Global Steel at a Crossroads

Why the global steel sector needs to invest in climate-neutral technologies in the 2020s

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Dear reader,

In November, world leaders will meet in Glasgow for the 26th UN Climate Change Conference (COP26). Their mission is to reach a consensus on how to increase climate ambition and accelerate the global energy transition in the 2020s. This means setting in place changes in technologies and infrastructure to secure significant emissions reductions before 2030 and enable further emissions cuts in the following decades. The global steel sector will play a vital role in this transformation.

The 2020s will be a crucial decade for the transformation of the global steel sector. Two key facts underline this. More than 70% of existing coal-fired blast furnaces – comprising 2.4 million jobs and around 2.2 Gt of carbon dioxide emissions – will reach the end of their lifetimes by 2030. At the same time, emerging economies are currently building new coal-based steelmaking capacity to meet rapidly rising steel demand.

If all these (re)investment decisions continue to rely on coal-based steelmaking technologies, the outcome will be long-term carbon lock-in. And "bailing out" coal-based assets by retroactively equipping them with CCS after 2030 is a highly risky bet.

Instead, the global steel sector must use the 2020s to invest massively in low-carbon steelmaking technologies such as direct reduced iron and electric arc furnaces. This paper examines the challenges of and options for steelmaking asset transformation in a variety of countries. It is the first in a series of Agora Industry publications on the global steel transformation.

We hope you enjoy reading this study.

Frank Peter,
Director, Agora Industry

Key findings

1	**The global steel sector is at a crossroads. Before 2030, 71% of existing coal-based blast furnaces (1090 Mt) will reach the end of their lifetimes and require major reinvestments.** Meanwhile, emerging economies with rising steel demand will require at least 170 Mt of new capacity. Meeting these needs with coal-based capacity will create long-term carbon lock-in and lead to stranded assets, endangering jobs and putting any pathway compatible with 1.5°C out of reach.
2	**The global steel transformation needs to start in the 2020s. Key low-carbon technologies are ready and can be deployed now.** The project pipeline of green steelmaking capacity that will come online before 2030 is growing rapidly. 40 Mt of direct reduced iron (DRI) capacity is already planned and many operators have announced that they will switch to secondary steel production. Retroactive post-combustion CCS for coal-fired blast furnaces may be a dead-end road.
3	**Aligning the steel sector with a 1.5°C compatible scenario needs to put the asset transition from coal to clean at its core.** The best strategy from now on is to avoid reinvestments into blast furnaces by prolonging lifetimes of old assets by 2-5 years and after 2025, invest into DRI directly. By 2030, the global steel sector would require 390 Mt of DRI capacity and 278 Mt of additional secondary steel capacity. This is feasible – and would save the atmosphere 1.3 $GtCO_2$ per year.
4	**A single-speed global steel transformation can bring enhanced international cooperation and a level playing field.** Steel is a globally traded commodity. The sector's transformation will require international cooperation. Meeting the asset transition targets would transition some 1.3 million existing jobs in the steel industry from coal-based to future-proof green jobs while creating 240,000 new green jobs in emerging economies.

Content

1 Introduction

Steel is a versatile material that is used in infrastructure, cars, household appliances and machinery. Despite the potential for changing materials in some products, a modern life without steel is hard to imagine. For many countries, the steel sector is a source of well-paid jobs and the cornerstone of industrial value chains for value creation and jobs.

However, steel production today is highly CO_2-intensive, accounting for 7-8% of global greenhouse gas emissions (IEA 2021b).[1] Moreover, due to growing demand for steel in emerging and developing economies, steel emissions risk increasing in the future.

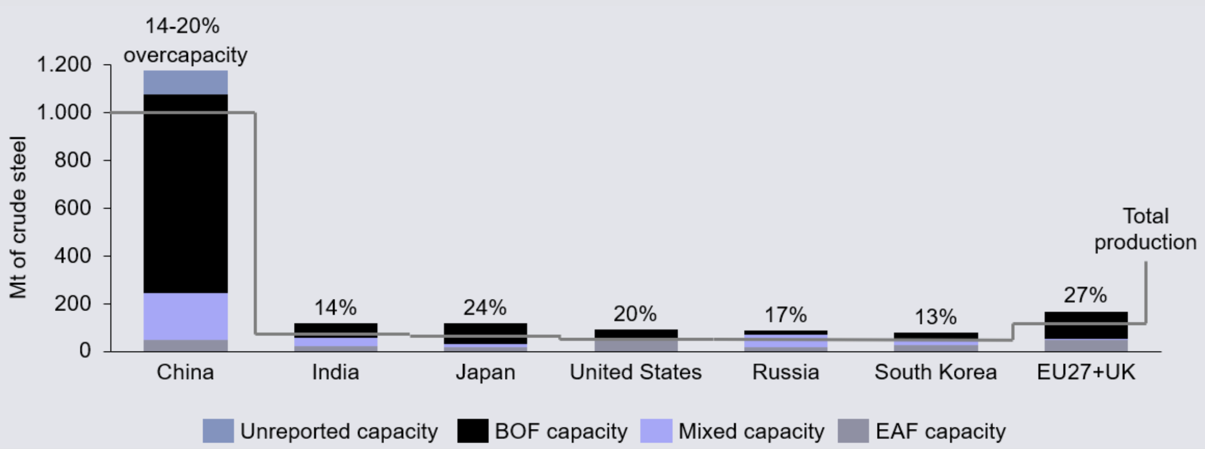
This is avoidable. Key low-carbon technologies compatible with climate neutrality are ready and can be deployed now. The global steel transformation needs to start in the 2020s with investments into these technologies.

2 Global steel at a crossroads

2.1 COP26 must kick-start the industrial transition to climate neutrality

Currently, the announced climate pledges of governments would put the world on a pathway to 2.1°C global warming by 2100 (IEA 2021a). Steep emissions reductions in the 2020s are necessary to put the world on a pathway that is compatible with limiting global warming to 1.5°C. The steel sector is a

Figure 1: Steelmaking overcapacity – 2019 steelmaking capacity vs production in top producing countries



Agora Industry, 2021 based on Global Energy Monitor, 2021

1 There are different ways to allocate steel sector emissions. In IEA publications, emissions from on-site industrial power plants are allocated to electricity and heat production and not to the steel sector. This explains the differences between the accounting method used in this study and other approaches.

crucial factor for success, both in the short term and in achieving climate neutrality by 2050.

One starting point is to reduce steel production overcapacities (see figure 1). For the past decade, overcapacity in the global steel sector has been a serious problem (OECD 2019; AIST 2021). It has produced depressed prices and raised concerns about unfair competition. Reducing overcapacity by closing the most inefficient and polluting plants is a clear no-regret measure that can secure some emission cuts. But this is insufficient to put the global steel sector on a pathway compatible with 1.5°C. For that, the steel sector requires an asset transition of unprecedented scale from coal-based to clean technologies.

2.2 The 2020s is a crucial decade for global steel

In the past, the steel sector was considered hard to abate. This is no longer true. Indeed, as we will see in section 2.3, several low-carbon technology options are now available.

But while the 'hard to abate' label no longer applies, even progressive net-zero scenarios for 2050 continue to assume that the global steel sector transformation will pick up pace only after 2030. This is a serious misconception, for it ignores an important reality: a large share of existing capacity will require reinvestment already in the 2020s, and the decisions steel producers make will shape the sector for decades to come.

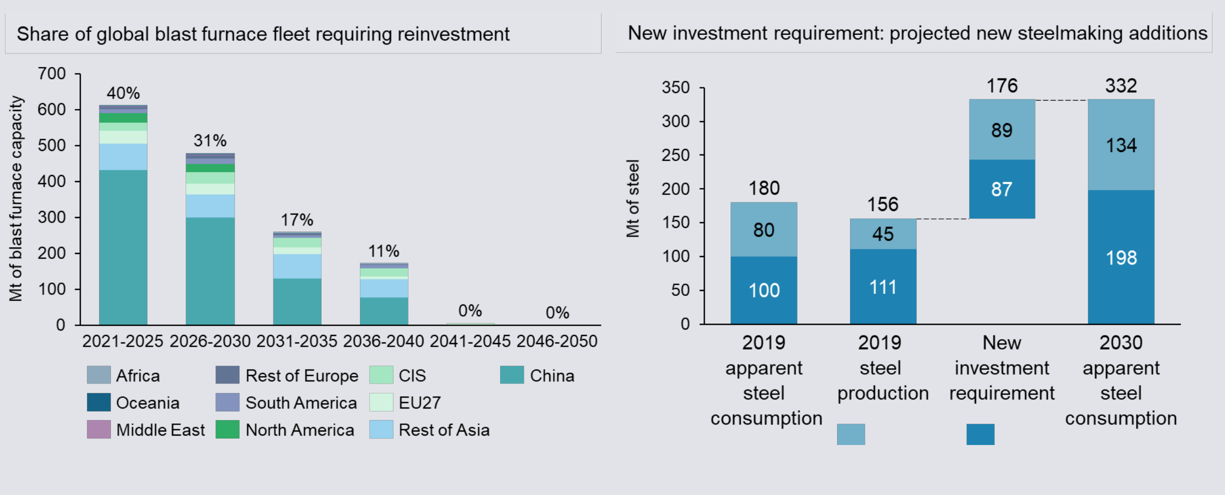
Around 1090 Mt (71%) of the world's coal-based steel blast furnace capacity will reach the end of its operating lifetime before 2030. In order to continue operation, this capacity will require reinvestments – a so-called relining of the blast furnace (see figure 2).[2] In China, 78% of existing coal-based steelmaking capacity will need a relining before 2030. The share is 70% in Europe, 76% in Japan and 72% in South Korea. In the US, the share is close to 97% (see Agora Industry Global Steel Transformation Tracker).

