Greening Steel:

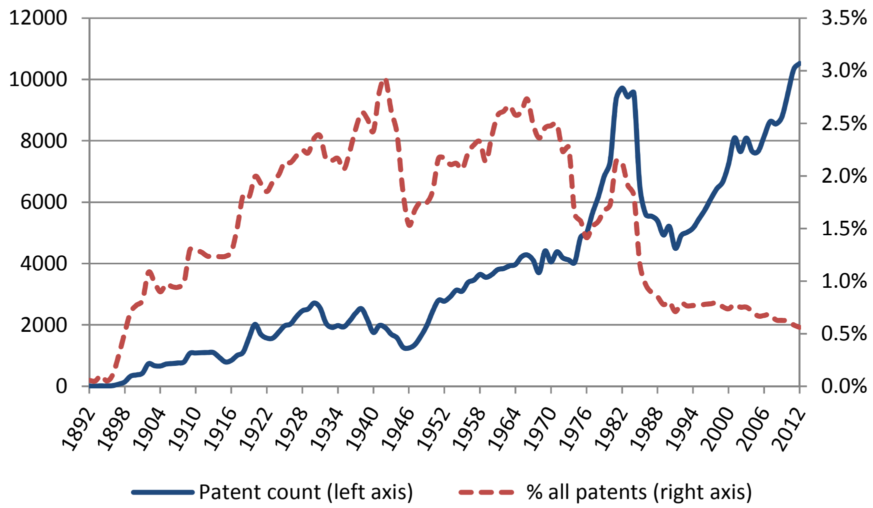
Innovation for Climate Change Mitigation in the Steel Sector

The world steel industry is an important CO_2 emitter and is therefore being called on to play a major role in mitigating climate change, not only by reducing the CO_2 emissions of its production processes[1] but also by contributing to the infrastructure of a low-carbon economy. In the long run, significantly reducing the industry's emissions will require a shift away from current production methods towards new methods of production. The industrial application of already existing technologies could contribute significantly to mitigating climate change. As an example, wider diffusion of the use of more energy-efficient production practices could significantly reduce CO_2 emissions. In the longer term breakthrough technologies will be required to reduce the impacts still further. In particular, the adoption of Carbon Capture and Storage technologies would reduce CO_2 emissions from the sector drastically. Public policy has an important role to play in encouraging such developments (OECD, 2011, 2012).[2] A better understanding of how to incentivise and induce both incremental and radical innovations in steel that can help mitigate climate change is needed.

Trends in steel-related technologies

In this Brief we use patent counts as a proxy for inventive activity. While there are a number of measurement challenges due to the way the data are collected and organised[3], the information drawn from patent filings can be used to develop useful measures of innovation which are comparable across countries and over time, and which can be disaggregated at a relatively fine level.

Figure 1. Evolution of steel-related patents, 1892-2012



Note: Patent counts are the total number of steel-related patents in each year. The percentage of all patents is calculated as the ratio of steel-related patents to total patents in each year.

Source: OECD calculations based on data from PATSTAT.

An analysis of the historical evolution of the number of steel patents since 1892 shows that there was rapid growth in steel-related technologies relative to other fields during the first half of the 20th century (Figure 1). Technological innovations in steel experienced another surge during the late 1970s and early 1980s, but their importance relative to other technologies has since declined.

