NUMERICAL EVALUATION OF ENERGY AND MATERIAL EFFICIENCY IN IRON AND STEEL SECTOR

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Overview

Primary steel production from iron ore involves CO_2-intensive processes. Secondary steel production requires less energy and lower CO_2 emissions than the primary steel production, but the expansion of secondary steel is limited by the global availability of steel scrap. Global steel-sector CO_2 emissions were estimated to be 2.6 $GtCO_2$ in 2010, including indirect emissions from power generation. There are two major directions for reducing CO_2 emissions from the global steel sector: (i) energy/carbon efficiency and (ii) material efficiency. These two directions have different characteristics, as shown in Table 1.

Table 1. Qualitative overview of energy/carbon and material efficiencies in iron and steel sector

	Energy/carbon efficiency	**Material efficiency**
Definition in this study (unit) [boundary]	• Energy intensity (e.g., GJ/tcs) [steel plant] • Carbon intensity (e.g., tCO_2/tcs) [steel plant]	• Yield ratio (%) [steel plant, manufacturing plant] • Primary steel ratio [global] • Steel intensity in society (e.g., ton of steel demand/GDP) [country, global] ➢delivering service with less steel ➢delivering GDP with less service
Typical measures for improvements	• Energy intensity: diffusion of energy saving technologies; recovery and effective use of by-product gases. • Carbon intensity: fuel switching; carbon capture and storage.	• Yield ratio: replacement of open hearth furnace and ingot casting. • Primary steel ratio: enhancing end-of-life recycling rate. • Steel intensity (delivering service with less steel): lightweighting as a result of more intelligent design or improved properties (e.g., high-tensile steel); intensified use (e.g., car rental, carpooling). • Steel intensity (delivering GDP with less service): material substitution (e.g., aluminum instead of steel), service substitution

Note) tcs: ton of crude steel.

Material efficiency provides a wide range of measures, and it implies at least (a) the improvement of the yield ratio in steel plants, (b) lightweighting of the finished products (e.g., high-tensile steel use for vehicles), and (c) enhancement of the end-of-life recycling rate.

The purpose of this study is to conduct a numerical comparison between the effects of CO_2 emissions reduction derived from the energy/carbon and material efficiencies. In addition to this numerical analysis, a qualitative discussion of the opportunities and obstacles is presented. This analysis provides a wide range of implications for CO_2 emission reductions in the iron and steel sector.

Methods

To evaluate the future possibilities for improving the energy/carbon efficiency, we use a global energy systems model, which we call DNE21+. DNE21+ explicitly treats the vintages and lifetimes of the steel plants in each region, as well as in other sectors (e.g., power plants). We can obtain a cost-minimum trajectory of the technological change for each scenario of global carbon limitation (Oda et al., 2007).

The material efficiency includes a wide range of concepts (see Table 1). This makes it complex because some concepts/measures are ongoing phenomena, while other concepts are desirable and normative targets from the CO_2 mitigation viewpoint. For a numerical evaluation of material efficiency, we focus on the possibility of enhancing the end-of-life recycling rate. To examine a realistic potential rather than a normative one, we apply a material flow analysis to the iron and steel industry and foundries on a global scale. Old scrap generation depends on the in-use stock of steel. The lifetime duration varies from a week to a century. Thus, the analysis covers a very long period, i.e., the past (1840–2012) and the future (2013–2050).

Results

A baseline and two policy cases are studied.

i) Baseline case–No additional mitigation policies. For reference, based on the DNE21+ results, the volume of global energy-related CO_2 emissions in 2050 is 56.2 $GtCO_2$/yr. The global mean temperature increase above pre-industrial levels is 4.1 in 2100.

ii) 650 case–Stabilizing the atmospheric GHG at 650 ppm CO_2-eq in the long-term. The 650 case is equivalent to representative concentration pathways (RCP) 4.5. The volume of global energy-related CO_2 emissions in 2050 is limited to 36.6 $GtCO_2$/yr. The global mean temperature increase above pre-industrial levels is 2.8 in 2100.

iii) 450 case–Stabilizing the atmospheric GHG at 450 ppm CO_2-eq over the long term. This is equivalent to RCP3PD (peak and decline). The volume of global energy-related CO_2 emissions in 2050 is limited to 13.1 $GtCO_2$/yr. The global mean temperature increase above pre-industrial levels is 1.9 in 2100.

