Achieving Net Zero Heavy Industry Sectors in G7 Members

International Energy Agency

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Abstract

Achieving Net Zero Heavy Industry Sectors in G7 Members is a new report by the International Energy Agency that focuses on the implementation of policies aimed at drastically lowering CO_2 emissions from heavy industries in the G7 and beyond. This work, requested by Germany's 2022 G7 Presidency, builds on analysis from the IEA's *Net Zero by 2050: A Roadmap for the Global Energy Sector*. It follows *Achieving Net Zero Electricity Sectors in G7 Members*, produced as an input to the UK's G7 Presidency in 2021.

This report focuses on two key areas for achieving net zero heavy industry sectors in G7 members, both of which are priority areas for Germany's 2022 G7 Presidency. The first is a toolbox of policies and financing mechanisms to initiate and sustain the industry sector transition. The second is a series of common and practicable definitions of what constitutes near zero emission steel and cement production – a key step to establishing future policy mechanisms, irrespective of the exact mitigation pathway or the specific technologies chosen. The report is designed to inform policy makers, material producers and consumers, investors, leading sectoral initiatives and the research community in the lead up to the G7 Climate and Energy Ministerial in May 2022 and beyond.

Foreword

In order to meet the world's energy and climate challenge, we have to drive down emissions across all the major sectors of our economies while ensuring they remain dynamic, productive and beneficial for our societies. In some areas, such as the electricity sector, the key solutions to achieve significant emissions reductions while continuing to provide secure and affordable energy supplies are already on the market today. They include renewables such as solar, wind and hydro, other low emissions electricity sources like nuclear, as well as energy efficiency, energy storage, modern power grids and digital technologies.

In some other crucial parts of the economy, the tools for significant emissions reductions are at an earlier stage of commercial development. This is particularly evident in the case of heavy industry sectors such as steel and cement, which face unique challenges when it comes to substantially reducing their stubborn emissions. Heavy industry sectors' direct carbon dioxide (CO_2) emissions amount to around 6 billion tonnes per year, more than one-sixth of total CO_2 emissions from the global energy system.

The International Energy Agency (IEA) is committed to leading efforts by countries around the world to securely transform energy systems in order to meet international climate goals. And heavy industries are a critical part of this undertaking for which our Agency has long been working on different technology and emissions reductions pathways. I was therefore very pleased that the German government requested this report on *Achieving Net Zero Heavy Industry Sectors in G7 Members* under its 2022 Presidency of the G7. In this way, it will inform policy makers, industrial leaders and other decision makers ahead of the G7 Climate, Energy and Environment Ministers' Meeting – chaired by Robert Habeck, German Federal Minister for Economic Affairs and Climate Action – on 25-27 May 2022 and beyond.

The world's leading advanced economies clearly have both a responsibility and an opportunity to take a leadership role in driving forward the global transformation of heavy industry sectors. These sectors are responsible for more than 15% of coal use and about 10% of oil and gas use in G7 members. This makes the net zero transition in heavy industry an important pillar for reducing the reliance on fossil fuels in the G7 in the wake of Russia's invasion of Ukraine. Based on the IEA's landmark report *Net Zero by 2050: A Roadmap for the Global Energy Sector*, this report draws on our Agency's unrivalled energy data and modelling capabilities to set out the actions G7 members can take to accelerate the changes that are essential for a transformation of global heavy industry towards clean energy.

The report contains two key elements: a toolbox of policies and financing mechanisms that may be used by G7 members and beyond to initiate and sustain the industry sector transition; and a series of common and practicable definitions as to what constitutes "near zero emission" materials production, which is a key ingredient to establishing future policy mechanisms.

The report proposes 10 key recommendations for the G7 and other governments to draw upon. If they are implemented, I believe these steps can enable G7 members to accelerate the transition to a cleaner and, at the same time, more secure energy future.

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Acknowledgements

Achieving Net Zero Heavy Industry Sectors in G7 Members was prepared by the Energy Technology Policy (ETP) Division of the Directorate of Sustainability, Technology and Outlooks (STO) of the International Energy Agency (IEA). The project was designed and directed by Timur Gül, Head of the Energy Technology Policy Division. Araceli Fernandez Pales, Head of the Technology and Innovation Unit, and Peter Levi co-ordinated the analysis and production of the report. The lead authors were Peter Levi and Tiffany Vass.

The development of this report benefitted from contributions provided by the following IEA colleagues: Leonardo Collina, Alexandre Gouy, Jérôme Hilaire, Paul Hugues, Martin Kueppers, Tobias Lechtenbohmer, Hana Mandová, Tomás de Oliveira Bredariol, Faidon Papadimoulis, Diana Perez Sanchez and Leonie Staas.

The following IEA colleagues contributed with valuable comments: Simon Bennett, Jose Bermudez, Laura Cozzi, David Fischer, Paolo Frankl, Tim Gould, Will Hall, Ilkka Hannula and Brian Motherway.

Liselott Fredriksson, Reka Koczka, Diana Louis, Mao Takeuchi and Per-Anders Widell provided essential support throughout the process.

Thanks also to Astrid Dumond, Merve Erdil, Grace Gordon, Jad Mouawad, Jethro Mullen, Taline Shahinian, Gregory Viscusi and Therese Walsh of the Communications and Digital Office. Nicola Clark edited the manuscript.

The work could not have been achieved without the financial support provided by the Federal Ministry for Economic Affairs and Climate Action, Germany.

The report benefitted from the insights gathered during two high-level expert workshops on “Achieving Net Zero Heavy Industry Sectors in G7 Members: Policy and financing mechanisms” (held on 17 February 2022) and “Defining a standard for near zero emission materials production” (held on 18 February 2022).