These upcoming reinvestments are a golden opportunity for adopting alternative steelmaking technologies. If operators take the business-as-usual approach – reinvesting into coal-fired blast furnaces – they risk locking in conventional asset cycles that are not compatible with a 1.5°C pathway to climate neutrality.

Reinvestments in existing capacity are only part of the problem. Despite global overcapacity, emerging economies want to develop local capacity. During the 2020s, at least 175 Mt of *new* steelmaking capacity (new investments) will be required to meet rising local demand in these regions (see figure 2). Project pipelines in India and Southeast Asia already comprise 76 Mt (Agora Industry based on IBEF 2021) and 62 Mt (SEAISI 2020) of capacity, respectively. Other emerging economies, notably on the African continent, may also require more steel in the future. In all these instances, the crucial point is this: if emerging economies build new capacity using coal-based technology, they will lock in new emissions for decades to come (see figure 2).

[2] The reinvestment needs were calculated based on the Plantfacts Capacity Database of World Steel Dynamics. For advanced economies, we assumed an operating life of 15 years after the last relining; for emerging economies, we assumed a lifetime of 20 years. For the EU (Agora Industry dataset, plant-specific lifetime, average: 13 years), China (16 years) and Japan (20 years), we deviated from the aforementioned assumptions. For China, a team of researchers from Wuppertal Institute, Lund University and Agora Industry used the yearly pig iron production increase over time to approximate the reinvestment cycles of blast furnaces and refined this with own assumptions from the OECD and World Steel Dynamics.

Figure 2: Reinvestment and new investment requirement



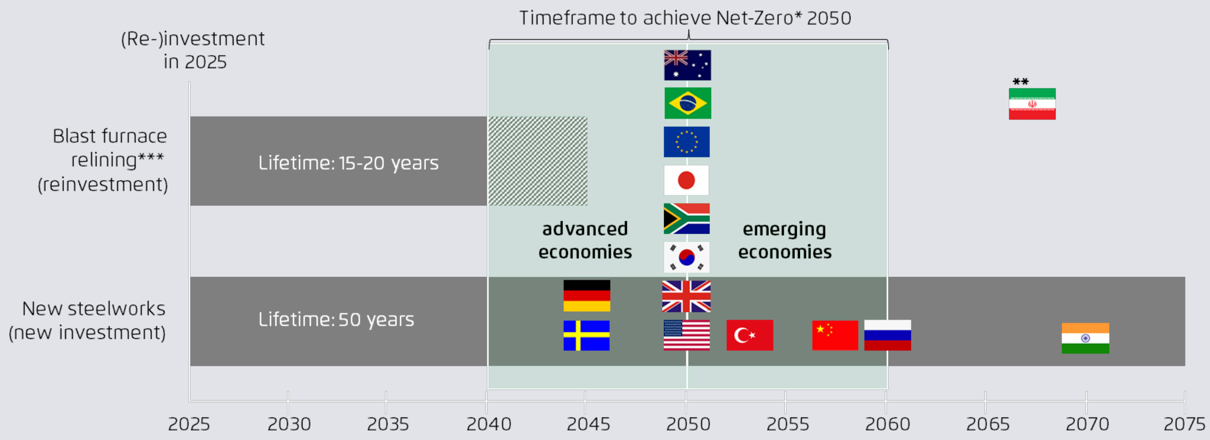
Left: Agora Industry analysis based on World Steel Dynamics, 2021; Agora Industry, Wuppertal Institute & Lund University for China, 2021
Right: Agora Industry analysis based on World Steel Dynamics, 2021, TERI 2020 and SEASI 2020

In sum: steelmaking assets have long lifetimes. Blast furnace relining will add another 15 to 20 years of service life to a conventional plant. And new coal-based steelworks can remain in operation for as long as 50 years (see figure 3).[3] Accordingly, technology choices for reinvestment and new investment decisions in the 2020s will be critical for the transition of the global steel sector.

The good news is that two low-carbon technologies are market ready and can be deployed now, provided that policies enabling a business case for low-carbon steelmaking are put in place.

3 We assume 50 years of lifetime for a new coal-based steelworks. While the first "campaign life" of a blast furnace is only around 20 years before major refurbishments are required, other parts of the steel plant such as the coking plant and the basic oxygen furnace have technical lifetimes of around 50 years and may have to be closed down prematurely before the end of their technical working life, if countries strive to achieve climate neutrality by mid-century.

Figure 3: Technical lifetime of coal-based primary steel production capacity and timeframe to achieve Net-Zero 2050



Agora Industry, 2021

* South Korea and South Africa have announced carbon neutrality targets. The targets of Australia, Russia and Turkey are not official yet. All others have announced net zero targets. **n/a; no target *** 15 years lifetime in advanced economies; 20 years lifetime in emerging economies

2.3 Key low-carbon technologies are ready and steel companies want to switch before 2030

The two market-ready low-carbon steelmaking technologies deployable at scale are DRI for primary steel and electric arc furnaces for secondary steel. Both technologies use electricity and hydrogen or natural gas instead of coal as primary energy carrier and reductant, which allows them to significantly reduce related carbon emissions:

→ DRI plants can produce primary steel using natural gas or clean hydrogen. The iron ore is reduced to produce DRI, which can then be smelted in an electric arc furnace to produce primary steel. Another way to deploy this technology is to geographically separate the process of DRI production and steelmaking. For example, iron ore-exporting countries with cheap and abundant potential for renewable hydrogen production could produce green DRI domestically and export it to other countries, where the second step of steelmaking takes place. DRI can be transformed to hot briquetted iron (HBI) to facilitate long-distance transportation.

→ Another option that is available now is to replace coal-based steelmaking capacity with secondary steelmaking capacity. Increasing steel scrap supply over time will allow to feed a growing number of electric arc furnaces that melt steel scrap to steel.

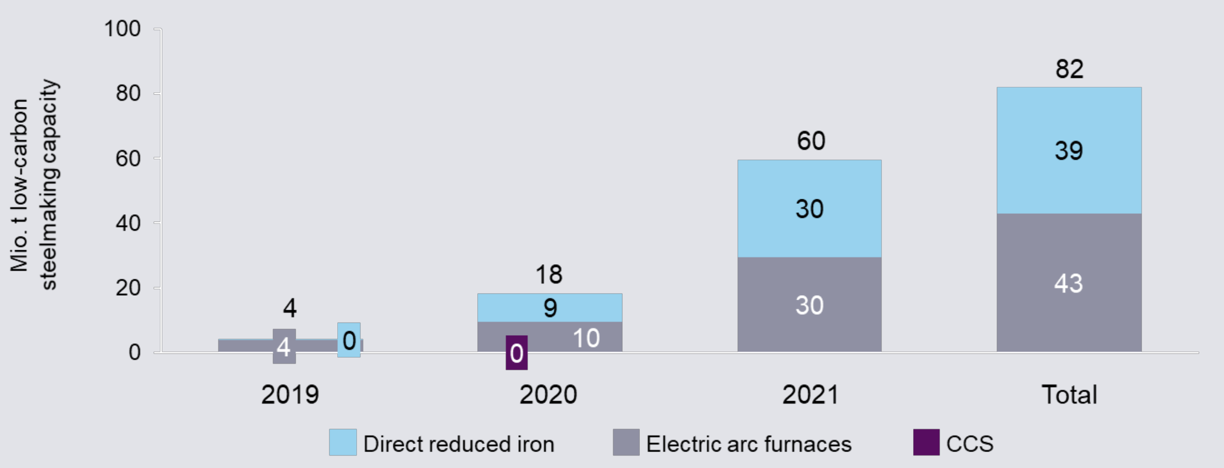
The project pipeline for announcements to build low-carbon steelmaking capacity is growing rapidly, and around 80 Mt of capacity is already due to come online before 2030 (see Global Steel Transformation

Tracker). Of this 80 Mt, around 50% is DRI[4]; additional secondary steelmaking capacity via electric arc furnaces makes up 50%. The announced low-carbon steel projects based on DRI cover four continents – Oceania, Asia, Europe, North America – meaning that this is already a global development. The first industrial-scale hydrogen-based DRI plant will go online in China in early 2022.[5] The first industrial-scale DRI plant in Sweden is scheduled to begin operation in 2024.[6]

With appropriate policy support, that trend could be vastly accelerated.

Until sufficient supplies of clean hydrogen are available, DRI plants can be operated with natural gas. Over time, they can blend in increasing shares of clean hydrogen without requiring retrofits. At the same time, scaling up high-quality scrap steel supply chains in the circular economy will allow substituting coal-based steelmaking capacity with electric arc furnaces. There are additional costs that will need to be covered, however, especially for low-carbon DRI-based steel. For this, policies enabling a business case for low-carbon steel are required. While some government support will likely be required for the first wave of projects, large-scale private sector demand for green and low-carbon steel will also develop well before 2030.

Figure 4: Global low-carbon steel announcements to be built before 2030



Agora Industry, 2021 based on Agora Industry Global Steel Transformation Tracker, 2021

4 We define all future gas-based DRI capacity as low-carbon steelmaking because it can flexibly operate with any share of natural gas and clean hydrogen. Even if a plant is initially operated with fossil natural gas, it can produce virtually climate-neutral steel without retrofitting once it switches to renewable hydrogen. That is to say, gas-based DRI plants are at no risk of carbon lock-in and are thus compatible with climate neutrality.

5 The plant is scheduled to be operated with hydrogen-rich gases, which may be non-renewable to start.

6 For a full overview of projects by country, see Global Steel Transformation Tracker.

2.4 Green lead markets for green and low-carbon steel

Private sector demand for green and low-carbon steel is at an early stage but is likely to expand rapidly. More and more companies have signalled their intent to lower the carbon footprint of their products before 2030 by buying green steel.

Car companies are leading the change. While the move from internal combustion engines to battery-electric vehicles requires billions of euros in investment and new production lines, the switch from conventional to green steel for car manufacturing comes at a relatively low cost. Green steel would eliminate roughly 19% of the life-cycle emissions of a battery-electric vehicle at low cost without the need for complex reengineering (figure 5). This makes it an attractive measure to improve the climate balance of cars – and an easy win for the car sector.

