Wuppertal Institut

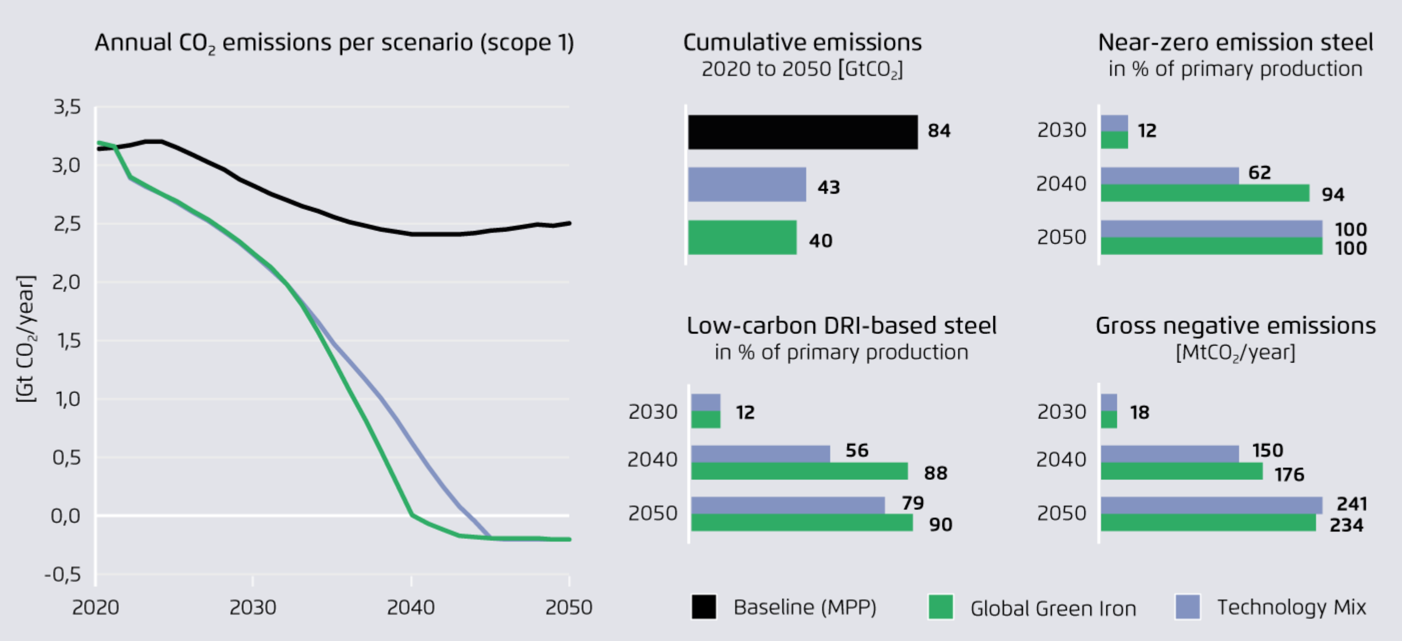
Agora Industry

15 insights on the global steel transformation

Wido K. Witecka, Agora Industry
Stefan Lechtenböhmer, Wuppertal Institut

Insight 1: A net-zero steel sector by the early 2040s is technically feasible

Pathways to net-zero: annual CO_2 emissions in the steel sector (left) and key metrics (right) Figure 1



Agora Industry and Wuppertal Institute (2023). Note: We did not model the Baseline scenario ourselves, but directly retrieved it from Mission Possible Partnership (MPP 2022). MPP's Baseline scenario covers scope 1 and scope 2 emissions. DRI = Direct reduced iron.

The global steel industry can turn from a hard-to-abate to a fast-to-abate sector

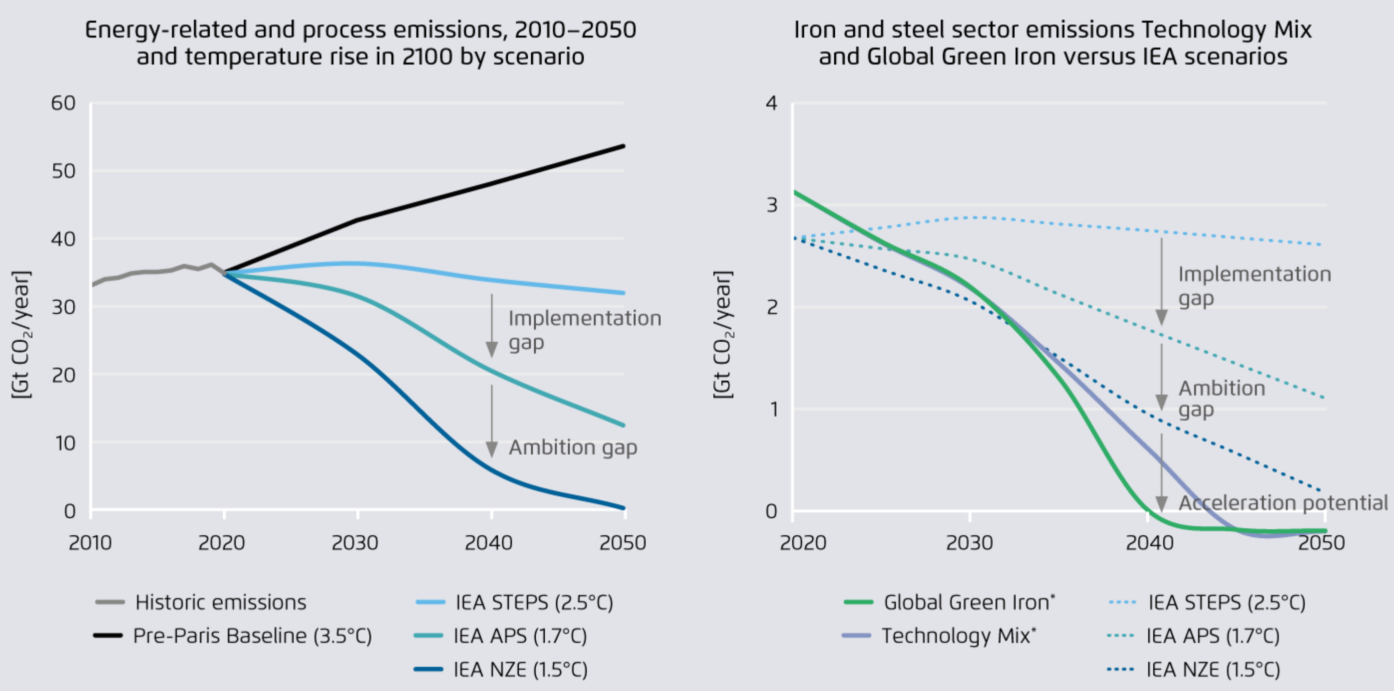
From hard-to-abate to fast-to-abate: how the steel sector's role is changing — Figure 2

	The old narrative: Steel is hard-to-abate because...	The new narrative: Steel can be fast-to-abate because...
Technology	...the low-carbon technologies are not market-ready	...important key technologies to start the transition are available now and we know key strategies and further promising technologies to get to net zero.
Cost	...green steel is too expensive	...while green steel can cost up to 30–60% more than conventional steel, in most end products the cost increase is only 1–2%. Smart policies can address the issue of cost.
Zero-carbon electricity	...will require a lot of zero-carbon electricity	...the steel sector is one of the best use cases for zero-carbon electricity. Both the coal to electricity and the coal to renewable H_2 fuel switch will provide one of the largest CO_2 reduction levers per unit of zero-carbon electricity.
Speed	...will be one of the slowest sectors to decarbonise	...the steel sector can be one of the fastest sectors to reach net zero. If the full acceleration potential is realised a net-zero steel sector by the early 2040s is technically feasible.

Agora Industry and Wuppertal Institute (2023). Note: Green steel refers to near-zero emissions primary steel. The additional cost range for green steel given here is calculated based on Molten oxide electrolysis (MOE) and renewable H_2-based direct reduction (H_2-DRI-EAF) in the 2030s compared to a coal-based blast furnace – basic oxygen furnace route (BF-BOF) that is not subject to a CO_2 price. These global average costs will vary based on local cost parameters.

