CAMP-ISIJ Vol.31 (2018)-99

Modernization scenarios for iron and steel industry towards meeting the climate change mitigation target

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1. Purpose

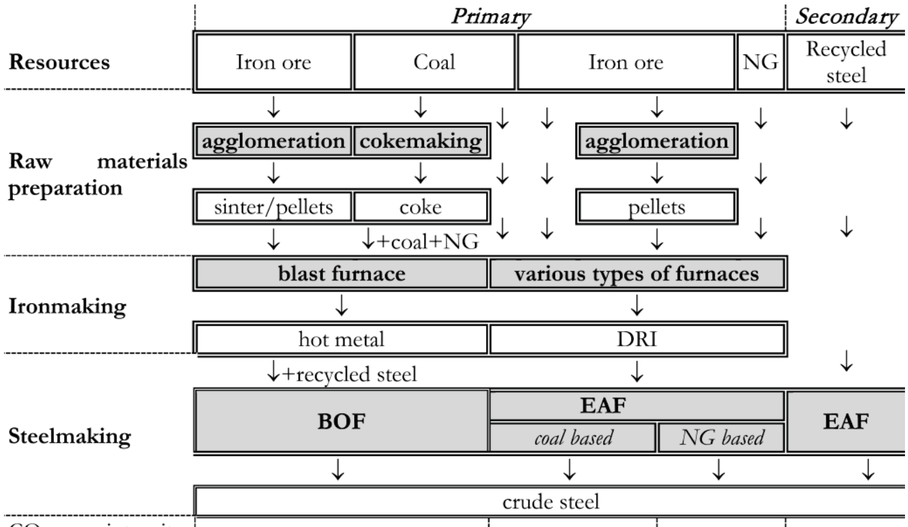
Climate change mitigation is increasingly important driver behind current and future modernization of steel industry, which globally accounts for 6.7% of anthropogenic and 31% of industrial CO_2 emissions [1)]. Historically, steel production was always coupled with CO_2 emissions. The potential for production growth, including that from virgin raw materials, is still high - even if technology advancement will result in lower steel intensity of industrialization in the developing countries [2)]. Hence CO_2 emissions from steel sector shall inevitably increase in a long term. Nevertheless, International Energy Agency (IEA) in its 2 Degrees Scenario (2DS, describes energy system consistent with limiting global warming to 2°C with 80% probability) sets 28% CO_2 emissions reduction target for steel sector in 2050 compared to 2011 despite growth of production by 51% projected for the same period [1)]. In this paper possibilities for decoupling the CO_2 emissions from production growth towards reaching climate change mitigation targets are studied.

2. Methodology

Fig.1 summarizes current state for steel production. For the simplicity some technologies with small market share as well as some materials, energy carriers and by-products are omitted. Emissions intensities for specific routes vary in a wide range. Average data for each route are derived from World Steel Association (WSA) statistics [3)] using balance calculations based on average intensity of 1.9 tCO_2/t steel in 2016 [4)]. With respect to impact of each route and specific weight of particular stages, substantial cutting of CO_2 emission requires: (i) increasing share of secondary route; (ii) improvement of energy efficiency by deployment of best available technologies (BAT); (iii) delivery of innovative technologies (e.g. ironmaking methods allowing phasing out cokemaking and ore agglomeration); (iv) deployment of carbon capture & storage (CCS).

2.1 CO_2 abatement by optimization of steel production routes

Increased share of steel produced from scrap can reduce sector's CO_2 emissions, though current and future steel demand cannot be met only using the scrap available. 2DS aims at 37% of steel produced in EAF from scrap in 2025 [1)]. Another forecast [5)] assumes that global demand for steel can be met by producing 40% of steel from scrap in EAF by 2035. Pauliuk et al [6)] argue that up to 50% of steel demand can be met by scrap available in 2050. Despite such projections, statistic data (Fig.2) show that, on average, world moves in the directly opposite direction with 25.3% of steel produced in EAF in 2016. Jumping from current state to EAF market share of 37% in just 9 years is hardly possible with respect to existing production infrastructure lifetime, scrap availability and steel quality issues. In this paper S-curve was used to estimate market share of EAF in global steel production. We found no reliable data on scrap load to BOF which for individual producers varies in a wide range (usually 15-30%). Assuming that