Switching to green steel may also bring commercial advantages to first-mover car companies. The additional premium for green steel (~200 to 300 USD per tonne of steel) can be passed on to end consumers, only marginally increasing the price of the car (<1% for a small car containing 1 tonne of steel and priced between 20,000 to 30,000 USD). Marketing these cars as green might allow manufacturers to increase their margins or market share.

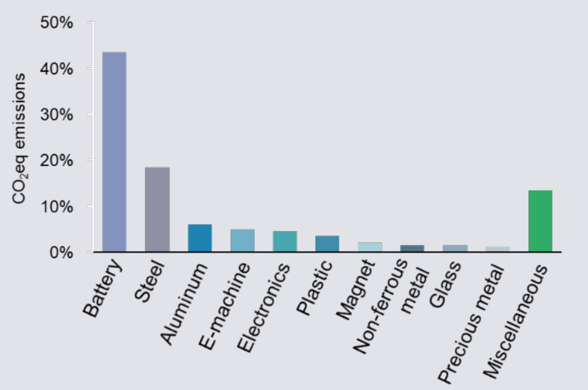
Demand for green steel has the potential to grow rapidly, particularly in traditional car manufacturing economies such as China, Japan, Germany, Korea, and the US.

Figure 5: Green lead market cooperation announcements and life-cycle emissions of battery-electric vehicles

Green lead market cooperation (vehicle manufacturers only)

Companies that have announced a cooperation to produce…	…and consume low-carbon steel	Start of cooperation
Nucor	General Motors	2022
SSAB	Volvo Group	2021
H2GreenSteel	Scania	2024
H2GreenSteel	Daimler Group	2025
Salzgitter Flachstahl GmbH	Daimler Group	2021
Big River Steel	Daimler Group	2020

Life-cycle emissions battery-electric vehicles



Left: Agora Industry, 2021
Right: Agora Industry, 2021 based on Volkswagen ID3, 2021

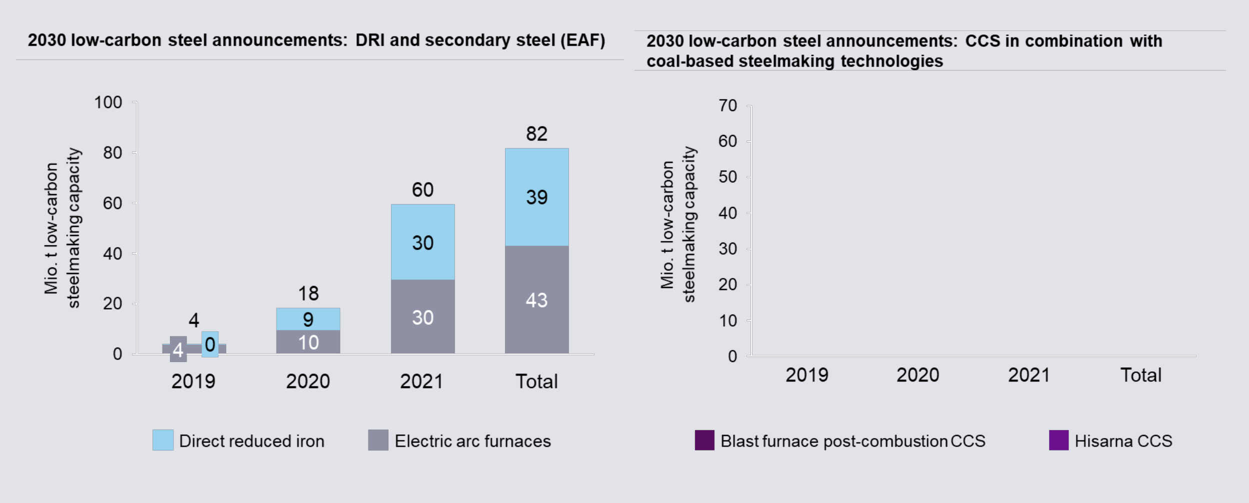
2.5 Retroactive retrofits of coal-based steelmaking capacity with CCUS may prove unrealistic

The alternative technology route to emissions reduction in the steel sector is much less promising. Decarbonisation scenarios have long assigned carbon capture (CCS or CCUS) a large role, including in steelmaking. Even the new IEA Net Zero Emissions scenario (IEA NZE) still sees a massive role for CCUS in the steel sector, with 53% of production using CCUS in 2050.[7]

The reality, however, is that not a single steelmaking company has announced an industrial-scale installation of CCS for coal-based steel production.[8] And the few companies that aimed to develop CCS for coal-based steelmaking such as Tata Steel IJmuiden in the Netherlands have since abandoned their plans and opted for hydrogen-based DRI (Tata Steel 2021). Although the retroactive retrofit of coal-based steelmaking capacity remains a theoretical option, none of the steel companies that have put forward concrete low-carbon steel projects are currently pursuing this option.

At best, retroactive CCS for coal-based blast furnaces would be a flawed solution: because of imperfect carbon capture rates on several different point sources, CCS would likely achieve only around an

Figure 6: Retroactive CCS retrofits on coal-based steelmaking capacities may prove to be unrealistic



Left: Agora Industry, 2021
Right: Agora Industry, 2021

[7] The IEA NZE mentions three different CCUS technologies that are used in the steel sector by 2050, but does not give a breakdown of their individual share. These technologies are innovative smelting reduction processes, natural gas-based DRI production and innovative blast furnace retrofit arrangements. While the first two technologies would also imply an asset transition away from the coal-based blast furnace, this paper puts emphasis on the reality that there is currently no single project worldwide to commercialize "innovative blast furnace retrofit arrangements".

[8] There is one project to commercialise CCUS on natural gas-based DRI plants in the United Arab Emirates. However, currently the captured CO_2 of the Al Reyadah Carbon Capture, Use and Storage Project is used for enhanced oil recovery (CSLForum 2021).

83% reduction in CO_2 relative to conventional technology (Wuppertal Institute based on Chisalita et al 2018).[9] The remaining emissions would have to be compensated for by credible carbon offsets.

It is also unclear whether green lead market businesses such as car companies would be willing to accept coal-based steel made with CCS as "green" in view of a virtually climate-neutral green steel produced with hydrogen-based DRI.

2.6 Continued investment in coal-based steelmaking in the 2020s poses high risk

The 2020s put the global steel industry at a crossroads: each reinvestment and new investment presents a choice between either coal-based steelmaking capacity and the risk of carbon lock-in or implementing low-carbon steelmaking technologies that are compatible with climate neutrality.

Relining all coal-based production capacities due for refurbishment between 2021 and 2025 would lock in yearly emissions of about 1200 $MtCO_2$/year until 2040.[10] If capacities slated for reinvestment between 2026 and 2030 remain unabated and coal-based, this would lock in another 955 $MtCO_2$/year until 2045.

Similarly, if all new steel investment from now until 2025 goes into unabated coal-based capacity, the emission lock-in levels would total 176 $MtCO_2$/year until 2075. If investments in new unabated coal-based steel mills continue between 2026 and 2030 this would lock in another 176 $MtCO_2$/year until 2080 (see figure 7).

Not only would this outcome put any 1.5°C emissions pathway out of reach; it would also result in a global crisis of stranded assets in the steel sector.

The IEA NZE has proposed the phase-out of unabated coal in the power sector in advanced economies by 2030 and for emerging economies by 2040. China has pledged to peak emissions before 2030 and reach carbon neutrality before 2060. Both the EU and the US have climate neutrality targets by 2050. The EU aims to phase out coal in the power sector by the early 2030s, while the US wants to have a zero-carbon electricity mix by 2035.

Given the availability of alternative low-carbon technologies, it is very unlikely that new investments in unabated coal-based steelmaking capacity in emerging economies added in the 2020s would be allowed to operate until the end of its lifetime, in the 2070s. Similarly, in the EU and in the US, any unabated coal-based steelmaking capacity will be amongst their respective economy's highest emitting assets by the early 2030s.[11] For steel companies and policymakers alike, therefore, the focus must lie in modernising the global steelmaking fleet and building low-carbon steelmaking capacities well before 2030.

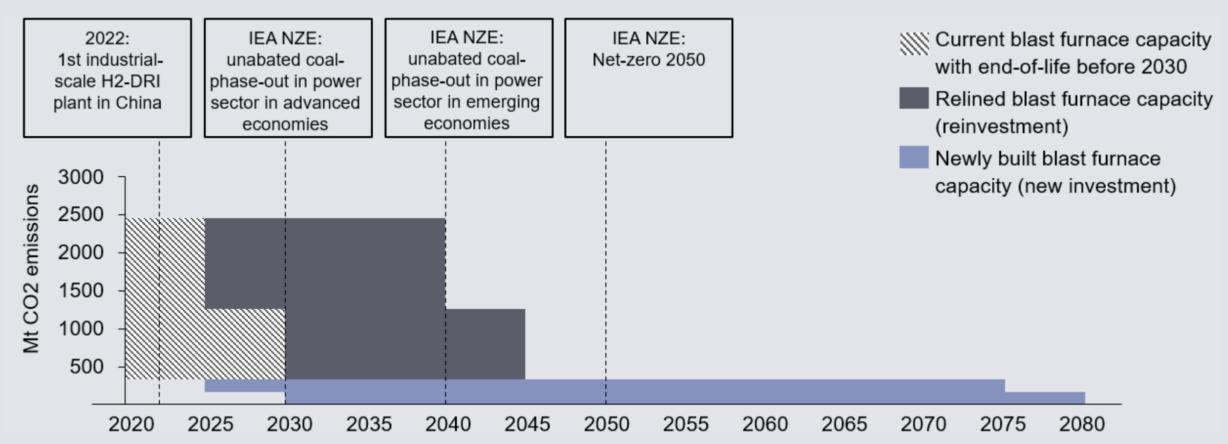
The rest of this paper examines what an asset transition in the 2020s without retroactive CCS might look like for the global steel industry.