Insight 2: An accelerated steel transformation can be a key element to increase climate ambition

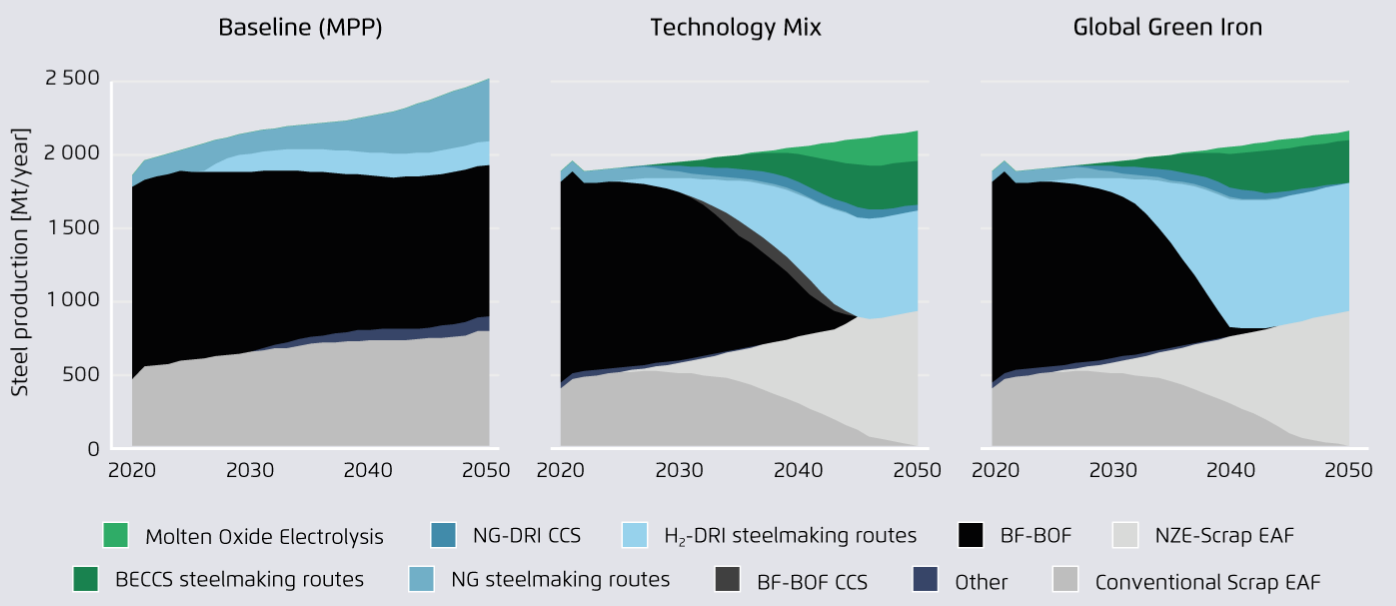
Scenario comparison: Global CO_2 emissions (left) and iron and steel sector emissions (right) — Figure 3



Agora Industry and Wuppertal Institute (2023) based on IEA (2022a). Note: STEPS = Stated Policies; APS = Announced Pledges; NZE = Net-Zero Emissions. *CO_2 emissions from industrial power plants on integrated steel sites accounted for in steel CO_2 emissions instead of power sector.

Insight 3: The key levers enabling a 1.5°C compatible steel decarbonisation pathways are material efficiency, scrap- and H2-based steelmaking as well as BECCS

Scenario comparison: steel production per route (2020–2050) Figure 5

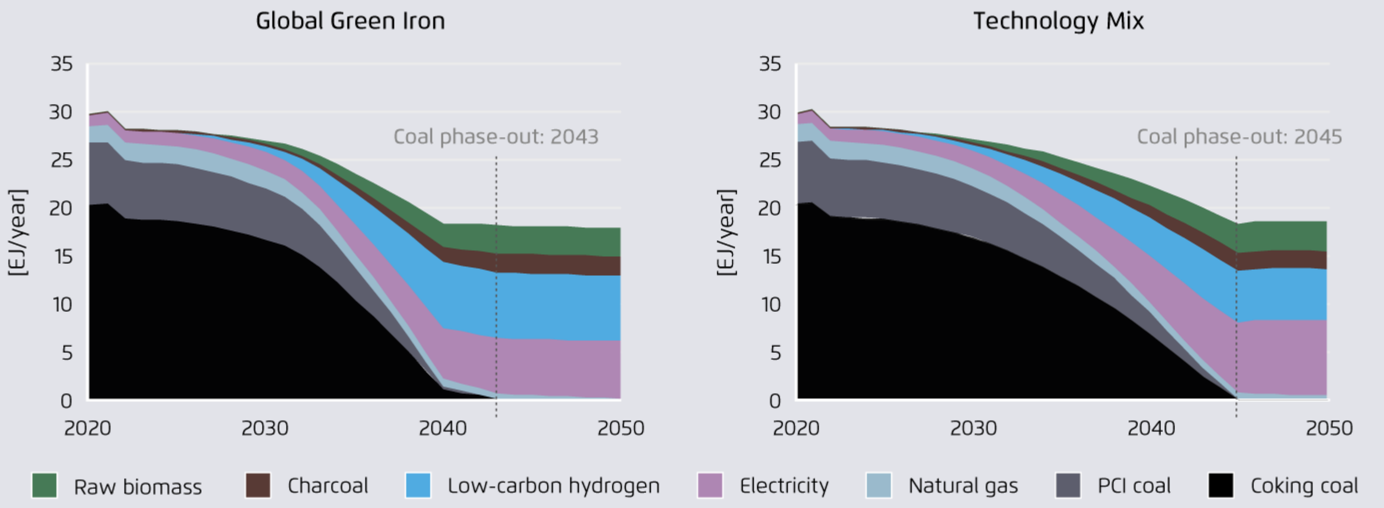


Agora Industry and Wuppertal Institute (2023), MPP (2022). NZE-scrap EAF stands for near-zero emissions scrap electric arc furnace which is defined as a scrap-EAF route with lower emissions than 0.01 tCO_2 per t of crude steel. NG = natural gas; BECCS = Bioenergy and carbon capture and storage.

Insight 4: A phase-out of coal in steelmaking by the early 2040s is technically feasible

Scenario comparison: Final energy demand

Figure 7

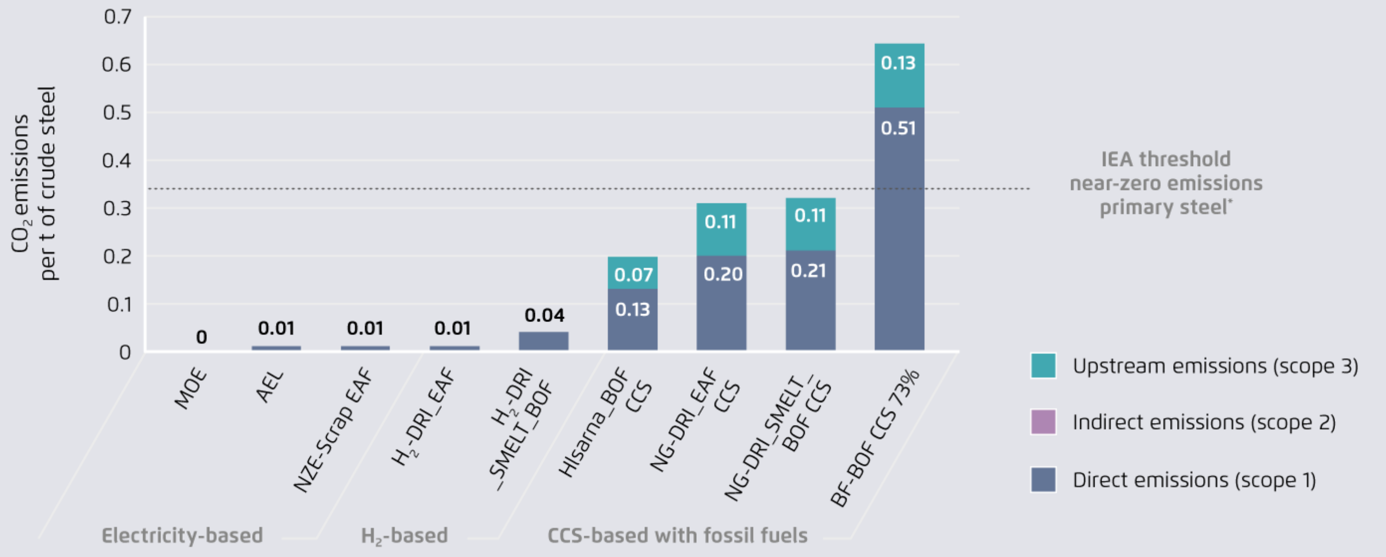


Agora Industry and Wuppertal Institute (2023). Note: Our modelling scope was limited to ironmaking and steelmaking. The energy demand from steel finishing is not included. PCI = pulverised coal injection.