	BOF	EAF coal based	EAF NG based	EAF (secondary)
CO_2 intensity, tCO_2/t steel: range (2016)	1.8-2.6 (2.29)	3.3-3.7 (3.5)	1.3-1.6 (1.4)	0.2-0.9 (0.6)
Market share,%	74.7	0.58	2.77	21.95
CO_2 emissions share,%	89.37	1.08	2.04	7.51

Fig.1 Steel production routes (BOF – basic oxygen furnace, EAF – electric arc furnace, NG - Natural gas, DRI – direct reduced iron)

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increased EAF share in steel production will consume most of available scrap, in our model scrap load to BOF is fixed at 20%. We assume phasing out of coal-based DRI by 2050 with market share of NG-based DRI kept constant.

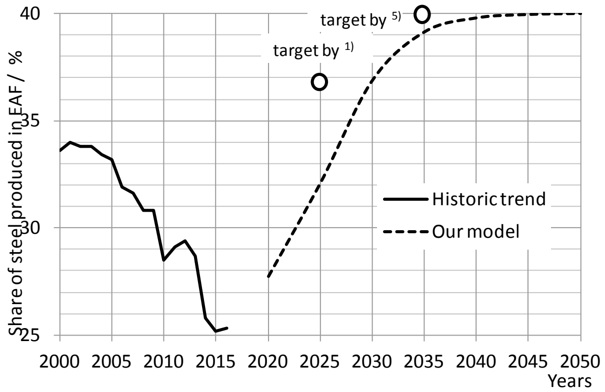

Fig. 2 Share of steel produced in EAF

2.2 CO_2 abatement by deployment of the best available technologies (BAT)

Since 1960 specific energy consumption dropped by 60% [7], so for leading enterprises only very expensive BAT might be still unexplored. But for many producers a large room for improvement still exists. In our model we use IEA estimate for CO_2 emissions reduction via BAT deployment - 19% by 2050 compared to 2010 [1]. We assume that BAT penetration follows the S-curve with rapid growth start in 2025. IEA assumes that electricity used for EAFs will be powered by fossil fuels only by 20% compared to 70% in 2011 [1]. Based on this we assume that CO_2 emissions in the EAF thanks to electricity decarbonisation and BAT deployment will be down by 70% in 2050 from current level.

2.3 CO_2 abatement by deployment of breakthrough technologies

A number of technologies are developed worldwide aiming at breakthrough in decarbonisation. In or study we consider several key technologies briefly represented below. We refrain from criticism concerning possible problems of these technologies taking CO_2 reductions claimed by the developers for granted.

Top Gas Recycling Blast Furnace (TGR BF) concept implies separation of CO_2 from the top gas and injection of remaining gas mixture back into BF - a possibility for new enterprises and for retrofitting. Trials at experimental LKAB BF in Luleo (Sweden) show that recirculation ratio of 90% decreases coke consumption by 25% which corresponds to cutting 24% of CO_2. However, in such case energy mix of integrated steelwork will be deprived from the BF top gas making this recycling ratio economically unviable. Reduction of CO_2 emissions intensity by 15% with limited top gas recycling ratio is more feasible [8] and taken in our model.

Pilot implementation of TGR was planned in 2015 at ArcelorMittal Florange (France) but suspended owing to financial issues. Although no information was found on new timeline, we assume that the basis attained is sufficient to ensure start of TGR implementation in 2025, rapid growth from 2030 and saturation by 2050.

Developed in Japan **COURSE50** project aims at CO_2 emission reduction by ca 30 % via cumulative effect of several strategies including use of H_2-amplified coke oven gas for injection to BF, iron ore pre-reduction, enhancing coke quality for high-H_2 operation, separation and recovery of CO_2 from BF gas using exhaust heat etc. Project completed two R & D stages to schedule, though practical application and diffusion are planned only after 2030 [9]. In our model we consider start implementation in 2030, rapid growth from 2035 and saturation by 2050.