Peer reviewers provided essential feedback to improve the quality of the report. They include: Nour Amrani (FLSmidth); Michael P. Apicelli, Joe Cresko and Dennis Mesina (Department of Energy, United States); Marlene Arens (Heidelberg Cement); Paul Balserak and Brandie Sebastian (American Iron and Steel Institute); Russ Balzer (World Auto Steel); Chris Bataille (IDDRI); Claudia Bernarding, Malte Bornkamm, Michael Buechl and Stela Ivanova (Federal Ministry for Economic Affairs and Climate Action, Germany); Javier Bonaplata (ArcelorMittal);Clare Broadbent, Åsa Ekdahl and Andrew Purvis (World Steel Association); Antonio Carrillo and Cedric de Meeûs

(Holcim); Jen Carson and Iva Munro (The Climate Group); Grace Chen and Wang Yutao (China Cement Association); Rebecca Dell (ClimateWorks Foundation); Karl Downey (Science Based Targets Initiative); Madison Freeman (Department of State, United States Government); Jean Theo Ghenda (Eurofer); Alain Gingras (Environment and Climate Change Canada); Alasdair Graham, Rafal Malinowski and Gillian Nelson (Mission Possible Partnership); Emily Hickson (Climate Catalyst); Hishmi Jamil Husain (Tata Steel); Richard Janecky, Sonia Krylova and Tim Stock (Department for Business, Energy and Industrial Strategy, United Kingdom); Laura Martin and Fiona Zuzarte (Natural Resources Canada); Jesper Kansbod (Hybrit); Yukihiro Kawaguchi, Shinichi Kihara, Saki Oura, Tomoki Ooka and Takafumi Ushio (Ministry of Economy, Trade and Industry, Japan); Shiva Kumar and Matthew Wenban-Smith (Responsible Steel); Stefan Lechtenboehmer (Wuppertal Institute); Eric Lecomte and Cyril Loisel (European Commission); Yvonne Leung (Concrete Action for Climate); Claude Lorea (Global Cement and Concrete Association); Hongyou Lu (Lawrence Berkeley National Laboratory); Erika Mink-Zaghloul (ThyssenKrupp); Manabu Nabeshima (Ministry of Foreign Affairs, Japan); Masanobu Nakamizu, Ryoji Saito and (Japanese Iron and Steel Federation); Dietram Oppelt (National Designated Entity, Germany); Jonas Otterheim (Volvo); Pieter Parmentier and Cécile Seguineaud (OECD Steel Committee); Frank Peter, Oliver Sartor and Jesse Scott (Agora Energiewende); Julia Reinaud (Breakthrough Energy); Alexander Sharabaroff (International Finance Corporation); Varun Sivarum (Department of State, United States Government); Cecilia Tam (OECD); Martin Theuringer (German Steel Federation); Rob van der Meer (CEMBUREAU - The European Cement Association); Domien Vangenechten (E3G); Julien Viau (Ministry of Ecological Transition, France); Tanja Wulf (Federal Ministry for Economic Affairs and Climate Action, Germany); Zhang Xian (Agenda 21 Management Center, China); Li Xinchuang (China Metallurgical Industry Planning Institute); Chan Yang (European Climate Foundation); Naoki Aoki (Japan Cement Association).

The individuals and organisations that contributed to this study are not responsible for any opinions or judgements it contains. The views expressed in the study are not necessarily views of the IEA's member countries or of any particular funder or collaborator. All errors and omissions are solely the responsibility of the IEA.

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Executive summary

The G7 has an opportunity to accelerate the global transformation of heavy industry sectors. G7 members – Canada, France, Germany, Italy, Japan, the United Kingdom, the United States plus the European Union – in 2020 accounted for around 40% of the world's economy, 30% of its energy demand and 25% of energy system CO_2 emissions. The G7's economic heft, its leadership at the innovation frontier, and the international alliances it can mobilise, mean the Group has outsized power to inspire successful energy transitions around the world. Efforts to accelerate the transition for heavy industry sectors are no exception.

Heavy industry is responsible for more than 15% of coal use and about 10% of oil and gas use in G7 members. This makes the net zero transition in heavy industry an important pillar for reducing the reliance on fossil fuels in the G7 in the wake of Russia's invasion of Ukraine. The war has caused turbulence in global energy and commodity markets, posing risks for the industry sector transition, but also reinforcing the impetus for it. Russia's war in Ukraine bolsters the case for heavy industries to reduce their dependence on fossil fuels, with energy security concerns echoing the thrust of climate-oriented motivations.

There is a need for policy to explicitly target emissions from heavy industry sectors. This report[1] focuses on two key areas for achieving net zero heavy industry sectors in G7 members, both of which are priority areas for Germany's 2022 G7 Presidency. The first is a toolbox of policies and financing mechanisms to initiate and sustain the industry sector transition. The second is a series of common and practicable definitions of what constitutes near zero emission steel and cement production – a key step to establishing future policy mechanisms, irrespective of the exact mitigation pathway or the specific technologies chosen. The report is designed to inform policy makers, material producers and consumers, investors, leading sectoral initiatives and the research community in the lead up to the G7 Climate and Energy Ministerial in May 2022.

Emissions from heavy industry sectors are hard to abate

Industry's direct CO_2 emissions are currently around 9 Gt of CO_2 per year, or about one quarter of total energy system CO_2 emissions. Heavy industry sectors – steel, cement and chemicals – account for around 6 Gt (or around 70%

[1] This report follows *Achieving Net Zero Electricity Sectors in G7 Members*, produced by the IEA on request by the UK's G7 Presidency in 2021.

of industrial emissions), meaning that reaching net zero emissions is impossible without dramatic reductions in emissions from heavy industries. Yet, demand for these products is set to grow in the context of a sustainable future for the energy system, given their extensive use in the construction of wind farms, nuclear power plants, transmission lines, electric vehicles and other clean energy infrastructure.

Heavy industries face unique challenges when it comes to substantially reducing emissions. Four key obstacles need to be overcome for heavy industry sectors to be able to reduce emissions at a scale that is compatible with achieving a net zero emissions energy system. First, many technologies required for the industry sector's transition are still at prototype or demonstration stage and not yet ready for deployment at scale. Second, new production processes with substantially lower emissions intensities will – at least initially – have higher costs. Third, many products of heavy industries such as steel are traded internationally in competitive markets, with margins that are too slim to absorb elevated production costs and encourage first movers to adopt new technologies. Finally, heavy industry facilities are long-lived and capital intensive, locking in emissions inertia. Existing efforts to overcome these challenges are not yet sufficient to deliver substantial emissions reductions on a time scale commensurate with reaching net zero emissions by 2050. A multi-faceted technology and policy response is required, spanning innovation, infrastructure and supply chains.