CCS-based technologies with fossil fuels leave comparatively high residual emissions – electricity- and H2-based steelmaking routes allow to reduce them to almost zero

Residual CO_2 emissions (scope 1 and 3) of breakthrough technologies and proposed IEA near-zero emission threshold for primary steel

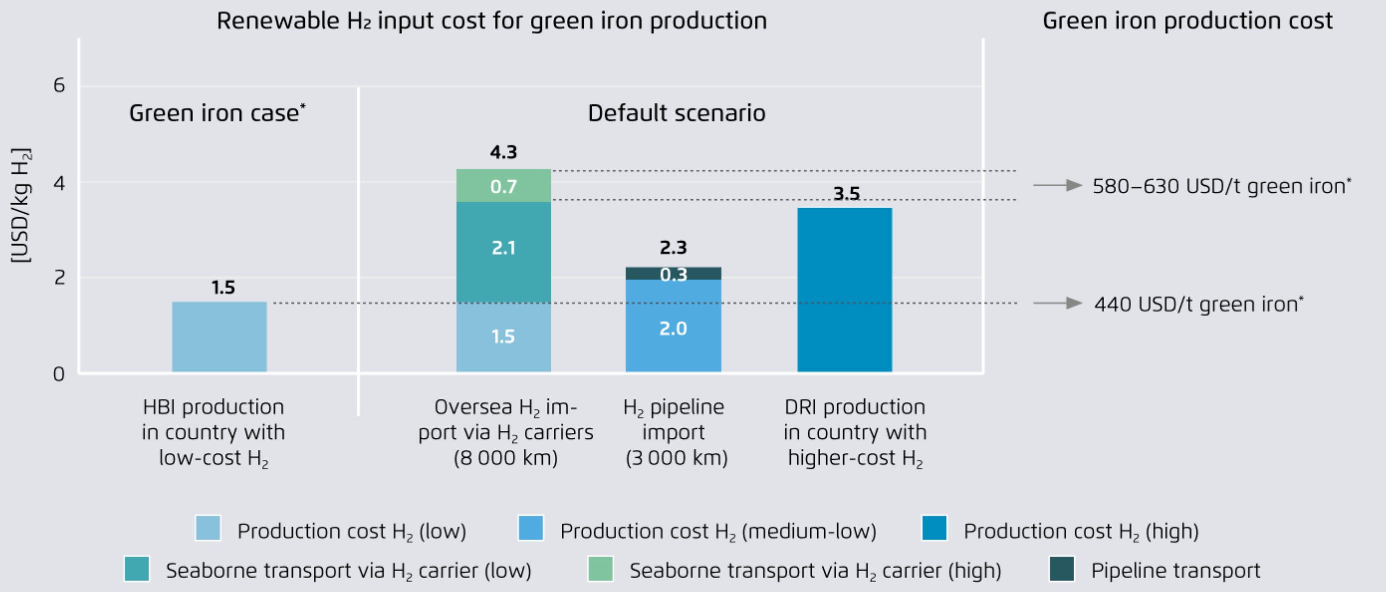
Figure 8



Agora Industry and Wuppertal Institute (2023), based on authors' analysis and IEA (2022g). Note: All primary steel production technologies in this figure have been calculated with a share of 16.5% scrap. *Due to scrap share adjustment the IEA threshold for near-zero emissions primary steel is around 0.34tCO_2/t of crude steel. Upstream emissions for CCS technologies are retrieved from IEA (2022) based on 2050 values for "indirect emissions of fossil fuels". They assume already large cuts of methane emissions relative to today. Indirect emissions (scope 2) are assumed to be zero if only zero-carbon electricity is used. MOE = molten oxide electrolysis; AEL = alkaline iron electrolysis; NZE-scrap EAF = near-zero emission scrap electric arc furnace; DRI-EAF = direct reduction and electric arc furnace; DRI-SMELT-BOF= direct reduction, electric smelter and basic oxygen furnace; BF-BOF CCS = blast furnace-basic oxygen furnace with post-combustion CCS.

Insight 5: International green iron trade can lower the costs of the global steel transformation

Impact of renewable H_2 input cost on green iron production cost 2030 under various scenarios — Figure 9

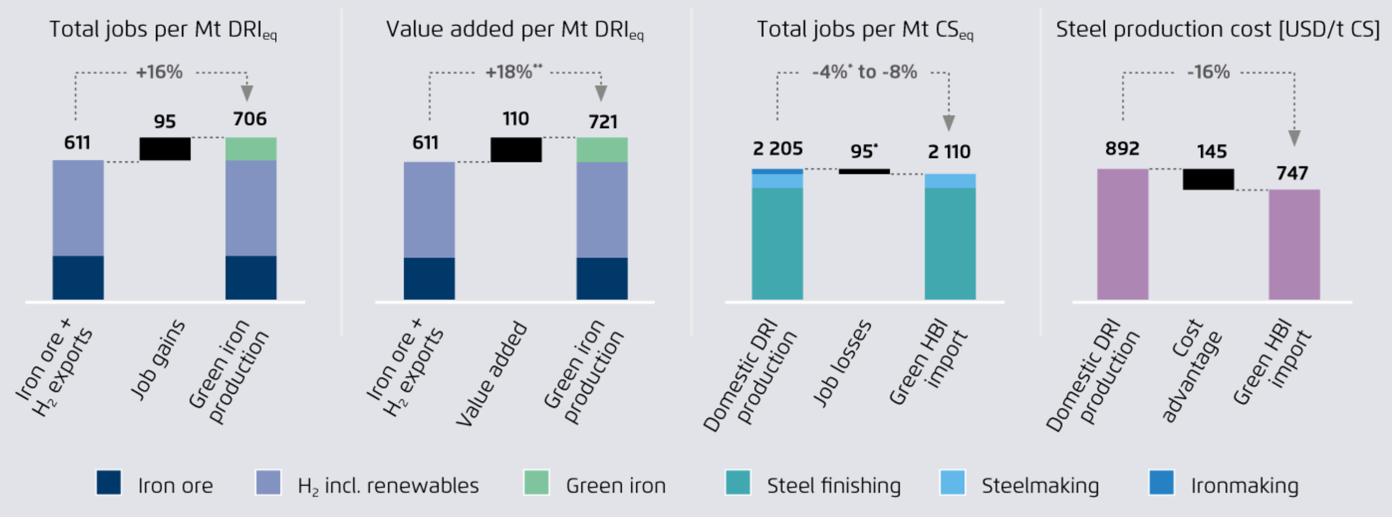


Agora Industry and Wuppertal Institute (2023), authors' analysis based on IEA (2022c). Note: Renewable H_2 production costs are derived from BNEF (2022a) and IEA ETP (2023) but are for illustration only. Actual assumptions in our modeling can deviate (see upcoming publication on key technologies for a net-zero steel industry). *According to IRENA (2022a), shipping costs of green iron could range from 15 to 50 USD/t. According to McKinsey (2022), shipping costs for green iron in the form of hot briquetted iron (HBI) are similar to those of iron ore pellets; reheating the HBI for use in steelmaking would require 100 to 150 kWh.

Insight 6: International green iron trade can be a win–win for importers and exporters