The results of the material flow analysis indicate that the end-of-life recycling rate has no clear trend, although short-term variations depend on economic fluctuations. More importantly for future steel scrap availability, they also indicate that about 53% of obsolete products become usable old scrap for the steel industry and foundries, while the other 47% go into a repository, which is called "obsolete stock," long-term "hibernating," and "waste." Abandoned tunnels and pile foundations are typical examples of obsolete stock. The World Steel Association defines the end-of-life recycling rate as "(old scrap consumption)/(recoverable obsolete product)," and has the goal of increasing the recycling rate from 85% (current level estimates) to 90% (2050 targets). In the 450 case, we assume that the steel sector can utilize the additional old scrap compared to the baseline case based on the World Steel Association targets of enhancing the recycling rate.

The composition of the CO_2 emissions from the global steel sector in 2050 is summarized in Fig. 1. The carbon intensity (vertical axis) includes indirect power generation emissions. In the 450 case, because of the recycling rate enhancement, the crude steel production from the scrap-EAF route is larger than that of the baseline case. However, overall, carbon intensity improvements in individual routes have greater effects on CO_2 emissions. The carbon intensities of BF-BOF and DRI-EAF strongly depend on the carbon capture and storage and energy efficiency measures in the steel sector, as well as a low-carbon grid power supply.

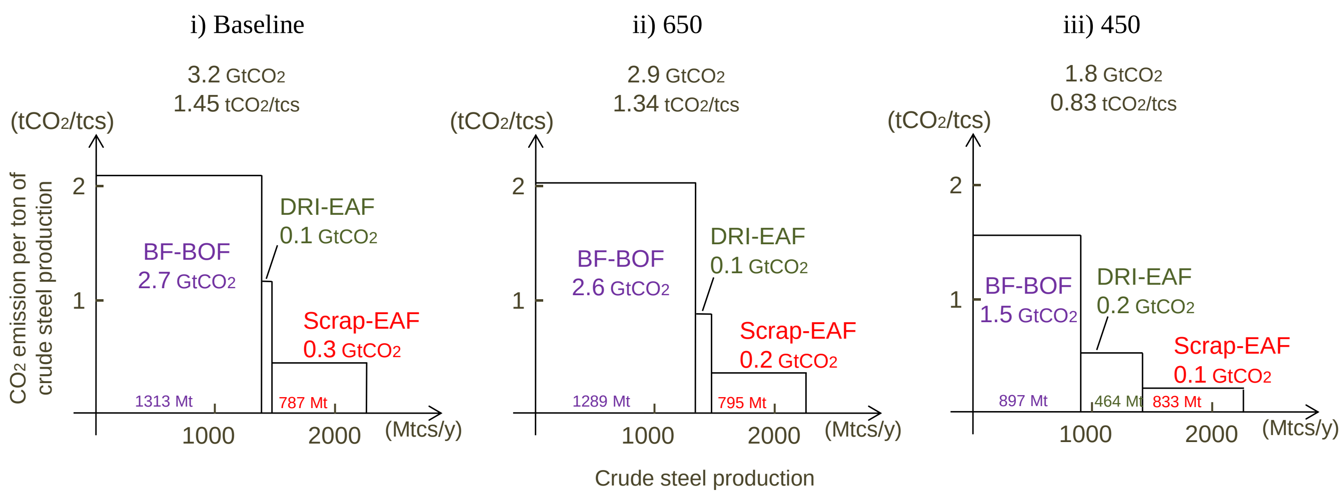

Fig. 1 Results for composition of CO_2 emissions from global steel sector in 2050

Note) BF-BOF: blast furnace-basic oxygen furnace; DRI-EAF: direct reduced iron-electric arc furnace; Scrap-EAF: scrap-electric arc furnace.

Conclusions

Using the world energy systems model, DNE21+, and a material flow analysis, we conducted a numerical comparison between the effects of the energy/carbon and material efficiencies. While enhancing the recycling rate, which is one of the material efficiency measures, has a certain effect on CO_2 emission reductions, the carbon intensity has a greater effect. Determining the detailed feedback effects (e.g., steel demand for carbon capture and storage), analyzing the recycling rate enhancement feasibility, and determining the material substitution dynamics remain as future work.