HIsarna project combines Cyclone Converter Furnace (CCF) and Smelt Reduction Vessel (SRV). CCF has been developed by then Hoogovens company since 1990-s to produce molten partially reduced ore with temperature of 1450°C. SRV backs to HIsmelt technology with demonstration plant of 0.80 Mt/year capacity operated in 2005-2008 in Kwinana (Australia) in collaboration among Rio Tinto, Nucor Corporation, Mitsubishi Corporation and Shougang Corporation. During financial crisis HIsmelt was relocated to China and we found no reliable information on the current status of this project. HIsarna, a hybrid of the CCF and HIsmelt, is developed by Tata Steel in Ijmuiden (The Netherlands) in collaboration with Rio Tinto and some other steelmaking and engineering companies. In 2012-2015 pilot plant (8 t/hour) underwent a series of campaigns reaching 88% of designed productivity in a long term. HIsarna generates more CO_2 than BF but, thanks to phased out cokemaking and sintering, aggregate CO_2 emissions are 20% lower [10]. Demonstration was planned in 2018 with up-scaling and commercialisation after 2020 [11]. Although no mention to confirm this schedule was found in recent literature, we assume that deployment of HIsarna can start in 2025, rapid growth in 2030 and saturation by 2050.

FINEX is the ironmaking technology developed by South Korean POSCO in collaboration with Siemens VAI based on Corex prototype commercialised in South Africa and India. FINEX substitutes Corex's shaft furnace by a cascade of fluidized bed reactors to heat up and pre-reduce iron ore and applies briquetting machine to enable use of low grade and fine raw materials. In 2003 a demonstration plant (0.6 Mt/year) was erected, followed by launching of the commercial plant (1.5 Mt/year) in 2007 at Pohang Works. More advanced plant (2 Mt/year) with simplified design was launched in 2014. Best result achieved corresponds to 97% of average fuel consumption in BF (combined with cokemaking and agglomeration). Better process control shall bring this figure down to 90% [12]. Based on this we assume CO_2 emissions reduction by 10%. Market readiness is high enough to assume start of global deployment in 2025, rapid growth from 2030 and saturation by 2050.

2.4 CO_2 abatement by CCS

Two of the options– TGR and COURSE50 – employ carbon capture as part of the technology. Here we do not go into details and optimistically assume that (i) substantial progress achieved worldwide will be sufficient to ensure cost-effectiveness and (ii) legal barriers worldwide will not bar large scale deployment.

2.5 Global crude steel production forecast

Comprehensive steel production forecast developed by IEA [1] was published in 2014 and uses 2011 as a baseline. It takes into account a number of factors offering two options - for low and high demand. As shown in Fig.3 both options essentially deviate below the linear extrapolation of historic trend. In fact, during 2011-2014 production was very consistent with linear interpolation to high demand option, but from 2015 production dives even below the interpolation to low demand option. Many other projections for steel demand can be found in literature. One most recent [5] was presented in 2017 and uses 2015 as a baseline, delivering a pathway towards 2035. It is nearly consistent with low demand option of IEA until 2030, but then reduces growth rate with the peak of production reached by the mid-century. Being aware of uncertainties for steel production and consumption forecast, we stick in our study to IEA low demand scenario with emissions intensity pathway derived by Krabbe et al [13].

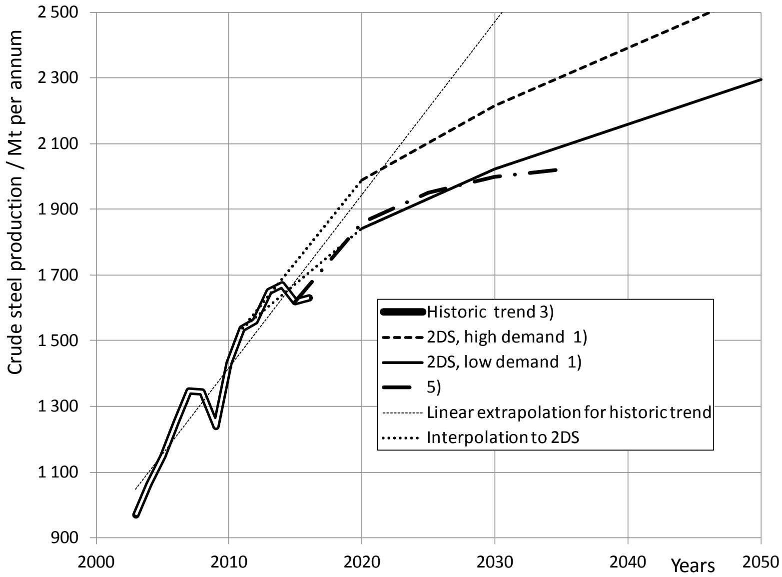

Fig.3 Historic trend and forecast for crude steel production

3. Results and discussion

Results of modeling are presented in Fig. 4. Business as usual (BAU) line represents the case when the specific emissions are kept on current level. Global BAT deployment allows decreasing emissions substantially, even decoupling them from growth in 2025-2035; however, then this measure`s potential is exhausted. If EAF's share will grow as planned, then, together with BAT deployment, it will bring CO_2 emissions to the IEA pathway by 2033 but only for few years.

