbon Trust Analysis; CICERO/SEI/CMU GTAP7 MRIO Model (2004).

Most countries have a net imbalance between the emissions associated with their domestic production, and those associated with consumption: this is illustrated in the above figure. For example, the UK production of steel in 2004 caused emissions of 25 $MtCO_2$, but its consumption of steel products caused 51 $MtCO_2$ of emissions. This means that while, from a production perspective, steel emissions are only 3% of UK emissions they are actually just over 5% of the total emissions relating to the UK's consumption.

Steel is consumed across a wide range of sectors

Global consumption of embodied iron and steel emissions, by region and sector of final consumption (global emissions 2.6GtCO_2e)



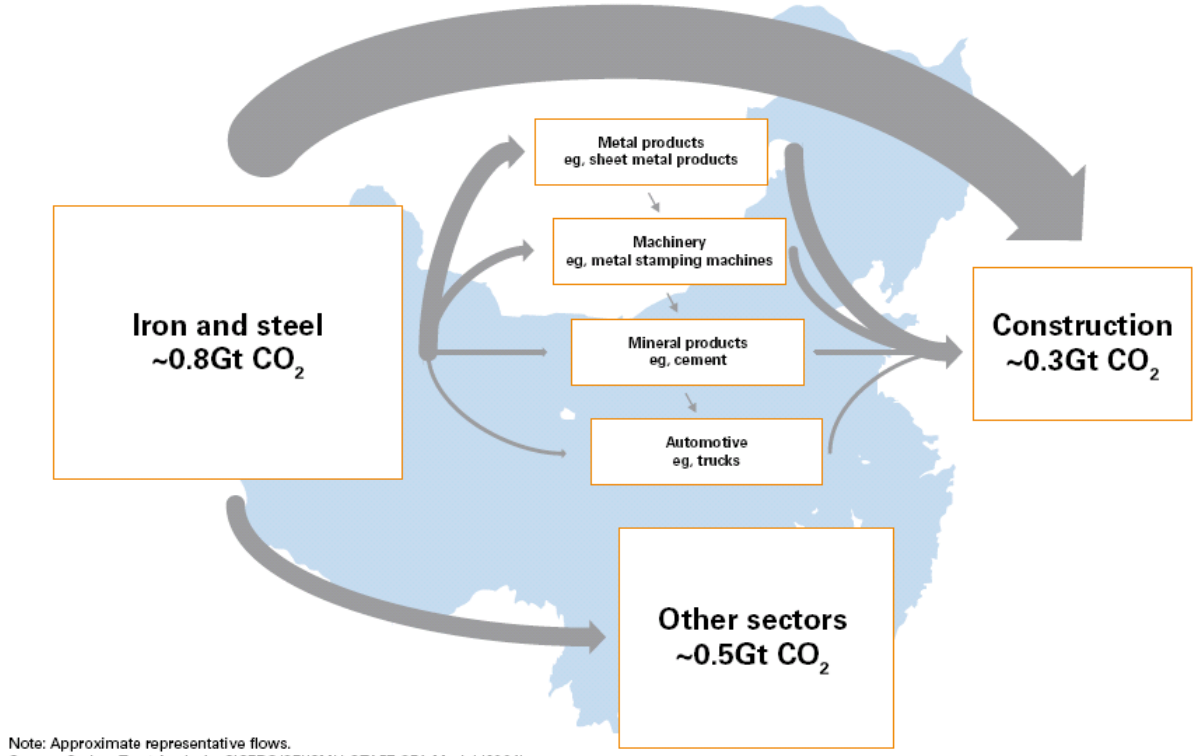
Note 1: Includes Scope 1 (direct emissions) only.
Source: Carbon Trust Analysis; CICERO/SEI/CMU GTAP7 MRIO (2004) model.

Emissions arising from the production of iron and steel were around 2.6GtCO_2e in 2004 (including Scope 1/direct, and Scope 2/indirect from electricity generation). This iron and steel, and hence the emissions from iron and steel production, were consumed across a wide range of sectors, with construction, machinery and motor vehicles being the largest sectors of final consumption.

There are significant differences between regions in the relative importance of steel emissions in different sectors. For example, consumption of embodied steel emissions in China is dominated by the construction sector, which is the world's single-largest sector of embodied steel emissions consumption (see Case Study, next page). This reflects the high levels of infrastructure investment currently occurring in China; by contrast, infrastructure investment in Europe and North America has slowed, and embodied steel emissions in the construction sector in these regions are relatively small. Motor vehicle consumption is a significant driver of embodied steel emissions, particularly in North America.

Case study: Chinese consumption of iron and steel in the construction sector

Case study of emissions flows from Chinese iron and steel industry to Chinese construction

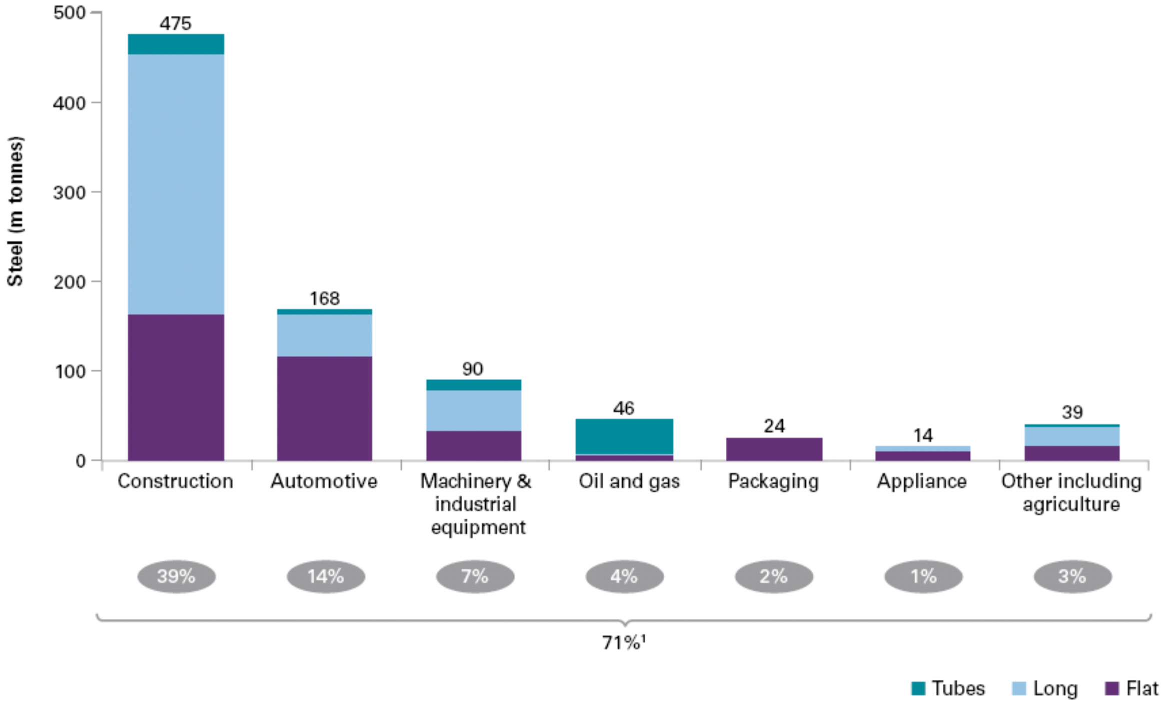


Note: Approximate representative flows.
Source: Carbon Trust Analysis; CICERO/SEI/CMU GTAP7 SPA Model (2004).