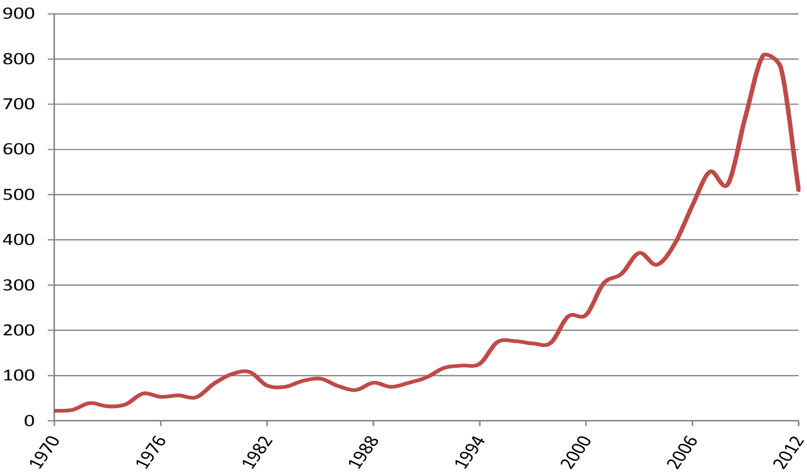
Innovations for green(er) steel

While the steel industry has often been subject to critique for its environmental performance, it has nevertheless been making efforts to innovate and to improve its environmental performance. For example, World Steel Association members have agreed on a common framework to work towards reducing their carbon footprint. This includes: i) the development and application of new steels to improve the energy efficiency of steel-using products in society; ii) expenditure on research and development to identify breakthrough steelmaking technologies with the potential of reducing steel's CO_2 emissions significantly; iii) improving plant performance through benchmarking and technology transfer; and iv) a common measurement and reporting system for steel plant CO_2 emissions (World Steel Association, 2013).

These efforts are reflected in patent data. Due to the fine-grained nature of patent classification systems, such data can provide some insights into technologies that have climate change mitigation potential. The system for tagging low carbon-related patents developed by the European Patent Office (see Veefkind et al., 2012 and EPO, 2013 for details) has allowed for the identification of inventions that may contribute to mitigating climate change (see Haščič, I. and M. Migotto 2015 for indicators of environment-related innovation). Recent work at the OECD analyses the trends in climate change mitigation technologies and how policy can contribute to the acceleration and diffusion of innovations in this field (see OECD 2012).

The rate of innovation in carbon mitigation related technologies in steel has been increasing over the last decades. Figure 2 depicts the evolution of the number of patents that relate climate change mitigation in the steel sector.[4] It is interesting to observe that, from 1970 until around the financial crisis of 2008, the number of low-carbon patents in steel technologies increased very rapidly.

Figure 2. Carbon mitigation related patents in steel



Note: Environmentally related patents are obtained through the Cooperative Patent Classification system tag Y02 "Technologies or applications for mitigation or adaptation against climate change". Steel patents related to the environment result from the intersection of steel-related patents and Y02, as described in Silva (forthcoming).

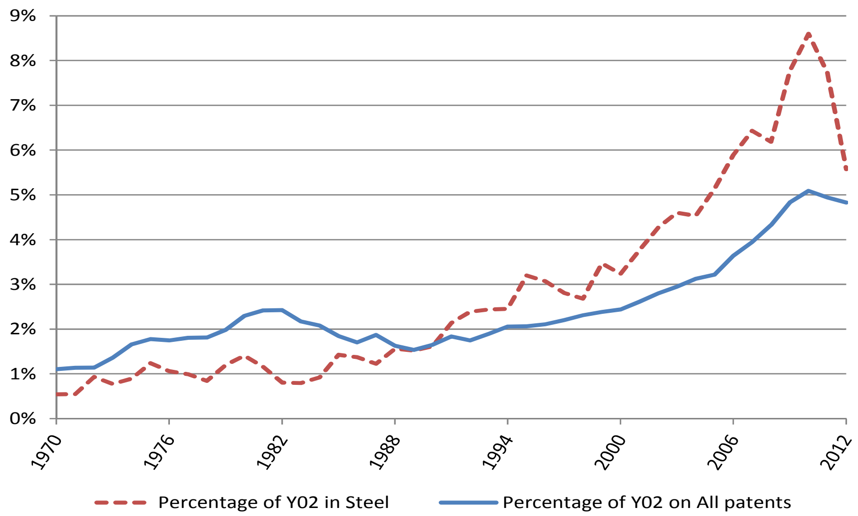
Source: OECD calculations based on data from PATSTAT.