Green iron trade can be a win-win for importers and exporters

Figure 11

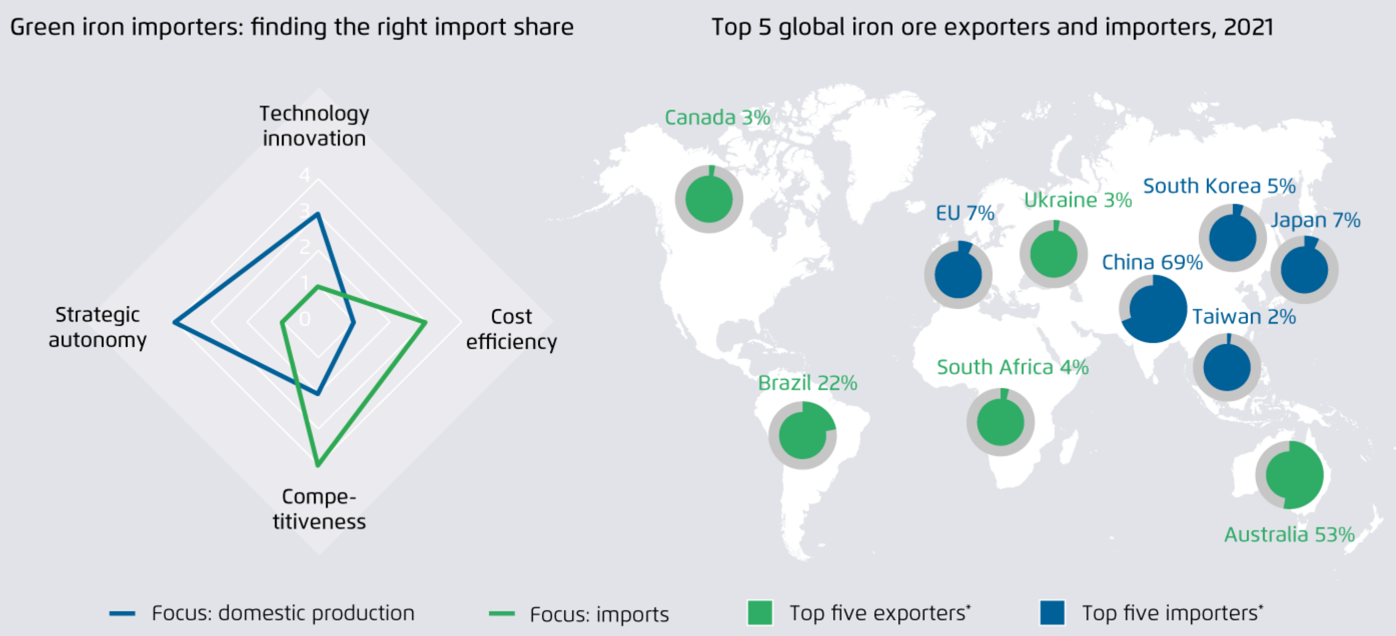


Agora Industry and Wuppertal Institute (2023). Note: The job intensity of steelmaking varies significantly across different countries. For our calculations we used a weighted average for iron ore mining jobs in the largest five iron ore exporting countries and assumed a job intensity of 8 full time equivalents for the production of 1000 t renewable H_2 per year and 53 kg H_2/per t of DRI. The numbers for green iron importers are derived from employment numbers in steelmaking from Germany. *The 4% share includes direct jobs in DRI ironmaking but does not include potentially associated jobs in administration and logistics. **Wages of jobs per Mt DRI_{eq} used as proxy + 2% depreciation rate of CAPEX. DRI = direct reduced iron; CS = crude steel

Unlocking the full speed and scale of the green steel transformation requires an international level playing field and strategic partnerships

Green iron importers and exporters: due to potential market power risks diversified strategies will be key

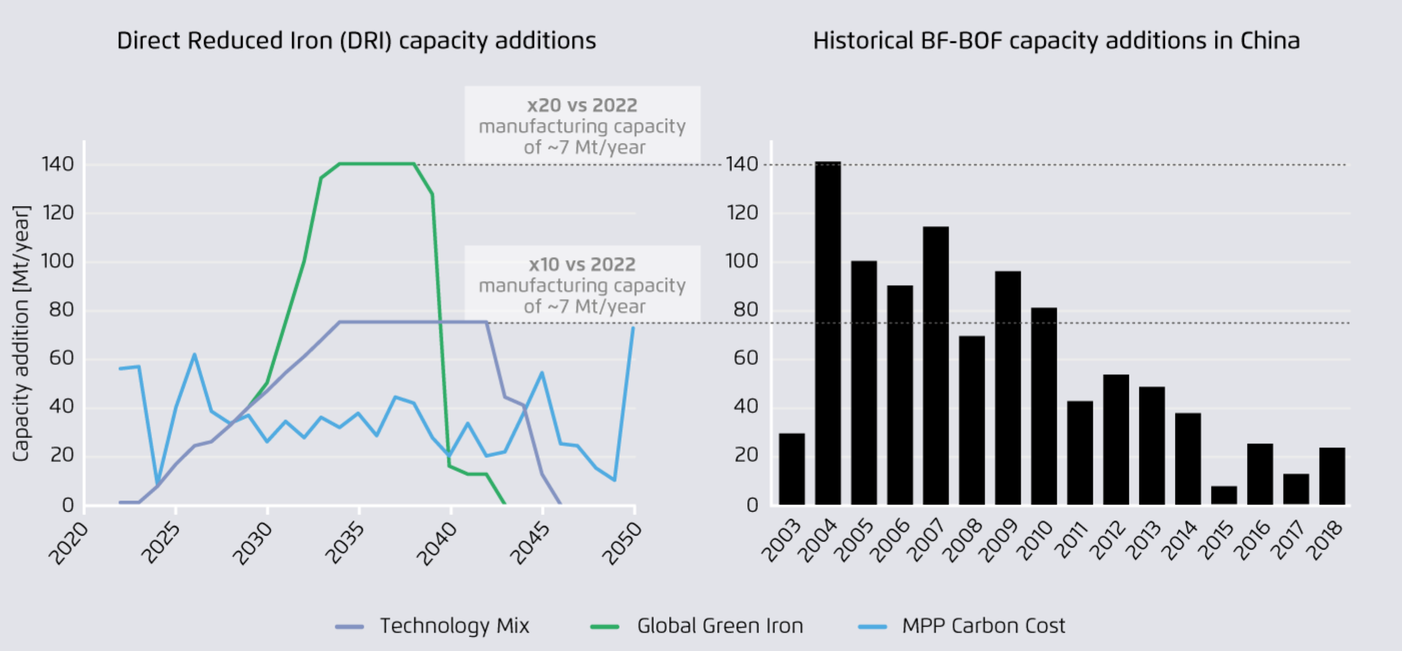
Figure 12



Agora Industry and Wuppertal Institute (2023) illustration (left) and Australian government Resources and Energy Quarterly, 2022 (right). The examples in the spiderweb diagram are for illustration only. They assume that the production cost of green iron in countries with cheap and abundant renewables and the purchasing cost for green iron importers does not deviate too much, so that the cost advantage is to some extent passed on to allow for greater cost efficiency. This does not always have to be the case in reality. *% of world imports/exports in 2021 world trade data

Insight 7: DRI plant engineering and construction capacities are currently a major bottleneck and need to be massively scaled up as they will set the pace of the global steel transformation

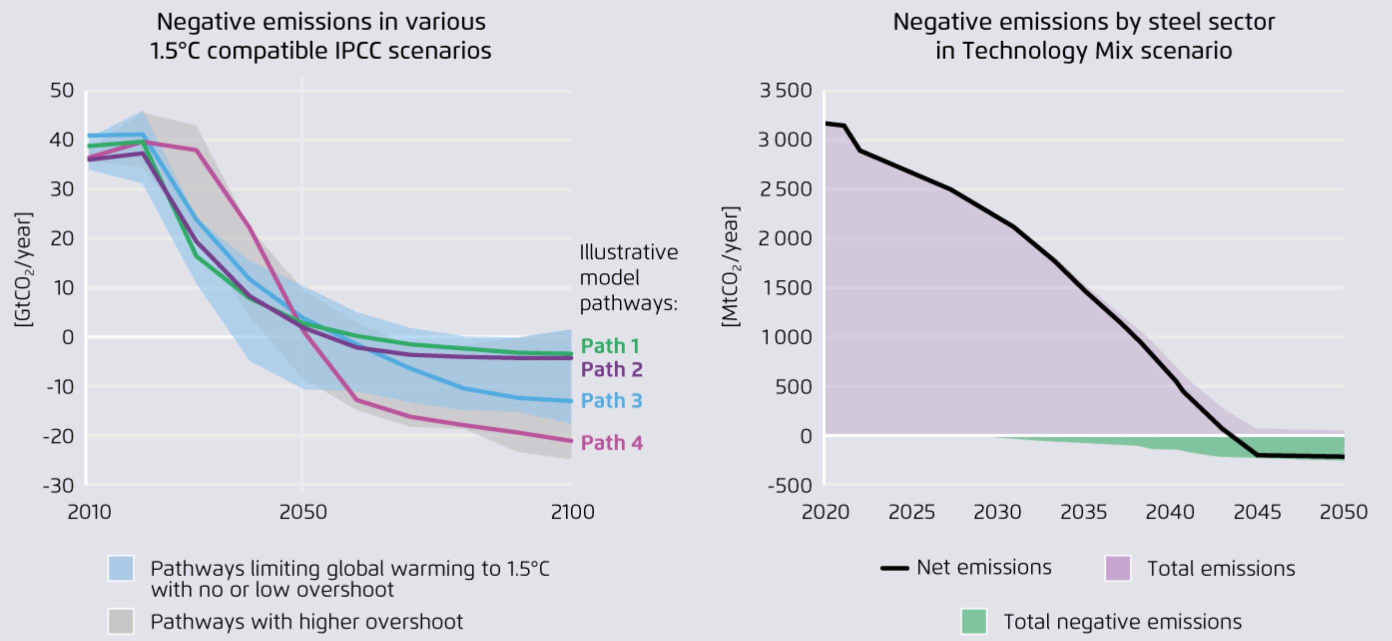
A massive scale-up of DRI is necessary to accelerate the global steel transformation — Figure 13



Agora Industry and Wuppertal Institute (2023) left; Vogl et al (2021) right. Note: MPP = Mission Possible Partnership's 1.5°C compatible Carbon Cost Scenario from September 2022; Technology Mix and Global Green Iron Scenario by Agora Industry and Wuppertal Institute (2023).