The G7 can lead the way to achieving net zero heavy industries

G7 members alone cannot deliver net zero heavy industries globally, but they can make a pivotal contribution. The IEA's *Net Zero by 2050* roadmap lays out *a* pathway to net zero emissions by 2050 – but not necessarily *the* pathway – in which global industrial CO_2 emissions decline by nearly 95% by 2050. The G7 produces 17% of the world's steel, 8% of cement and 28% of primary chemicals: China is the only single country with larger heavy industry sectors than the G7 members combined. The G7 members must therefore make a significant contribution to global industrial decarbonisation. In the Net Zero Emissions by 2050 Scenario, industrial CO_2 emissions from G7 heavy industry sectors decline by 27% by 2030 relative to today, compared to 18% for the rest of the world.

Commercially available technologies and strategies for reducing emissions can only take us part of the way to net zero. Material efficiency and energy efficiency make important contributions to reducing industrial emissions, accounting for around 25% of emissions reductions by 2050 in the Net Zero Emissions by 2050 Scenario, relative to today's levels. Technologies which are not yet available on the market at the scale needed – hydrogen, direct electrification technologies, and carbon capture utilisation and storage (CCUS) – take the world most of the rest of the way to net zero. Technologies at the prototype and demonstration phase today account for about 60% of emissions reductions by 2050 in the Net Zero Emissions by 2050 Scenario.

Near zero emission material production is a key area for G7 leadership. In the Net Zero Emissions by 2050 Scenario, by 2030, innovative technologies for producing materials account for around 10-20% of primary steel, cement and primary chemicals production in the G7, depending on the sector, on average about two-thirds higher than the level in the rest of the world. In the G7, hydrogen-based direct reduction is the leading near zero emission primary steel production route in 2050, followed by CCUS-equipped routes, although there are important differences by country reflecting each G7 member's own circumstances. In the cement sector, CCUS-equipped production does the heavy lifting across the world, but the G7 moves faster: 12% of production is CCUS-equipped by 2030, compared with 9% for the rest of the world. By 2050, uptake of innovative technologies has largely converged across regions, but the first movers in G7 economies have the opportunity to establish early lead markets: around 25 Mt per year each of near zero emission primary steel production and clinker used in cement production by 2030 in the Net Zero Emissions by 2050 Scenario, or 10-15% of current production levels of G7 members combined.

Governments hold the pen in enabling net zero heavy industries

Ambitious, stable and well-designed policy frameworks are vital to create conditions for heavy industry sectors to transition rapidly; this report proposes a policy toolbox that the G7 and other countries may draw upon. Many governments have already stated their ambitions in this area, but the sector is not on track to reach net zero emissions by mid-century. Governments need to create a level playing field for near zero emission material production in competitive international markets. International cooperation can raise global policy ambition, better harmonise policies, and catalyse global technology development. The next few years are critical to develop and strengthen policy frameworks to stay within the narrow opportunity for achieving net zero by 2050. Leadership from G7 members can provide valuable impetus for global acceleration.

Push and pull measures are needed in tandem. "Push" policies focusing on the supply side are essential to overcome project risks for innovative technologies. Targeted public financial support can leverage private investment by lowering risk:

full-scale demonstration, early commercial projects and the build-out of infrastructure (including for low emission hydrogen and electricity, and for CO_2 transport and storage) are important areas that can merit direct use of public funds. "Pull" demand side policies can reinforce the business case. Carbon contracts for difference, public procurement and near zero emission material mandates and quotas can create differentiated markets for materials produced with near zero emissions, which at least in the short term will face higher costs than those produced with conventional technologies. Measures supporting material efficiency and circularity strategies can serve to reduce the scale of the challenge on the supply side.

Common definitions for "near zero emission material production" can establish a shared vision of the future for key production processes in heavy industry sectors. This report proposes such definitions for the consideration of the G7; they are designed to be stable, absolute and ambitious, and they are compatible with a trajectory that reaches net zero emissions from the global energy system by mid-century. Interim measures that substantially lower emissions intensity of materials production – but fall short of the near zero thresholds – should also be recognised. As such, complementary – but distinct – definitions for "low emission production" of steel and cement are also proposed as part of this report; they are needed to recognise the important interim steps taken towards lower emissions intensity. An important distinction must however be made between technologies that can achieve low emission production now, and near zero emission production later – and those never able to meet the near zero emission thresholds without significant reinvestment.

Recommendations for the G7

The G7's economic heft, its leadership at the innovation frontier, and the international alliances the Group can kindle, mean that it can have a major impact on the rest of the world, as it has in the past. Efforts to accelerate the transition for the industry sector are no exception.

Policies developed within the next five years will be critical to put the industry sector on a path compatible with achieving net zero emissions for the energy system by mid-century. The G7's leadership in this domain can raise ambition and provide learnings to accelerate the global transition. As such, the IEA has developed ten recommendations for consideration by G7 members. The focus is on steel and cement production, but many of the principles are applicable to other energy-intensive commodities.

1. **Develop ambitious long-term sustainable transition plans for industry, backed by policy.** By no later than the mid-2020s, G7 members should develop or update national industry sector roadmaps and plans in collaboration with industry stakeholders, providing a robust signal on the direction and pace of travel by developing clear targets and milestones. Plans should be backed by clear policies that align incentives and create a business case for innovative technologies and material efficiency strategies. There are many policies available in the toolbox proposed in this report that governments may use, including carbon pricing, regulations and finance. Plans and policies should account for the nature of industry investment cycles, such as through retrofit-ready policies that require any unabated capacity added or refurbished in the next few years to have the technical capacity and space requirements to integrate near zero emission technologies when they become available.
2. **Finance a portfolio of demonstration projects for near zero emission industrial production technologies.** Within the next one to two years, G7 members should take decisions on funding for innovation and mitigating investment risks of demonstrating critical technologies. The objective is to collectively enable at least two or three full scale projects in different regions and configurations for each technology at demonstration or large prototype stage today, with a range of representative input material qualities. This should include at least two or three different near zero emission methods to produce both steel and cement. International collaboration in this area is important to speed up innovation cycles, and can increase the likelihood that near zero emission industrial production technologies will be ready for market deployment by the mid-2020s. Once technologies are ready for deployment, continued international cooperation on technology co-development for first-of-a-kind projects will also be important.