The flows can often follow complex economic pathways and the embodied emissions can frequently be transferred from sector to sector. The Figure above illustrates one such flow of emissions from the largest regional source of iron and steel emissions, China, to the largest consumer of iron and steel emissions, Chinese construction. While the largest flow of emissions is direct from the Chinese iron & steel sector to the Chinese construction sector, there are also intermediate flows of emissions through metal products, machinery and even automotive (e.g. cars owned by construction companies) before subsequently flowing to Chinese construction.

Different sectors consume steel in a variety of forms

Product demand by type of steel



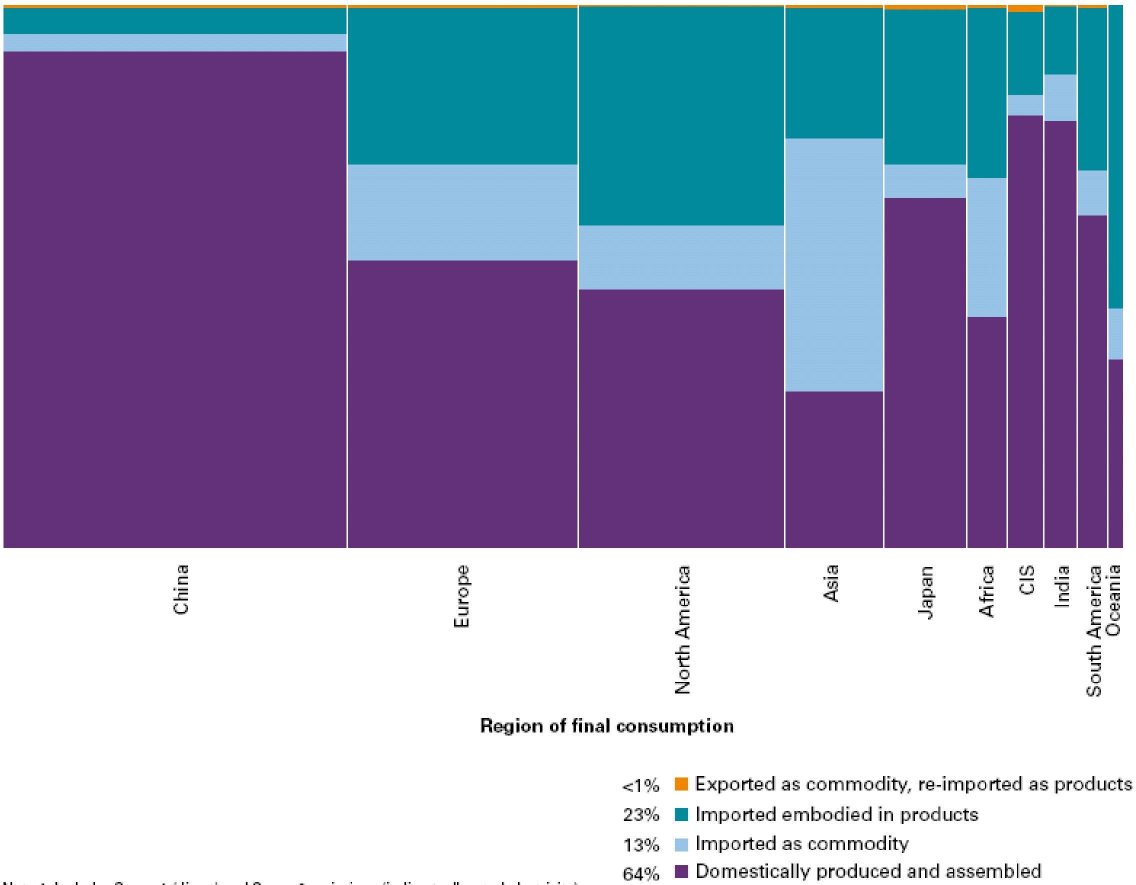
¹ 29% of global finished steel demand consumed in intermediary steps, including converting, processing and steel service centre.
Source: World Steel Dynamics; BCG analysis.

More than a billion tonnes of iron and steel are consumed each year and this figure is expected to roughly double by 2050. Steel is used mainly in construction (39%), automobiles (14%) and industrial equipment and machinery (7%). The main consumers are in the large economies of China (33%) the EU (17%) and North America (12%). China has the fastest growing consumption, averaging 10% a year between 1980 and 2007.

The interplay of these factors means the largest single use of steel globally is construction in China. Consumer demand can be categorised into several thousand different types of steel, but these can be described as three broad types: long steel, flat steel and steel tubes. Flat steel is mainly used in automotive and can have quite particular requirements. It tends therefore to have a higher value ($1000 – 1500/tonne) and consumers source the material from specific suppliers and are more comfortable with costs of up to $100/tonne to transport the steel across a region or the world. Long steel is mainly used in construction and typically has less specialised requirements. It tends therefore to have a lower value and to be sourced locally and interchangeably. Steel tubes represent a minor component of global steel consumption, with very limited demand outside of the oil and gas sector.

Reliance on embodied emissions flows to support domestic consumption of iron and steel varies widely by region

Domestic versus imported iron and steel emissions by category of consumption (global emissions 2.6GtCO$_2$e)

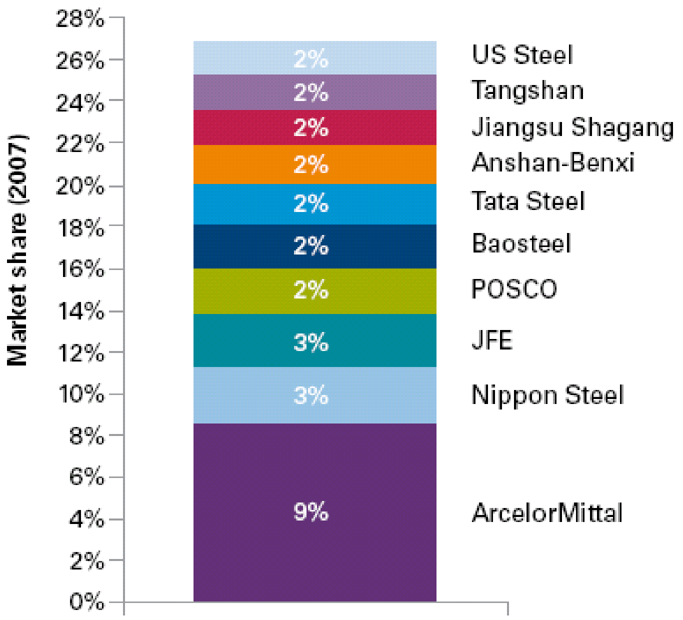


Note 1: Includes Scope 1 (direct) and Scope 2 emissions (indirect, allocated electricity).
Source: Carbon Trust Analysis; CICERO, SEI and CMU – GTAP7 EEBT & MRIO model.