9 Higher CO_2 reduction levels are possible in principle, but would also significantly increase the CO_2 abatement costs.

10 For simplicity's sake, we assume that all reinvestments for 2021–2025 are made in 2025.

11 Low-carbon and zero-carbon electricity will also help to supply large amounts of renewable hydrogen for the decarbonisation of primary steelmaking. It can also be used directly to eliminate most emissions in secondary steelmaking.

Figure 7: Continued investment in coal-based blast furnaces produces a carbon lock-in



Agora Industry, 2021

3 Asset transition targets for the 2020s

3.1 2020s transformation gap: reinvestment

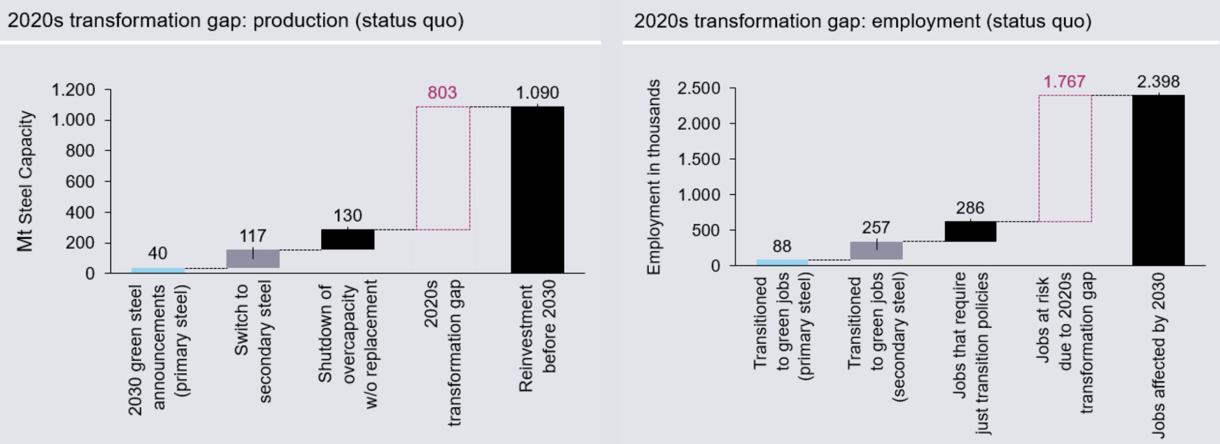
For the steel sector, the transition challenge in the 2020s is enormous. Globally, a total of 1090 Mt of coal-based steelmaking capacity will reach the end of its lifetime and need replacing – directly affecting some 2.4 million jobs.[12]

Answers are available, however. In most cases, steelmakers can transition jobs associated with coal-based capacity to low-carbon production within the same company and site. Companies have already announced plans to build ~40 Mt of DRI capacity by 2030. We estimate that in a business-as-usual scenario, secondary steel production could also increase by at least 117 Mt (World Steel Dynamics 2021).

But while these indicators are encouraging, there remains 803 Mt of coal-based steelmaking capacity requiring imminent reinvestment. 1.77 million jobs hang in the balance, and there is no transition plan to ensure long-term future-proof employment while putting the sector on a pathway to climate neutrality and maintaining competitiveness in a rapidly changing global market.

12 We calculated the employment intensity per Mt of finished steel in various countries. Based on our analysis, we estimate the global employment intensity to be around 2200 workers per tonne of finished steel.

Figure 8: The 2020s transformation gap – reinvestment requirement (status quo)



Left: Agora Industry, 2021; switch to secondary steel based on World Steel Dynamics, 2021
Right: Agora Industry, 2021

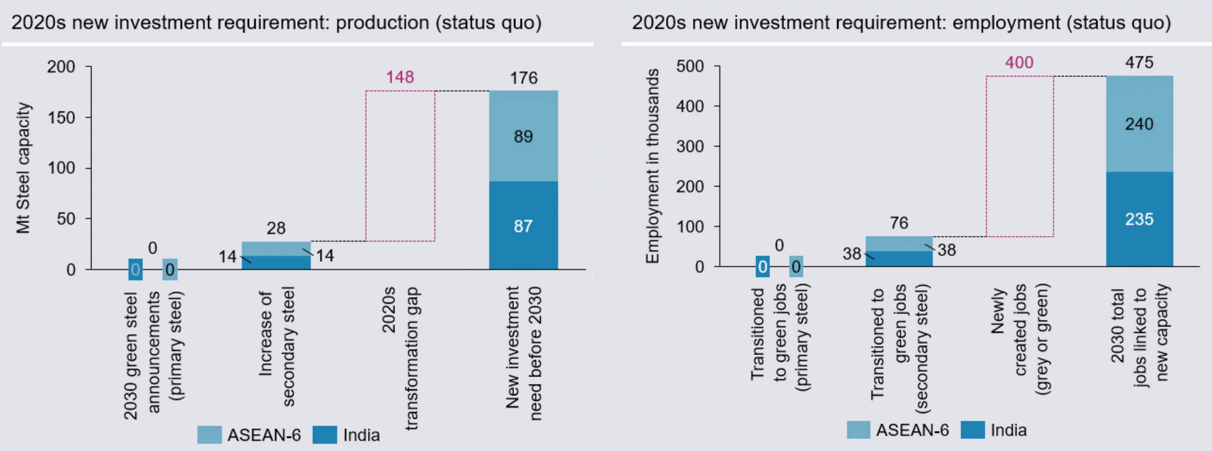
3.2 2020s transformation gap: new investment

Despite the global overcapacity in steelmaking, some emerging economies with rapidly rising steel demand such as India and parts of Southeast Asia are planning additional new steelmaking capacity.

Local scrap steel is in short supply in these economies, which is limiting the option to significantly increase secondary steel production (28 Mt) (World Steel Dynamics 2021). The current project pipeline in these countries consists almost exclusively of new coal-based integrated steel mills, whose lifetimes could in theory extend far beyond 2050. While some governments and companies might be inclined to dismiss the resulting carbon lock-in and risk of stranded assets as a future concern, a prudent and forward-thinking strategy would begin investing in low-carbon steelmaking capacity already in the 2020s. A "technology leapfrog" would create the foundation for a strong, future-proof domestic steel industry in those countries and enable global exports in the future.

In other words: there is no doubt that the 2020s represent a critical decade. But what should the target ambition level be?

Figure 9: The 2020s transformation gap – new investment requirement (status quo)



Left: Agora Industry, 2021 based on World Steel Dynamics and TERI, 2021
Right: Agora Industry, 2021

3.3 Asset transition targets for the 2020s

New research by the Energy Transition Commission estimates that the global steel sector would have to reduce its emissions by 1300 $MtCO_2$ relative to 2019 levels by 2030 to put the global steel sector on a trajectory compatible with 1.5°C (ETC 2021). While there are several potential technology pathways, none will be easy to achieve.

To help define a realistic scenario, we analysed both technology choices and assets lifetimes. We believe that a focus on capacity and forward-looking investment decisions in the 2020s will be vital to a successful and affordable transition.

Our scenario rests on four important conditions:

→ By 2030, the global steel industry is aligned with a 1.5°C compatible pathway
→ The reinvestment cycle in steelmaking capacity before 2030 is factored into assumptions
→ No CCS retrofits may be carried out for coal-based steelmaking plants after 2030
→ Stranded assets in coal-based steelmaking capacity should be avoided after 2030

3.3.1 Approximately 70% of coal-fired blast furnaces slated for reinvestment by 2030 should be replaced with low-carbon alternatives:

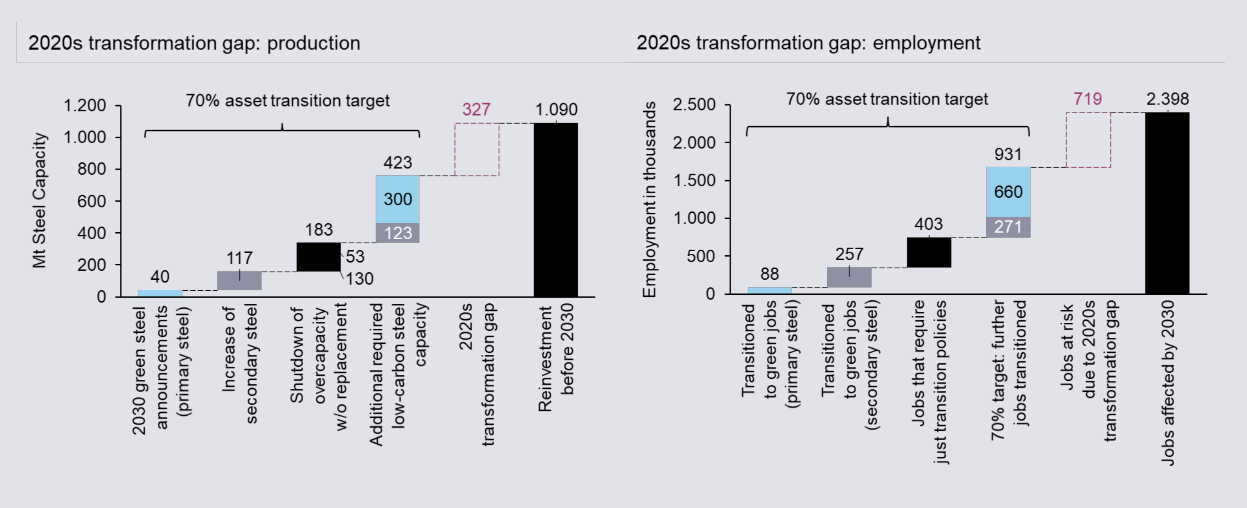
To fulfil the above four conditions in our scenario, we estimate that around 70% of steelmaking reinvestment in the 2020s – around 763 Mt – must come in the form of low-carbon alternatives.