3. **Develop finance mechanisms to support deployment of near zero emission industrial technologies and associated infrastructure.** Over the next three years, G7 members should formulate finance strategies for the deployment of near zero emission technologies at new and existing domestic industrial plants, as well as for supporting infrastructure (including for CO_2 transport and storage, low emission hydrogen and electricity production and distribution, and improved end-of-life material collection, sorting and recycling). Various finance mechanisms could be used, such as direct grants, low-interest and concessional loans and blended finance instruments. In the case of shared supporting infrastructure, governments should consider an active role in planning and coordinating build out. Clear and widely accepted definitions (see below) should be used as a guide for access to finance, including for technology-neutral transition finance mechanisms, and such that by 2030 only production that is already near zero emission or has clearly demonstrated a pathway to soon become near zero emission is eligible for government finance. G7 members may also collectively contribute to international finance mechanisms and work to support the industry transition in emerging and developing economies through capacity building and technology co-development.
4. **Create differentiated markets for near zero emission material production.** G7 members should develop policies ideally within the next three to four years that create demand for near zero emission materials production, designed taking into consideration each country's own circumstances and the timeline for technological innovation. G7 members should consider the advantages of policies that guarantee long-term support for industry players establishing the first handful of commercial plants for each technology type; opportunities include, as examples, carbon contracts for difference, long-term public procurement contracts and advance market commitments. Policies should also be developed to support subsequent plants, such as sustainable or "green" public procurement policies or regulations requiring a growing minimum market share of near zero emission materials production. Clear and widely accepted definitions should be used to differentiate eligible material production under such policies, with higher and longer-term support for near zero emission production, and time-limited support for interim measures that deliver substantial improvements in emissions intensity.
5. **Explore a non-binding intergovernmental international industry decarbonisation alliance in support of the industry transition.** G7 members should consider forming an international industry decarbonisation alliance in 2022. The alliance could build from the G7 International Decarbonisation Agenda, and three key transformations could mark the founding of the alliance: 1) a shift to include a comprehensive suite of concrete commitments, 2) opening the doors to members beyond the G7, and 3) housing the alliance within a permanent secretariat. An institutionalised alliance would help ensure continuity of efforts between changing G7 Presidencies in a way that prioritises the long-term decarbonisation goal. The alliance's primary mission would be to raise ambition on the industry transition, through coordinating the implementation of comprehensive accelerating mechanisms and seeking for voluntary collective and national commitments. This would include helping coordinate member efforts

within existing initiatives and ensuring its work plan is complementary. By working to increase ambition on the industry transition globally, such an alliance could be helpful in moving towards an increasingly level playing field for low and near zero emission industrial production.

6. **Establish a cement sectoral Breakthrough at COP27.** Recognising the positive influence the Glasgow Breakthrough Agenda has had in establishing a sectoral focus on the steel industry in international climate dialogues – and specifically with respect to work defining near zero emission steel production – the IEA recommends that a similar approach be adopted for cement. This should be done using existing frameworks and secretariats, avoiding the potential for duplication and the need for additional layers of co-ordination.
7. **Consolidate existing work on measurement standards, ensure their fitness for purpose, and avoid the development of duplicate standards and protocols.** International standards and accounting frameworks already exist or are under development for evaluating the emissions intensity of certain materials, both for production (e.g., ISO 14404, ISO DIS19694-3, ResponsibleSteel, Cement CO_2 and Energy Protocol) and products (e.g. ISO 20915, Environmental Product Declarations). G7 members should agree on a common set of measurement standards and reporting frameworks to use for evaluating the emissions intensity of production for each material, addressing any gaps in these standards' coverage or completeness. The fitness for purpose of these standards must be appraised with a view both to existing methods of production and to the innovative processes we hope to deploy at scale in the future. The creation of new measurement standards should be avoided unless none already exists for a particular material. Product standards for finished materials (e.g., steel rebar) and multi-material products (e.g., reinforced concrete) should use these harmonised material production standards as inputs. Ideally, all bulk materials under consideration should be covered by a single, consistent set of measurement protocols.
8. **Adopt stable, absolute and ambitious thresholds for near zero emission material production that take account of sector-specific nuances.** The thresholds for near zero emission production outlined in the report target levels of emissions intensity that are compatible with IEA scenarios that achieve net zero emissions from the global energy system, notably the IEA's Net Zero Emissions by 2050 Scenario. Inherent features of the sectors that influence the emissions intensity of production in a given plant, portfolio or country are fundamental to the thresholds proposed. The threshold ranges for steel production are 50-400 kg of CO_2 equivalent per tonne ($kgCO_2e/t$) and 40-125 $kgCO_2e/t$ for cement production, with the precise threshold value depending on the amount of scrap use and the clinker-to-cement ratio respectively. The thresholds we propose are technology neutral and are not intended to imply a specific production pathway or exclude a specific strategy, denote a specific carbon content (e.g., "low carbon steel") or entirely rule out any residual emissions (e.g., "net zero" or "zero" emission steel).
The G7 should recognise the definitions proposed herein as a starting point this year, and establish processes to develop and extend them as needed.

9. **Value interim steps taken to substantially lower emissions intensity, without compromising the stringency of the thresholds for near zero emission production.** There are several efforts underway to achieve substantial reductions in the emissions intensity of steel and cement production, but they do not currently reach a level that is compatible with an energy system at net zero emissions. Some of these measures will provide a stepping-stone to near zero, whereas some will form only a temporary solution. These interim measures deserve quantitative recognition, alongside – but distinct from – the recognition of near zero emission production, given they are ready, or closer to be ready, for market deployment, and the need to meaningfully cut CO_2 emissions by 2030. The IEA therefore proposes a continuous scale of evaluation of 'low emission production', with the quantity being proportional to the reduction in emissions intensity achieved. G7 members should recognise the key principles of the approach we propose this year, with the details of implementation being subject to international agreement and the consideration of individual country circumstances.
10. **Extend the reach of work on definitions down existing supply chains, and into new ones.** More work is needed to ensure continuity between definitions of near zero emission *production* – the focus of this report – and near zero emission *products* and *projects*. By the end of 2022, G7 countries should consolidate all work on the interoperability of thresholds, building on the work carried out in this report. We also recommend that the principles established in this work be applied to other bulk materials, taking account of their sectoral specificities. The IEA considers choice candidates for addressing next to be ammonia, methanol and aluminium.