In addition to the movement of 'raw' or commodity steel, emissions embodied in steel also flow between regions due to the trade in complex products that contain steel, such as cars or machinery. As illustrated above, on average around one third of a region's total consumption of iron and steel related emissions are satisfied by imports of steel commodity or steel embodied in products, versus two thirds domestic production. Almost twice as many emissions (23% of total global emissions) are associated with the manufacture of steel in complex products, compared to the emissions associated with traded commodity steel (13%).

The world's top 10 steel producers meet around one-third of global demand for steel

Market share of top 10 steel producers



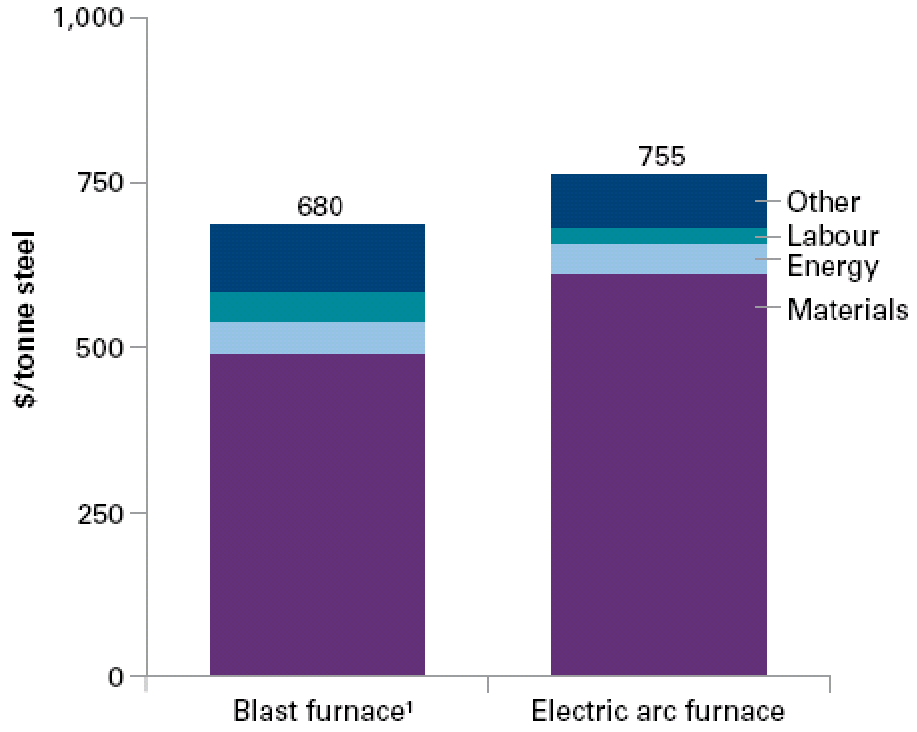
Source: Royal Steel Association.

Steel is a large ($1 trillion+) and politically sensitive industry, influenced at multiple levels by government activities. There is frequently an imbalance between supply and demand because demand is strongly tied to economic cycles, while supply is very inelastic over periods of less than a year because closedown decisions are costly and relatively irreversible.

The largest steel makers now have global footprints across the entire supply chain. The industry has consolidated over the past decade and is expected to consolidate further but remains quite fragmented with the top 10 producers responsible for only a quarter of production. AccelorMital is the largest (9% of production) followed by Nippon Steel (3%), JFE (3%), POSCO (2%) and Baosteel (2%).

Materials dominate production costs for blast furnace and electric arc furnace production

Typical cost structure for steel production by technology



Note: Approximate data only.

1. Data shown for hot rolled steel only.

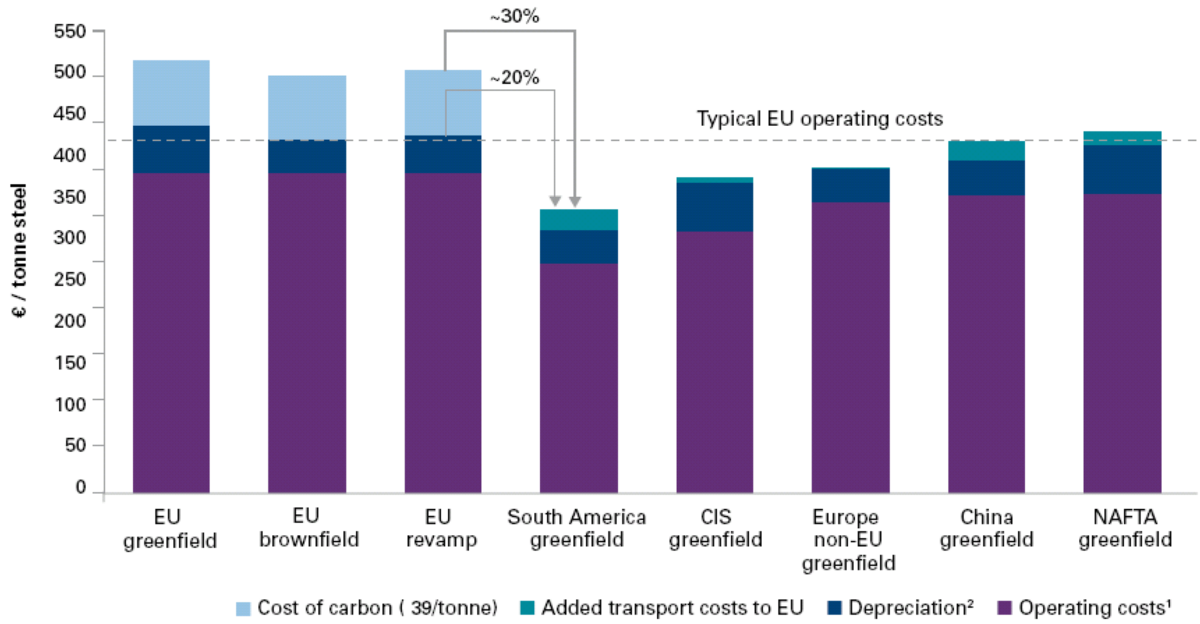
Source: WSD World Cost Curves, September 2008.

Steel is produced using three main approaches: blast oxygen furnace (65%); electric arc furnace including DRI-EAF (32%); and open hearth (3%). Open hearth is an obsolete technology and industry reports suggest it will be mostly phased out within the next decade at most. Electric arc furnaces use electricity to recycle scrap steel and generally produces more of the lower quality long steel. Blast oxygen furnaces use iron ore and coke to produce steel, which is more frequently of the higher value flat steel.

Steel produced in a blast furnace costs in the order of $700/t. This disguises a large variation both across regions (20% cheaper in South America, 5% more expensive in Western Europe) and within regions (+/- 25%). Raw materials are the biggest cost (72%) followed by the cost of energy (8%). Steel produced in electric arc furnaces tends to be a little more expensive ($750/t) with even more stark variation in costs across regions (50% cheaper in South America, 10% more expensive in Western Europe). The economics of electric arc furnace production are driven by the cost of scrap material (80% of costs). Given that all available scrap steel tends to be used, this implies that suppliers of scrap set their prices in order that, wherever possible, it is used in place of virgin steel.