Doing this requires changes at three levels:

→ **Overcapacity shutdown without replacement:** 183 Mt of coal-based capacity in advanced economies and China will need to shut down without replacement due to declining steel demand in those countries. For the ~400,000 affected jobs, just transition measures and policies are required.

- **Switch to secondary steelmaking:** A large volume of coal-based steelmaking capacity can be replaced with 240 Mt of new secondary steelmaking capacity. The majority (150 Mt) will happen in China and advanced economies (50 Mt) such as the US (20 Mt). The growth rate of secondary steel production in the rest of the world will be rather moderate: 40 Mt[13] by 2030 (a 6.6% increase relative to 2019). Globally, the move would transition around 530,000 workers from coal-based jobs to green jobs.
- **Switch to low-carbon primary steelmaking:** The remaining coal-based steelmaking capacity will need to be replaced with 340 Mt of low-carbon primary steelmaking capacity. This would transition another 750,000 jobs from coal dependency to future-proof jobs. The target is ambitious, but the growing number of DRI projects in the pipeline (figure 4) suggests that it is obtainable.

Figure 10: Asset transition targets for the 2020s – reinvestment requirements



Agora Industry, 2021

13 The number for secondary steel excludes India and Asean-6 countries, which fall under "new investment".

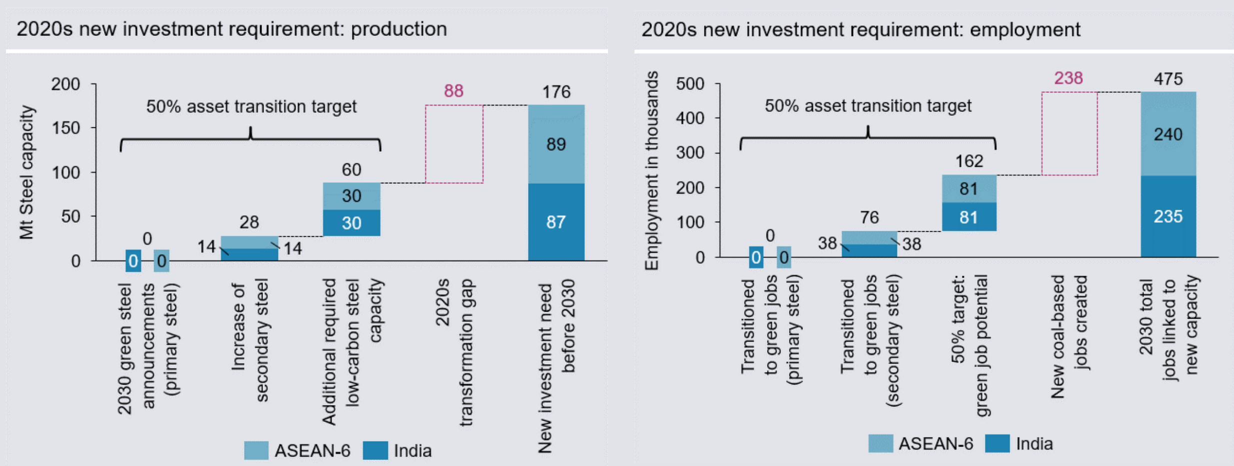
To achieve this target, most of the DRI plants will be built in advanced economies (160 Mt).[14] However, China will assume technology leadership in hydrogen-based steelmaking after 2030. By 2030, it could have added 100 Mt of DRI capacity. Another 40 Mt of DRI capacity will be built in emerging economies with flat steel demand such as Russia, Iran and Turkey. A further 100 Mt of DRI capacity will be installed in iron ore-exporting countries that have the opportunity to tap into abundant and cheap renewable hydrogen supply such as Australia (40 Mt), Brazil (35 Mt), Sweden (20 Mt) and South Africa (5 Mt). The green DRI/HBI could be transported for further processing in Asia, Europe and North America.

3.3.2 Approximately 50% of new investment requirements by 2030 should be built with low-carbon alternatives:

In this scenario, as well, emerging economies with rapidly rising steel demand and plans to make new investments in steelmaking capacity opt to use new low-carbon technologies in around half of the cases.

If no unabated coal-based steel plants are built after 2025 – the ideal case – around 240,000 future-proof green steel jobs can be created in those countries by 2030.

Figure 11: Asset transition targets for the 2020s – new investment requirements



Left: Agora Industry, 2021 based on World Steel Dynamics and TERI, 2021
Right: Agora Industry, 2021

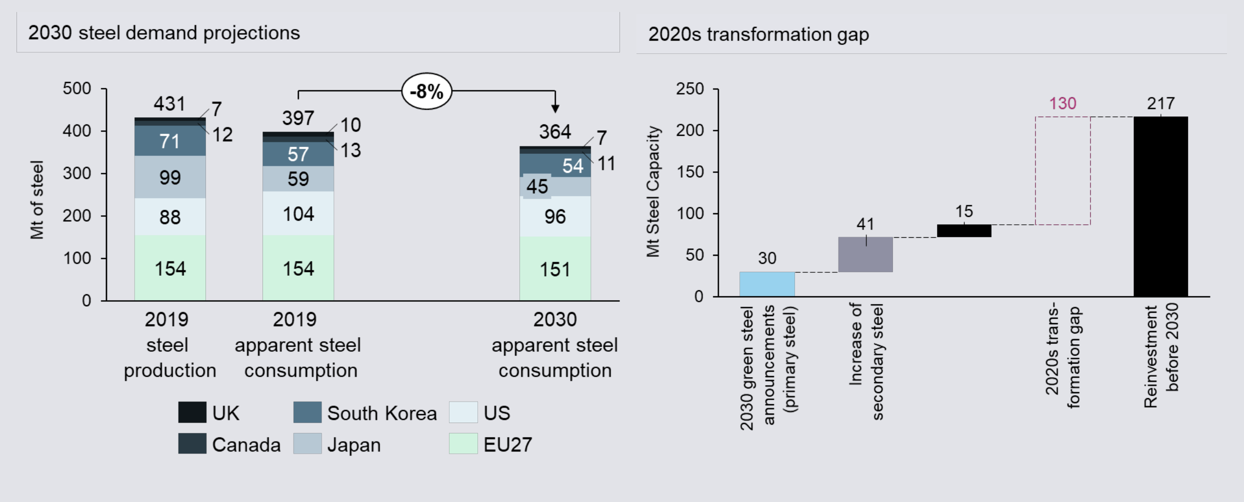
14 The 160 Mt DRI capacity includes DRI production in green iron-exporting or potentially green steel-exporting countries such as Australia (40 Mt) and Sweden (20 Mt). If they are excluded, the added DRI capacity in the remaining members of the advanced economies group (EU27 excluding Sweden, Japan, Korea, the US, Canada and the UK) account for 100 Mt of DRI.

4 Common challenges, but different starting points – 4 groups to map the global steel landscape

Achieving these highly ambitious asset transition targets will require unprecedented change. The many challenges faced by steel companies and governments differ depending on local and regional circumstances. To spotlight some of the key factors, we have divided the key steelmaking countries into 4 distinct groups.

4.1 Group 1: Advanced economies – flat/declining steel demand in 2030

Figure 12: Advanced economies – flat / declining steel demand in 2030 (Group 1)



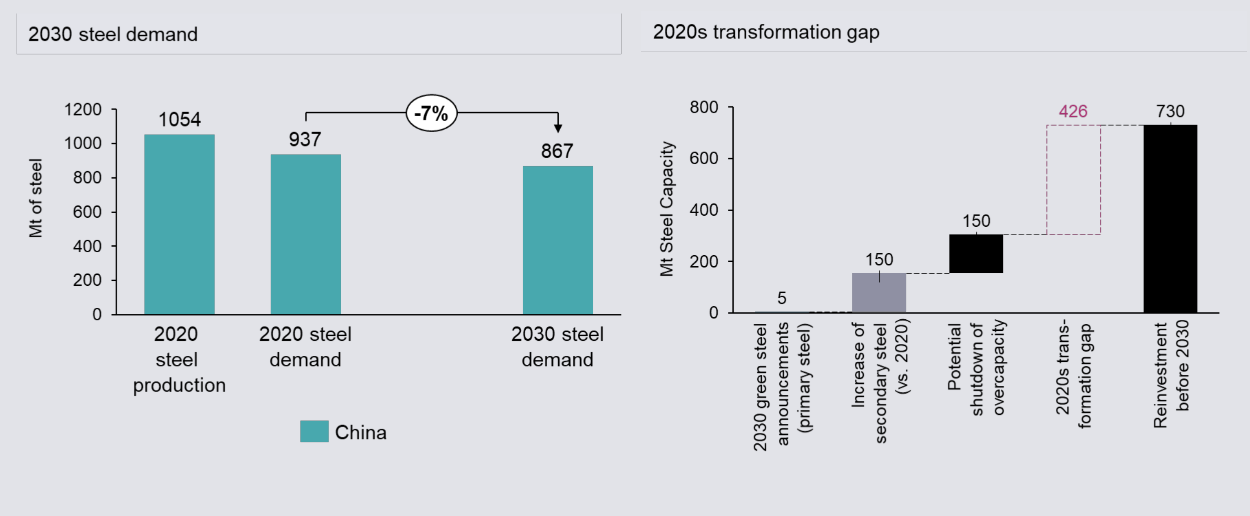
Left: Agora Industry, 2021 based on World Steel Dynamics, 2021
Right: Agora Industry, 2021