Introduction

Achieving Net Zero Heavy Industry Sectors in G7 Members is a new report by the International Energy Agency that focuses on the implementation of policies aimed at lowering CO_2 emissions from heavy industries in the G7 and beyond.

This report was produced at the request of the German government, which holds the 2022 G7 presidency. It is designed to inform policy makers, materials producers, investors, leaders of sectoral initiatives and the research community in advance of the G7 Climate and Energy Ministerial in May 2022.

Our work builds on analysis from the IEA's *Net Zero by 2050: A Roadmap for the Global Energy Sector* to identify the opportunities and challenges of a net zero transition for heavy industry – specifically the steel, cement and chemicals sectors – and to frame the key findings. The IEA's roadmap constitutes *one* pathway to net zero emissions by 2050, but it is not the only one. Regardless of the path followed, heavy industries will need to overcome four main challenges:

- Many technologies needed for the transition of heavy industry sectors remain under development and are not yet ready to be deployed at commercial scale.
- New production processes with substantially lower emissions intensities than will – at least initially – involve higher costs than conventional methods.
- Many of the materials produced by heavy industries are traded on the global market, where pricing is competitive and profit margins are already slim – thus creating a disincentive for "first movers" to invest in the transition.
- Heavy industry facilities are long-lived and capital intensive, locking in emissions inertia.

This report begins with an overview of the trajectories of the energy system and the heavy industries to net zero by 2050. It then goes on to address two key topics that are integral to any efforts to overcome the challenges listed above, with a focus on the steel and cement industries:

- Building a toolbox of policies and financing mechanisms that may be used by G7 members and others to initiate and sustain the heavy industry transition.
- Creating common, employable definitions and standards for "near zero" emissions materials production – a critical foundation for establishing future policy.

For each of these components, an actionable set of recommendations is provided for G7 members to consider.

Chapter 1: Heavy industries in a net zero energy system

Highlights

- Industry accounts for about 9 Gt of direct CO_2 emissions globally, or about one-quarter of all energy and process CO_2 emissions. Three heavy industries account for 70% of those emissions: steel, cement and chemicals production. Drastically reducing their emissions is vital to address the climate challenge.
- The G7 as a bloc is the second-largest contributor to heavy industry emissions after China, with 14% of the global total. Over the past two decades, G7 production has been relatively stable, while output in emerging market and developing economies has grown rapidly. Still, the G7's share of current global output is sizeable: 17% of steel, 8% of cement, and 28% of primary chemicals.
- In the IEA's Net Zero Emissions by 2050 Scenario, global direct CO_2 emissions from heavy industries decline by more than 90% by 2050 relative to today. The G7 moves faster than the global average, reducing emissions by more than 25% by 2030 (compared to 20% globally) and 95% by 2050. As "first movers," the G7 members can have a disproportionate impact: through leadership in technology innovation, provision of finance, policy development and market creation, the group can help accelerate the transition beyond its borders. Being first movers has challenges, but also opportunities: the scenario implies a G7 market size of about 25 Mt of near zero emission production of both primary steel and clinker by 2030, around 10-15% of current production.
- In the Net Zero Emissions by 2050 Scenario, material and energy efficiency help reduce G7 industry emissions. Hydrogen, CCUS and direct electrification technologies – most of which are not yet available at commercial scale – get the group the rest of the way to net zero. Among the G7, by 2030, near zero emission routes account for more than 10% of primary steel, cement and primary chemicals production; by 2050, they account for upwards of 90% of production. Deployment of innovative routes reflects the unique circumstances of G7 members. For instance, hydrogen is the leading near zero emission primary steel production route by 2050, in contrast to CCUS leading globally.
- Given the longevity and cost of key industry assets, 2050 is just one investment cycle away. In the G7, many industrial plants are quite old and will face a major investment decision this decade. Rapidly bringing near zero technologies to commercial-scale is critical so they can replace or enable retrofits of aging plants and avoid locking in high emissions for several more decades.

A net zero emissions energy system by 2050 and the role of the G7

Achieving net zero emissions globally by 2050 will require an energy system transformation of unprecedented speed and scale. The IEA's Net Zero Emissions by 2050 Scenario[1] examines the energy sector component of this transformation. The energy sector accounts for around three-quarters of global CO_2 emissions today; the Net Zero Emissions by 2050 Scenario describes a plausible pathway to reach its eponymous goal without using any offsets outside of the energy sector. The Net Zero Emissions by 2050 Scenario contrasts substantially from the pathway implied by current policies in place to date, and even the pathway of targets announced but not yet backed by policy.

In the Net Zero Emissions by 2050 Scenario, global energy-related and industrial process CO_2 emissions fall by 40% between 2020 and 2030, and to net zero in 2050. Advanced economies as a whole fall to net zero by around 2045 and collectively remove around 0.2 Gt of CO_2 (on a net emissions basis) from the atmosphere in 2050. All sectors of the economy see a rapid reduction in emissions, including the main energy supply and demand sectors: electricity generation, fuel supply, industry, transport and buildings. Sectors moving the fastest include those where zero or near zero emission technologies are already on the market at commercial scale – such as electric vehicles – as well as those that, in many cases, already compete with conventional technologies, such as renewable electricity generation. Meanwhile, sectors where emissions are harder to abate – heavy industries and long-distance transport modes – move more slowly, but still require a rapid transition.