Steel production costs vary widely between regions

The relative fully loaded cost of producing iron and steel in the EU compared with other regions. Indicative figures for comparison only.



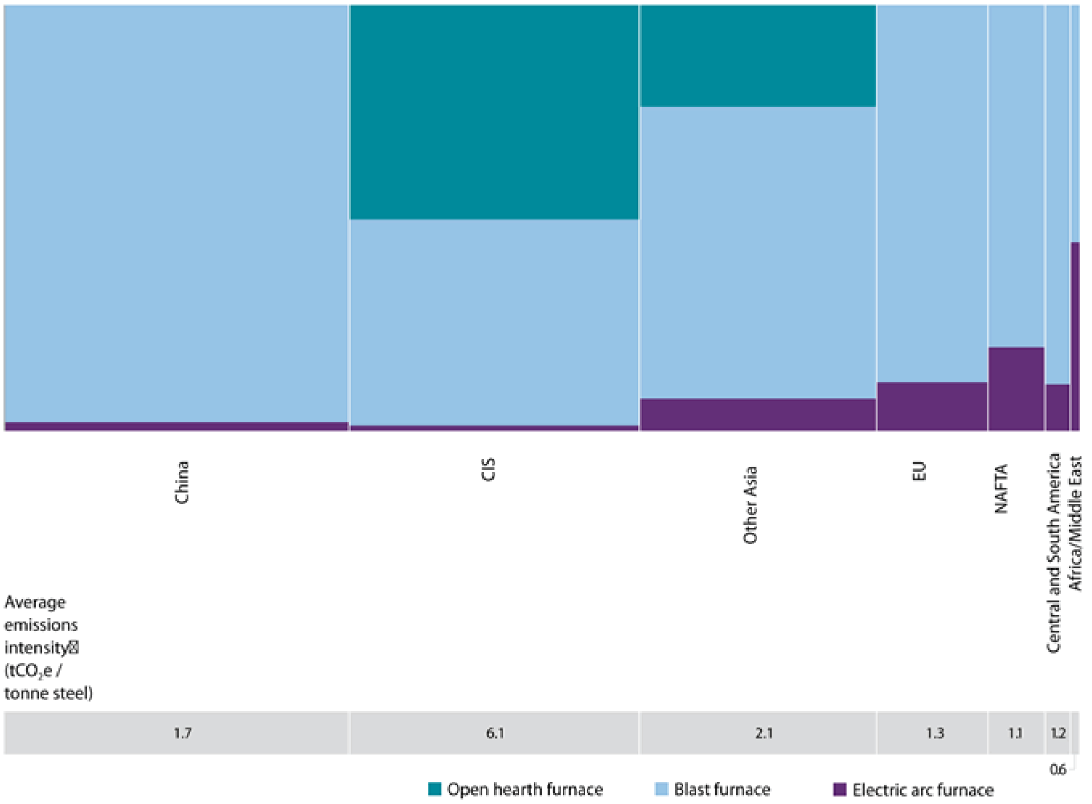
Note 1: "Greenfield" development refers to the construction of a new steel plant on a new site. Investment costs estimated at 3.5bn for greenfield development of 3mt capacity steel plant in EU and North America, with 30% lower investment costs in other markets
Note 2: "Brownfield" refers to building a new plant on an existing site. Investment costs estimated at 70% of greenfield investment due to savings on site development
Note 3: "Revamp" refers to significant retrofit of existing plant with new technology. Investment costs estimated at 40% of greenfield investment cost
[1] Operating cash costs are a weighted average for region
[2] Assumes straight line depreciation with 20-year lifetime for greenfield and brownfield development and 10-year lifetime for revamp of existing site.
Source: Carbon Trust and BCG Analysis; industry interviews; World Steel Database.

Developed world cap and trade systems, together with renewable incentives, have so far only been applied to reduce domestic production emissions. This does not help reduce the emissions associated with increasing imports of commodities and products from lower cost countries which may not take equivalent action to decarbonise their production. As the above Figure illustrates, the EU is one of the higher cost regions for production of steel, with South American production ~20% cheaper than the EU, even before a cost of carbon is applied. All else being equal, and irrespective of the cost of carbon, it is generally more profitable to locate new production outside of the EU and re-import due to lower operating costs. Once outside the EU, production sites will generally face less pressure to abate.

Whilst the Clean Development Mechanism (CDM) provides an incentive mechanism to reduce emissions outside of the EU, it is voluntary and its rules concerning additionality limit the extent to which the steel industry uses the mechanism to help reduce emissions. In addition, many end-products containing steel are imported in finished or semi-finished form, having been produced in countries which do not bear a cost of carbon.

Blast furnace emissions dominate global steel production emissions

Greenhouse gas emissions from steel production by technology and by region (global emissions 2.6GtCO_2e)



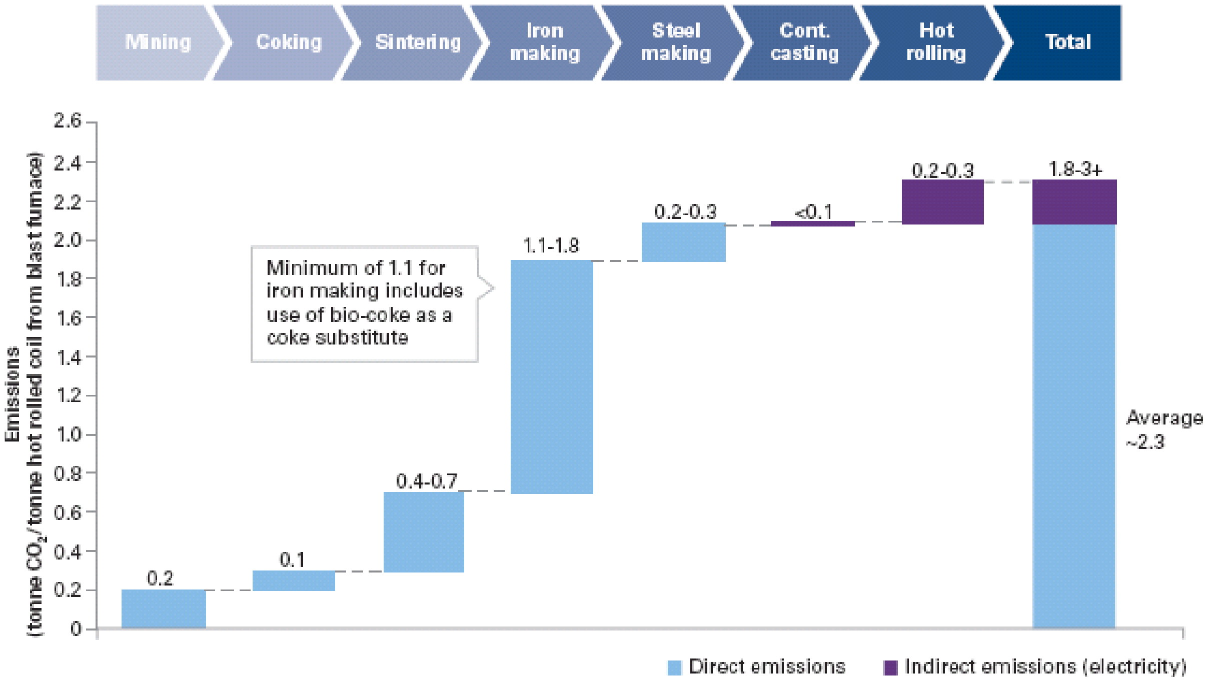
Note 1: Approximate analysis based on interviews and data on different types of technology penetration by region. Detailed data on the emissions intensity of individual plants not available.
Source: Carbon Trust & BCG Analysis based on data from: World Steel Association; Pathways to a low carbon economy (McKinsey & Co, 2009); World Steel Dynamics.