Insight 8: The steel sector can contribute to negative emissions via bioenergy carbon capture and storage (BECCS)

Negative emissions in different IPCC scenarios (left) and in our Technology Mix scenario (right) Figure 15

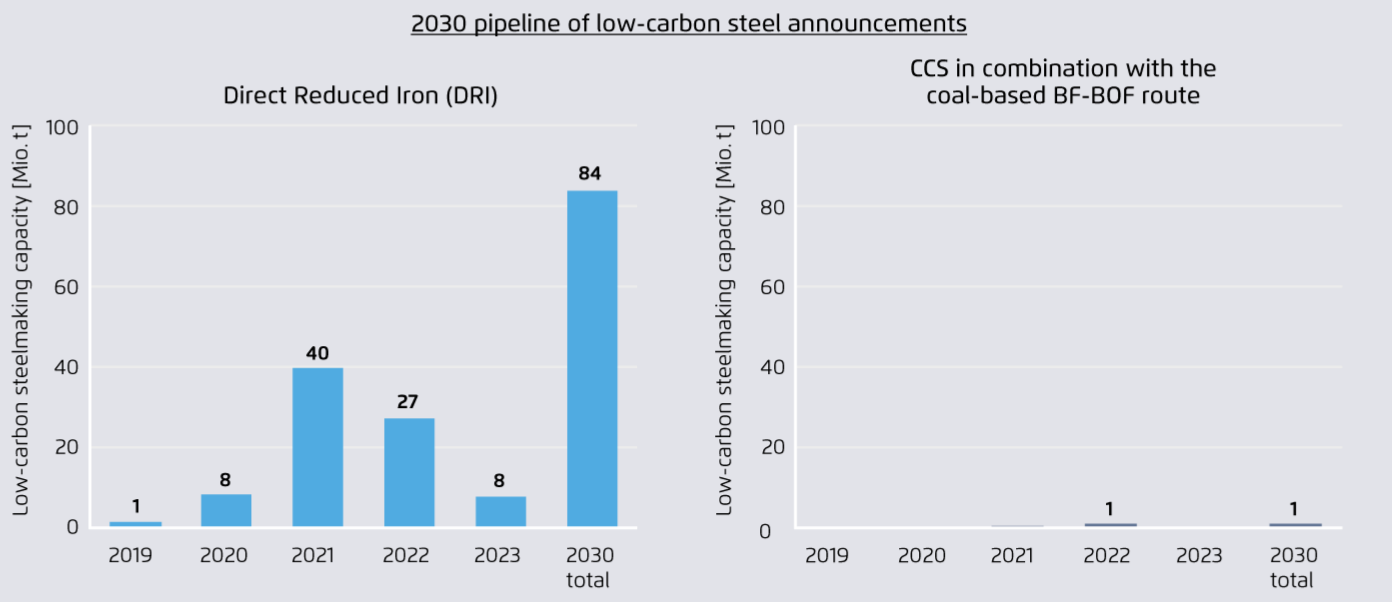


Based on IPCC 2018 (left) and Agora Industry and Wuppertal Institute (2023) (right)

Insight 9: CCS on the BF-BOF route will not play an important role in the global steel transformation

Where the global steel industry is heading: 2030 pipeline of low-carbon steelmaking announcements

Figure 17



Agora Industry, Global Steel Transformation Tracker (2023). Note: The 2030 project pipeline of DRI plants includes H_2-ready DRI plants that may operate with natural gas initially. To date, the 3D project in Dunkirk is the only demonstration-scale CCS project on the BF-BOF route announced and aims to capture 1 $MtCO_2$ per year.

→ CCS leaves high residual emissions

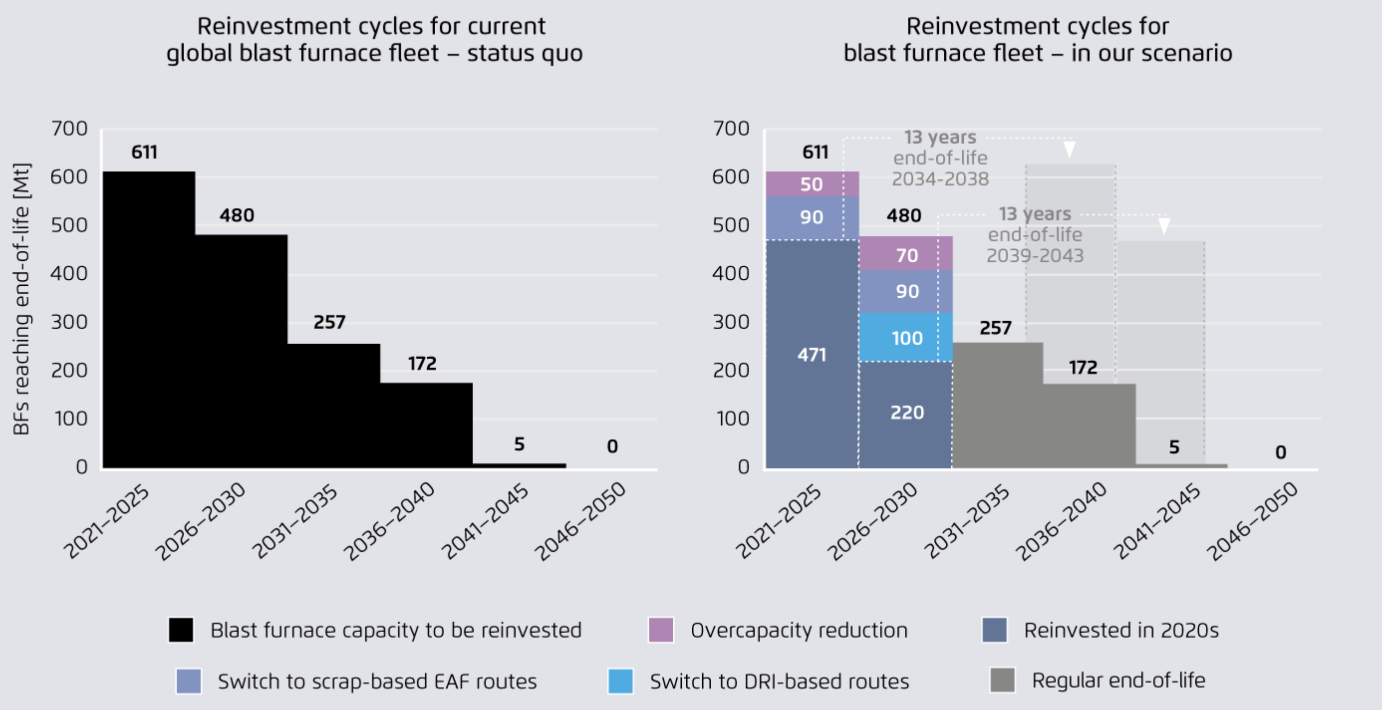
→ It will be prone to disruptive technology developments by competing technologies

→ It cannot address upstream emissions which can become an additional business risk

→ It faces an offtake risk in green lead markets

Insight 10: By 2040, over 90% of existing blast furnaces can be phased-out without a premature shutdown

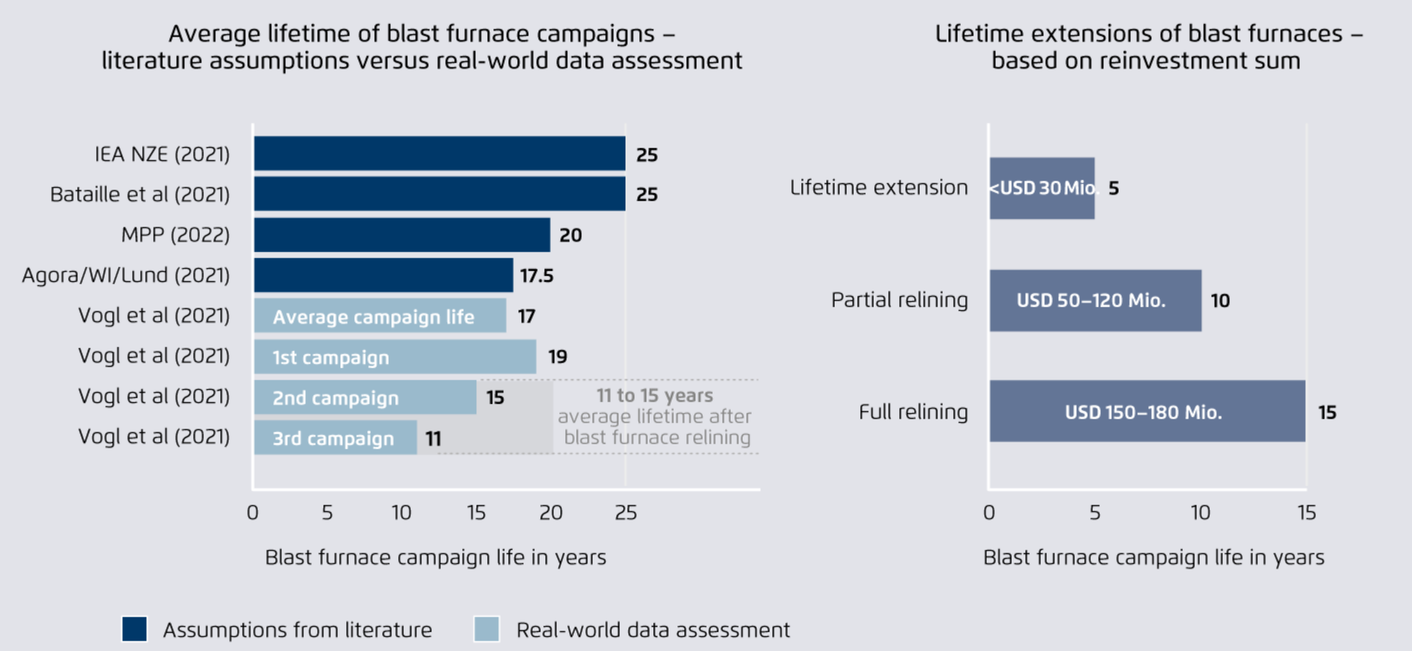
By 2040, over 90% of existing blast furnaces can be phased out without a premature shutdown Figure 19