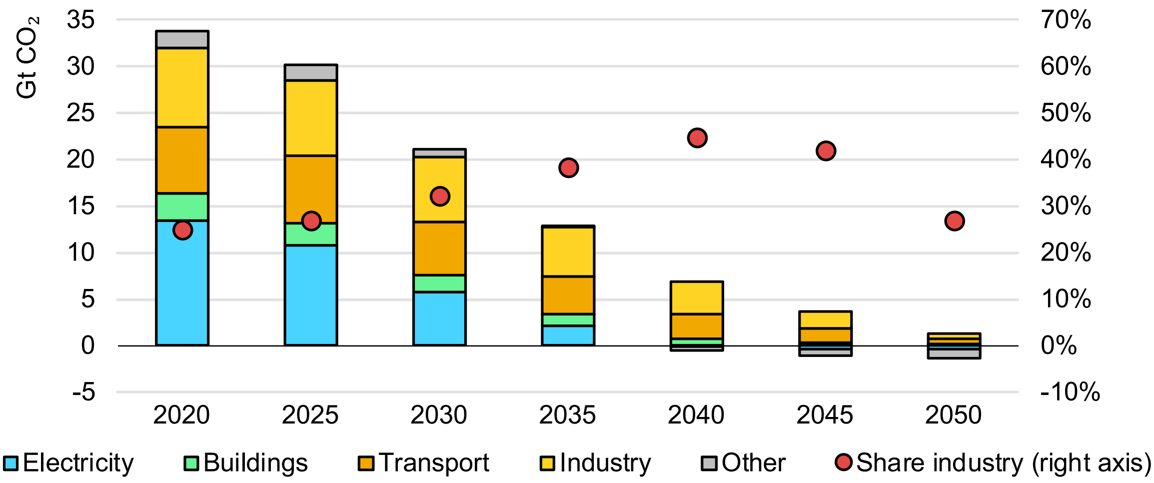
The Net Zero Emissions by 2050 Scenario sees a broad transition away from fossil fuels toward renewables. By 2050, total coal demand falls by 90%, oil demand by 75% and natural gas by 55%. The fossil fuels that remain in 2050 are used in the production of non-energy goods where the carbon is embodied in the product (like plastics), in plants with carbon capture, utilisation and storage (CCUS), and in sectors where low-emissions technology options are scarce. Meanwhile, renewables scale up quickly, to account for nearly 70% of total energy supply by 2050, and another 10% of supply comes from nuclear.

Enhanced energy efficiency, wind and solar provide around half of the emissions savings achieved by 2030 in the Net Zero Emissions by 2050 Scenario. They

[1] This publication is designed to unpack several of the heavy industry- and G7 member-specific components not yet presented in the original publication, and not to provide a full update.

continue to deliver emissions reductions beyond 2030, but the period to 2050 sees increasing electrification, hydrogen use and CCUS deployment. Though some of these latter technologies are not yet available on the market, they eventually provide more than half of the scenario's emissions savings between 2030 and 2050. Behavioural changes by citizens and businesses also facilitate clean energy transitions, accounting for about 12% of reductions by 2050. International collaboration is also important: without the cooperation assumed in the Net Zero Emissions by 2050 Scenario – including measures to create demand and reach economies of scale, manage trade and competitiveness, and accelerate innovation and technology diffusion – the deployment of key technologies could be delayed by decades, and with it the achievement of net zero emissions.

Figure 1.1 Global CO_2 emissions by sector in the Net Zero Emissions by 2050 Scenario



Notes: Other = agriculture, fuel production, transformation and related process emissions, and direct air capture. Values on the right axis represent the share of industry emissions over global gross emissions.

The G7 will play a crucial role in achieving global net zero emissions by 2050, including through co-operative efforts involving countries beyond the G7. The G7 brings together some of the world's largest advanced economies: collectively, they currently account for about 40% of global GDP, 13% of the global population, around 30% of global energy demand and 25% of energy-related CO_2 emissions. G7 members have a history of catalysing innovation, developing new technologies and commercialising them through supportive policies within a stable environment. They also lead in the subsequent deployment of low-emission technologies.

Despite higher initial costs in some areas, G7 leadership on decarbonising energy systems would bring benefits to its members through the creation of new expertise, technologies and jobs. It would bring wider advantages, too: the sharing of lessons learned could help reduce uncertainties and accelerate transitions in other countries that incorporate G7 innovations, policies and regulations into their own circumstances. This could reduce the cost of low-emissions technologies and make energy transitions more affordable for all.

This report focuses on the role of heavy industries in the transition to net zero, including the potential for the G7 to accelerate global progress. As with the energy system as a whole, G7 members could achieve significant benefits as first movers in the industry transition, in terms of advancing the climate agenda as well as capitalising on gains from technology development and markets for near zero emission material production.

Heavy industries today

Industrial activity is the second-largest global source of energy sector CO_2 emissions, accounting for around 9 Gt of CO_2 in direct emissions today, or around one-quarter of total energy system emissions – including both energy-related and industrial process emissions. When indirect emissions from electricity and imported heat generation are included, this increases to around 16 Gt of CO_2 or about 45% of total energy system emissions[2]. Thus, the industry sector has a vital contribution to make in achieving the net zero goal. Three key industries account for 70% of those emissions: steel[3], cement and chemicals production, which we collectively refer to as heavy industries.

The materials produced by these industries form some of the fundamental inputs to buildings, infrastructure, vehicles, consumer goods, food production and many other uses that are integral to thriving economies and our daily lives. This includes meeting demand for materials required by the technologies and infrastructures crucial to delivering a net zero emission energy system, such as rail infrastructure and renewable electricity generation technologies. Society will still need these materials far into the future – even if the most ambitious efforts to pursue material efficiency, behavioural change and a circular economy are implemented.

[2] Indirect emissions are approximated based on the regional average grid intensity of imported electricity and heat, except for a portion of the electricity and heat consumed in the iron and steel sector, where the first choice of fuel for electricity is assumed to be coke oven gas and blast furnace gas.
[3] References to the "steel sector" and the "steel industry" are used interchangeably to refer to the iron and steel sector.

Drastically reducing emissions from heavy industries is therefore an important response to the climate challenge. These emissions are particularly hard to abate for several reasons. For one thing, there is a lack of market-ready, near zero emission technologies that can replace current industrial processes that are highly reliant on fossil fuels – for generating high-temperature heat, as reduction agents, and as a chemical feedstock – and generate process emissions.

