

Energy-Intensive Industries: Decision making for a low-carbon future

The Case of Steel

Peter Wooders

November 2012



**TRADE INVESTMENT
& CLIMATE CHANGE**

International Institute for Sustainable Development

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IISD's TRI-CC Program

This work is an output of IISD's Trade, Investment and Climate Change Program (TRI-CC). Related research will aim to deepen understanding of energy intensive industries, so as to better understand the effect of policies on these sectors. In particular, it forms part of an assessment of trade impacts of BCAs in developing countries, and will be followed by a complementary analysis of how BCAs affect exports from South Africa. Related research will aim to deepen understanding of energy intensive industries, so as to better understand the effect of policies on these sectors. Together, these analyses will inform research on the practical aspects of developing and implementing a BCA system.

Other similar areas of work in the TRI-CC Program include developing guidance for policy makers in elaborating and implementing BCAs, deepening understanding of climate policy for the steel and cement sectors, and work on emerging issues such as GHG-intensity standards and subsidies for green industrial development. Under TRI-CC's Investment and Climate Change theme, IISD will work with host country governments to develop policies that help catalyse flows of climate friendly investment.

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Key Messages

Steel remains a ubiquitous product, fundamental to the world economy. Globally, annual consumption of steel is projected to roughly double in the period to 2050.¹ To maintain greenhouse gas emissions (GHGs) from the steel sector at current levels over this period would therefore require halving emissions per unit of steel produced; reducing global emissions would require even more stringent reductions.

GHG emissions from steel are projected to increase globally. The iron and steel sector currently emits somewhere between 5 and 10 per cent of world GHG emissions, depending on the scope of the system considered and on the data used.² Reductions in the average GHG emissions per unit of steel produced globally are projected, but not of a sufficient scale to offset increases in production. Four categories of currently available GHG mitigation options, and two that could be developed in the future,³ drive these projections. The full implementation of each would yield useful reductions in emissions, though not sufficient to change the direction of the trend.

There is, at present, little firm evidence that current differential carbon pricing policies have altered trends in either production of steel from existing plants (where there is the potential for short-term leakage⁴) or investment location decisions (where long-term leakage could occur). This is to be expected: the only significant carbon pricing scheme to date has been the European Union Emissions Trading System (EU ETS), but⁵ steel plants in the EU have tended to receive allowances at around their levels of emissions and there is no clear indication that future carbon prices will be high or volatile.

The cost of emissions allowances under the EU ETS is a significant cost if these are paid for, but is less than the differences in average production costs between key steelmaking regions. A typical price of emissions allowances on the EU ETS is €15 per tonne of carbon dioxide (tCO₂),⁶ which would represent around 5 per cent of the value of a tonne of steel produced in a typical existing blast furnace or around 1 per cent of that from an electric arc furnace (EAF) using scrap steel. There are strong existing trends explaining why plants are built in different parts of the world—notably being close to sources of new demand (domestic and exports), having access to high-quality raw materials in sufficient quantities, and comparative advantages around costs of new sites and labour. A tentative conclusion can be drawn that carbon costs under current schemes may not significantly affect plant location decisions.

Far higher differences in relative production costs could result if one or a limited number of countries decided to make significantly deeper reductions in production emissions than those that would occur from using the best available current technology. Plants would need to employ breakthrough technology, potentially including carbon capture and storage (CCS). While costs remain unclear, they could be of the order of \$100/tCO₂⁷ or around \$200/t of steel produced from a blast furnace. This extra cost of around 25 per cent of the cost of standard steel is clearly of much higher significance than current carbon prices and we would expect this to be a major driver of plant location decisions if a limited number of countries or regions imposed the need for breakthrough technologies (either through a cap on GHG emissions or by regulation or standards).

¹ For example, the International Energy Agency (IEA) projects total production in 2050 of 2,300 million tonnes (Mt) crude steel (“low” scenario) and 2,800 Mt crude steel (“high” scenario) in 2050, from a baseline of 1,250 Mt in 2006 (IEA, 2009).

² In 2009, IEA Online statistics (www.iea.org/statistics) estimated that the world iron and steel sector was responsible for 5.2 per cent of emissions from fuel combustion. Other sources present estimates of a similar order of magnitude, with higher figures resulting if emissions from imported electricity and other parts of the life cycle—notably mining and freight—are included.

³ The four current categories are: 1. The closure of inefficient, highly polluting plants—such plants tend to be old and small, and may feature obsolete technologies or processes; 2. Improving energy efficiency and carbon efficiency at existing, non-obsolete plants; 3. Ensuring that new plants are built using best available technology; 4. Increasing the use of recycled scrap. Future options are the deployment of carbon capture and storage and the development of new steelmaking technologies.

⁴ “Leakage” is the increase in emissions outside a country due to a particular policy, divided by the reduction in emissions within the country due to the same policy (Intergovernmental Panel on Climate Change, 2007). Leakage reduces the environmental effectiveness of a policy.

⁵ Between 2000 and 2010, the EU-27 countries’ share of world crude steel fell from 22.8 to 12.8 per cent, with China’s increasing from 15.1 to 44.3 per cent (worldsteel Association, 2011)

⁶ The EU ETS is nearing the end of its second phase (2008–2012). The first phase spanned 2005 to 2007. Prices on the EU ETS for an “EUA” (1 tonne of CO₂) have been below €10/tCO₂ throughout 2012. Prices were around €15/tCO₂ in the years 2009–2011. Prices tended to be higher in the period 2005–2008, although they collapsed to close to zero in the second half of 2008. See, for example: www.bloomberg.com/quote/EUETSS1:IND/chart.

⁷ All prices are expressed in U.S. currency unless otherwise indicated.

In steelmaking we cannot state with certainty that there is any breakthrough technology that would significantly reduce GHG emissions and that could be immediately deployed on a widespread scale. This is in contrast to the power generation and automotive sectors, where we can identify decarbonized technologies that are available if investment were forthcoming—for example, renewable electricity generation and electric vehicles. There are many private and collaborative research and development activities underway. There has been only very limited experience of pilot CCS plants at steelworks. The research, development, demonstration and deployment (RDD&D)⁸ programs of the collaborative COURSE50 (Japan)⁹ and ULCOS (Europe)¹⁰ programs are targeting breakthrough technologies and initial results strongly suggest that CCS is very likely to be part of any technology that significantly reduces emissions.

It is not clear that current RDD&D arrangements, under current carbon costs, will develop and implement—as quickly as possible—the breakthrough technologies that the steel industry will need if it is to fully take place within the low-carbon economy. Current RDD&D generally includes a large role for companies in bringing technologies and processes to commercialization, with government funding supporting much of the more basic research. It is often stated by companies that they do not independently have the resources to develop breakthrough technologies and that the risks and costs in “going it alone” are too high; governments can also find it difficult to prioritize investments in large-scale demonstration programs given their other funding priorities.¹¹ Collaborative approaches such as COURSE50 and ULCOS allow the sharing of costs and benefits between organizations, and include, or plan to include, demonstrations.

Scaling up RDD&D activities such that breakthrough technologies are developed and implemented as quickly as possible is likely to require a more collaborative approach. This could be at the national level—COURSE50 includes several of the key Japanese manufacturers among its contributors—or at the international level. In either case, there will need to be a clear plan, targets of what the initiative is aiming to achieve and by when, and the necessary resources will need to be raised. This could all come from the government—as per COURSE50, although this money is raised from levies on industry—from companies (for example through a levy on production), or from both sources. The issue of hypothecation is a central consideration: if income is raised from the sector from carbon taxation or pricing, including potentially through border carbon adjustments, could—or should—some or all of this be returned to the sector to allow it to prepare for the low-carbon economy? Some steel producers also argue that the upstream iron ore miners, whom they now consider to benefit from much of the profit of the steelmaking cycle, should also contribute.

A life-cycle approach to use and disposal from upstream mining could ensure the benefits of steel to the low-carbon economy are not disincentivized. Steel is a ubiquitous product whose uses include railway tracks, wind turbine components and any number of products that mitigate GHG emissions. A life-cycle approach to GHG emissions reduction is advocated by many, including the World Steel Association (worldsteel Association, n.d.). The basic principle is to ensure that policy interventions are equitable across the supply chain, notably that parts of the economy whose production is regulated for carbon should be incentivized if their products reduce carbon emissions in unregulated parts of the economy. The steel sector points to the new steels that certain products need, and to the fact that the production of these steels requires more intensive processes, with higher associated GHG emissions per tonne of steel produced. There are considerable challenges technically and in designing the appropriate economy-wide incentives.

There is a need to debate and plan for the steps needed if deep cuts in the longer term are to be achieved. Carbon pricing alone is unlikely to provide sufficient incentives or certainty for companies to invest in the development and implementation of breakthrough technologies. The rate of technology turnover in the sector is low, and there remain only one or two opportunities to change the main plant technology before 2050. So what types of technology should the industry be investing in in 20 years’ time? And how can we ensure that the best set of technologies and options are available?

⁸ (Widespread) diffusion then represents the next step.

⁹ For more information, see: www.jisf.or.jp/course50/outline/index_en.html

¹⁰ For more information, see: <http://www.ulcos.org/en/index.php>

¹¹ For example, CCS plants in the power sector, where decisions on government funding (for instance, demonstration plants in the EU and United Kingdom) have been subject to a series of delays. Governments in mature markets also face austerity and wish to reduce their debt.

A “coalition of the willing” may be the best way forward in what is an internationally and nationally competitive steel market.

Relatively few countries dominate world production of steel—China, Japan, the European Union and Korea may all be amenable to ambitious plans. Brazil and India could be added to this list, but it is harder to include Russia and the United States. If a “coalition of the willing” were to agree to mutually move forward with developing and implementing new technologies, including CCS, this may represent the best chance of progress within competitive markets. There would be formidable, but not impossible, implementation challenges: production costs would be higher from plants with new technologies and CCS; investors could pass up these plants, countries within the coalition or the steel sector more generally; funds to finance new investments would need to be raised; and the competitive advantage of countries outside the coalition would likely need to be subjected to border charges or exclusions of market access, for both steel as a commodity and steel embedded in product. Introducing a carbon price for the steel sector would raise funds and would, to some extent, incentivize lower-carbon solutions.

The challenge of reconciling environmental performance while taking account of competitiveness and leakage concerns remains fundamental to how the steel sector could become part of the low-carbon economy. Forums are needed to take the debate forward.

Informed debate and discussion straddling the environmental and economic issues is necessary—but which forum(s) should host such debates? The United Nations Framework Convention on Climate Change has not, as yet, been able to focus specifically on single industrial sectors, and its sectoral approach debate has not considered economic issues in detail, nor has it considered competitiveness and leakage issues more generally. The Organisation for Economic Co-operation and Development’s (OECD) Steel Committee draws countries from all major steel-producing nations within and without the OECD, often supported by their industry associations and companies. The Steel Committee’s focus is on trade issues, and the level of understanding of the drivers facing the industry is very high. It has an environmental agenda item as part of all its biannual meetings, but this capacity would need to be strengthened. Alternative forums could also contribute to take the debate forward, and it is likely that the thorny issue of competitiveness and leakage—and the possible need to introduce remedies such as border carbon measures—would need to be debated seriously.