Agora Industry (2023), authors' calculations based on Global Steel Transformation Tracker (2023). Note: We assume that out of 150 Mt additional DRI capacity that could be built by 2030, 100 Mt are used to replace existing capacity. Overcapacity reduction assumptions are based on company announcements and an estimation of the capacity swap mechanism in China.

This is because blast furnaces have significantly shorter campaign lifes than is widely assumed

Lifetime of blast furnace campaigns and various blast furnace retrofit measures — Figure 20

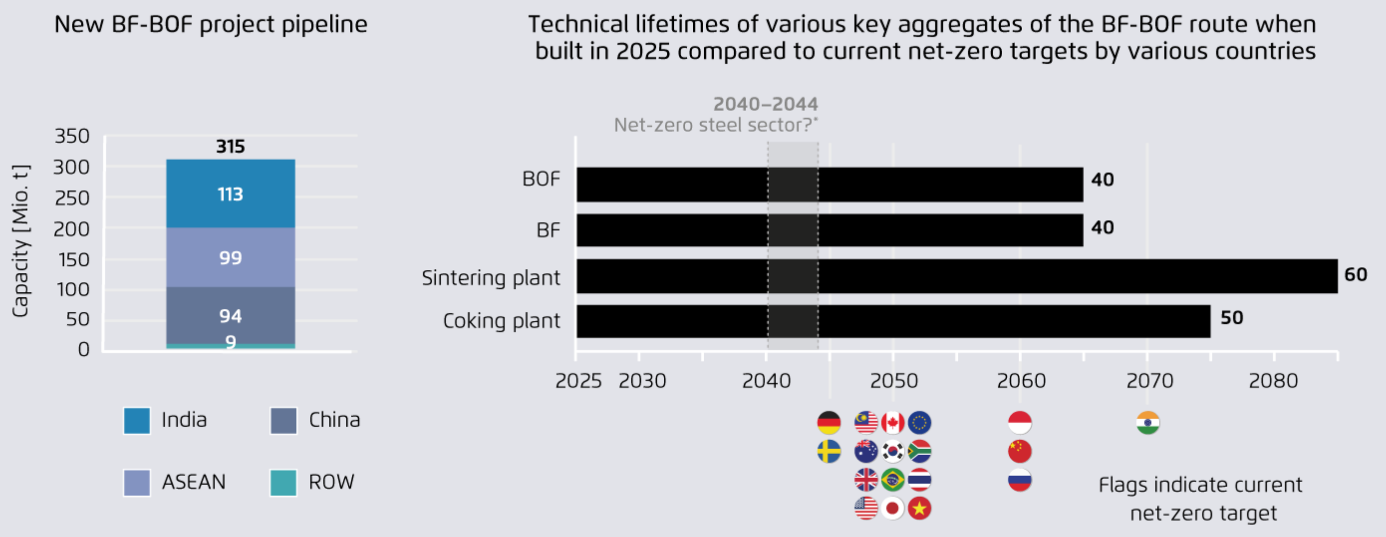


Agora Industry (2023) based on Vogl et al (2021) and own analysis (right). Note: The numbers on the right-hand side are based on our analysis of retrofit measures by various European steelmakers.

Insight 11: The current 2030 pipeline of unabated coal-based blast furnaces in emerging economies is facing a large carbon lock-in and stranded asset risk

The current project pipeline for new coal-based BF-BOF plants is facing a large carbon lock-in and stranded asset risk

Figure 21

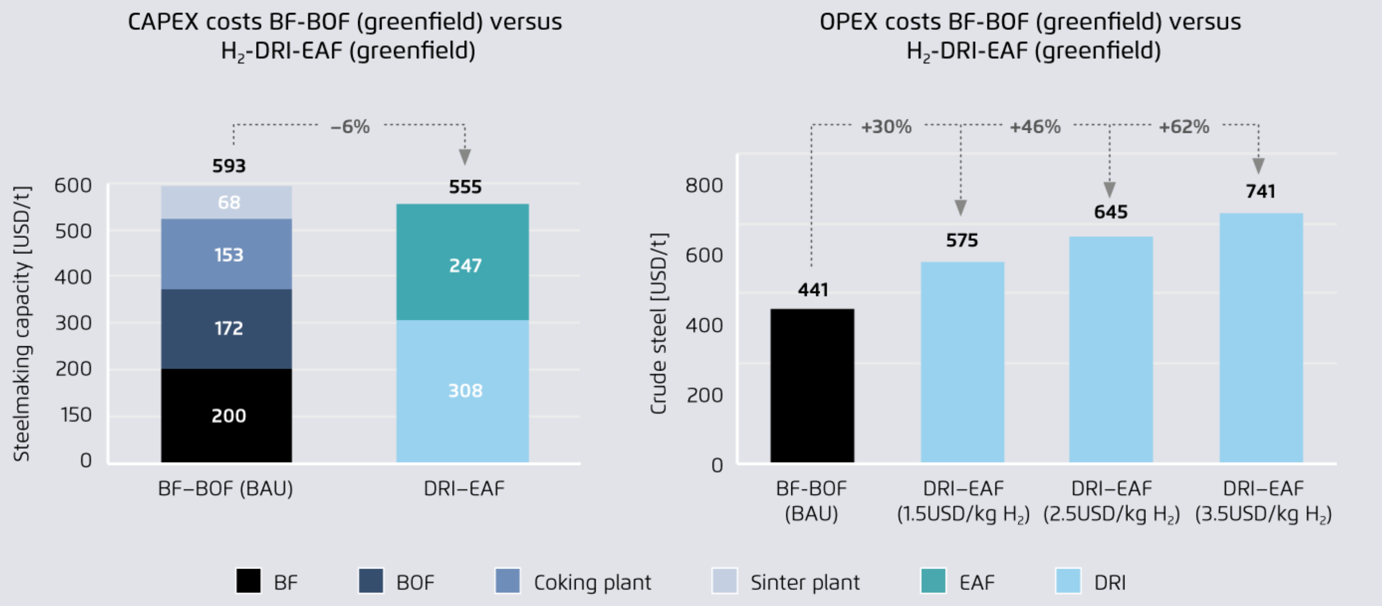


Agora Industry (2023) assessment and IEA (2020a), Paul Wurth (2022). Note: The current blast furnace – basic oxygen furnace (BF-BOF) pipeline is based on an analysis of announcements in India (IBEF 2022, GEM 2022 and various press releases); for Southeast Asia we used data from OECD (2022) based on data from the Southeast Asian Iron and Steel Institute; for China we analysed public quarterly local government statistics; data for rest of the world is derived from GEM (2022). *2040 and 2044 are the net-zero dates in our Global Green Iron and Technology Mix scenarios.