The carbon intensity of production of steel varies quite widely according to the technology used and the age of the plant used to produce it. Globally, emissions from blast furnace operations (figure above) dominate steel production emissions, with Chinese steel production emissions almost exclusively occurring from blast furnaces. Significant steel production occurs in the NAFTA region from the operation of electric arc furnaces (recycled steel produced using electric arc technology emits about 0.2–0.4 tCO_2e per tonne of recycled steel), while Africa and the Middle East have the highest proportion (on very low production levels) of emissions from electric arc furnaces. While production volumes from open hearth furnaces are low, emissions from this type of production are significant for CIS states (and, to a lesser extent, Other Asia countries) due to the carbon intensity of the process.

All current processes to produce virgin steel from iron ore involve the reduction of iron oxide by carbon, and therefore produce emission of CO_2 as an inevitable by-product of the process. New (virgin) steel is usually produced by either blast oxygen furnace (BOF), open hearth furnace plants (OHF) and occasionally in directly reduced iron electric arc furnace plants (DRI-EAF). BOF plants tend to emit between 1.8 to 3.0 tCO_2e per tonne of virgin steel produced. DRI-EAF plants emit 2–3 tCO_2 per tonne of steel when using coal and 0.7–1.2 tCO_2/t steel when using gas. Some old, inefficient OHF plants emit more than 12 tCO_2e per tonne of virgin steel. The distribution of emissions across regions and technologies is illustrated in the above Figure.

Direct emissions from iron making are the key driver of GHG emissions from blast furnace production

Greenhouse gas emissions by step in the blast oxygen production of steel

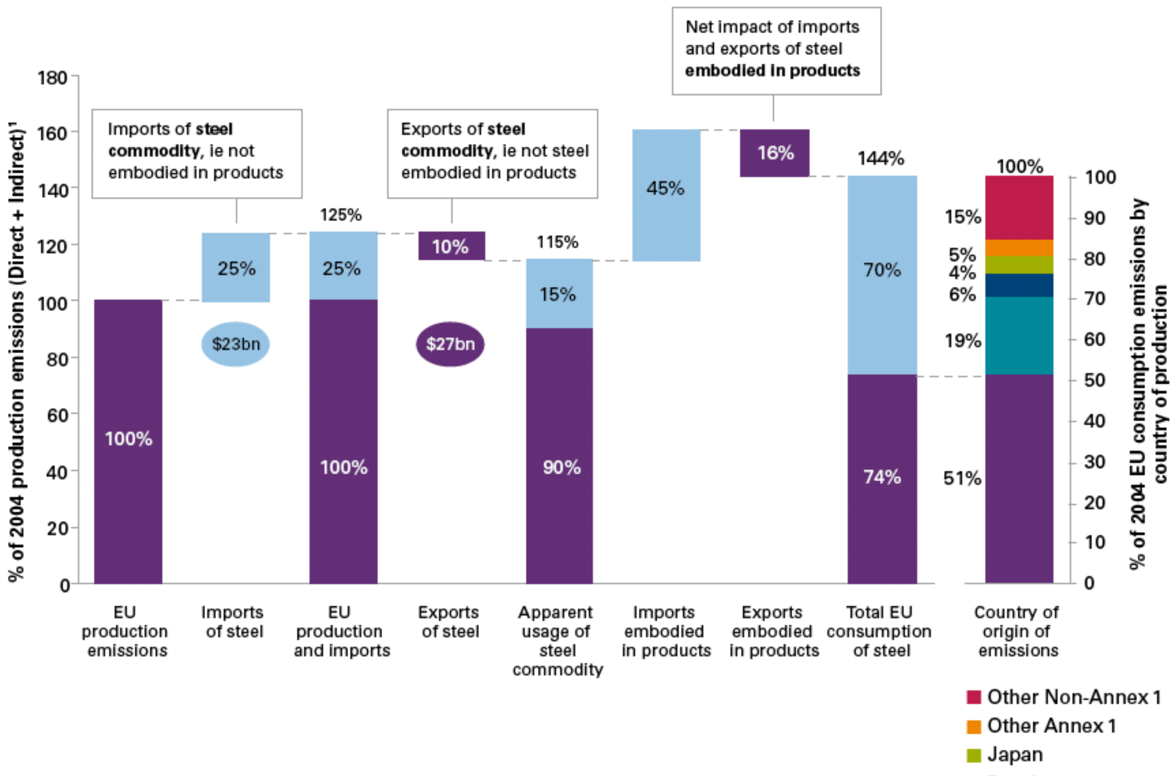


Note 1: Approximate data only.
Source: Carbon Trust Analysis; BCG Analysis; Industry interviews.

Emissions from electric arc plants are mostly indirect – they are not emitted by the plant, but by the electricity generators providing the electricity to power the process. Conversely, emissions from BOF plants are mainly direct process emissions, primarily arising from the reduction of the iron ore by the coke and oxygen in the blast furnace using coke. As can be seen from the above Figure, the most significant step from a greenhouse gas perspective is the iron making (~55%) followed by the sintering of the iron ore and coke (~13%), steel making and the hot rolling of the finished steel (~12% each), and the mining of iron ore (~9%).

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

Ratio of EU iron and steel 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: Carbon Trust Analysis; CICERO / SEI / CMU GTAP7 MRIO/EEBT Model (2004).

Imports of commodity steel into the EU ETS increases the sector's emissions footprint by 25%. After accounting for exports, from an emissions perspective, EU consumption of steel commodity is 15% higher than domestic production. Once the trade in complex products is accounted for, the total emissions associated with EU consumption of steel is 44% higher than the emissions that fall within the EU ETS, and only just over a half of such emissions are associated with steel production that occurred within the EU and which are therefore covered by the EU ETS. It is worth noting that the values in the above Figure (and throughout all of our analysis of traded emissions) have been calculated on the basis that the emissions intensity of steel imported into the EU is equal to the average of the emissions intensity of steel production in the exporting country. In other words, a typical bar of steel produced in the Ukraine for export to Germany is the same from an emissions perspective as a bar of steel that is produced in Ukraine for domestic consumption. In the context of iron and steel, this means that EU steel imports are three times more carbon intensive (by unit value expressed in US$) than steel produced within the EU.