About This Paper

Carbon dioxide emissions from the steel sector are significant and growing: global emissions of carbon dioxide from fuel combustion in the sector increased by 61 per cent between 2000 and 2009, an annual average growth rate of 5.4 per cent.¹² Emissions are projected to increase in future years driven by ongoing growth in demand for steel, predominantly by developing countries continuing along their development paths (International Energy Agency, 2009). As such, the sector has been at the centre of the debate on policies to reduce emissions of carbon dioxide, particularly policies that introduce a price for carbon. Most recent discussions have focused on the possibility that these policies, as introduced in the European Union, damage national competitiveness and lead to relocation of production. To address these concerns, Phase 3 of the European Union Emissions Trading System has continued with the allocation of free allowances to the sector,¹³ and retained the option of including imports into the region in the scheme.

The effect of these policies is not currently clear, and is only likely to become so with time, if at all. This obviously poses problems for the policy-making process where evidence is valuable input to future policies. In the absence of this evidence, a good understanding of the workings and structure of the industry is more important than ever.

This guide is aimed at furthering understanding of how decisions are made within the industry and how policies may affect this decision-making process. The intent is to broaden the focus of current discussions to encompass the long-term decisions made by firms and to consider whether and how the investments required for the realization of a low-carbon economy could be supported.

¹² World iron and steel emissions from fuel combustion, as measured by IEA Online statistics (www.iea.org/statistics), were 933.65 million tonnes (Mt) CO₂ in 2000 and 1500.30 MtCO₂ in 2009. Emissions from fuel combustion from the whole economy rose by 23 per cent over the period 2000–2009.

¹³ Albeit with free allowances in Phase 3 (2013–2020) capped at the level of the best 10 per cent of performers in the EU and with emissions allocations set to decline further due to a reducing overall cap on allowances year-on-year.

Section One: Industry Issues—Setting the Context

Section One outlines the steel production process and links this to the drivers for decision making. This discussion is set in the context of empirical evidence on investment, production and trade. Box One introduces steelmaking and steel.

BOX ONE: AN INTRODUCTION TO STEEL

Steel is composed of iron, with carbon and other elements added (“alloyed”) to give it properties such as flexibility, strength and resistance to corrosion. Iron is found naturally within iron ore, and the production of steel needs to separate (“reduce,” in chemical language) the iron from the oxygen that makes it a stable mineral. This is the key part of the process for carbon emissions: commercial methods for reducing iron ore require large inputs of fossil fuels, with coal used for the vast majority of production within blast furnaces, which dominate production from the “primary” route (starting with iron ore). As a rough rule of thumb, the production of a tonne of steel from iron ore will lead to emissions of around 2 tonnes of carbon dioxide (tCO₂). Used steel can be recycled by melting, which is done on an industrial scale principally using electricity in an electric arc furnace (EAF). CO₂ emissions are around five times lower from this “secondary” route, with the specific value dependent on how much carbon is emitted when electricity is generated.

While there are a wide variety of different steels with an associated variety of properties, the vast majority of steel sold is of the relatively simple “bulk” variety. Speciality steels—such as stainless steel—have a relatively low market share by volume, and while they are significantly more expensive to produce, they do not lead to significantly higher emissions per tonne from their production.

The Value Chain

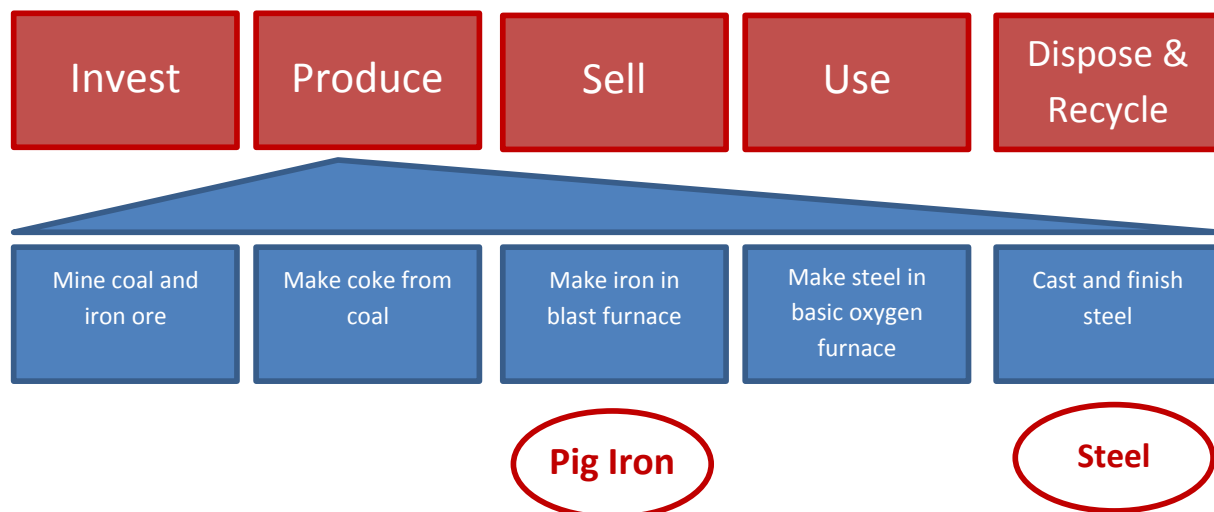


FIGURE ONE: STEEL VALUE CHAIN: PRIMARY ROUTE, USING A BLAST FURNACE

Produce: Making steel from the primary route—starting with iron ore—accounts for the majority of steelmaking worldwide (70 per cent in 2010) (worldsteel Association, 2011). Over 90 per cent of this steel—representing 65 per cent of total steel production from the primary and secondary routes¹⁴—is produced from blast furnaces, which use coke (coal with the impurities driven off) to reduce the iron ore and provide the heat needed to produce liquid iron. This “pig iron,” which contains high concentrations of carbon and is therefore very brittle, is then taken to a basic oxygen furnace (BOF) where oxygen injection drives out impurities and reduces the carbon content to target levels. Secondary steelmaking processes then impart specific properties to the steel and form it into the desired shape.

There are alternatives to the blast furnace-basic oxygen furnace (BF-BOF) route for primary steelmaking. Open-hearth technologies of varying sizes remain in some countries¹⁵ but the processes are obsolete—they use large quantities of fuel, mainly natural gas, and are heavily polluting—and are being phased out.¹⁶ Direct reduced iron (DRI) uses fossil fuels (coal or natural gas) directly in the iron ore reduction process. It has the advantage of allowing smaller plants that can still be competitive to be built, particularly in localized markets; on the other hand, the cost of fuel (gas or coal) is higher than for the BF-BOF route, and can be prohibitive. DRI accounted for 5 per cent of world production in 2010, with India accounting for over one third of production and Iran, Saudi Arabia, Russia and Venezuela being significant producers (worldsteel Association, 2011a). Steel produced from DRI using coal emits around 2.5 tonnes CO₂ per tonne of steel, around a quarter more than a typical blast furnace. Using natural gas sees emissions reduced to around 1.1 tCO₂ per tonne of steel. But DRI is not seen as an alternative to blast furnaces for large-scale production; rather, it is a niche technology, servicing local markets in India and in other countries where smaller plants can gain a good share of those local markets.

Invest: While costs vary by region, building a plant requires significant sums of capital, which is recovered over many years of operation. Blast furnaces—the main component of an integrated plant—typically have a minimum life of at least 25 years. Other components of a plant are typically refurbished or replaced as and when the economic case can be made. The high sunk costs and long investment cycles mean that the decisions made today have effects well into the future, and that these decisions are subject to significant analysis. This will involve consideration of location, capacity and technology to be deployed—each of these factors is discussed in turn in Section Two.

The BF-BOF route is capital-intensive and there are considerable economies of scale. A rough rule of thumb is that typical prices are \$700/t of capacity and, for a typical integrated plant size of 3 million tonnes per year (the capacity of a hot strip mill), a new steel plant will cost a minimum of \$2 billion. There are further diminishing economies of scale beyond this capacity, and they must be balanced against the inflexibility of having a very large plant in a single location.

In 2007 green-field investment costs in advanced countries were around \$1,750/t of capacity, with those in China under half of that (at \$800/t) and those in other developing countries around \$1,000/t (World Steel Dynamics, 2008). Brown-field investment costs—upgrading and extending existing capacity—depend on the specific case, but are considerably cheaper. The improvement of existing blast furnaces—notably increasing their capacity—has been a key factor. For 2007, figures of \$550/t (advanced), \$250/t (China) and \$375/t (other developing) have been quoted for brown-field investment costs (World Steel Dynamics, 2008).

¹⁴ The worldsteel Association (2011) shows 71.3 million tonnes (Mt) of iron (5 per cent of world production) produced by the DRI process in 2010.

¹⁵ There is a large stock of open-hearth furnaces at Zaporizhstal in Ukraine; see: www.zaporizhstal.com/en/about/production/furnace.

¹⁶ Open-hearth technologies represented only 1.3 per cent of world production in 2010, mainly from Ukraine and other parts of the Commonwealth of Independent States (worldsteel Association, 2011).

Discounting the costs of capital investments at a 10 per cent real interest rate over 15 years gives a capital requirement of \$60-130/t of steel produced from an average plant in the three groupings of countries shown above. This is roughly 10-20 per cent of the typical value of steel produced; it represents a significant part of costs, but is far from the dominant cost.

Investment in a plant depends on the strategic situation: in developing countries, it is linked to growth in demand in a country; in developed countries with mature markets, it is linked to strong cash flow. Figure Two shows new orders at U.S. steel mills collapsing with the financial crisis of 2008, at a time when steel prices also collapsed, quoting figures and analysis from industry analyst World Steel Dynamics' (Wooders & Cosbey, 2010) report that investment tends to follow cash flow with a two-year lag.

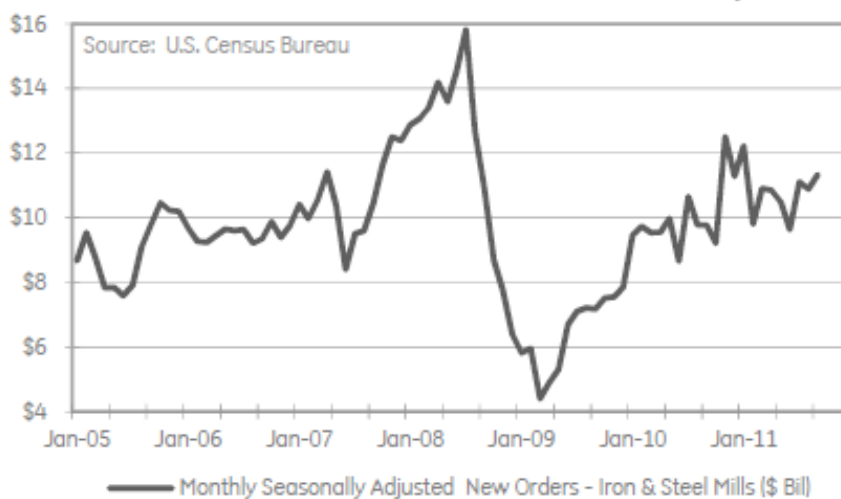
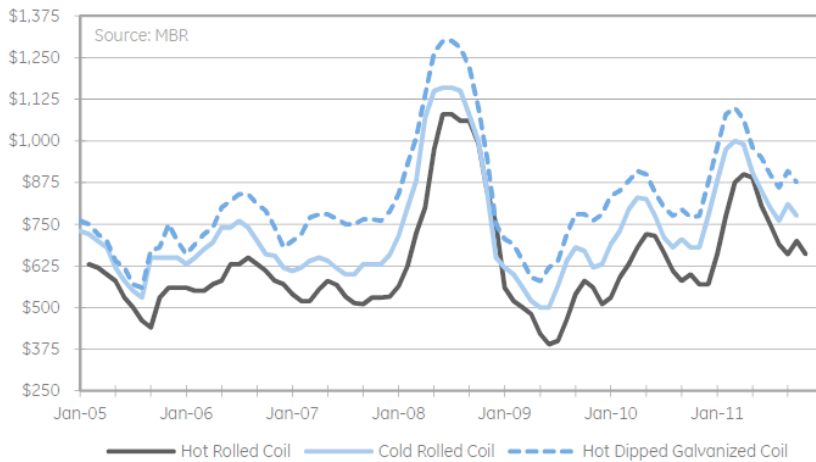


FIGURE TWO: NEW ORDERS FOR U.S. IRON AND STEEL MILLS

Source: GE Capital (2011)

Sell: Bulk steels are of two main types. “Long” products are typically general construction materials, such as wire rod and reinforcing bar (“rebar”). “Flat” products are often of higher quality, and include slabs and hot rolled coil. Both sets of products are highly traded internationally. As a rule of thumb, bulk steel typically retails for around \$600/t, although this price varies significantly across the economic cycle: bulk steel prices were around \$1,100/t at the market’s height in July 2008 but had fallen by over 55 per cent to under \$500/t by April 2009. The prices for both sets of products follow the same economic cycles.