The rate of increase was about the same rate as the total number of low-carbon patents in all fields combined. However, given that the rate of increase of patent counts overall in the sector is lower than the rate of patenting in the economy overall, the share of carbon mitigation related patents in steel has increased at a faster rate than the share of low-carbon innovations in general. This suggests that the "direction" of innovation in steel related technologies is gradually moving towards climate change mitigation, to a greater extent than elsewhere.

The count of patents related to climate change mitigation in all fields should nevertheless be regarded with some caution. Some economic activities may feature minor emission and environmental impacts but yet spawn large inventive activity. Therefore, as efforts to mitigate climate change become more concerted, it would be expected that the rate of climate mitigation innovation in the steel sector would increase relative to the economy as a whole. It is therefore not surprising that low-carbon innovation has become relatively more prominent in the steel sector when compared to patented climate change mitigation inventions in general since the late 1980s. Moreover, as can be seen in Figure 3 the share of carbon mitigation related patenting activity in steel has been decelerating in recent years, at a higher rate than overall climate change mitigation in all combined fields.

Figure 3. Low carbon related patents as a percentage of total

Steel versus all technologies



Note: Low carbon related patents are obtained through tag Y02. Steel patents related to climate change mitigation result from the intersection of steel-related patents and Y02, as described in Silva (forthcoming).

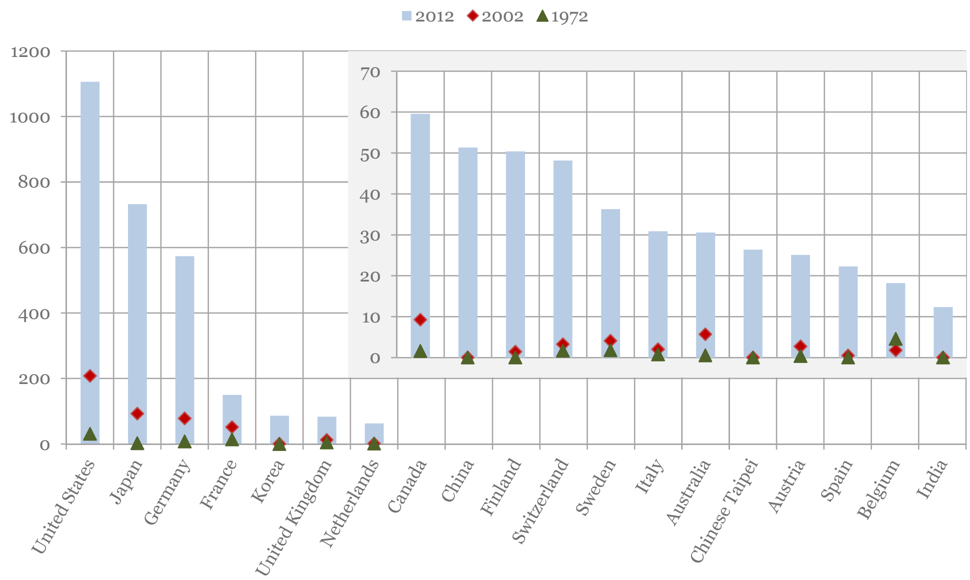
Source: OECD calculations based on data from PATSTAT.

Patenting activity is very different across economies. Figure 4 shows the carbon mitigation, steel related patents across selected economies. The United States boasted the highest carbon mitigation patent stock in 2012 as well as in 2002 and 1972. A large number of carbon mitigation patents related to steel production were also patented by Japan and Germany during the last ten years, resulting in a very high stock of steel-related carbon mitigation technologies in these economies.

It is important to note that innovations relevant to mitigation in the steel sector come from a wide variety of actors. Indeed, steelmaking companies do not appear to be predominant as the owners of patents for steel-related carbon mitigation technologies. Out of the top 100 entities with the highest patent stock in this field in 2012, only two steelmaking companies were identified – Thyssenkrupp with a total stock of 4.3 and JFE Steel with a patent stock equal to 4.1.[5] By and large, patenting activity in steel-related carbon mitigation seems to be carried out mostly by companies in upstream mining companies (Sumitomo Metal Mining with a patent stock of 4.8) or downstream automotive companies (Nissan Motor with a patent stock of 2.5), business services companies that focus on providing services and technologies for steel companies (e.g. Outotec, 4.2), or even public research institutes (e.g. Korea Institute of Industrial Technology, 4.0) and universities (e.g. Massachusetts

Institute of Technology, 2.0).[6] However, it should be noted that innovative research projects resulting in patented inventions may be carried out in collaboration with or commissioned by steelmaking companies.