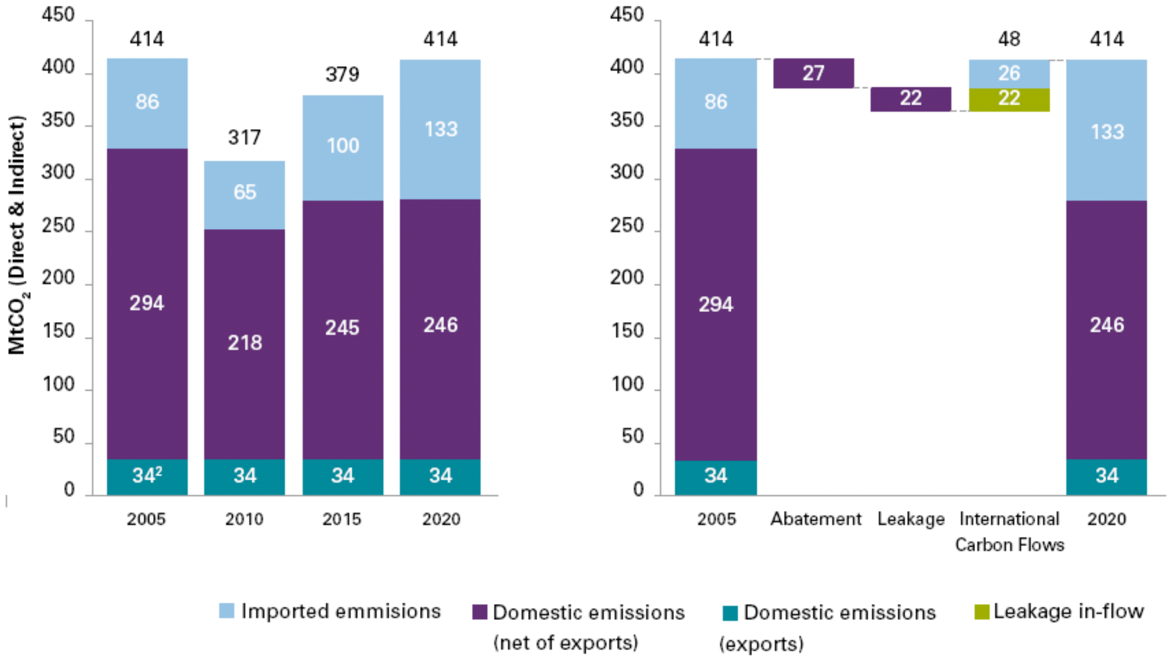
In reality, countries may only export their higher value and higher quality steel, which is likely to be produced in more modern, less carbon intensive steel plants. This effect will be particularly strong for steel exported from the CIS, where, as can be seen in earlier charts, due to the number of old open hearth plants the average carbon intensity of steel production is over 4.5 times higher than in the EU. However, even if we assume that all steel exported from the CIS comes from steel plants with an average carbon intensity of 2.1tCO_2/ tonne steel (the global average for blast furnace steel) versus the CIS average of 6.1tCO_2/tonne steel and also that Chinese exports are 20% less carbon intensive than the average of domestic production (based on moving from average to best practice carbon intensity) the EU would still consume 30% more carbon embodied in iron and steel than it produces.

There has been much focus in recent years on estimating the extent of potential 'carbon leakage' – in which European energy intensive business may be competitively forced out of Europe to less regulated geographies which do not bear such a high, or any, 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 emissions up to 2020 without any mitigating actions (see *Tacking carbon leakage: Sector-specific solutions for a world of unequal carbon prices*, Carbon Trust.) However in the steel sector there is evidence to suggest it could be up to 8%, and across Steel, Aluminium and Cement, on average 7%.

Whilst a carbon price might exacerbate the competitive position of steel companies in Europe, there is already a strong economic case for further migration of production, in particular of new plants, outside of the EU. In the context of a future doubling of global steel production and consumption over the next 40 years, there is a strong possibility that European steel production will not grow significantly above current levels, whilst steel consumption within Europe continues to rise. This scenario could enable the industry's emissions to remain within the overall cap, whilst growth continues apace outside of the EU, enabling rapid growth in overall consumption-based emissions within Europe.

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

(Left) Evolution of EU iron and steel production and consumption; (Right) Drivers of change between 2005 and 2020 emissions



Note1: Assumes no decarbonisation of intensity of imports 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. Production baseline based on EU emissions from iron & steel production as reported in 'Pathways to a Low Carbon Economy' (McKinsey, 2009).
Source: Carbon Trust Analysis based on data from: Pathways to a Low Carbon Economy (McKinsey & Co, 2009); Addressing leakage in the EU ETS: Results from the Case II Model (Climate Strategies, 2009); CICERO / CMU / SEI GTAP 7 MRIO/ EEBT Model (2004).

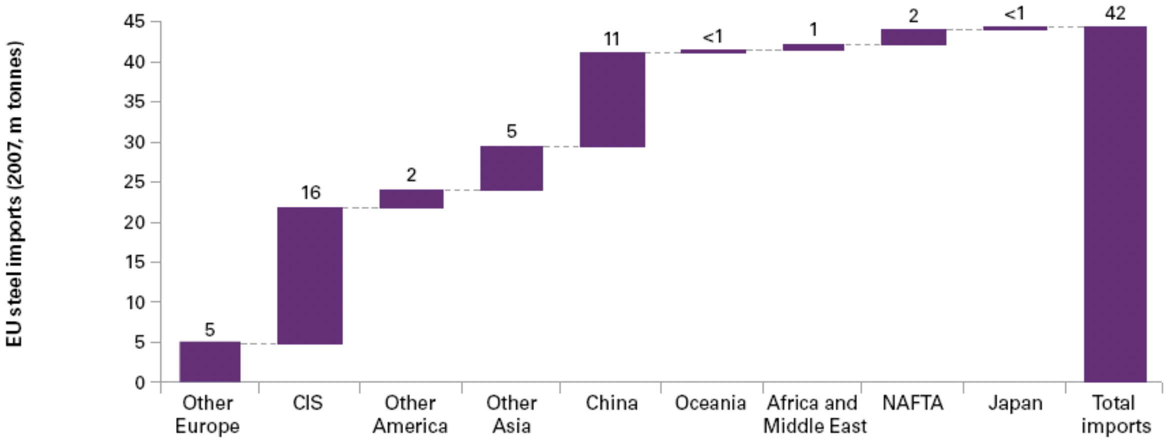
One scenario for future iron and steel emission consumption in Europe is illustrated in the above figure, for the period 2005 – 2020. In the period 2005 – 2010, both European steel production and imports fell rapidly, driven by the global recession and reduction in demand in steel intensive industries such as construction and automotive.