U.S. Flat-Rolled Steel Prices (\$/ton)



U.S. Steel Long Product Prices (\$/ton)

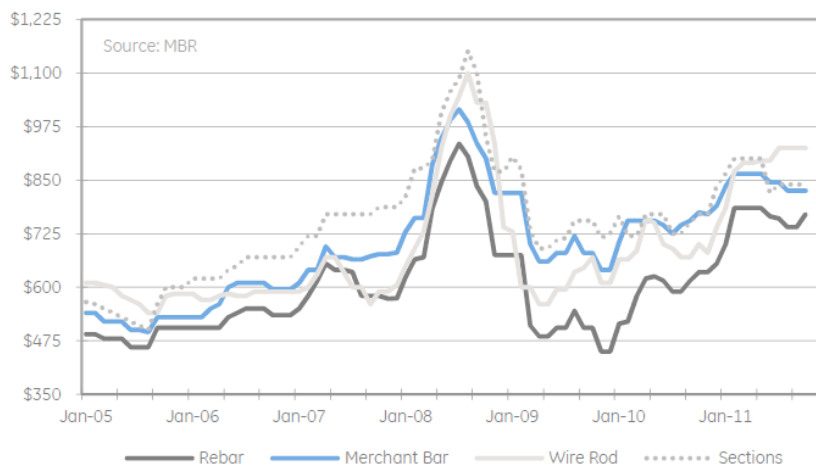


FIGURE THREE: PRICES FOR BULK U.S. STEELS, 2005–2011

Source: GE Capital (2011)

Levying a carbon price of €15/tCO₂ (\$20/tCO₂) on steel whose production led to the emissions of 2 tCO₂/tonne of steel would lead to an extra cost of \$40/tonne of steel. If the price of steel were \$600/t, this levy would add 7 per cent to the price. Speciality steels can sell for several times the price of bulk steel, and hence the percentage increase from a carbon levy would be lower in inverse proportion.

Prices for steel vary by location, but widespread trade and product homogeneity mean that these differences are relatively small. Steelmakers thus face a liquid and competitive market over which they have little pricing power. In previous decades, they were able to tie up long-term contracts for coal and, in particular, for iron ore. The markets for both these key raw materials are now much more short term in nature. For iron ore, three companies—Vale, Rio

Tinto and BHP Billiton—now control over 70 per cent of the iron ore market, of which 98 per cent goes to steelmakers. Typical contracts are now quarterly and spot markets are growing (e.g., SMX in Singapore). Steelmakers are therefore unable to protect their margins through long-term raw material contracts. A possible strategy for them going forward is to buy into upstream mining, and companies such as ArcelorMittal are currently investing much of their discretionary capital into mining.

The transport of raw materials such as iron ore and coking coal/coke for steelmaking represents a large part of the world transport volume of bulk dry goods.¹⁷ Within this, the transport of raw materials from Australia to China, and from Brazil to China, are key routes, and the subsequent export of part of the steel produced adds further transport demand. The decade 1998 to 2008 saw unprecedented increases in the Baltic Dry Index, a long-standing index of the costs of shipping bulk dry goods.¹⁸ Figure Four shows that the index rose by a factor of over six between 2000 and early 2008. Primary steelmaking per tonne of final product typically requires 2 tonnes of iron ore and 0.75 tonnes of coal;¹⁹ in 2007, with transport costs from Brazil to China at \$50/t and those from Australia to China at \$20/t (World Steel Dynamics, 2010), transport costs were becoming prohibitive. The Baltic Dry Index subsequently collapsed from its peak value of 12,000 to around 1,000, again making the strategy of relying on raw material inputs for production for export commercially sustainable.

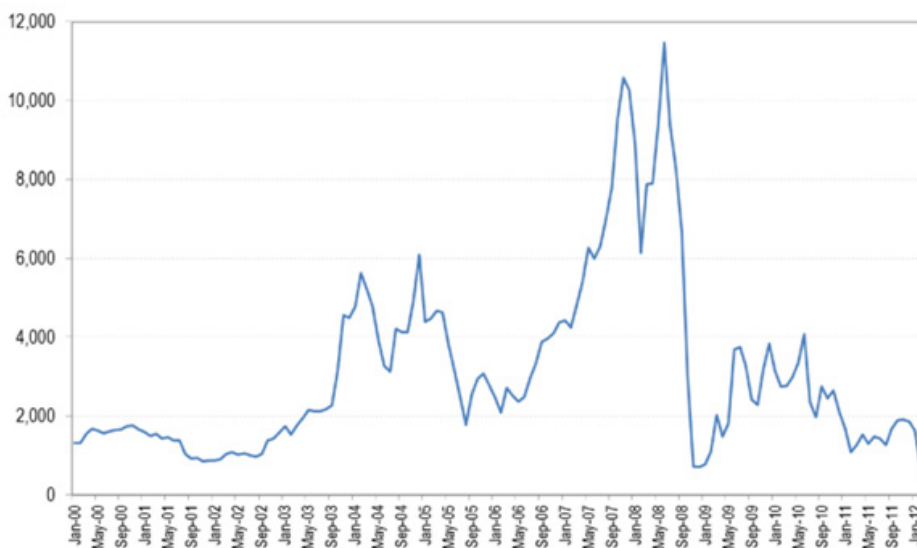


FIGURE FOUR: BALTIC DRY INDEX 2000-2012

Source: Bloomberg (2012)

¹⁷ The five “major bulks”—iron ore, grain, coal, bauxite/alumina and phosphate—represent around a half of all seaborne trade, and similar quantities of crude oil and products were shipped in 2010 (UNCTAD, 2011).

¹⁸ Iron ore, coal and wheat are key volumes of such trade. Other products, such as cement, take prices set by trade of the more dominant products.

¹⁹ See for example, www.worldcoal.org/coal/uses-of-coal/coal-steel/, which notes that the best blast furnaces in Japan consume around 700 kilograms of coal per tonne of steel produced.

For the blast furnace route, “steel no longer is a labour intensive industry—it is capital intensive and raw materials intensive and, one might even say, freight intensive” (World Steel Dynamics, 2010). Figure Five illustrates this: raw materials represented \$590/tonne of steel (70 per cent) out of an average global steel production cost of \$812/t around the peak of prices in September 2008 and \$323/t (55 per cent) of the lowered global average production cost of \$563/t in June 2009.²⁰ Of note is that net energy costs are around zero, with the value of selling by-products (notably coke oven gas from the production of coke from coking coal) offsetting energy purchases.²¹

These average figures disguise significant differences in average costs by country or region. A cumulative cost curve for 2009 around the average global price of \$563/t showed the average in the lowest-cost countries and regions—Commonwealth of Independent States and Mexico—around \$100/t below this average, and average costs in Canada and Japan around \$100/t above the average (World Steel Dynamics, 2010). With all costs denominated in U.S. currency, changes in exchange rates relative to the U.S. dollar can have a major impact. For example, the 10 per cent loss of value of a currency against the U.S. dollar would have had a similar impact on costs in 2009 for the average non-U.S. producer using the primary route as a carbon charge of €15/tCO₂.

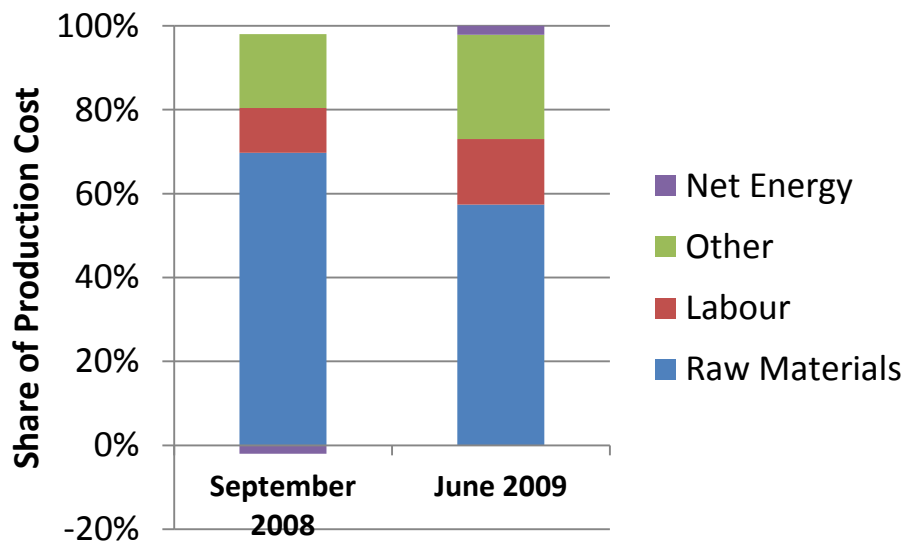


FIGURE FIVE: GLOBAL AVERAGE COST OF STEEL PRODUCTION, SEPTEMBER 2008 AND JUNE 2009 (WORLD STEEL DYNAMICS, 2010)

²⁰ Trends in steel prices were even more pronounced than those for production costs over this period (see Figure Three). In September 2008 profit levels were high historically; in June 2009 many producers were selling steel close to, or in some cases even below, the marginal cost of production.

²¹ The conclusion that energy costs are around zero applies to well-run, integrated plants with coking ovens and blast furnaces. Net energy costs for older, less-run plants—with many examples outside the Organisation for Economic Co-operation and Development (OECD)—may be substantial.

Use: Figure Six shows that the construction sector accounts for half of world steel consumption, with transport (notably automobiles), machinery and products accounting for the majority of the remainder.