Table 1: Advanced economies – flat / declining steel demand in 2030 (Group 1)
Countries: EU27, Japan, South Korea, US, Canada, UK
Characteristics: All countries have flat or declining steel demand and a fairly old asset base. The countries are comparatively wealthy and can finance the additional costs of transitioning to low-carbon steelmaking in the 2020s.
Status quo: The majority of coal-based steelmaking capacity will reach the end of their operating life before 2030. There are already significant announcements to replace them with low-carbon steelmaking capacities such as DRI and electric arc furnaces, but there continues to be little real investment. The IEA Net Zero Emissions Report proposes a coal phase-out for advanced economies in the power sector by 2030. Due to the long lifetimes of relined blast furnaces (15-20 years), there is a high risk that unabated blast furnaces relined in the 2020s will go offline before the end of their technical lifetimes and will thus end up as stranded assets. Retroactive CCS on coal-based steelmaking may offer a solution, but it is an iffy bet that comes with high risk. Carmakers and other private-sector actors have already shown great interest in green steel, but the regulatory framework and policy instruments for a green business case have yet to be put in place.
What needs to happen in the 2020s: Advanced economies must fully close the transformation gap while maintaining a robust steel sector. Through the process, they can transition hundreds of thousands of workers to future-proof jobs that are compatible with climate neutrality. For each blast furnace that reaches the end of its campaign life, steel companies need to devise a transformation plan. DRI plants must replace coal-based blast furnaces and at the same time serve as an anchor for the gradual market introduction and infrastructure build-up of clean hydrogen. That way, clean hydrogen can gradually replace the natural gas in DRI plants that could not be operated with clean hydrogen right from the start. Governments must provide a regulatory framework for low-carbon steel, covering the additional costs of low-carbon steelmaking, devising a certification scheme for green steel, developing green lead markets for low-carbon steel and building a hydrogen supply and infrastructure.
Asset transformation strategy: These countries make no reinvestments in unabated coal-based steelmaking capacities. For blast furnaces that reach the end of their operating life before 2025, steel companies may continue and extend the operation for 2–5 years, but avoid the cost of a full long-lived refurbishment for 15 to 20 years. In 2022, governments announce their intention to introduce a low-carbon regulatory framework by 2025 and introduce carbon contracts for difference to ensure that investment decisions for low-carbon steel plants can be made as early as 2022. One progressive country in the group takes the lead and defines minimum standards around the abovementioned target for a coalition of the willing.

Agora Industry, 2021

4.2 Group 2: China – declining steel demand in 2030

Figure 13: China – declining steel demand in 2030 (Group 2)



Left: Agora Industry, 2021 based on World Steel Dynamics, 2021
Right: Agora Industry, 2021 based on own assumptions and Rocky Mountain Institute, 2021

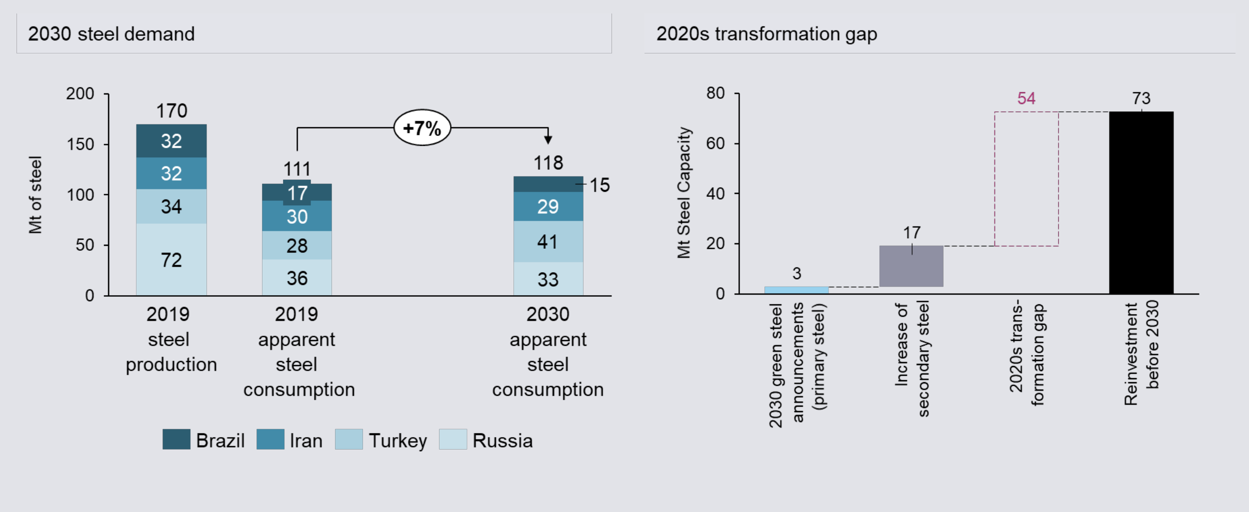
Table 2: China – declining steel demand in 2030 (Group 2)

Countries: China
Characteristics: China has vast overcapacities now and projects declining steel demand by 2030. The leading steel companies have net-zero 2050 targets and ambitious 2030/2035 targets.
Status quo: 78% of China's coal-based steelmaking capacity will reach the end of its lifetime before 2030. In the past, several dozen million tons of coal-based steelmaking capacity were shut down each year, but this was more than compensated for by new coal-based steelmaking capacity – leading to a net growth in coal-based steelmaking capacity and overcapacity issues. Production curbs ordered by the government are common. For example, in August 2021, the average utilisation of Chinese blast furnaces was only around 55%. Yet the project pipeline for new coal-based steelmaking capacity is still large. China's current capacity replacement policy that mandates that the shutdown of coal-based steelmaking capacity can only be replaced with around 80% of that capacity, if it is coal-based, will lead to capacity reductions. By improving recycling methods, the quality of an increasing scrap supply can be improved and a considerable increase of secondary steelmaking by 2030 is possible. The world's first industrial-scale, mostly hydrogen-based DRI plant will start operating in 2022 (though the hydrogen may not be renewable initially) and other plans have been announced for building hydrogen-based steelmaking capacity before 2025. A recent breakthrough at Jianlong's CISP project deployed an innovative hydrogen-based melting reduction that may reach industrial-scale before 2030. Relative to the reinvestment requirements by 2030, however, the announced projects for low-carbon primary steelmaking capacity are still small.
What needs to happen in the 2020s: Due to declining steel demand by 2030, China makes sure that its overall steelmaking capacity shrinks accordingly. In the 2020s, once the historic pattern of new coal-based steelmaking capacity overcompensating for closures of outdated capacity comes to a gradual end, there is an opportunity for fast capacity adjustment. Following the lead of low-carbon steel announcements in other countries, China strengthens its international cooperation while adopting and commercialising green steelmaking technologies. China promotes the steel sector as key pioneer for decarbonization to further its ambition of becoming a climate change mitigation leader. To this end, China starts developing green DRI hubs based on renewable hydrogen in the western and northern regions, which have curtailment issues as well as significant potential for renewables. This DRI could either meet local demand and or be transported to the steelmaking centres on the east coast. An initiative to ramp up renewable hydrogen production capacity to 100 gigawatts by 2030, known as Renewable H2-100, was announced in September 2021 (Heynes 2021). China is also considering importing green DRI/HBI from other countries. By moving to low-carbon steelmaking technologies, China will have enough low-carbon steelmaking production for exports to avoid paying potential border carbon adjustment mechanisms in the EU and elsewhere. China should include the steel sector in its national emission market and work proactively with the EU and other countries that have set net-zero emissions targets to avoid carbon leakage.
Asset transformation strategy: China continues to shutdown (inefficient) coal-based steelmaking capacity at historic rates, and gradually replaces them with low-carbon steelmaking technologies instead of coal-based capacity. Replacement with new secondary steelmaking capacity is a no-regret option and is in line with announced government targets (Ministry of Industry and Information Technology of the People's Republic of China 2020). China strengthens its current capacity replacement policies (People's Republic of China State Council 2021). Existing capacity measures for new coal-based steel capacity building are expected to reduce overcapacity over time. China introduces just transition measures for affected workers, including skill training for alternative employment. China carefully assesses whether DRI hubs for low-carbon primary steel can be developed in regions with cheap and abundant renewables so that it can become a world leader in hydrogen-based steelmaking.

Agora Industry, 2021

4.3 Group 3: Emerging economies – flat / moderately increasing steel demand in 2030

Figure 14: Emerging economies with flat steel demand (Group 3)



Left: Agora Industry, 2021 based on World Steel Dynamics, 2021
Right: Agora Industry, 2021

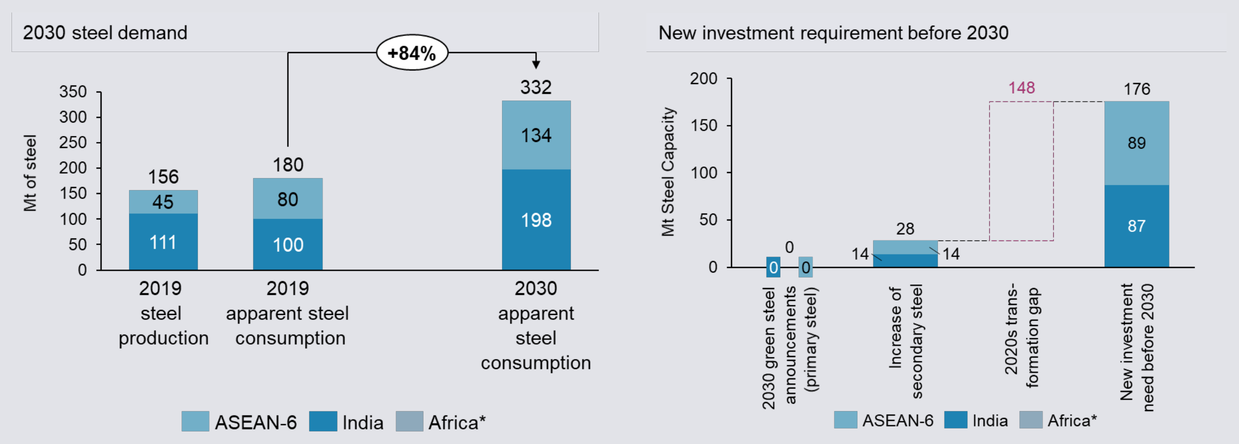
Table 3: Emerging economies – flat / moderately increasing steel demand in 2030 (Group 3)