Over the next 10 years, demand for steel is expected to recover, driving growth in overall consumption. However, the majority of this demand will be met by growth in imports, with slower growth in domestic production. In the scenario illustrated above, production emissions are capped at 15% below their 2005 level (the expected contribution from the steel industry to the declining ETS cap – see *Tacking carbon leakage: Sector-specific solutions for a world of unequal carbon prices*, Carbon Trust) while consumption is held constant due to a ~50% increase in imports.

Significantly, the right hand side of the above figure illustrates that the growth in imports due to increased 'carbon flows' associated with imported production is greater than the impact due to leakage (i.e. that arising from the direct result of the carbon price).

CIS countries are the largest exporters of emissions embodied in iron and steel to the EU

Share of exporting countries' iron and steel that is destined for the EU



	Other Europe	CIS	Other America	Other Asia	China	Oceania	Africa and Middle East	NAFTA	Japan
Proportion of exporter regions' total production	14%	13%	5%	3%	2%	2%	2%	1%	<1%
Proportion of exporter regions' total exports	40%	24%	15%	10%	17%	13%	9%	9%	1%

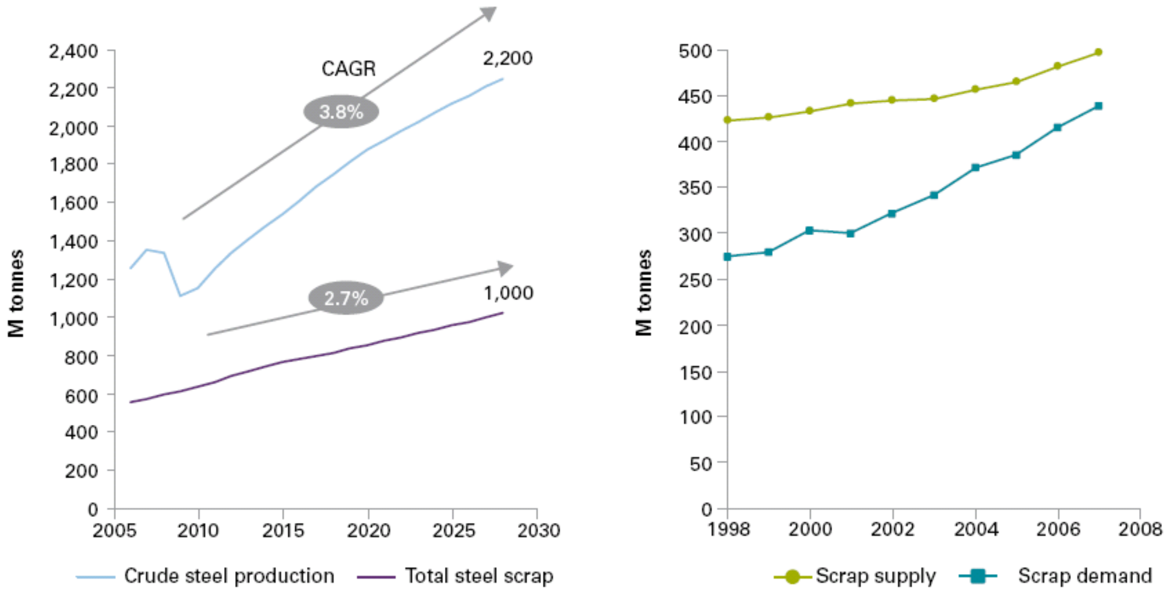
Source: World Steel Association, World Steel in Figures (2007).

Measures to reduce the carbon intensity of steel imports are likely to help to reduce the EU's overall consumption of carbon, and therefore to reduce global emissions. However, they may not have a significant effect on the overall carbon intensity of production in other markets.

For many such markets, the proportion of production destined to the EU is 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), up to 40% of domestic production is bound for export to the EU and so measures to reduce the carbon intensity of imported steel would have a significant effect on all production.

Steel scrap is increasingly available, and increasingly used, to satisfy consumption of new steel

(Left) Growth in scrap availability versus crude steel production; (Right) Utilisation of available scrap

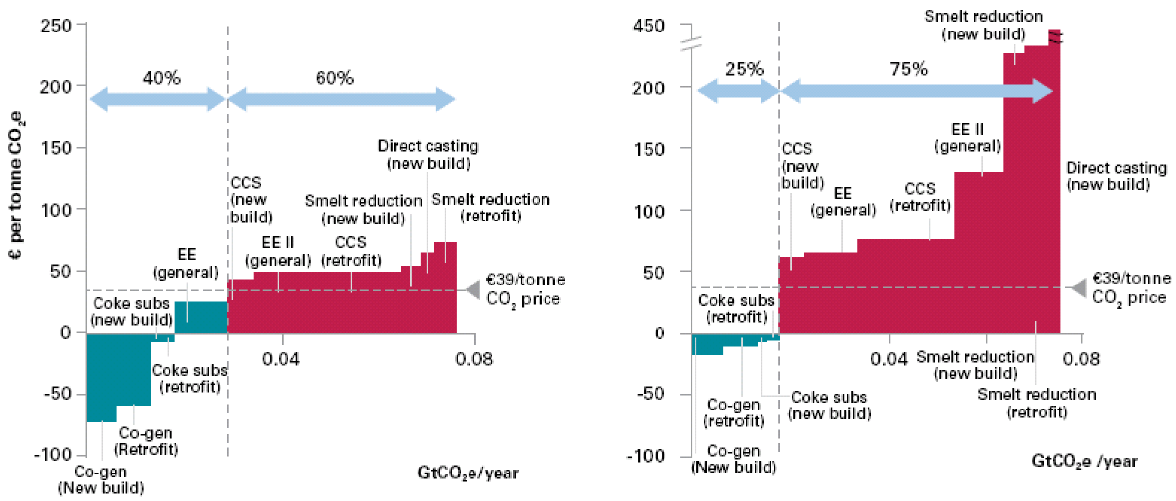


Source: BCG Analysis, Worldsteel Committee on Economic Studies (2008).

In searching for ways to reduce the carbon intensity of steel production globally, it is tempting to try to raise the proportion of recycled steel made from scrap via the electric arc furnace process. However, there are limits to how much more steel can be successfully recycled. Growth in scrap steel is slower than growth in total production. Also, scrap demand is getting very close to total available scrap supply, indicating that already a very high percentage, perhaps as high as 80-90% of all steel scrap is already recycled globally. This figure will be even higher in some countries, whilst others may offer some recycling opportunity.