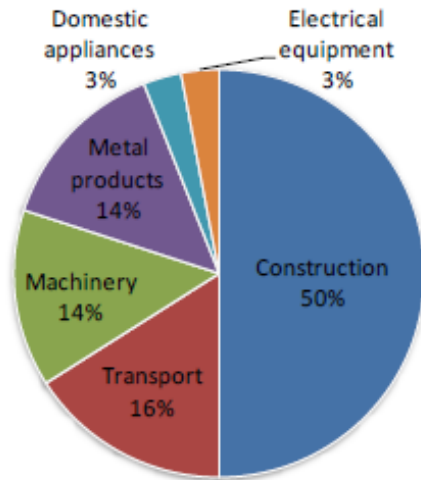


FIGURE SIX: WORLD STEEL CONSUMPTION BY CATEGORY (OECD STEEL COMMITTEE, 2010)

Source: OECD Steel Committee (2010)

Steel consumption tends to grow strongly as countries develop and they build up their stock of capital goods and infrastructure and increase their consumption of goods such as cars and white goods (refrigerators, washing machines, etc.). It then saturates. Thus consumption in Western Europe, North America and Japan was roughly flat over the decade 1998–2008, while consumption grew strongly in developing Asia. Chinese growth is notable, with the consumption of finished steel products increasing by 4.5 times over the decade 2000 to 2010 (worldsteel Association, 2011a; worldsteel Association, 2011b).²² Consumption in China is variously projected to saturate at some point in the period 2020 to 2040. For example, Zhou (2011) projects Chinese production saturating in the range 800–950 Mt steel between 2020 and 2050, compared to production of around 125 Mt in 2000 and 550 Mt in 2010. Chinese consumption would be of the order of 700 kilograms per capita at the saturated level.

Dispose and Recycle: In 2010, 28.8 per cent of world production came from EAFs (worldsteel Association, 2011). EAFs use an electric current to directly melt steel that was originally produced from a primary route (this primary route steel could be more than one re-use cycle ago). They are therefore recyclers relying entirely on scrap steel (arising from when goods containing steel are scrapped and from waste products from primary steelmaking). Because recycling avoids the need to produce coke and to acquire raw materials, scrap steel has a very high value, typically around \$200–300 per tonne less than bulk, lower-quality products. It is also notable that the BOFs used for steelmaking can also typically include up to 30 per cent of scrap steel along with the “primary” pig iron from the blast furnace. Scrap prices follow the same international cycle as primary steel production (see Figure Seven).

²² It then fell by at least a third in 2009, due to the impacts of the financial crisis, and is now recovering. For full statistics on steel production and consumption, see the annual Steel Statistical Yearbook series, and a summary annual *World Steel in Figures* series at www.worldsteel.org.

There is a strong trading market for all grades of scrap steel and this market is an international one. This allows certain countries—notably Turkey, which has built its relatively large EAF industry almost entirely on imported scrap—to use quantities of scrap steel in excess of their local production. It also means that a very large proportion of scrap steel is collected, with figures of over 80 per cent generally quoted worldwide. There is therefore very little potential for increasing scrap collection to reduce emissions on the global level. By changing where primary steel is produced, changing trading patterns for scrap would change the quantities of emissions from countries.

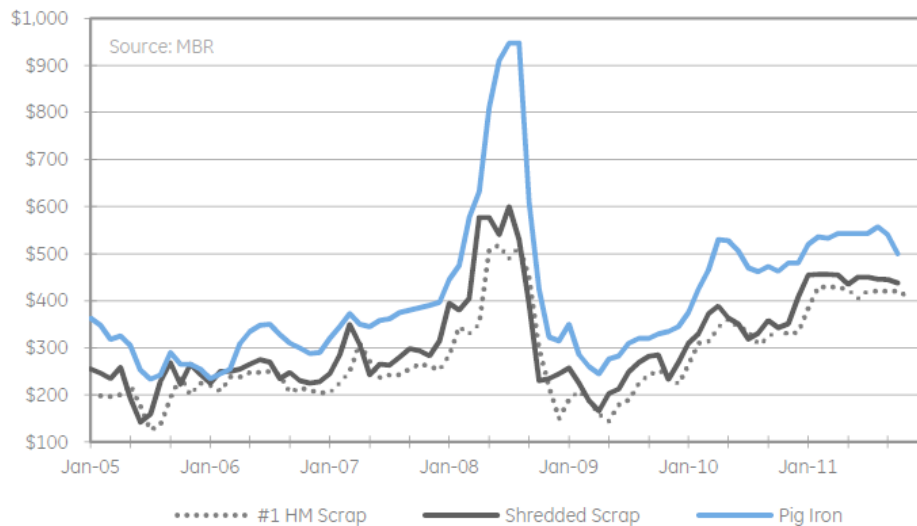


FIGURE SEVEN: U.S. STEEL SCRAP AND PIG IRON PRICING (\$/T)

Source: GE Capital (2011)

Scrap steel is created when goods such as cars and consumer goods reach the end of their life cycles and when buildings and other capital goods are demolished.²³ We therefore see relatively higher levels of scrap collected in countries where economies have been highly developed for long periods of time—for example, the United States and the United Kingdom—compared to countries that have been rapidly developing only recently, notably China. Given that the EAF process typically emits only around one fifth of the emissions—of the order of 0.4 tCO₂/tonne of steel (International Energy Agency [IEA], 2008), depending on how the electricity is generated—we would therefore expect countries that have more scrap steel available to have lower average emissions per unit of steel produced (see Box 2). The trade of scrap complicates the picture, with more scrap exported from countries that are physically close to others—such as the United Kingdom—compared to those that are more isolated, such as the United States.

²³ A smaller amount of “prompt” scrap is also generated from the primary steelmaking process itself and from subsequent stages of steel forming.

BOX TWO: WHY DO EMISSIONS PER TONNE OF STEEL PRODUCED VARY BY COUNTRY?

The availability of scrap steel is one of the main predictors of which countries have lower emissions per unit of steel produced. Another is the proportion of the small and/or obsolete plants that many developing countries still retain. Beyond these criteria, it is remarkable that new plants tend to be similarly specified across countries. We can therefore expect emissions per unit of steel to converge as countries develop, building new plants to meet their new demand and generating increasing rates of scrap. This convergence may take several decades for developing countries.

The majority of emissions arise from blast furnaces, and there do remain some differences in emissions from similar plants by country, with Japan keen to stress that its plants are more efficient than those in other countries. Looking only at large, relatively modern plants, there are two major reasons for differences in energy efficiency:

- Waste heat and gas recovery: The use of the energy and heat contained in recovered streams and gases from the blast furnace and coke oven (if part of an integrated steel mill) is standard practice in the most efficient plants and has been one of the main investments made under the Clean Development Mechanism (CDM).²⁴
- Better management of what is a very complex process, using technological and “soft” techniques.

Maximizing these two opportunities may result in the reduction of around 0.2 tCO₂/tonne of steel produced from similar plants with blast furnaces, or around 10 per cent of typical emissions (Wooders, Cook, Zakkour, Harfoot & Stiebert, 2009; Tata Steel, 2011).²⁵

Trends in the Industry—Empirical Evidence

Decisions made by firms are influenced by the broader trends in the industry. The following section examines production, investment and trade.

Production and Investment: Figure Eight shows that global steel production grew only slowly between 1970 and 2000, with production increasing from around 600 Mt to around 800 Mt. In the decade from 2000 to 2010, global production almost doubled, at an average yearly rate of around 5 per cent. The financial crisis of 2008 saw a reduction of over 100 Mt within a year, but the strong trend in global growth was then re-established (worldsteel Association, 2011).

²⁴ As of October 2009, 227 such CDM projects, which were expected to be validated, had been submitted. India and China had each submitted more than 100, with China representing 70 per cent of the expected generation of reductions (Wooders, Cook, Zakkour, Harfoot & Stiebert, 2009)

²⁵ Tata Steel has a target to reduce their emissions to below 1.9 tCO₂/tonne of steel in 2015 and below 1.7 tCO₂/tonne of steel in 2020, recognizing that “short- to medium [term] improvements are possible but are limited with current technology” (Tata Steel, 2011).

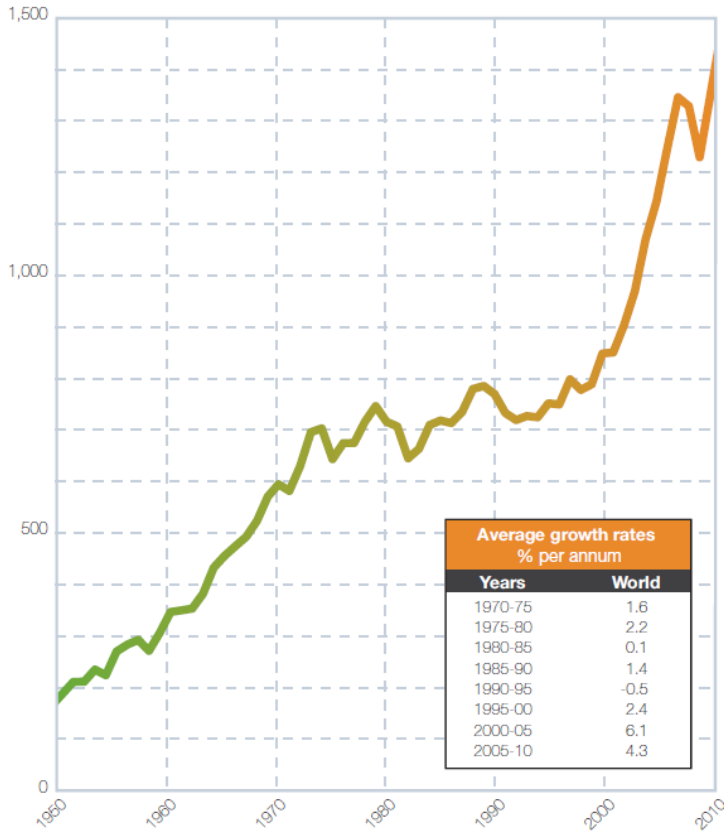


FIGURE EIGHT: WORLD STEEL PRODUCTION 1950-2010

Source: worldsteel Association (2011)

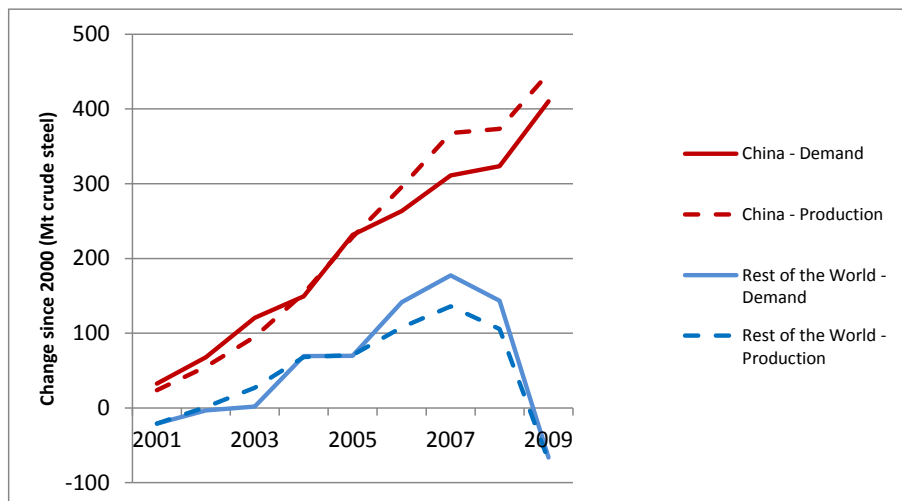


FIGURE NINE: CHANGES IN STEEL PRODUCTION AND CONSUMPTION 2000-2009

Source: Author, using data from OECD (2011)

The strong growth over the past decade has been driven by increased production in the developing world, notably in China. Figure Nine shows how production in China and in the rest of the world has changed since 2000. Production in the rest of the world in 2009 was similar to that in 2001; in China, it was 400 Mt higher.