Four remaining scenarios bring key technologies on top of cumulative effect of BAT and EAF penetration. Gradual substitution of all remaining BFs with FINEX helps to bring emissions to sustainable pathway earlier and even to keep them below IEA line for almost decade; but then market becomes saturated with all three interventions (BAT, EAF and FINEX) which results in 700 Mt of CO_2 emitted above the target in 2050.

Carbon cutting for TGR is more substantial than for FINEX, hence period of overachievement is 3 years longer, whereas for HIsarna emissions deviate from devised by IEA since 2045. Finally, COURSE50, if successful, is the only option to make emissions consistent with IEA plan from 2033 through mid-century.

Weak part of all scenarios is inability to cut emissions earlier than 2030 owing insufficient technology readiness level. Aggregate excess amounts of CO_2 emissions for each scenario over the IEA trajectory, determined using earlier presented procedure [14] are shown in Fig.5. Only COURSE50, if implemented in the defined timeframe, overachieves the IEA target. However, HIsarna option looks also very attractive – not only because cumulative emissions are just slightly higher than planned by IEA: this scenario doesn't require CCS, which has to be seen as great advantage. Moreover, HIsarna might be good green field option for developing regions where cokemaking and ore agglomeration infrastructure doesn't exist but potential for growth is very high.

Obviously, all scenarios will inevitably encounter a number of hurdles on the way to implementation: lack of funding, technological barriers, cost-efficiency, legal basis, limited technology transfer coupled with impossibility to control technology choices made in the developing countries and so on. Moreover, a number of currently existing BFs in 2025 will be still too good to be demolished or even retrofitted, whereas delay in modernization will inevitably cause accumulation of excessive amounts of CO_2, making the 2°C target unreachable.

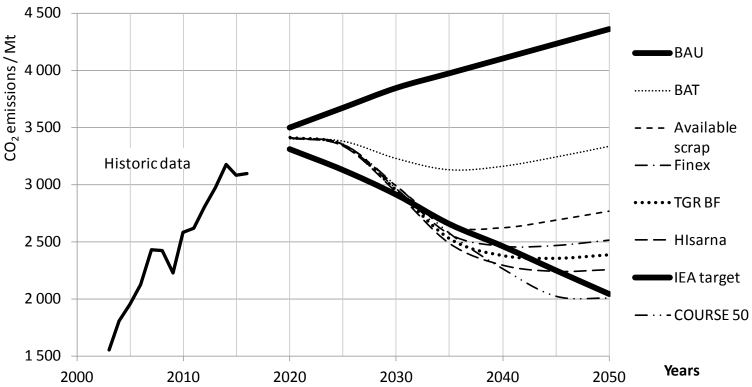

Fig.4 Historic trend, IEA target and results of modelling

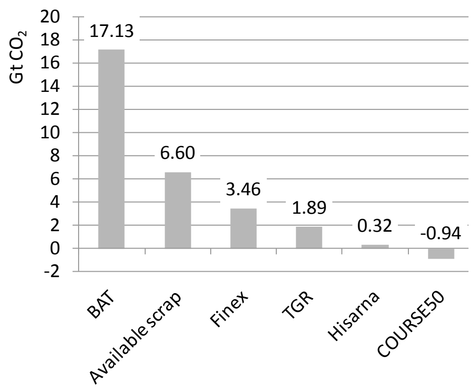

Fig. 5 Amounts of CO_2 emitted in excess to the IEA targets during 2020-2050

4. Conclusions

Bringing of CO_2 emissions of the steel industry to the pathway consistent with global warming mitigation target is still possible, though requires rapid and drastic international action for infrastructural change and technology transformation.

Acknowledgement

This study has been performed in the frames of EUClim project funded by the European Union under Erasmus+ Programme: 564689-EPP-1-2015-1-UAEPPJMO-MODULE (http://euclim.com/).

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