Near-term and longer-term emission reduction opportunities for steel are heavily dependent on carbon price and discount rate assumptions

(Left) Abatement cost in 2030 (social discount rate, 4%)[1]; (Right) Abatement cost in 2030 (project discount rate, 15%-20%)[2]



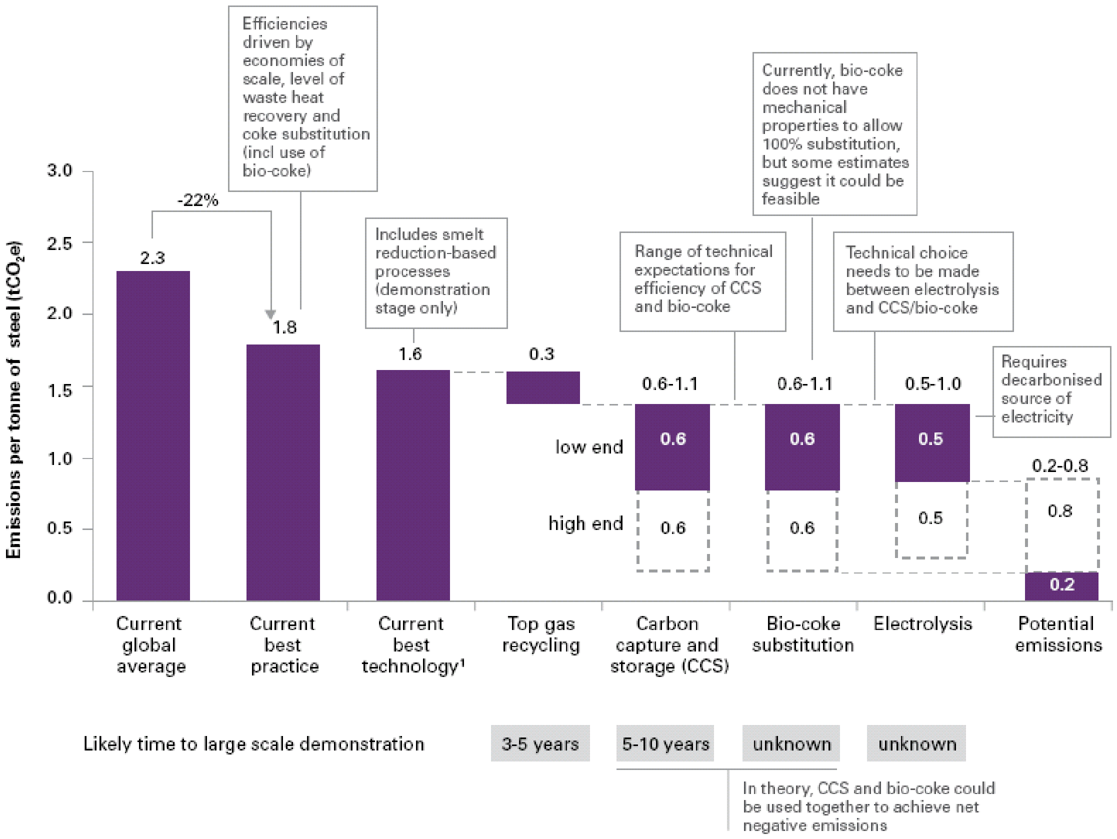
1. Social discount rate set at long term average government lending rates (4%) 2. Project discount rate set at typical cost of capital for investment projects for corporates (15-20%).
Note 1: Cost data does not include taxes, potential subsidies.
Note 2: Co-gen: Co-generation; Coke subs: Coke substitution; EE: Energy Efficiency; CCS: Carbon Capture & Storage.
Source: Pathways to a low carbon economy (McKinsey & Co, 2009); BCG Analysis.

The various available nearer term emissions reduction opportunities carry a cost, a number of which are illustrated in the above Figure in an industry 'marginal abatement curve'. A key assumption in this analysis surrounds the cost of capital used, or the 'discount rate', which can be thought of as the interest rate that would need to be paid on a loan to pay for any new equipment required. The left hand chart (above) uses a social cost of capital of only 4% and therefore shows much lower overall costs. At this rate, approximately 40% of the total abatement opportunity would be economic at a cost of carbon of €39/tonne – the highest cost of carbon in the EU ETS over the period to 2020 forecast by the European Commission. The right hand chart (above) uses a discount rate of 20% for breakthrough R&D projects (e.g. CCS), and 15% for investments to improve best available technology, which more closely reflects the level of interest rate applicable to industry funding of such projects. This more accurately reflects the cost of carbon required to make such actions break even. At this higher discount rate, only ~25% of abatement opportunities are economic at €39/tonne CO_2.

The cheapest actions are coke-substitution and onsite co-generation of heat and electricity. The most expensive changes are smelt reduction and direct casting. In-between lies carbon capture and storage. It should be noted that these costs assume that research has delivered the technology as predicted. As can be seen, there are few abatement opportunities that cost nothing (without policy-led incentives such as a cost of carbon). Therefore the industry needs some form of encouragement to take action and accelerate investments to further reduce the costs beyond that which can be achieved from basic energy efficiency improvements.

Deep reductions in the carbon intensity of iron and steel production are possible in the medium term

Technologies that can reduce carbon intensity of blast furnace steel



Note 1: Approximate data only.
[1] Current best technically achievable.
Source: IEA; BCG Analysis; Carbon Trust Analysis; industry interviews.

Improvements in the carbon intensity of BOF vary in their immediate technical feasibility. The most feasible reduction opportunities are a range of efficiency improvements, particularly around the use of coke and co-generation of heat and electricity, which manufacturers usually implement as a matter of course on new plants because they reduce costs. Modern best practice plants emit ~22% less CO_2e/t steel with operating costs of ~17% less per tonne steel and include use of combined cycle power plant (CCPP) technology. Further reductions require the use of alternative technologies, some of which are technically possible, but not currently cost effective. Broadly, these can be broken down into four categories: coke substitution, alternative coal based technologies, carbon capture & storage and electricity based steel-making.

1. Coke substitution: Bio-charcoal is currently used in iron making at a small scale in Brazil as a substitute for coke. A processed type of charcoal with enhanced mechanical stability is currently under development. Waste plastic can also be injected into blast furnaces and coke ovens to help reduce CO_2 emissions.

2. Alternative coal-based technologies: The main alternative coal based technology is smelt reduction. Smelt reduction reduces emissions by effectively eliminating the coking and sintering steps in the blast

furnace. The process has been successfully demonstrated at small industrial scale by POSCO of Korea (utilising the FINEX process) and in Australia (the Hlsmelt process) with efficiencies on par with the best blast furnaces.

3. Carbon capture & storage (CCS): the use of this technology on steel plants is probably around 10 years from commercial deployment and, if implemented, might halve today's average level of emissions. Top gas recycling, the process of separating the carbon monoxide (CO) and carbon dioxide (CO_2) emitted by blast furnaces and re-injecting the CO into the blast furnace is a critical step towards achieving cost effective CCS for steel and would itself reduce emissions by 13 – 20% on today's average level. It is worth noting that CCS does not eliminate all of the CO_2 emissions from integrated iron and steel making since substantial amounts are emitted from non-core processes (e.g. coke ovens, sinter plants and rolling mills), and it would likely be impracticable to fix CCS equipment on the full range of point sources of emissions at a steel works.

4. Electrolysis of iron ore would allow the transformation of iron ore into metal and gaseous oxygen using only electrical energy. However, this process is the least developed technology currently under consideration, and is unlikely to make a significant contribution in the next 20 – 40 years.

Combining the above technologies and taking account of overlapping or mutually exclusive savings gives the potential to reduce emissions per tonne of steel by ~70 – 90% over the next 20 – 30 years, if research and development delivers at the rate possible.

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