Ownership has consolidated to some extent, but less than in many other industries and there remains plenty of competition globally. Forty-six worldsteel Member Companies produced over 3 Mt crude steel in 2010, with the largest production being ArcelorMittal's 98.2 Mt (representing approximately 7 per cent of world production) and the next largest being China's Bao Steel, producing 37 Mt (only a 2.6 per cent share of world production) (worldsteel Association, 2011)

Trade: Steel is widely traded, including internationally. In 2009 international trade of 326 Mt steel represented 26 per cent of production (worldsteel Association, 2011). Figure Ten shows that trade in 2009 was approximately 30 per cent below that in 2008, and that this decrease represented a significant break from the trend: it could have been expected that around 40 per cent of steel would have been traded in 2009 if trends had continued.

A further 80–90 Mt of scrap steel was traded between countries. Differential carbon prices would be expected, at first sight, to increase the value of scrap in regions with higher carbon prices, as the cost of producing steel from primary routes would increase. On the other hand, higher carbon prices will also increase electricity prices, making EAF production less competitive and incentivizing scrap to be used outside regions with higher carbon prices. To date, there has been little evidence that the European Union Emissions Trading System (EU ETS) countries have attracted more or less scrap steel to the region, but it is difficult to say that this has established a trend: carbon prices in the EU have been relatively low to date and producers have received free allowances approximately equal to the quantity of their actual emissions.

Quantum indices 2000 = 100

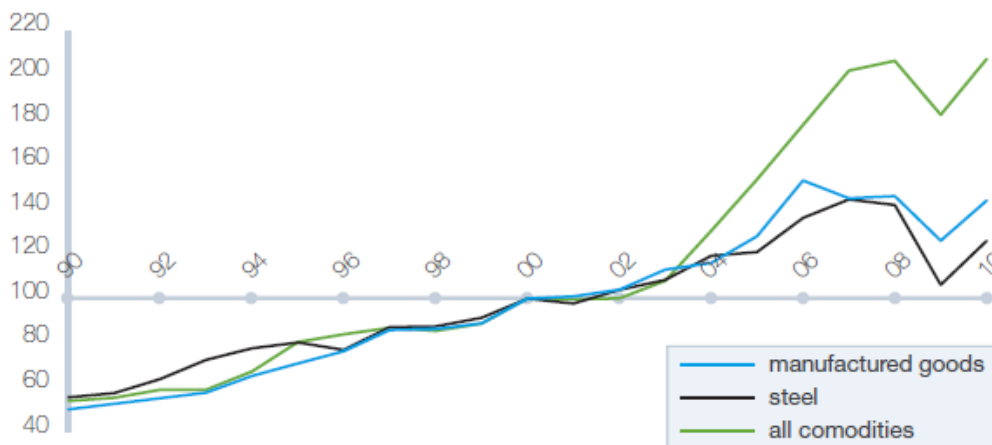


FIGURE TEN: TRADE 1990–2010

Source: worldsteel Association (2011)

Section Two: Decision Making

The following section assesses decision making in the short and long terms, highlighting the range of factors that are of importance, and how carbon policy links with these. In this context, “short term” is defined as the period in which the existing capital stock is fixed, with only minor modifications possible. In the long term, major modifications or new construction is possible.

Short-Term Decision Making

In the short term, a producer faces a number of decisions. Key among these are how much to produce and at what price, where production takes place and the method of production. The following discusses the drivers underlying these decisions.

The Quantity and Pricing Decision

It was previously noted that producers should have little pricing power, since there is a competitive world market and no producer has a high market share. But producers do have some pricing power: existing relationships between consumers and trusted suppliers often allow somewhat of a premium to be charged, and local market conditions over the very short term will allow some pricing power.

The main choice that producers have in the short term is whether or not to produce. Blast furnace economics are such that profits are only made at high-load factors (i.e., when the blast furnace is running at high loads for long periods). There are numerous examples of blast furnaces being mothballed for planned or open-ended periods, notably in Europe and the United States during and after the 2008-2009 economic crisis. The scale of mothballing during this period was unprecedented.

The financial crisis also demonstrated that significant cost savings could be made at existing plants. ArcelorMittal's experience is instructive. Figure Eleven shows that it was able to reduce its average costs of hot rolled coil production by around \$100/t between 2008 and 2009, noting that the proportion of savings from raw material price decreases was not stated; other steelmakers followed similar strategies. Reducing costs tends to exclude investment in new plants or processes, and may even ultimately end up in asset sweating, where investment in maintenance is reduced or delayed.

Annual average HRC production cost with overhead

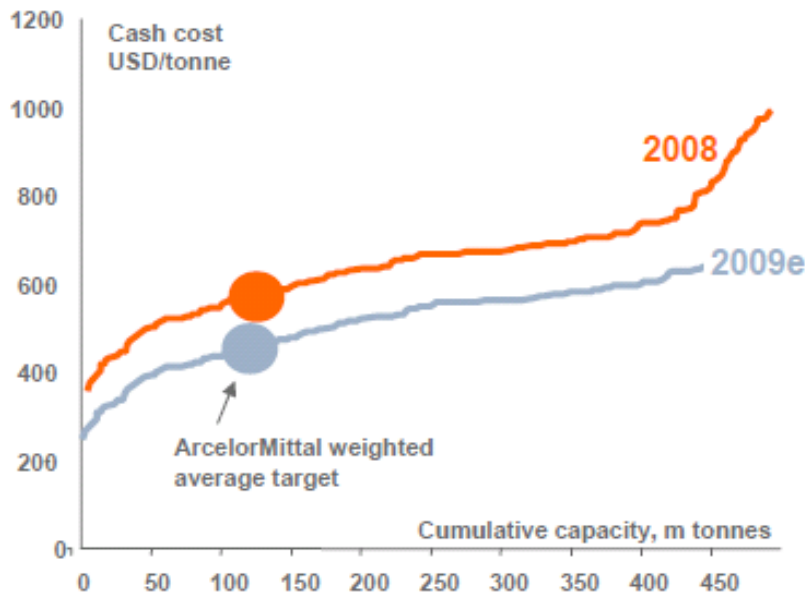


FIGURE ELEVEN: REDUCTIONS IN ARCELORMITTAL HRC PRODUCTION COST WITH OVERHEAD, 2008-2009

Source: Mittal (2009)

The Location Decision

Steelmakers continually invest in their integrated plants, refurbishing and replacing individual parts. They may also choose to make improvements, which may yield higher energy efficiency and/or lower GHG emissions.²⁶

There tend to be several opportunities to invest at any integrated plant, and steelmakers face the decision of whether to invest and, if so, at which location(s). They also have the option to invest in new capacity rather than to improve existing capacity, and this option is often preferred in rapidly growing markets such as China and other parts of Asia. One oft-stated barrier to improvement in the energy and carbon performance of existing plants is scarcity of investment capital, but it is not clear that making more investment capital available would necessarily mean more investments being made in these areas. Companies do have other priorities.

Expected, or potential, carbon prices in the future will be a factor in decisions, with certainty a key consideration. While there is little direct evidence to date that carbon prices have made much difference to the trends around investment, companies regulated under the EU ETS have made the point that it is part of their consideration.²⁷ Short-term net carbon costs have been low to date, but the possibility of higher, and uncertain, carbon costs in the future remains. Factors other than carbon are currently more pertinent to investment decisions, with examples highlighted by Steel Business Briefing in some of their monthly summaries (shown in Box Three).

²⁶ For example, Tata Steel recently invested around £60 million in a Basic Oxygen Steel (BOS) Gas Recovery system at their Port Talbot site in the United Kingdom, increasing onsite generation capacity from 61 megawatts to 76 megawatts and reducing annual CO₂ emissions by 240,000 t/year (Tata Steel, 2011)

²⁷ Note for example comments made at IISD's Trade, Investment and Climate Change workshop, Searching for Progress on Key Issues, held October 13, 2011: http://www.iisd.org/trade/crosscutting/tri-cc/conference_2011.aspx

BOX THREE: SELECTED EXAMPLES OF THE FACTORS THAT AFFECT FIRMS' DECISION MAKING ABOUT INVESTMENTS

March 2012

- Coking coal mergers and acquisition (M&A) activity rises in Canada's Peace River
- Question and answer with Raw Materials Group's Magnus Ericsson
- Focus: South Africa worries about ferrochrome export future
- Post-quake scrap recovery very slow in Japan
- Coking coal prices flat in March

July 2011

- Iron ore supply recovery timeline pushed back
- Posco looking to boost ferro-alloy sources
- Indian iron ore miners could be forced to shut down
- China more wary about overseas investments
- Indian scrap imports plunging

Source: Steel Business Briefing (2011, 2012)

The CDM under the United Nations Framework Convention on Climate Change (UNFCCC) has increased investments in certain carbon-reduction processes and equipment in the steel sector, notably those that involve waste heat recovery for subsequent electricity or heat generation.²⁸ Waste heat recovery is standard in new plants in all countries and has been retrofitted to the majority of plants that did not have it in developed economies.

The Technology Decision

Technology decisions in the short term will include only improvements on current processes and proven technologies, where capital and operating costs are known (Tata Steel, 2011). New blast furnaces include waste heat recovery, and the capture and use of coke oven gas and blast furnace gas, generally for power generation.²⁹ Coke dry quenching³⁰ and top-gas recycling turbines³¹ have been implemented under the CDM in some Chinese plants, and are increasingly considered for new plants.

²⁸ As of October 2009, waste heat recovery was the main technology for 77 per cent of iron and steel sector projects under the CDM (representing 88 per cent of expected reductions) and was a secondary technology in many others (Wooders, Cook, Zakkour, Harfoot & Stiebert, 2009).

²⁹ For example the 3.4 million tonne per year Blast Furnace #7 at NLMK's Novolipetsk site, Russia's first new blast furnace for 25 years, includes a co-generation plant (<http://www.steelnews.com/tabid/36/Doc/9442/Default.aspx>).

³⁰ Coke dry quenching uses gas in a closed system to cool down the red-hot coke from the coke oven. The conventional process uses water sprayed onto the coke, with the resultant steam (and the heat contained within it) released to the atmosphere.

³¹ A top-gas recycling turbine uses the high pressure and hot gases taken from the top of the blast furnace to generate electricity through an expansion turbine.

Long-Term Decision Making

The long term affords the opportunity to invest in new sites and new technologies. Pricing and quantity decisions—discussed above in the section on short-term decision making—are not considered in this section. The assumption is made that, over the long term, plants must cover their costs in full.

The Location Decision

Traditionally, steel plants have been built where there is access to good quality raw materials, strong and growing local markets, and sufficient demand to justify building a new plant (noting that the economic size for a primary steel plant is around 3 Mt/year). The key question concerning carbon leakage is whether differential carbon pricing and policy will alter this dynamic.

There have been exceptions to this logic. Turkey has based its production on importing scrap, largely serving its domestic market and nearby ones. It is a strong competitor in its regional market. Certain Gulf countries and Thailand have pursued growth strategies based to some extent on exports, often taking advantage of cheap sources of natural gas and new infrastructure (worldsteel Association, 2011b; OECD, biannual; Reuters, 2012).³² China has built up a sector that became a significant exporter from 2005, despite lacking sufficient high quality iron ore. Its move to become an exporter was driven by certain favourable domestic policies, for example the export tax rebates that were in place until recently. As evidenced at least in part by its removal of the export tax rebates, it is not clear if China wishes to satisfy more than its own market as a long-term policy; export volumes have been erratic since 2005 (see Figure 9).

Having a sufficiently large domestic market that is possibly supplemented by strong demand from close by markets (ThyssenKrupp, 2012)³³ is a key to the locale of new capacity. Here, developing countries are the most attractive to investors. Countries may also offer attractive conditions to investors as they build up their steel production capacity: the steel industry continues to be seen by many countries as a strategic one.