Figure 4. Stock of steel patents categorised as low carbon, selected years



Note: Patent stock is calculated as the cumulative sum of patent counts over time, depreciated at a 15% annual rate.

Source: OECD calculations based on data from PATSTAT.

Capture and storage of greenhouse gases

The industrial application of already existing technologies could contribute to mitigate climate change. As an example, increasing the dissemination and application of Carbon Capture and Storage (CCS) technologies could, in the future, significantly reduce CO_2 emissions. The integration of CCS in iron and steel making processes is currently recognised as the only available way to enable the deeper carbon emissions reductions levels required to stabilise emissions.[7] Box 1 provides a brief overview of CCS. Further detail is available in the latest edition of the *Energy Technology Perspectives* published by the International Energy Agency (IEA, 2015).

Within the system for tagging low carbon-related patents developed by the EPO, a specific sub-tag has been created to identify technologies that relate to the capture and storage of greenhouse gases. Recent work at the OECD suggests that the rate of invention has accelerated in CCS (OECD 2012). While the low number of observations in such a narrow technological field renders the analysis of CCS technologies (a sub-category of greenhouse gas mitigation technologies) rather challenging for steel, it is nevertheless remarkable that tagging can be made at such a granular level.[8]

While the technologies required for the separation of carbon date from the early 1900s, these were not developed with a view towards carbon capture and storage but for other purposes. It is not until the 1990s that inventive activity in these areas starts to pick up, reflecting the increased recognition of the potential value of such technologies in climate change mitigation. Nonetheless, the number of steel-related patents associated with these technologies remains very limited. Nevertheless, Figure 5 below shows the evolution of patenting activity in this area and compares steel-related patents to the total number of inventions associated with capture and storage of greenhouse gases.

Box 1. Carbon Capture and Storage

Carbon capture and storage, or CCS, prevents CO_2 from fossil fuel combustion from accumulating in the atmosphere. In CCS, CO_2 can be captured from large emissions sources or, potentially, directly from the air. It can be stored deep underground or even bound in minerals. The most common example of CCS today involves capture of CO_2 from fossil fuel use, followed by CO_2 transport via pipeline and its permanent storage in geological formations, such as deep saline aquifers or depleted oil and gas fields. CCS is expected to play a unique and vital role in the global transition to a sustainable low-carbon economy, in both power generation and industry.

The reduction of iron ore is the largest energy-intensive step for the production of primary steel. There is limited energy savings potential when comparing current state-of-the-art blast furnaces (12 GJ/t crude steel or 1.2 t direct CO_2/t crude steel) to practical minimum energy requirements (10.4 GJ/t crude steel or 1.1 t direct CO_2/t crude steel). In this context, the integration of CCS in iron and steel making processes is recognised as the only available way to enable the deeper carbon emissions reductions levels required.

The component technologies for CCS are well-understood and many have been used commercially for decades. For example, the Sleipner oil and gas project in Norway has had almost 20 years of successful CCS operations. There are now 15 large-scale CCS projects operating globally across a range of applications, with a further 7 projects expected to come online in the next 2 years. These include the Emirates Steel Industries project that will capture 0.8 million tonnes of CO_2 per year from a direct reduced iron (DRI) steel plant when it begins operation in 2016. The CO_2 will be supplied to Abu Dhabi National Oil Company (ADNOC) for use in CO_2 enhanced oil recovery and its permanent retention in the oilfield will be monitored.