To shift investments from coal to clean addressing higher OPEX is key

Shifting investments in emerging economies from coal to clean will require a solution for the higher OPEX costs

Figure 22

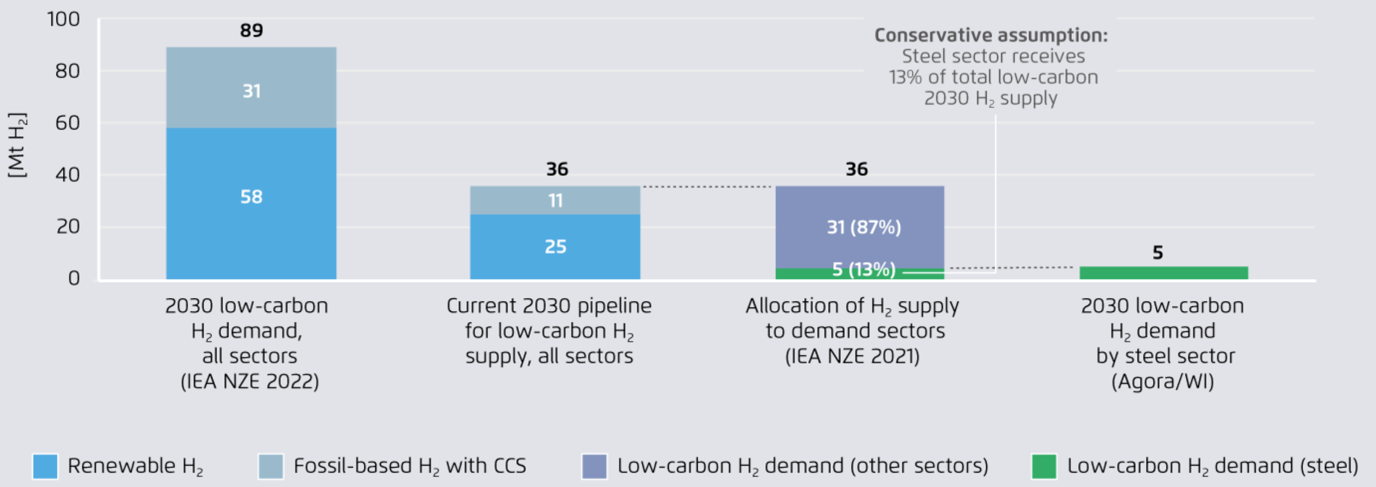


Wörtler et al., 2013 (left) and Agora Industry and Wuppertal Institute, 2023 (right). Note: Numbers on the left were originally given in euros for the year 2010. We adjusted the numbers from euros to US dollar based on the conversion rate from 1 to 1.34 for the relevant year (2010). Right: authors' calculations. CAPEX = capital expenditure; OPEX = operational expenditure.

Insight 12: Low-carbon H2 supply will likely not be a major bottleneck for the global steel transformation…

2030 low-carbon H_2 supply pipeline versus low-carbon H_2 demand from steel sector by 2030 in our scenarios

Figure 23

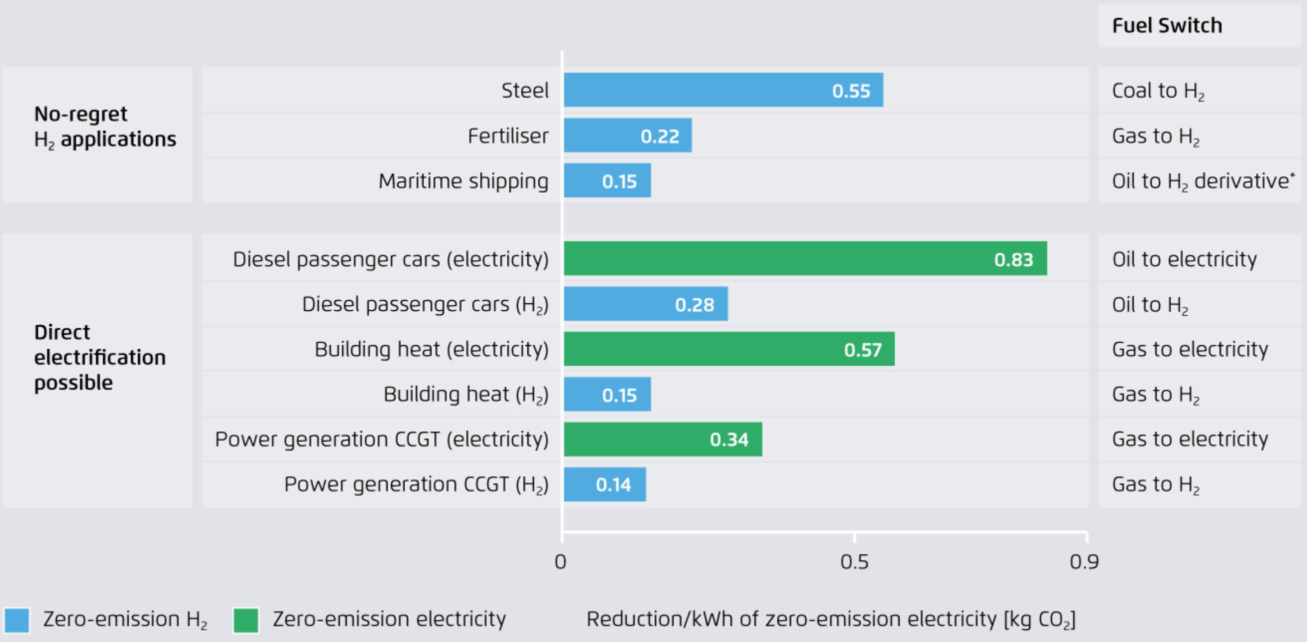


Agora Industry (2023) based on IEA (2021), IEA (2022a), IEA (2023) and BNEF (2022b). Note: H_2 allocation to steel compared to other sectors based on IEA NZE (2021). 2030 low-carbon H_2 demand from steel sector based on Technology Mix scenario.

… if the limited supply of low-carbon H_2 is channeled into no-regret applications

No-regret H_2 use: steel has the highest CO_2 mitigation potential compared to various other H_2 applications

Figure 24



Agora Industry and Wuppertal Institute (2023) based on concept developed by RMI (2022) and authors' calculations in Agora Energiewende (2023). Note: We assume 2.1 t CO_2/t of crude steel for a world average conventional BF-BOF plant and an electricity requirement of 3.84 MWh/t of crude steel for the DRI-EAF route that runs on 100% renewable H_2. *For maritime shipping based on RMI 2022, we assumed that ammonia replaces heavy fuel oil in a 39% efficient internal combustion engine. All other assumptions are retrieved from Agora Energiewende (2023).

Insight 13: Availability of DR-grade ore is a potential bottleneck. Solutions exist, but they need to be actively pursued

How the bottleneck of DR-grade pellets can be addressed

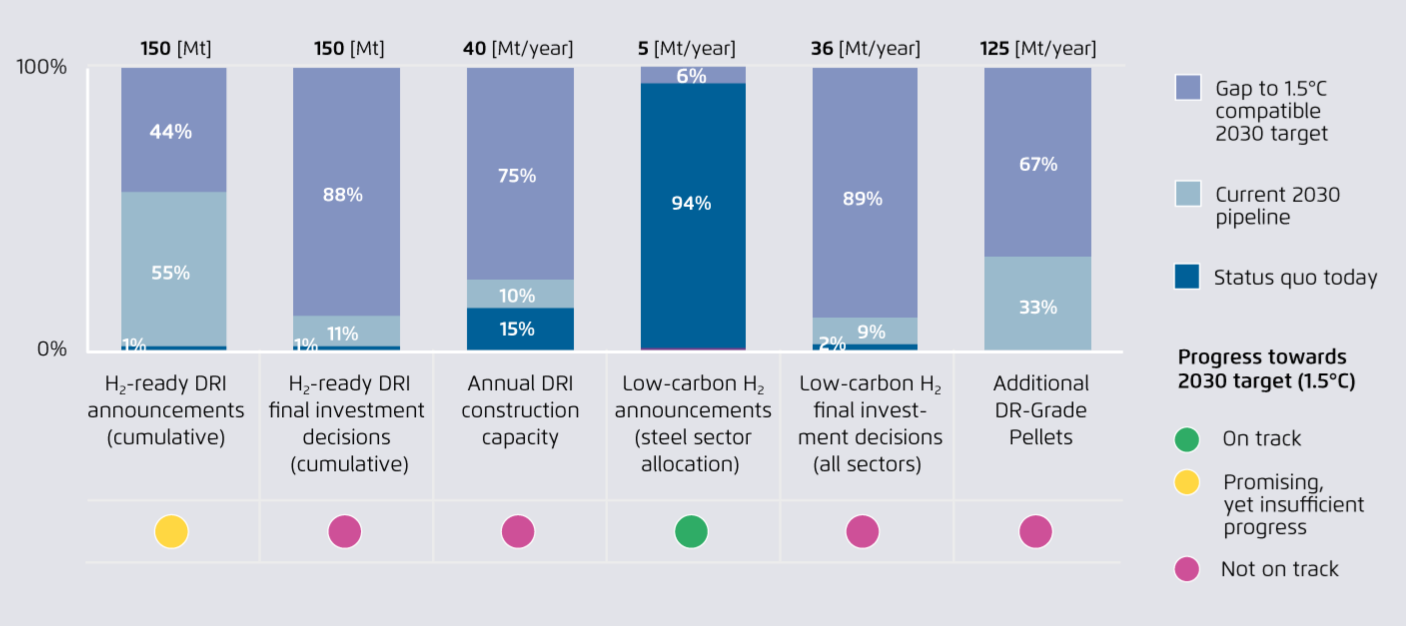
Figure 25

Agora Industry and Wuppertal Institute (2023), based on MPP (2021). Note: DRI-SMELT-BOF = direct reduced iron – electric smelter – basic oxygen furnace; DRI-EAF = direct reduced iron – electric arc furnace. DR-grade pellets refers to direct reduction grade pellets, which are required for the DRI-EAF route, but not the DRI-SMELT-BOF route.