The key issue for carbon leakage is whether investment patterns will change if there are differential carbon prices, particularly if there are high potential upsides in the carbon price. It does not seem likely that choices about new capacity investment will be affected by differential carbon prices at their current levels or at the EU ETS's peak value to date (around €30/tCO₂).³⁴ What seems more important is to ask whether decisions about maintaining investments in plants, investing in new processes or extending capacity in regions such as the European Union, where low annual demand in growth combines with a carbon price, will be affected. At present, there is little evidence to show that trends have changed, but it is almost certainly too early to draw concrete conclusions.

³² Thailand's SSI, Southeast Asia's largest fully integrated steel sheet producer, invested \$1.1 billion in early 2011 to acquire Teesside Cast Products integrated mill (including a blast furnace) in the U.K. from Tata Steel, in order to meet its shortage of slab production.

³³ For example, ThyssenKrupp Steel invested nearly \$5 billion in November 2007 in the State of Rio de Janeiro to serve the North American market. Recent reports (May 2012) have them offering to sell the plant.

³⁴ For a detailed analysis of Austria, which is a representative EU example and where allowances granted to steel installations across the sector were at around their verified emissions over the period 2005–2009, see Wooders, Keller, Anzinger & Moerenhout (2011)

The Technology Decision

The following section considers only primary steelmaking. EAFs will continue to be used for scrap recycling, and the demand for scrap is expected to increase as carbon costs increase and as the costs for primary steelmaking increase.

An investor looking for which technology to employ in a primary steelmaking plant in the future can say with certainty only that those plants that are available today will also be available in the future. There are a wide variety of technologies for what may represent new or “breakthrough” technologies (see Box Four), but the capital and operating costs of these will depend on many factors. The ability to spread financial risk will be an important consideration, as is the assessment of future carbon price (Tata Steel, 2011).

When faced with the choice of whether to invest in a non-standard technology, a steelmaker will see downsides: the technology may involve extra cost, include unproven processes or techniques, and reliability and the optimization of the steelmaking process may also be cause for concern. First movers are likely to see disadvantages.

The Research and Development Decision

Again this section focuses on primary steelmaking using the blast furnace route: DRI is expected to remain a niche technology and the demand for scrap steel will strengthen.

If we start with the premise that new technologies need to be developed, demonstrated and deployed as quickly as possible, the key consideration is how this can be delivered. Traditional arrangements in the industry have seen research, development, demonstration and deployment (RDD&D) activities led by plant suppliers, with governments focusing their support on more fundamental research.³⁵ This model is now being questioned: the industry is asking whether they have the resources to invest in the development of fundamentally new technologies, and whether the upsides (lower cost production and selling the technologies they develop) outweigh the downside (the costs).

Uncertainties about the future costs of carbon complicate these considerations. Many organizations within the industry are asking for an increased government role in carbon reduction policy, including in funding demonstration projects. Such requests can be linked to the issue of hypothecation of government revenues—some companies argue that they contribute strongly through taxation and that at least a share of this revenue should go to assisting them in the transition to technologies with lower environmental impact. Such requests are strongest where companies are subject to carbon taxation or are under an emissions trading scheme; such claims are less robust in jurisdictions where carbon does not result in costs.

The “best available technology” for a blast furnace within an integrated plant includes waste heat recovery, gas recovery and possibly cogeneration, and can extend to coke dry quenching and top-gas recycling turbines. It will maximize the use of natural gas and direct coal use, have a sophisticated IT-based control system and emit 1.5 tCO₂/tonne of steel produced. Such technologies are readily available on the market. Suppliers and operators note that it is only with good management that the best efficiencies and carbon intensities can be achieved—sub-optimal management could see emissions rise by 0.1 tCO₂/tonne of steel or more.

³⁵ Note that plant suppliers and steelmakers still account for the majority of fundamental research.

Reductions beyond the current best available technology from primary steelmaking can be made in two main areas: developing ways to make existing steelmaking processes less carbon-intensive and developing entirely new steelmaking methods (Wooders, Beaton & McDaniels, 2011).³⁶

BOX FOUR: OPTIONS TO REDUCE CARBON EMISSIONS FROM PRIMARY STEELMAKING

1. *Improving existing processes.* “Biocoal”—a form of charcoal made from biomass—could theoretically be used in the blast furnace, but it lacks the mechanical stability of coke (which provides the physical structure within the blast furnace to allow the necessary chemical reactions to take place sequentially). Waste plastic is an alternative form of fuel that could be used as a small part of the required energy feed, much like natural gas, and the injection of plasma is considered by the IEA to be a proven technology that could result in 50 per cent lower emissions. The highest-profile technology to reduce the intensity of the existing process is the use of CCS, which is under serious consideration, but would need a redesign of the blast furnace to enable the separation of the CO₂ stream. A redesign would cost money in terms of investment and downtime, plus is not guaranteed to work as well as an existing technology. The subsequent capture, transport and sequestration of CO₂ would add at least \$40-60/tCO₂ (IEA, 2009), representing \$80-120/tonne of steel produced in a typical current blast furnace.
2. *New steelmaking methods.* FINEX and HIs melt technologies are examples of using coal directly in the blast furnace, avoiding the expensive and polluting coke production phase. They could reduce coal demand (and hence CO₂ emissions) by around 20 per cent. Both processes are suitable for carbon capture. Hydrogen plasma smelting reduction is an alternative to using coal, and is at an early stage of development. If the hydrogen were generated from a process with a low-carbon life cycle—noting that hydrogen is typically produced by the electrolysis of water—emissions could be very significantly reduced. Similarly, electricity could be used directly, through melting ore (as per aluminium and other metals). The IEA (2009) speculates that such technology is unlikely to gain a significant market share over the next 20-40 years.

Faced with a landscape where there is no clear technology that is proven, affordable and offers significant CO₂ reductions, companies and governments have reacted by initiating some joint research programs. Two leading examples are summarized below. Of particular note is that the options they are considering that would significantly reduce carbon emissions would all require CCS.

1. CO₂ Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50 (COURSE50) is a Japanese research program investigating innovative technologies for the reduction of carbon emissions in steelmaking. The program is run by the New Energy and Industrial Technology Development Organisation, an incorporated administrative agency largely funded by the Ministry of Economy, Trade and Industry. COURSE 50’s goal is to develop technologies that can reduce steelmaking-related CO₂ emissions by approximately 30 per cent (IEA, 2009). The aim is for the technologies to be “established” by 2030 and “industrialized and transferred” by 2050 (Japanese Iron and Steel Federation, n.d.). COURSE 50 is exploring two general routes for reducing CO₂ emissions in the steelmaking process: hydrogen reduction of iron ore and capture and recovery of CO₂ from blast furnace gases.

³⁶ This paper includes a full review of technology options and their status, drawing strongly from IEA (2009).

2. Ultra-Low CO₂ Steelmaking (ULCOS) is a cooperative research and development program investigating innovative technologies for the reduction of carbon emissions in steelmaking. It was begun in 2004 and is run by a consortium of 48 European companies and organizations from 15 European countries, supported by the European Commission (EC). ULCOS's goal is to cut CO₂ emissions by at least 50 per cent in comparison to today's cleanest steelmaking routes. ULCOS is exploring four general routes for reducing CO₂ emissions in the steelmaking process: (i) a top-gas recycling blast furnace (potentially combined with CCS or biocoke); (ii) Hlsarna, a combination of a melting cyclone and iron ore smelter (potentially combined with CCS or biocoke); (iii) a low-cost process for DRI using natural gas, in a project called ULCORED (potentially combined with CCS); (iv) electrolysis, in two projects called ULCOWIN and ULCOLYSIS.

Wooders, Beaton & McDaniels (2011) compare the costs of the COURSE50 and ULCOS programs in profit, capital expenditure and tax for Japan's largest four steelmakers, who produce around 75 Mt of steel per year. Average annual profit (EBIT), capital expenditure and tax receipts³⁷ over the period 2000–2009 are used as indicators of the resources available to the sector, noting that, in practice, companies may have uses and plans for the resources available to them, and that incentives may be required to raise resources to invest in increased RDD&D.³⁸ Figure Twelve compares the three indicators of potential resources available to the sector to various current and planned costs of the ULCOS and COURSE50 programs:

- Less than 1 per cent of any of the indicators of resources would be required to finance the costs of either of the two phases of COURSE50 or the first phase of ULCOS.³⁹
- Two to six per cent of the indicators of resources would be needed for ULCOS Phase 2, which includes a demonstration project.
- The "demonstration" projects have been discussed within the ULCOS program, and the figure extrapolates the costs of financing four CCS demonstration plants over a 10-year period and a €1.5 billion breakthrough technology demonstration plant. Two to five per cent of the indicators of resources would be needed for CCS demonstration, and 4–12 per cent for the ULCOS breakthrough technology demonstration plant.

³⁷ Estimated by applying the corporate tax rate to the EBIT profit measure.

³⁸ The industry will point to the challenges it already faces in finding investment capital in the volatile and cyclical steel market; companies weigh up the attractiveness of investing in developing markets against the challenges of investing in mature ones; governments would find raising funding challenging in mature markets at present. Implementation would then be far more expensive, potentially leading to the competitiveness impacts noted elsewhere in this report.

³⁹ These are hypothetical considerations; we would not expect Japanese steelmakers to contribute to ULCOS.

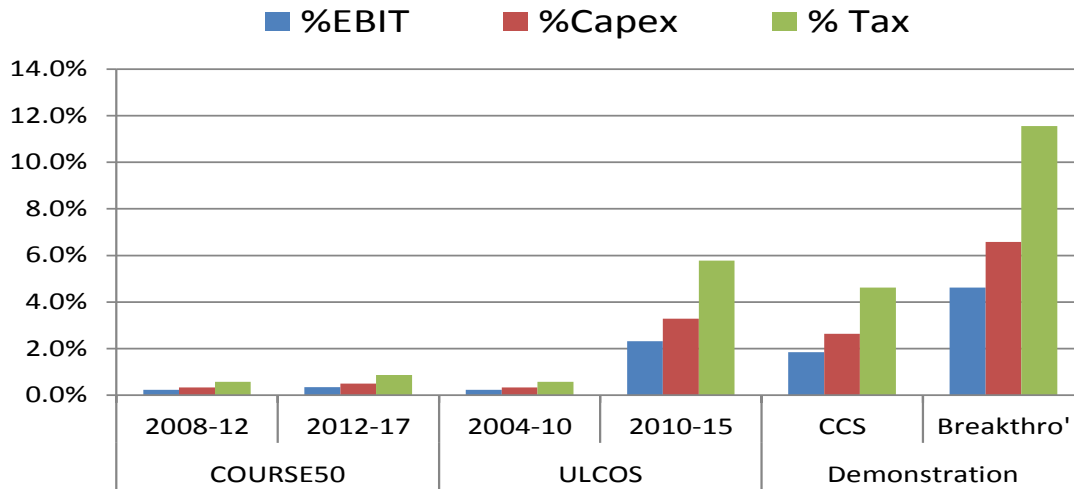


FIGURE TWELVE: COMPARISON OF RDD&D COSTS IN COLLABORATIVE PROGRAMS TO EBIT (PROFIT), CAPEX (CAPITAL INVESTMENT) AND TAX OF JAPAN'S FOUR LARGEST STEELMAKERS

Source: Wooders, Beaton & McDaniels (2011)

Several lessons can be drawn from these comparisons:

- It appears that the sector generates sufficient resources to finance research, development and demonstration. This does not suggest that either industry or government, or a combination thereof, should be responsible for this financing, nor does it detail how such resources could be raised in practice.
- It is not clear that the level of current and planned financing within programs such as ULCOS and COURSE50 is sufficient to guarantee that technologies will develop as fast as is possible.
- Moving to deployment would see a step change in costs; for example, CCS may cost at least \$40-60/tCO₂, whereas the options shown in Figure Twelve are in the range \$0.1-2.7/tCO₂ emitted.