Industry's long-lived and capital-intensive assets also pose a challenge. Retrofitting or retiring plants early to switch to alternative technologies would be costly – and in some cases retrofitting may be technically unfeasible. Furthermore, in the highly competitive global markets where bulk materials are traded, profit margins are often thin. This both constrains companies from making the large investments required for near zero emission technologies and makes it difficult for them to pass these higher costs on to customers. The uniformity of bulk materials and products also makes it difficult for those consumers who might be willing to pay more for lower-emission products to differentiate.

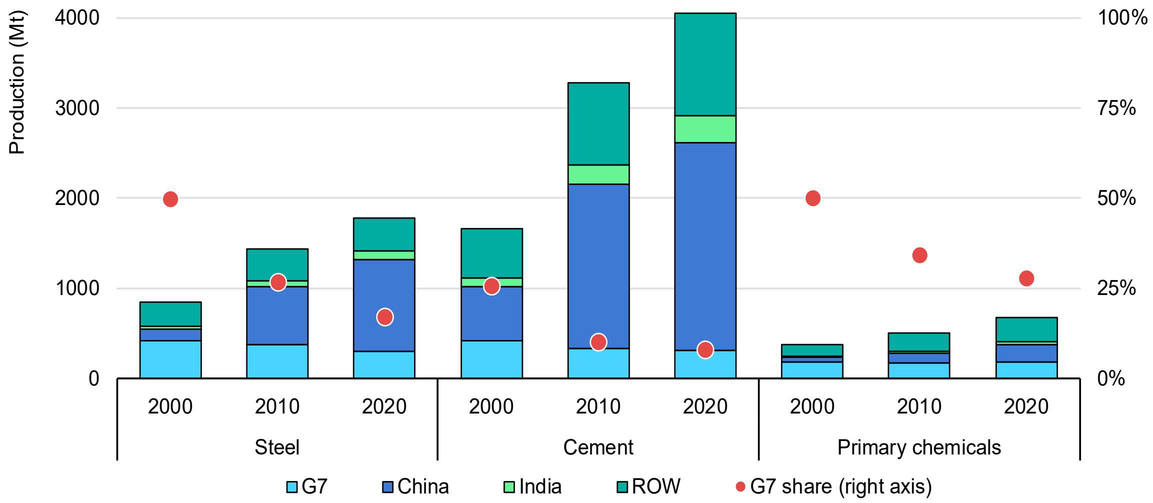
Here, the G7 can play a leading role, acting as a group of "first movers". Through leadership in technology innovation, provision of finance, market creation and policy development, the G7 can help accelerate the industry transition. In the following sections, we provide an overview of the G7's role in the industry sector, both today and on a path to net zero emissions for the energy system.

Materials production

Over the past two decades, as the global population has grown by 25% and global GDP has doubled, demand for materials produced by heavy industries has grown considerably – by about 110% for steel, 140% for cement and 80% for primary chemicals.[4] Rapid economic development in some parts of the world, particularly The People's Republic of China ("China" hereafter), has been a key contributor to this growth.

[4] Primary chemicals include ammonia, methanol and high value chemicals (ethylene, propylene, benzene, toluene and mixed xylenes).

Figure 1.2 Materials production of G7 members in the context of global production



Notes: ROW = Rest of the World; Primary chemicals is the sum of ammonia, methanol, ethylene, propylene, benzene, toluene and mixed xylenes production.

In contrast to the global trend, total production of these materials in the G7 has been relatively stable (in the case of chemicals) or gently declining (in the case of steel and cement), which has reduced the bloc's share of the global total. This is the expected tendency for most mature economies. When countries are developing and building up their infrastructure, per-capita demand for materials tends to increase and stocks of in-use materials accumulate. As economies mature, these stocks tend to saturate, and additional demand is mostly for maintaining – rather than adding to – the existing stock of materials. Another factor at play is that mature economies tend to gradually pivot away from heavy industries as a source of GDP growth over time, pursuing higher value-added manufacturing, service- and consumption-based activities.

Rising demand for discretionary goods (e.g. second vehicles, more consumer goods, more packaging) offsets some of this downward trend. But these items tend to be less materials-intensive overall than early infrastructure development, and can often be produced elsewhere and imported. Additionally, some materials – cement in particular – are generally produced close to their point of consumption, such that maintaining production levels for export is unlikely. These trends are borne out in the regional production data for heavy industries. Despite its shrinking share since the turn of the millennium, the G7 still accounts for a sizeable amount of the output of these industries today – 17% of global steel production, 8% of cement production, and 28% of primary chemicals production.

Global trade is an important consideration for heavy industries: the trade in the materials themselves, the products made from them and their main raw-material inputs. For example, in the case of the steel supply chain, there is trade in crude steel, iron, iron ore, scrap, and metallurgical coal; trade in semi-finished steel products like hot-rolled coil and rebar; trade in product components like car parts, and finally in end-use products containing steel like vehicles and refrigerators and even the waste streams they produce. Cement, concrete and clinker are traded in smaller volumes and across shorter distances, due to their weight and the convenience of producing them close to the point of use. Chemicals tend to be traded in larger volumes once they are transformed into liquids and solids at various points in their supply chains.

Of the main heavy industry outputs, steel is traded in the largest volumes, with an export share of global production of more than 20%, according to worldsteel. The figure for ammonia is around 10%, methanol around 15%, and for ethylene, propylene, and cement it is around or below 5%, according to the International Fertiliser Association and the United Nations Comtrade database. Some derivatives – such as the polymers derived from ethylene and propylene – are traded in greater volumes than their precursor materials.

The G7's levels of material production exports are broadly comparable to the global average, with some differences in particular materials. Over time, the G7 share of materials exported has increased slightly, since domestic demand – mainly for new infrastructure development – has largely been met. In the case of steel, the G7's exports as a share of domestic production today are around 23% (excluding intra-European Union trade)[5], which is close to the global average. For ammonia, the share is at 8% – around two-thirds of the global figure. As at the global level, the G7 trades some derivative products of key heavy industry outputs to a greater extent than their precursors: for instance, urea – which is derived from ammonia – has an export-to-production ratio of almost 30%. Further up the supply chain, raw materials and feedstocks are traded as well, including iron ore, steel scrap, natural gas and oil products.