Insight 14: The bottlenecks for a 1.5°C compatible steel transformation pathway are manageable…

Key bottlenecks up to 2030: The state of play

Figure 27



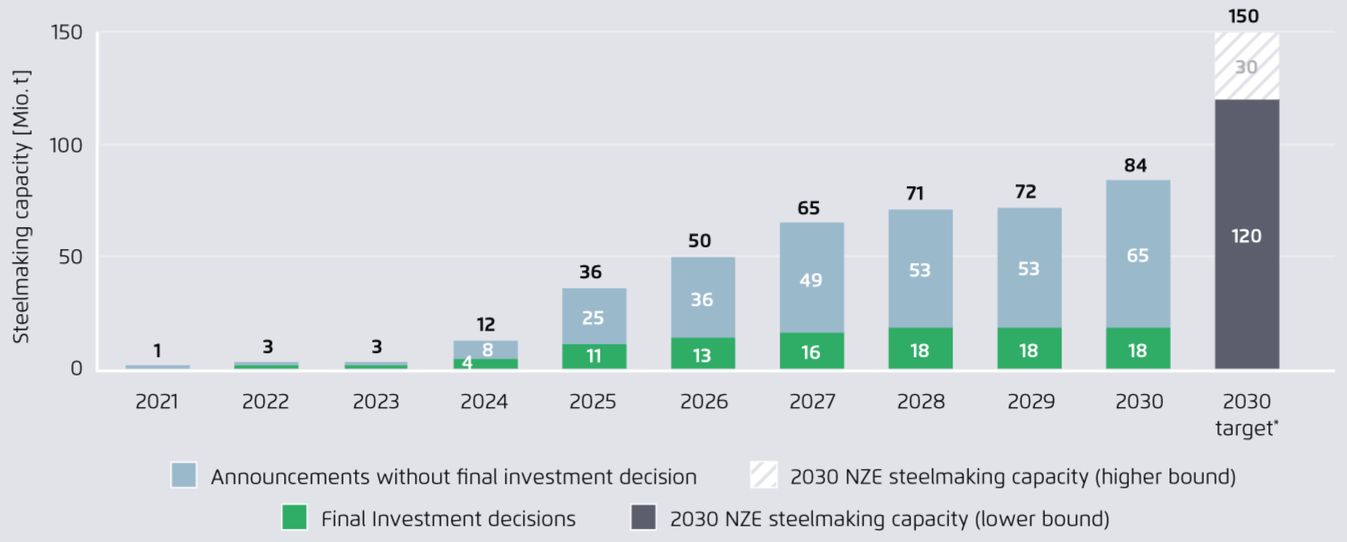
Agora Industry (2023), based on Agora Industry Global Steel Transformation Tracker (2023), IEA (2022a), IEA (2023), BNEF (2022b); IEEFA (2022a). Note: The target of 120 to 150 Mt H_2-ready DRI capacity is based on our modelling and the latest Breakthrough Agenda Report 2022 which called for "more than 100 Mt of near-zero emissions primary steel by 2030". The figure displays the upper range of the 2030 target numbers for H_2-ready DRI announcements (120 to 150 Mt) and additional DR-grade pellets (100 to 125 Mt). With regards to final investment decisions, status quo today refers to plants that have begun operations since 2021 and current 2030 pipeline refers to final investment decisions. Based on BNEF 2022b and IEA ETP 2023, we estimate the current low-carbon H_2 project pipeline to be 36 Mt by 2030. In our modelling scenarios the steel sector requires around 5 Mt low-carbon H_2 by 2030, which constitutes 13% of total low-carbon H_2 supply, if the entire current low-carbon H_2 project pipeline is realised.

…but joint action from governments *and* industry is needed

Insight 14: Currently, the share of final investment decisions for near-zero emission capable steelmaking capacity is still low

2030 pipeline: near-zero emissions primary steelmaking capacity announcements and final investment decisions

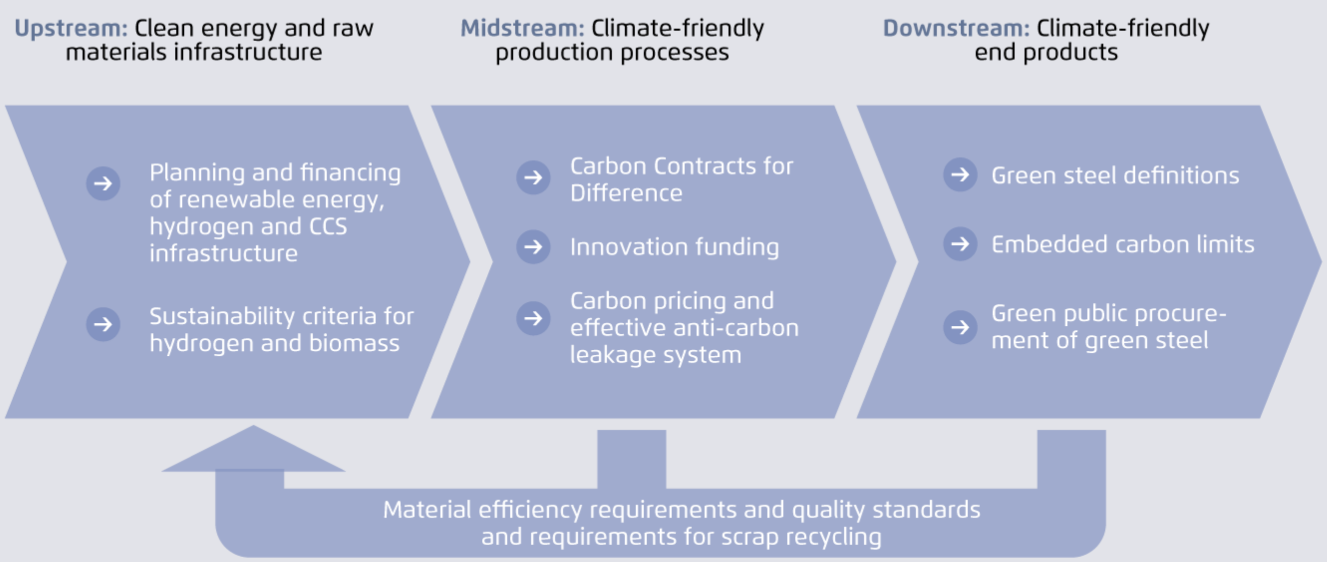
Figure 28



Agora Industry (2023), Global Steel Transformation Tracker (2023). Note: All announced projects can be H_2-ready DRI plants, in principle. However, to date only around 25% of the project pipeline is designed at outset to accommodate switch to renewable H_2. All other DRI plants will run on natural gas or a mix of natural gas and H_2 with the stated intention of most companies to switch to 100% low-carbon H_2 eventually, once it becomes available (see Agora Industry, Global Steel Transformation Tracker). *The 2030 targets refer to the near-zero emissions primary steelmaking capacity that would be needed to be on a 1.5°C compatible pathway based on IEA, IRENA, UN 2022 and authors' scenarios.

Insight 15: Achieving a net-zero steel sector will require governments to adopt a comprehensive policy framework that addresses the entire value chain. International coordination and cooperation will be key in this regard

A net-zero steel sector requires a comprehensive policy framework across the entire value chain — Figure 29



Agora Industry (2023)

Agora Industry
Anna-Louisa-Karsch-Str. 2
10178 Berlin

T +49 (0)30 700 1435 - 000
F +49 (0)30 700 1435 - 129
www.agora-industry.org

Please subscribe to our newsletter via
www.agora-energiewende.de
www.twitter.com/AgoraEW

Agora Industry

Wuppertal Institut

Thank you for your attention!

Questions or comments? Feel free to contact me:

Wido.witecka@agora-energiewende.de
Stefan.Lechtenboehmer@wupperinst.org