Section Three: Questions for policy-makers

Policy-makers wish to balance the economic benefits of a strong steel industry with the need for the industry to significantly reduce its CO₂ emissions in the long term. This situation is complicated by steel's supply chain: policies to reduce CO₂ emissions should ideally take account of emissions and reduction opportunities in the upstream mining and transport of materials and, perhaps particularly, in the use and recycling of products made from steel. Adding further complexity and political difficulty, steel is heavily traded internationally, and thus efforts to make changes in one jurisdiction may be undermined by a lack of similar effort in others. Overcoming this issue through collaboration and/or protection is a key issue facing policy-makers. Finally, new technologies will be required, and the development of these may need radically new arrangements than those currently contributing to RDD&D.

How to Address the Environmental Impacts of Production

CO₂ mitigation options applicable in the short term can be placed into four categories:

1. The closure of inefficient, highly polluting plants: such plants tend to be old and small, and may feature obsolete technologies or processes.
2. Improving energy efficiency and carbon efficiency at existing, non-obsolete plants.
3. Ensuring that new plants are built using the best available technology.
4. Increasing the use of recycled scrap.

The barrier to the first option is often a social one, with relatively small plants providing economic opportunities in relatively small communities in developing countries. While the plants may be relatively high in cost, inefficient and polluting, they may be difficult to close down without alternative economic opportunities and/or compensation. This paper earlier noted that access to capital may constrain investments to improve energy and carbon efficiency at existing plants, but that this scarcity may not be reflective of a lack of capital available to the sector; plants may simply have more profitable opportunities, notably in expanding capacity. New plants tend to be built to the best available technology, and the economic value of scrap means that the majority is collected without the driver of carbon policy.⁴⁰ We can conclude that there are limited opportunities to increase efficiency, and that policies other than carbon pricing may be best to realize these. Conversely, it is also important to note that setting regulations around standards of plants or their emissions may be a costly solution to improvements.

As far as mitigating emissions from production is concerned, the longer-term challenge revolves around developing new "breakthrough" technologies and deploying them as quickly as possible. Part of this is a technical question: which technologies should be researched, how and at what institutions? But the financing and competitiveness questions cannot be ignored, both within countries and internationally. The experiences of Japan (COURSE50) and the European Union (ULCOS) show the forms that collaborative approaches may take. COURSE50 was publicly funded, and its expenditure is linked to the revenue from an environmental tax.

⁴⁰ There is therefore little mitigation potential in increasing scrap use relative to that which would be required by the sector to move to significantly lower carbon emissions.

There are many other ways in which collaboration could be organized and incentivized. One of the key considerations presently is to generate open and informed debate, including both economic and environmental expertise and viewpoints. This debate should include industry, regulators, policy-makers and outsiders with expertise. Appropriate forums for these discussions are required, and the OECD Steel Committee may represent a good option as one of these.⁴¹

Maintaining the Competitiveness of the Industry

There has been little empirical evidence that current carbon price differentials have caused production to relocate for short-term (production) or long-term (investment) reasons. This is not entirely unexpected. Economic theory suggests that producers in the EU ETS should factor the opportunity cost of carbon into their decision making (Wooders & Cosby, 2010); however, they received these allowances, and it is not clear they have done so to date. Allowances given free in Phases 1 and 2 of the EU ETS (2005–2012) have been at very similar levels to the emissions of the steel sector.

Simulation modelling, using a range of different techniques and assumptions, projects a range of changes to competitiveness and hence leakage. Reinaud (2008) summarizes studies showing that leakage rates could range from 0.5 per cent to 70 per cent in the iron and steel sector. Again looking at steel, a study by Gielen & Moriguchi (2002) on the steel sector in Japan and the EU-15 shows a doubling of the leakage rate from 35 to 70 per cent when the carbon cost applied is increased from \$11/tCO₂ to \$42/tCO₂. The results of these models depend on their representation of short-term and longer-term decision-making, and it is not clear how well these match reality. One of the principal objectives for this paper and the others in this series is to start to explore actual drivers of decision making, notably in the longer term, based on the premise that models available were not necessarily providing representations that industry would recognize and accept. Longer-term investment decisions tend to have a powerful strategic component, and therefore differ by market and by location.

A blast furnace with a capacity of 1.5 Mt per year, operating at an 80 per cent load factor and emitting 1.8 tCO₂/tonnes of steel would emit around 2 Mt CO₂/year. At a carbon price of \$15/tCO₂, this would represent a cost of around \$30 million per year if all allowances had to be purchased from the market or auction, compared to revenue of the order of \$720 million per year at a steel price of \$600/t. The key questions on competitiveness and leakage are:

- Is the cost of this proportion sufficient to change existing trends in production and investment?
- Does the possibility of carbon prices rising higher under an ETS create uncertainty that could also change decisions? Using the example above, a carbon price of \$50/tCO₂ would represent costs of over \$100 million per year, which would likely preclude investment in new bulk steelmaking capacity⁴² and would also likely reduce investment in maintenance to the minimum to keep plants open.

A wide range of literature has considered mitigating the potential impacts of competitiveness and leakage; this has been driven by the recognition that the impacts are considered by many to be significant, even if the evidence to support this is not always available or may be disputable. Granting free allowances is, in economic terms, a compensation measure.

⁴¹ See Wooders (2010) paper for full discussion and details.

⁴² Anecdotally, it is claimed that there will be no new coal-fired power plants in Europe principally because of the potential increase in future CO₂ prices.

What companies do with the income from selling these allowances is not as yet clear. They may choose to: invest in new plants in the jurisdiction with carbon regulation, support their product price in the jurisdiction, return money to shareholders, invest overseas, spend the money outside the sector entirely, implement any combination of the above or choose a different option or set of options.

Border carbon adjustment (BCA) has been much discussed as a possible remedy to concerns around competitiveness (of producers) and leakage (the reduction in net environmental benefits due to increased emissions elsewhere), although it has yet to be implemented. An important conclusion of the modelling simulations is that BCAs can provide protection for the sector in question, but at a higher cost to other sectors in the economy and to the economies of other countries. Recent work highlighting the flows of carbon embedded in the trade of goods internationally⁴³ concludes that carbon embedded in steel in products traded internationally is higher than those embedded in steel commodities traded internationally; a BCA that covered only commodity trades would therefore cover less than half of the carbon embedded in trade.

Sectoral approaches and standards and labelling have also been proposed as solutions to mitigate competitiveness and leakage impacts, but they would only do so significantly if they could affect the root cause of competitiveness and leakage impacts: differential carbon prices. It seems unlikely that schemes will be implemented that will impact carbon prices. Perhaps the exception would be if China, the world's dominant producer, were to introduce carbon pricing and then use its influence to build a group of key countries that would do the same or similar. This option is considered further in Section Four.

The impacts on competitiveness and leakage, and the calls for protection and/or compensation, will be much stronger if a country or region undertakes very stringent action, for example requiring CCS on all plants (perhaps starting with new plants) or setting an emissions intensity target at less than 1tCO₂/tonne of steel (beyond the capability of the current best-available technology, blast furnace). In this case, there must be the very serious possibility of leakage undermining the integrity of the stringent environmental policy imposed, and the need for protection of domestic production would be compelling.

The Place of the Industry in a Low-Carbon Future

The issue of considering carbon emissions across the steel life cycle has been much discussed. Certain studies and commentators highlight some of the specific applications where products made using steel have positive environmental impacts, such as wind turbines. The worldsteel Association (n.d.) has been highlighting the need for policy to apply equally across the life cycle: if environmental policies reduce the amount of environmentally friendly goods that can be produced, then policy-makers should have cause for concern.

Including full life-cycle concerns and incentivizing GHG reductions equally across the value chain are legitimate aims, but practice is more difficult than theory. Among the key challenges is the technical issue measuring emissions through different parts of the value chain; however, it is the philosophy of any scheme developed that needs more consideration. Advocates of steel receiving benefits for its downstream uses are, in effect, arguing that it is the steel that is the key input for the low-carbon application, rather than the inputs of other materials or of the finance put up by investors or the factors of production supplied. Downstream crediting was included in Japan's bilateral Hatoyama Initiative as

⁴³ See for example, Peters, Minx, Weber & Edenhofer (2011)

presented to the 15th Conference of the Parties in 2009, but Wooders (2011) argues that steel would receive benefits from increased demand for its product if, for example, renewables were supported by policies. Wooders (2011) also argues that the industry would have to demonstrate a compelling case that its activities had caused additional investments in low-carbon technologies than would otherwise have been the case under business-as-usual scenarios.

Perhaps the strongest case occurs when new steels are developed specifically for low-carbon applications. Here, a range of policies as alternatives to carbon pricing—for example, sustainable public procurement and the promotion of energy-efficient and renewables solutions—could incentivize the use of higher-performance steels, but it may also be necessary for policy-makers to consider specific incentives to the industry to assist it to develop and deliver such steels. The most important policy failure occurs when steel production is regulated for carbon but the steel produced reduces carbon emissions in unregulated parts of the economy.

The major alternative to the cleaner production and life-cycle options discussed in this paper is to reduce demand for steel. Allwood (2012) identifies five stages:

1. Using less metal by design
2. Yield improvement
3. Delaying product end-of-life
4. Re-using metal without melting
5. Reducing final demand for services

Allwood (2012) concludes on “the influence of policy”:

Many of the recommendations made in this chapter concern removing barriers to material efficiency, but procurement and the development of certification and standards are both positive options that would support its expansion. Government funded pilot studies and the subsequent use of Government purchasing to develop appropriate markets are important opportunities to stimulate constructive change.

Considerations are similar, albeit at a larger scale, to those considered in the life-cycle debate: would steel be being treated fairly against other options to reduce carbon emissions in the economy? Because of the ubiquitous nature of steel use, it is likely that only an economy-wide carbon tax could give confidence that this aim had been met.

Section Four: Actions for a Low-Carbon Future

While there are some improvements that can be made through making the existing set of steel production plants less carbon intensive, “short to medium carbon footprint improvements are possible but are limited with current technology” (Tata Steel, 2011). In order for the steel industry to significantly reduce its emissions in order to become part of a low-carbon economy while maintaining production at around current levels, more radical action is required. The paper highlights five areas for action and all would be supported by open and expert discussions about the integrated policy needed to support steel’s role within a long-term low-carbon economy. Developing the forums for such consultations is vital, as is the need to see progress within the next plant replacement cycle (i.e., 20 years from now).

Deployment of Current Technologies

The retirement of obsolete and inefficient plants will lead to a one-off gain in emissions reductions. Such plants are mainly located in developing countries and their prompt retirement may require social policies that create alternative economic opportunities and the provision of compensation to affected workers and the wider community. New plants tend to be built to high standards across the world. The improvement of performance from existing plants can be encouraged through creating conditions whereby owners and operators feel confident in the long-term viability of their investments. Volatile carbon prices act against providing this certainty, adding to an already volatile and cyclical market for steel. Raw materials moving towards shorter duration contracts also act to increase this volatility. Higher volatility disincentivizes investment: new technologies that are more expensive than conventional ones will result in even more disincentives.