Countries: Russia, Turkey, Brazil, Iran
Characteristics: Apart from Turkey, projected steel demand in 2030 is flat. Although these countries have significant blast furnace capacities, they are well positioned to begin to decarbonise their respective steel industries before 2030.
Status quo: Given that domestic steel demand will not be a significant driver of additional steel production, the four countries can use their unique position and resource endowments to supply competitive products to a growing global market for low-carbon steel before 2030. Their starting positions are different, however: While Iran and Russia can use their low gas prices for competitive production of natural gas-based DRI, Turkey (70% of steelmaking in Turkey is secondary steelmaking already) and Brazil (low costs projected for renewable hydrogen) will be in a good position to supply low-carbon steel before 2030. If green lead markets for low-carbon products emerge, all four countries could supply those markets with their low-carbon steel provided that economic sanctions do not apply.
What needs to happen in the 2020s: Steel companies and state governments cannot afford to be complacent with a good starting position; instead, they must strive to strengthen it further. In Russia, coal-based blast furnaces that reach the end of their lifetimes should be replaced with natural gas-based DRI. In Iran and Russia, some natural gas-based DRI plants should be equipped with CCS to lower the carbon footprint even further. In Russia and Brazil this also opens up the mid-term option of supplying carbon-negative steel via Bioenergy and CCS (BECCS) by using sustainable biomass that meets the highest sustainability criteria. Turkey must build some DRI plants that can supply some of its electric arc furnaces using high quality feedstock to produce otherwise unfeasible steel products for export. Finally, Brazil should adopt policies that support the development of hydrogen production capacities. These have the potential to be among the world's most competitive projects for converting high-quality iron ore into DRI, which can be exported in the form of HBI. Governments and steel companies must implement infrastructure (CCS, hydrogen) and policy instruments to ensure to strengthen the excellent starting position.
Asset transformation strategy: The asset transformation strategy for the countries is two-fold. First, they assess whether coal-based steelmaking capacity that reaches the end of its lifetime before 2030 can be replaced with DRI plants. In Russia and Iran, investments into natural gas-based DRI plants are already economical; for Turkey and Brazil, investments in DRI capacity would also make sense. Second, Russia and Iran assess whether the carbon footprint of existing gas-based DRI capacity can be lowered still further (by equipping it with CCS, say), while Brazil looks into hydrogen-based DRI. Turkey assesses options for building its own DRI capacity or for importing green HBI as a feedstock to improve the quality of its scrap-based steel.

Agora Industry, 2021

4.4 Group 4: Emerging economies – rapidly rising steel demand

Figure 15: Emerging economies with rapidly rising steel demand (Group 4)



Left: Agora Industry, 2021 based on World Steel Dynamics and TERI, 2021
Right: Agora Industry, 2021 *For Africa most studies assume rising steel demand after 2030

Table 4: Emerging economies – rapidly rising steel demand (Group 4)

Countries: India, Asean-6, Africa
Characteristics: Most countries in the group will see rapidly rising domestic steel demand through 2030 and beyond. Africa's steel demand is projected to remain largely flat in the 2020s but to increase significantly after 2030 (World Steel Dynamics 2021; Morfeldt et al. 2014). Currently, these countries have a very low per capita steel consumption and cannot afford at present to introduce and operate low-carbon steelmaking capacities.
Status quo: Driven by rapidly rising domestic steel demand and comparatively cheap domestic coal resources, these countries are planning to build at least 150 million tons of new coal-based steelmaking capacity. Integrated steel mills built in the 2020s will have lifetimes of 50 years, taking them far beyond 2050. Calls to leapfrog the coal-based capacity and build low-carbon steel plants are not yet mainstream, but the idea is starting to gain steam in India and elsewhere (see TERI 2021).
What needs to happen in the 2020s: Steel companies and governments understand the risks posed by investments in durable assets. The IEA Net Zero Emission Report requires a global phase-out of unabated coal in the power sector by 2040. Considering this as a reference point for steel as well, from 2025 onwards, no new investments will be made in new unabated coal-based steel mills. Capital for coal-based steelmaking capacities (CAPEX) must be channelled into new gas-based DRI plants so that no additional costs arise. The higher operational expenditure (OPEX) costs of running the plants with natural gas or hydrogen should be borne in part by local government support and international funding. Additional natural gas demand and infrastructure requirements must be thoroughly assessed to avoid unnecessary investment in fossil-based infrastructure. After using natural gas as a transition fuel in DRI plants, by the late 2020s India starts to exploit its potential of cheap renewable hydrogen resources and becomes a green steel powerhouse.
Asset transformation strategy: Emerging economies in the group make no investments in new unabated coal-based steel mills after 2024. An international fund is established that can cover part of the additional OPEX costs of operating DRI plants with natural gas or clean hydrogen. By 2025, third-party countries including China halt financing for the construction of all new unabated coal-based steel mills.

Agora Industry, 2021

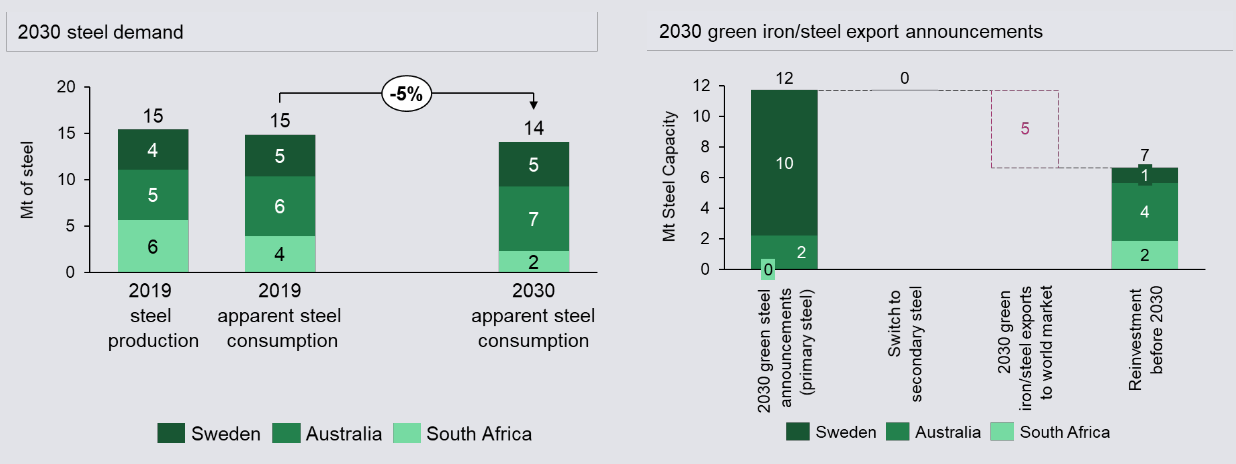
5 Green steel opportunities – first mover countries

Steel is a globally traded commodity. A single-speed global steel transformation can enhance international cooperation and establish a level playing field.

As the asset mapping in section 3 shows, however, there are first-mover countries. These are key countries that, instead of exporting iron ore, can switch to producing green DRI using iron ore and renewable hydrogen, and either export the green DRI as HBI or utilise it domestically. They are also countries in which very cheap renewable electricity can support a growing green steel sector for export.

Among the countries that can move from being iron ore exporters to green HBI exporters are Brazil, Australia and, to some extent, Sweden.[15] Among the countries that have the strongest near-term opportunities for developing green steel exports based on cheap renewable electricity are Sweden, India and South Africa.

Figure 16: Green steel opportunity countries – iron ore exporters with first-mover renewable hydrogen potential (Group 5)



Left: Agora Industry, 2021 based on World Steel Dynamics, 2021
Right: Agora Industry, 2021

[15] Further countries could be Canada and Russia.

Table 5: Green steel opportunity countries – iron ore exporters with low-cost renewable hydrogen (Group 5)

Countries: Brazil, South Africa, Australia, Sweden
Characteristics: These countries are iron ore exporters with very low future renewable hydrogen costs. Establishing a green iron/steel production by 2030 can massively exceed the reinvestment requirements of coal-based capacity and thereby turn those countries into green iron/steel exporters.
Status quo: These countries exploit their potential to varying degrees. While government and progressive steel companies in Sweden are working together to make the country a green iron/steel exporter in the 2020s, that is not the case in the other countries. In Australia, private companies have announced the construction of industrial-scale DRI plants in the 2020s, even though the government has so far failed to provide funding and policy support. South Africa has yet to see any such projects emerge.
What needs to happen in the 2020s: Governments and mining/steelmaking companies need to join forces to create an investment case for the first industrial-scale green iron projects before 2025. In the later 2020s, demand for green steel from the private sector (e.g. carmakers) in the world's major manufacturing hubs (Asia, Europe, North America) will unlock the full potential of green steel opportunity countries. Because carmakers can pass on the low additional costs of green steel to consumers (200 to 300 USD per car), it represents a large and growing market for green steel. Though government support for the first few industrial-scale projects before 2025 is required initially, a business case without subsidies for green iron/steel exports will soon emerge. Nonetheless, countries in which steel/mining companies and the government work together closely are better positioned to unlock their full export potential.
Asset transformation strategy: These countries have a limited number of coal-based assets that will reach the end of their operating life before 2030. Because of their massive potential, which widely exceeds domestic reinvestment requirements, these countries seek to become export hubs for green iron and steel by 2030.