However, for some applications, such as capturing the CO_2 from integrated steel mills or cement plants for climate change mitigation, the technologies have only been put together at a very limited number of installations. For iron and steel production, several options for deep emissions cuts integrating CCS are being explored. These include:

- An **upgraded smelting reduction (SR)** technology combining a hot cyclone and a bath smelter avoids the use of coke or sinter, and maximises the CO_2 content of the off-gases through pure oxygen operation, making CO_2 capture more straightforward. A 90-day pilot plant trial is planned for 2016.
- **Oxy blast furnace and top gas recycle**: The CO_2 content of the top gas is raised by replacing the air in the blast furnace with oxygen. The top gas is recycled back to the BF as reducing agent, after partially capturing the CO_2 contained, which decreases coke requirements.
- **Coke oven gas (COG) reforming**: Increasing the hydrogen concentration of COG through reforming tar contained in the gas provides an effective reducing agent to reduce iron ore in BF and SR processes with a direct benefit on net energy consumption. The integration of this technology in oxy blast furnaces maximises the emissions reduction benefit and enables an easier implementation of carbon capture.
- An **upgraded DRI process** that reuses off-gases from the shaft as reducing stream after CO_2 capturing. This process also avoids the need for coke or sinter.
- **CO_2 capture applied to on-site utilities and general combustion equipment**. Addition of a post-combustion CO_2 capture unit to one or more of: hot stoves, steam generation plant, coke oven batteries and lime kiln.

Source: For more information, see Chapters 5 and 6 of IEA (2015) and IEA's website: www.iea.org/topics/ccs/.

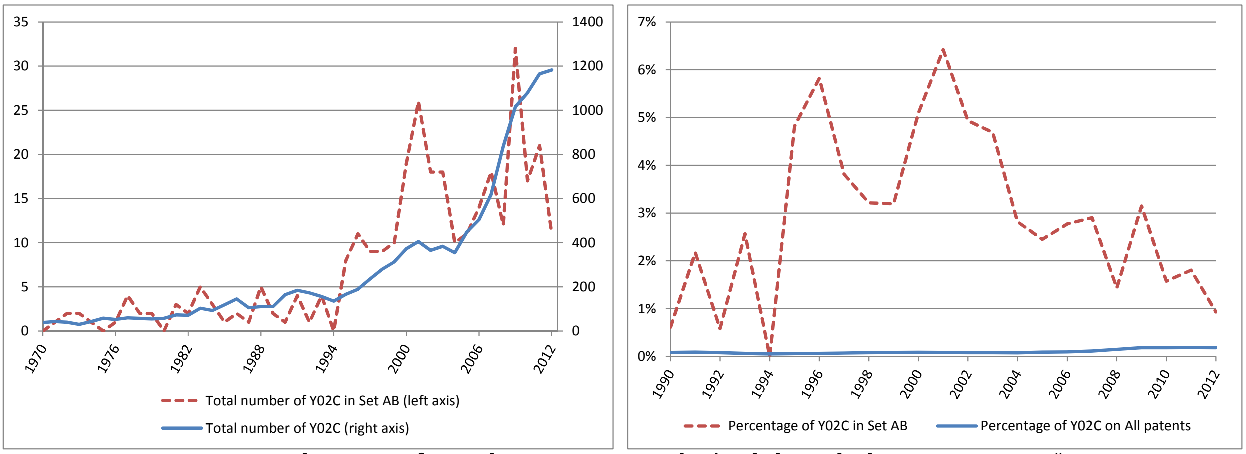
Inventions in steel-related technologies featuring elements of capture and storage of greenhouse gases (Y02C) were intermittent before the mid-1990s, with only a handful of new patents filed every year, if at all. During the late 1990s, patenting activity in steel related Y02C rapidly increased, in line with the increase in Y02C inventions in all technology fields (Panel A of Figure 6). Interestingly, the importance of Y02C in steel-related technologies was quite significant during the late 1990s and early 2000s, but has been decreasing ever since (Panel B). This contrasts with the steady growth in importance of technologies for capture and storage of greenhouse gases in general.

Geographically, inventions of capture and storage of greenhouse gases in steel-related technologies have been more prominent in economies such as the United States, Japan or Germany (Figure 6 below). It is interesting to note that patented inventive activity increased in Germany and Japan between 2002 and 2012, but fell in the United States, although the United States remains the most important patenting country in this field.