Development and Deployment of Carbon Sequestration Technologies

Much of the attention on CCS has focused on the power sector, although industries such as iron and steel also have many point sources with major annual CO₂ emissions. Perhaps the key danger with CCS is that, while it is much discussed as an option in the academic literature, efforts to progress it practically are not wholly convincing. Despite major investments by governments in RDD&D, there is little positive result to date. There have been very few demonstration schemes anywhere in the world, and the efforts of both industry and government could be criticized as being too slow. This paper shows that there could be the resources in the sector to implement multiple demonstration schemes, but that there is a challenge to realizing these. Such schemes would generate experience and lessons of use across the sector and to other industrial sectors, and schemes in one jurisdiction would generate learning and lessons for all others. Developing multiple demonstration schemes should be a priority action for the short-to-medium term, and it is likely to require resources from both industry and government.

Development and Deployment of New Steel Technologies

It is only by the development of new steelmaking technologies, often in conjunction with CCS, that steel could be part of a low-carbon economy while maintaining production at the current order of magnitude.⁴⁴ Tata Steel (2011) notes that “breakthrough technologies are needed for the medium to long term, but solutions need to be found for funding of demonstration plant and new generation technology.” It seems likely that increased funding and increased collaboration could increase the pace of development and deployment of new technologies. Annex One summarizes design considerations for the case of Japan alone. Box Five presents a possible mechanism for making progress internationally within what is a competitive sector. Other options could also be pursued. For example, given the sheer scale and value

⁴⁴ World production is projected to roughly double over the next 25 years—see Footnote 1 (IEA, 2009).

of the market for steel and for steel-producing plants, a country with significant financial resources—for example Qatar or Saudi Arabia—could decide to unilaterally invest in a new technology such as hydrogen plasma smelting reduction, particularly if the country was simultaneously investing in renewable electricity generation technology.⁴⁵

BOX FIVE: A COALITION OF THE WILLING TO REDUCE EMISSIONS FROM PRIMARY STEEL PLANTS

Relatively few countries dominate the production of primary steel (carbon steel). They all face the same challenge in significantly reducing their carbon emissions. Business-as-usual projections will see these emissions increase significantly over the coming decades.

Because the market for steel is internationally competitive, if one country or region were to impose higher standards, then they would be likely to lose market share and/or profit. However, if the relatively small group of dominant countries moved together, they could make progress. One possible mechanism would be for the group to agree both to introduce a code of conduct whereby each of them agreed that new plants and refurbishments should include new technologies, potentially including CCS, as and when these were required. Guaranteeing shared intellectual property for coalition members could help incentivize coalition membership; introducing a carbon price for the steel sector to the group would raise funds and would, to some extent, incentivize lower-carbon solutions. All members of the group—which must include China as the major producer, and should include also Japan, the European Union, Korea and perhaps Brazil and India—would need to ensure trust by making mutual progress (this would not necessarily need to be exactly the same actions). Countries where progress is politically very difficult—for example Russia and the United States—could be excluded, as they represent a relatively small share of world production.

This “coalition of the willing” would face formidable implementation challenges:

- Production costs from plants with new technologies, for example any with CCS, would be higher than from plants with older technologies. A carbon price would reduce this cost differential, but if there is still a higher cost with the new technology, it may be necessary to somehow support new technologies.
- Similarly, investors are free to pass up the opportunity of making investments in the steel sector in general, in countries that are part of the coalition and in the plants with new technologies. It seems likely that incentives will need to be given for these new plants in order to make them more attractive to investors than they otherwise would be.
- There will be a need to raise funds to pay for the new technologies, through RDD&D to implementation. These funds could be raised from industry and/or from government. The simplest method may be to raise a levy on all steel production in a country or region. This levy could also be applied to EAF production, since the steel scrap that is being used was once primary steel and thus released carbon emissions that were not regulated at the time. Some steel producers also argue that the upstream iron ore miners, who they now consider to benefit from much of the profit of the steelmaking cycle, should also contribute.
- There will remain some countries outside the scheme. If the extra costs and carbon prices in countries within the coalition made them uncompetitive compared to countries outside the coalition, this might require some form of border measure—either a charge or intensity-based import standards, or perhaps even the exclusion of steels from coalition markets. This would run into the problems around border measures, including that more steel is embedded within traded products than within the trade of steel as a commodity (Peters, Minx, Weber & Edenhofer, 2011).
- There may be a need to sequence decarbonization across sectors of the economy; the reduction of carbon emissions per unit of investment may be higher in power generation, for example. There does not seem to be any strong reason why decarbonization within steel and other sectors needs to be especially prioritized.

These problems are not insurmountable and the scheme suggested—carbon pricing plus a coalition of the willing—is clearly worthy of further investigation.

⁴⁵ See Box Four for a review of technologies.

Addressing Product Use

Increasing carbon prices will raise the price of products containing steel relative to those made with less carbon-intensive materials. A key challenge is to develop and maintain a consistent and equitable approach across the economy; an economy-wide carbon tax would be such an approach but is not likely to be implemented in many economies in the near future. Policies will therefore be partially applied and, in this case, a life-cycle approach is indicated.

Fitting the Industry into the Low-Carbon Economy

Steel is a component of a vast number of goods, some which are environmentally friendly. Efforts to regulate emissions from steel production may have unintended side effects if they also increase the price of such goods, and policy-makers need to be aware of this potential danger. That said, designing life-cycle approaches that treat mitigation options across the economy equally is difficult in practice. Interventions seem most justified when new steels are required for new environmentally friendly applications.⁴⁶ Sustainable procurement policies and other support for energy efficiency and renewables could be good options as alternatives to, or alongside, carbon pricing policies.

TRI-CC Summary

Together with a companion paper on the cement sector, this paper is being published following an IISD conference called Deepening the Understanding of Energy Intensive Industries, held in Brussels on September 26, 2011. Both the workshop and papers are part of IISD's Trade, Investment and Climate Change Program (TRI-CC).⁴⁷

The TRI-CC Program is sponsored by the Ministries of Foreign Affairs of Norway and Sweden. As part of the Program's Competitiveness and Leakage theme, it is aimed at deepening the understanding of Energy Intensive Industries, so as to better understand the effect of climate policies on these sectors. Other areas of work in the TRI-CC Program include research on the practical aspects of designing and implementing a BCA system, an assessment of trade impacts of border carbon adjustments in developing countries, and work on emerging issues such as GHG intensity standards and subsidies for green industrial development.

⁴⁶ Particularly if the production of such steels is more carbon-intensive than it would be for standard steels. In general, this is not the case—higher quality steels with increased properties tend to cost more to produce but do not tend to increase carbon emissions.

⁴⁷ See <http://www.iisd.org/trade/crosscutting/tri-cc/> for further details on this program.

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Annex One: A fully-resourced research, development, demonstration and deployment RDD&D plan for Japan (Wooders, Beaton & McDaniels, 2011)

A. THE MECHANISM TO BE EMPLOYED	
Discussion	Fundamental research tends to be financed by government, with industry then developing promising options towards commercialization. In Japan, it is the steel sector companies that have tended to perform this second role and that have retained the Intellectual Property Rights (IPR). The COURSE50 program involves funding from the New Energy and Industrial Technology Development Organisation, a public body that receives its funding from a share of the proceeds of the carbon and energy tax. It is natural to think of national-level collaboration, but this is not necessarily the best option. If company-level research and development is the normal model, then there will almost certainly be some disadvantages in moving away from this. Conversely, demonstration programs can be expensive and sharing costs and learning nationally and even internationally is indicated. The debate continues as to whether demonstration projects should be financed by government, industry or as a combination.
Proposal	The first step is to set out a plan showing how both breakthrough technologies and carbon capture and storage (CCS) could be most quickly developed and implemented, independent of financial, intellectual property rights or any other constraints. The starting point should be existing initiatives in Japan, notably COURSE50. Industry, government and the research community should all be involved in the planning exercise. It is recommended that research be conducted at a national level unless it can be shown that there are advantages in moving to a company level or to an international one. Demonstration programs should look for international partners as a way to share experiences and costs.
B. HOW FINANCE WOULD BE RAISED	
Discussion	At the government level, the possibility of increasing the scale of finance above current levels comes from the “environment tax” planned for the economy in 2011. Both the scale of this tax, and what it could be used for, remain uncertain and will be debated through 2011. The alternative, separately or in combination, is to make the steel sector liable for raising the necessary finance, whether this is spent internally within the companies or if it goes into a wider fund or scheme.
Proposal	The working assumption is that finance should be higher than the current financing for COURSE50. Notably, finance for CCS demonstration programs, and finance for the steel sector’s contribution to a feasibility study and the development of carbon sequestration in Japan, should be included. Who should contribute the finance is a matter for Japanese politics, but a contribution from the iron and steel sector in addition to the new “environment tax” deserves serious consideration. The ideal for finance would be an extended carbon tax, but a tax on production of steel from the blast furnace route would be a suitable proxy.
C. WHAT THE TARGETS SHOULD BE	
Discussion	The proposed sectoral approach, agreement and measure (SAAM) requires technologies to be developed and implemented as fast as possible. This requires sufficient—perhaps defined as “the maximum cost-effective”—resources and effort to be put in. Ascertaining what the optimum level is, and then measuring it, presents technical difficulties. It is also clear that the indicator would be an input, rather than a result. A financial indicator may be the easiest—for example, a fixed charge per tonne of carbon emitted from the primary production route—although quality of how funds were spent is a key consideration.

Proposal	Financial targets, annually over the first five years and then every five years thereafter, are recommended. These should then be apportioned down to the company level. A review mechanism for technology development and implementation is also required. Using the “giving directions” method of progressively developing targets (see Box 6) is indicated.
D. SHOULD OFFSETS BE INCLUDED?	
Discussion	Including offsets in the SAAM is an option that could be useful, particularly in the short-to-medium term and if it helped to demonstrate technology or assisted in the development of technology that could subsequently be used in Japan.
Proposal	Perform a feasibility study on the pros and cons of including offsets within the SAAM. Review on a periodic basis whether or not offsets are included. The recommendation at this stage is that they should not be included.
E. WHO WOULD BE RESPONSIBLE FOR MEETING THE TARGETS?	
Discussion	Responsibility could be either at the sectoral or company level, depending on the design of the scheme.
Proposal	Recommendation is that liability is devolved to the companies.
F. THE POSSIBILITY OF MAKING THE SAAM INTERNATIONAL	
Discussion	There are clear attractions to combining RDD&D efforts, at all stages of the cycle. Demonstration plants are often expensive and the latter stages of development and implementation may be most attractive for international collaboration on the basis of cost.
Proposal	Research programs should actively look to share experiences and even combine with other countries. Demonstration programs should look for international partners as a way to share experiences and costs.

BOX A1: GIVING DIRECTION: A PROCESS TO SET TARGETS PROGRESSIVELY

Detailing a precise long-term target at the beginning of a process immediately presents technical and political challenges. It is also clear that targets will need to be open to review and adaptation as new information comes to light.

One possible approach is for a government to “give direction” on how a target will develop. In terms of process, governments could annually add further information to a set of principles and more detailed quantification. In the early stages, such statements may simply cover general principles. For example: “this government will require significant reductions in GHG emissions intensity from all steel-producing plants within a period of not more than 20 years” or “this government is minded to require CCS to be fitted on all new plants from 2030 unless such plants can demonstrate emissions intensity reductions of at least 40 per cent compared to best available technology available today.”

The idea of “giving direction” is to provide investors with more certainty as to which investments are likely to become less profitable going forward and which may become more so. Statements must always build on previous ones, and amendments and changes of direction should be strongly avoided.



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