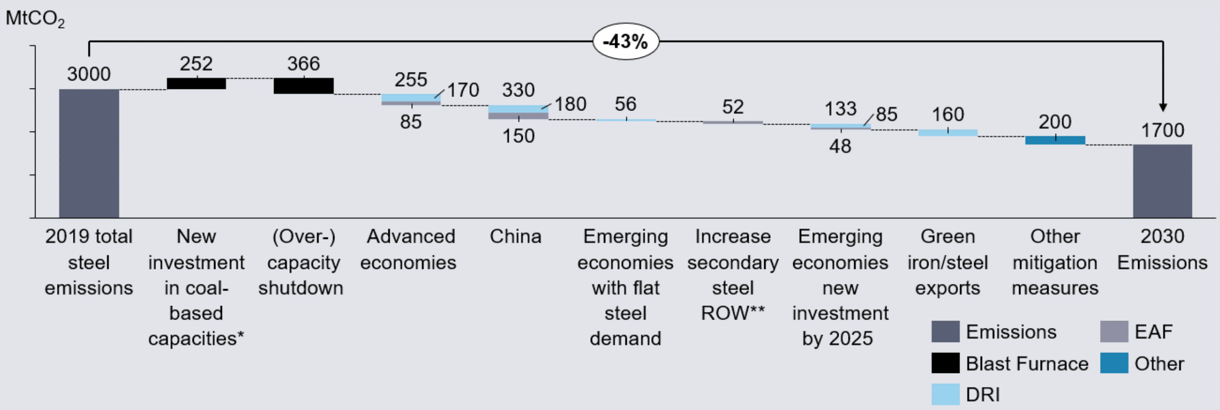
Agora Industry, 2021

6 A steel sector asset transition scenario compatible with a 2030 1.5°C pathway

In order to put the global steel sector on a pathway that is compatible with 1.5°C, steep emission reductions in the 2020s are required. For this, the Energy Transitions Commission estimates that the global steel sector would have to reduce its emissions by around 1300 $MtCO_2$ in 2030 relative to 2019, when it emitted around 3000 $MtCO_2$ (ETC 2021).[16] If retroactive CCUS on coal-based steelmaking capacity after 2030 were not to materialise and if all future stranded assets were to be avoided, what would a scenario that focuses on asset transition look like? How does it look for particular countries? And how would the aforementioned asset transition targets translate into CO_2 reductions in the different steelmaking country groups?

The subsequent analysis provides very rough estimates for CO_2 reductions based on assumptions about CO_2 intensity for different technologies (see table 6). It is not based on in-depth country-level analysis; rather, it is meant to broadly illustrate the required speed and scale of the global steel sector's asset transition in order to align with a 1.5°C scenario.

Figure 17: CO_2 reductions by the required low-carbon steel investments for a 1.5°C aligned global steel sector by 2030



Agora Industry, 2021 *Emerging economies with rising steel demand; **ROW excluding China and advanced economies

16 The IEA World Energy Outlook 2021 states that the global steel sector would have to reduce its emissions by around 600 $MtCO_2$ by 2030 compared with 2020 to align with a pathway that is compatible with limiting global warming to 1.5°C. The scenarios are not easy to compare, however. The main differences are that IEA uses a different accounting method for steel, which does not include on-site industrial power plant emissions. It relies heavily on material efficiency for emission reductions and does not explicitly take into account the huge reinvestment requirements of the 2020s.

- **New investment requirements:** In the reference scenario, the rapidly rising steel demand in emerging economies such as India and Southeast Asia is met with new coal-based steelmaking capacity. At least 148 Mt of new coal-based steelmaking capacity would increase annual emissions 2030 by **252 MtCO_2**.
- **(Over-)capacity shutdown:** In certain advanced economies and China, steel demand by 2030 will be lower than in 2020. Therefore, in advanced economies (-33 Mt) and China (-150 Mt) coal-based capacity is shut down without replacement. This will save **366 MtCO_2** of emissions.
- **Low-carbon steel in advanced economies (primary and secondary):** Advanced economies manage to close 100% of their 2020s transformation gap by investing in DRI and secondary steel and importing green DRI from exporting countries (see "green iron exports"). In many countries of this group, the gap is filled with the construction of DRI plants that are initially operated with natural gas and later with clean hydrogen as it becomes available. Overall, 100 Mt of DRI are built and operated with natural gas and/or rising shares of clean hydrogen, leading to an emissions reduction of **170 MtCO_2**. Apart from that, 50 Mt of secondary steelmaking capacity are added, with the US responsible for the majority of the new capacity (20 Mt). The increase of secondary steel leads to emission reductions of **85 MtCO_2**.
- **Low-carbon steel in China (primary and secondary):** China massively expands its secondary steel production by 2030, adding new capacity of 150 Mt (Rocky Mountain Institute 2021). This allows emissions reductions of **150 MtCO_2**. Apart from that, China also operates 100 Mt of DRI plants that are run with a mix of natural gas and clean hydrogen, saving another **180 MtCO_2**.
- **Low-carbon primary steel emerging economies with flat steel demand**: Emerging economies such as Russia, Iran, Turkey, Ukraine and Kazakhstan build another 40 Mt of DRI capacity. This saves an additional **56 MtCO_2**.
- **Increase secondary steel (ROW)**: Globally there is a moderate increase of secondary steel production by 2030. Excluding the increase of secondary steel production in advanced economies and China, secondary steel production in the rest of the world grows by 6.6% relative to 2019 production levels. The additional 40 Mt of secondary steel production helps to reduce emissions by **52 MtCO_2**.
- **Low-carbon steel investments in emerging economies**: By 2025, emerging economies start to invest in low-carbon steelmaking technologies. 50 Mt of DRI plants are built between 2025 and 2030. Initially, they are operated with natural gas, but before 2030 they use a growing share of renewable hydrogen. This saves **85 MtCO_2 of emissions** by 2030. Secondary steel production, which can satisfy most steel demand for construction and infrastructure projects, is increased by 38 Mt, reducing emissions by **48 MtCO_2**.
- **Green iron exports:** Green steel opportunity countries such as Australia (40 Mt), Brazil (35Mt), Sweden (20 Mt) and South Africa (5 Mt) realise their huge potential and start to export around 100 Mt of green iron (DRI/HBI) to the world markets. The green iron can either be used to replace the blast furnace process or be used as a feedstock in existing blast furnaces. The overall emission reduction can be as high as **160 MtCO_2**.
- **Other mitigation measures:** We assume that not all CO_2 mitigation efforts need to lie in asset transition. Measures such as improved material efficiency, increased scrap use, hydrogen injection into blast furnaces, and the replacement of old, coal-based DRI capacities with new, more efficient technology will also contribute a significant share to emission reductions. The overall emission reductions can be as high as **200 MtCO_2**.

If all these measures are implemented, the steel sector could, by 2030, reduce its emissions by **1300 MtCO_2** – or 43% relative to 2019 levels.

Table 6: Assumptions for CO_2 reduction in various regions

Category	Technology	Assumed CO_2 increase/reduction (t of CO_2 per t of crude steel)	Assumption
New investment requirement	Blast furnace – basic oxygen furnace	+1.7	We assume an emission intensity of best available blast furnace technology for the new coal-based steelmaking capacity.
(Over-)capacity shutdown	Blast furnace – basic oxygen furnace	-2	Capacity that is shut down.
Advanced economies	Primary steel (DRI-EAF)	-1.7	We assume a mix of natural gas and clean hydrogen.
	Secondary steel (EAF)	-1.7	We assume that the electricity mixes in these countries will be fairly clean.
China	Primary steel (DRI-EAF)	-1.8	We assume that new DRI plants will be mainly operated with renewable hydrogen.
	Secondary steel (EAF)	-1	Electricity mix will still rely on a larger share of fossil fuels.
Emerging economies with flat steel demand	Primary steel (DRI-EAF)	-1.4	We assume DRI plants will be predominantly operated with natural gas.
Rest of the world	Secondary steel (EAF)	-1.3	We assume that the electricity mix in those countries (i.e. Middle East, Mexico) will be fairly clean.
Emerging economies with rising steel demand	Primary steel (DRI-EAF)	-1.7	We assume the plants are initially operated with natural gas, but before 2030 they use a growing share of renewable hydrogen.
	Secondary steel (EAF)	-1.25	We assume the electricity mix in those countries will still contain a significant share of fossil fuels
Green steel opportunity countries	Primary steel (DRI and DRI-EAF)	-1.6	We assume green iron can either be used to replace the blast furnace process or be used as a feedstock in existing blast furnaces.

Agora Industry, 2021

7 Conclusion

The global steel sector is at a crossroads. Around 71% of the world's coal-based steel blast furnace capacity (1090 Mt) will reach the end of its operating lifetime before 2030 and require major reinvestments. At the same time, emerging economies with rising steel demand will require at least 170 Mt of new capacity. Meeting these needs with coal-based capacity will create long-term carbon lock-in and lead to stranded assets, endangering jobs and putting any pathway compatible with 1.5°C out of reach.

It is of paramount importance, therefore, that the industry invests now in key low-carbon steelmaking technologies that are compatible with climate neutrality. While the asset transition targets analysed in this paper may seem highly ambitious, the alternative – continuing to invest in coal-based steelmaking capacity – will expose assets and jobs to high risks in the 2030s and beyond.

Such a radical transformation will not happen on its own. Kickstarting the steel sector's transformation will require a massive increase of capacity in the global iron ore pellet market to feed the DRI plants, new infrastructure, government support and a regulatory framework for low-carbon steelmaking in the form of a robust policy package. This could include policy instruments such as carbon contracts for difference, green steel labelling and reporting standards, embedded carbon requirements, green public procurement, hydrogen support instruments and the construction of a hydrogen infrastructure. If the global steel industry moves ahead at the same speed, the resulting single-speed transformation will bring enhanced international cooperation and a level playing field.

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Agora Industry is a division of Agora Energiewende that develops strategies and instruments for climate-neutral industrial transformation – in Germany, the EU and globally. Agora Industry works independently of economic and partisan interests. Its only commitment is to climate action.

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