Figure 5. Capture and storage of greenhouse gases

A. Evolution of Y02C patents, 1970-2012: Steel versus all technologies

B. Y02C patents as a percentage of total, 1990-2012: Steel versus all technologies

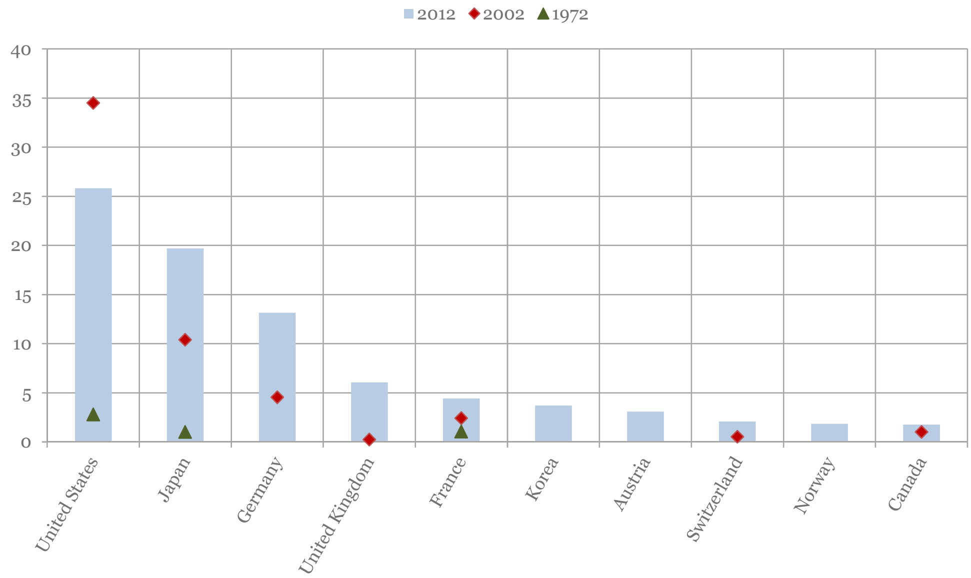


Note: Patents on capture and storage of greenhouse gases are obtained through the CPC tag Y02C "Capture, storage, sequestration or disposal of greenhouse gases (GHG)". Steel patents related to capture and storage of greenhouse gases are those resulting from the intersection of steel-related patents and Y02C, as described in Silva (forthcoming).

Source: OECD calculations based on data from PATSTAT.

Figure 6. Stock of steel patents related to the capture and storage of greenhouse

By economy, selected years



Note: Patent stock is calculated as the cumulative sum of patent counts over time, depreciated at 15% annual rate.

Source: OECD calculations based on data from PATSTAT.

Amongst the top 100 patenting entities, steelmaking equipment providers feature prominently with Siemens exhibiting the highest patent stock in 2012 (1.44) and Danieli highly ranked with 0.51. With regard to steelmaking companies, JFE Steel with a score of 1.04 is ranked first amongst steelmaking companies and third within the broad top 100 list. Hyundai Steel scores 0.01 and Nippon Steel also appears in the top 100 list with a score of 0.003 (the same as the 100th observation).

Deep reductions of emissions from integrated steel mills is a high cost climate mitigation step, but may nevertheless prove to be an important means of achieving significant overall emissions reductions. This means that, while CCS deployment may not be an immediate requirement for steelmaking, development of better technologies that can enable its wider adoption in the coming decades is more urgent. Because steel is a globally traded commodity, the level of carbon pricing that would make CCS economically attractive are politically and economically difficult to implement. While pricing is essential, the importance of targeted government support and research efforts for innovative projects in this area would be a necessary complement, driving down the costs of adoption over time. Recent work at the IEA provides an overview of the challenges with CCS deployment, as well as policy instruments that can be used to incentivise CCS in industrial applications (IEA, 2014 and Bennett and Heidug, 2014).

Policy could foster progress and dissemination of environmentally friendly technologies in steel

It has long been argued that a breakthrough steelmaking technology that can radically reduce CO_2 emissions is needed. The steel industry is making efforts to fund research into breakthrough low-carbon technologies and a number of R&D programmes have been put in place for this purpose (see OECD, 2010 and the World Steel Association, 2013 for an overview). There has been an increase in patented inventions since the 1980s, both in absolute terms as well as relative to environmentally related patents overall, but the latest available data show that patented inventions related to climate change mitigation are relatively more prominent in the steel sector when compared to patented low-carbon technologies in general since the late 1980s, as would be expected given the importance of the sector to climate mitigation efforts.

Data suggest that the direction of invention in steel-related technologies is turning towards climate change mitigation. However, a recent downward trend could be of concern given the environmental challenges ahead. Nevertheless, the key question is not so much about the number of inventions, but rather about their quality and the extent to which they are implemented and disseminated – only then is it possible to reap the economic and environmental benefits.

Technological change is essential to address environmental challenges and policy has an important role to play with this respect (OECD, 2011, 2012). A better understanding about how to incentivise and induce both incremental and radical innovations in steel that can help mitigate climate change is needed. In addition, the right incentives and framework conditions need to be in place to make sure that technologies that address pressing environmental challenges are diffused and adopted across the industry. This will require the use of both market-based measures, as well as targeted technology support policies. Further increasing energy efficiency, supporting research into carbon capture and storage, reusing industrial wastes and diversifying product applications are important goals for the steel industry. Economic uncertainty and policy unpredictability, and the need to manage risk and maintain competitive advantage, can create substantial challenges to technological progress. International collaboration and industry-government cooperation will be needed to further improve the energy and environmental performance of the steel sector.

Notes

1. In 2012, the sector emitted 2 552 Mt CO_2, thus accounting for 31% of all industrial CO_2 emissions and 7.4% of global direct CO_2 emissions that year (see IEA, 2015). This includes emissions from blast furnaces and coke ovens, and excludes indirect emissions related to power generation. Please note that emission intensity varies across economies and companies.
2. Further information available at: www.oecd.org/env/consumption-innovation/innovation.htm.
3. See OECD, 2009 for a more detailed discussion.
4. Not all patents are equal, and methodologies such as adjusting patent counts for patent quality using citations have been frequently used to identify the "quality" of inventions. More recently, efforts have been made to use the information contained in patent documents to for the identification of breakthrough technologies. See Squicciarini et al. (2013) for an algorithm to identify breakthrough patents and Egli et al. (2015) for an analysis of different attributes of inventions and how they can contribute to the development of leading indicators to identify breakthrough innovations in climate change mitigation technologies.

5 Please refer to Silva (forthcoming) for a detailed description of the approach used to investigate the patenting activity of steelmaking companies.

6 In this technological field, the entity in the first position scored 7.8, while the entity in the 100th position scored 1.2.

7 On the one hand, there is very limited scope for further emission reduction through efficiency improvement. With reduction of iron ore being the largest energy-intensive step for the production of primary steel, there is limited energy savings potential when comparing current state-of-the-art blast furnaces to practical minimum energy requirements. On the other hand, the use of coke and limestone as fluxing and reducing agents at blast furnaces results in process emissions (thought to be around 6% of total emissions) that cannot be avoided via energy efficiency or alternative fuels, but which can be mitigated using CCS.

8 The Y02C tag covers a set of technologies related to the "Capture, storage, sequestration or disposal of greenhouse gases (GHG)" that include not only capture and storage of CO_2 but also other pollutants such as nitrous oxide. Separation was first done for other reasons in the chemical industry. The tagging system has been designed such as to avoid the "tagging" of such cases, focusing on those of direct relevance to CCS. Even though a specific tag exists for CCS technologies (Y02C 10, "CO_2 capture or storage"), the low number of observations per year that pertain to steel in the subcategories of Y02C is not adequate for analysis. The patent counts in Y02C are already very low so further disaggregation would limit the scope of analysis. It should nevertheless be noted that, within steel-related Y02C, a considerable percentage of patents should be related to CCS technologies.

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