Among G7 members, much of trade in industrial commodities takes place with regional partners, although some trade across the globe also occurs. In the case of steel, 75% of imports by EU members comes from within the Union. For extra-EU trade, the EU's largest export destination is other non-EU European countries, followed by North America and Africa, while most imports come from other European and CIS countries. Much of Japan's steel trade is with other Asian

[5] The value excludes trade between EU countries but includes trade between the EU and other G7 countries.

economies. Meanwhile, Canada and the United States trade most commonly within North America, but also have substantial imports from other regions including the EU, South America and Asia. Ammonia provides another example of frequent regional trade: 60% of the ammonia imported by the United States originates from Trinidad and Tobago, while most of the rest comes from Canada. European countries also mainly trade ammonia among themselves. France, for instance, receives half of its ammonia imports from three of its neighbours: Germany, the Netherlands and the United Kingdom. Japan imports ammonia primarily from Indonesia and Malaysia.

The possibility of trading commodities at different stages along the materials and goods supply chains opens ample opportunities for governments and industries to define optimal strategies for their industrial operations. Such strategies would depend on the availability of raw materials and energy resources and/or access to these at a competitive price in international markets. They would also depend on the weight given to manufacturing industries in domestic socio-economic development plans.

As a result, a given country can have different weights or roles in international commodities markets for each material. For example, on the steel market, China is the largest exporter of finished and semi-finished products, followed by the Russian Federation ("Russia" hereafter), Japan and Korea, while net importers include the United States and the European Union. By contrast, in the ammonia sector, China is a net importer alongside the US and the EU, while the Middle East, Russia and Trinidad and Tobago are net exporters.

Differences in climate policy ambition can adversely affect trade patterns. Production cost differentials between regions can lead to increased volumes of imports from regions with less stringent climate policy and/or difficulties faced by exporting for regions with more stringent policy. In the future, this may even be the case for materials such as clinker and cement that currently are not highly traded. As discussed in the next chapter, sufficient measures will be needed to ensure competitiveness of producers in regions where more stringent climate policy is being applied. Conversely, decarbonisation objectives could lead to cost-saving shifts in trade that are also beneficial from a climate standpoint. This might include producing intermediates in regions with strong potential for low-cost, low-emission production and exporting them to other regions for subsequent production steps.

Energy and CO_2

Heavy industries are energy- and CO_2 emissions-intensive. Globally, they account for about 20% (90 exajoules [EJ]) of final energy consumption and more than one-sixth (around 6 Gt) of direct energy sector CO_2 emissions, including industrial process emissions. For G7 members, heavy industries account for lower – but still substantial – shares of energy consumption (15%) and direct CO_2 emissions (10%). Heavy industries in G7 members account for a total of about 0.9 Gt of CO_2 in direct emissions, and lead to about 0.3 Gt of CO_2 of indirect emissions from electricity and imported heat generation.

Fossil fuels are currently the main source of energy in heavy industries, accounting for about 85% of energy consumption both globally and in G7 members. Fossil fuels are particularly suitable for providing the high-temperature heat required by heavy industry production processes at relatively low cost. Additionally, in the steel sector they serve as a reduction agent for iron, while in the chemicals sector they act as a feedstock. In the steel sector, coal is the dominant fuel, used in blast furnaces directly, after conversion to coke and in the form of off-gases produced from coke production, functioning both as a reduction agent and for provision of thermal energy. Natural gas is used to a much smaller but growing extent, in direct reduction furnaces and ancillary processes. For cement production, the fuel requirements of kilns are quite flexible, as long as the fuel can provide sufficient high-temperature heat – coal is often used given its lower cost, but natural gas, oil products like petroleum coke, and waste (including biomass-based and non-renewable waste) are also used in some instances. In the chemicals sector, oil is the dominant fuel, followed by natural gas, given their roles as a feedstock. Coal contributes a relatively small share of energy needs for chemicals globally, besides some specific uses in China, particularly methanol and ammonia.

Electricity accounts for most of the remaining energy consumption today, with bioenergy, waste and imported heat also playing small roles. Uses of electricity include in electric arc furnaces for scrap and direct reduced iron-based steel production; in mechanical processes such as material grinding in the cement sector; and other ancillary processes. Electricity primarily drives pumps and compressors in the chemicals sector, and supports other ancillary processes and electro-chemical processes. Uses of bioenergy and waste include in cement kilns, as well as charcoal used in a small portion of blast furnaces, particularly in Brazil.

The large reliance on fossil fuels is a main contributor to the CO_2 emissions of heavy industries. Process emissions that result from the chemical reactions inherent to current production methods also contribute, accounting for just under a quarter of total global heavy industry direct emissions. Globally, the highest emitting heavy industry sectors are steel and cement, each accounting for about 40% of direct heavy industry emissions and chemicals accounting for the remaining 20%. For G7 members, the order is reversed – the chemical sector is the highest emitting with more than 40% of heavy industry emissions, followed by steel with a third and cement with around a quarter. These differences are largely a function of production volumes, since the G7 accounts for a smaller share of global cement and steel production relative to chemicals.

Industry's heavy reliance on fossil fuels takes on a new significance in the context of Russia's invasion of Ukraine. Russia is one of the world's top three producers of crude oil, vying for the top spot with Saudi Arabia and the United States, and it is the world's second-largest producer of natural gas, behind the United States. The war has caused turbulence in energy markets, and has particular significance for the EU, given that imports from Russia supplied almost 40% of EU gas demand in 2021. Short-term measures are being promoted to reduce oil and gas demand to the extent possible, largely through behavioural changes related to activities in the transport and buildings sector. Fewer options are available for reducing industry's use of fossil fuels. But in the medium-term, the war in Ukraine could motivate an accelerated shift toward alternative fuels and technologies in the industrial sector – particularly in the EU – including shifting toward production based on electrolysis supplied by renewable electricity or biomass-based pathways. These changes – such building out new production capacity, reinforcing electricity infrastructure and developing new supply chains – would require some time to implement. But they would both increase energy security and accelerate clean energy transitions.

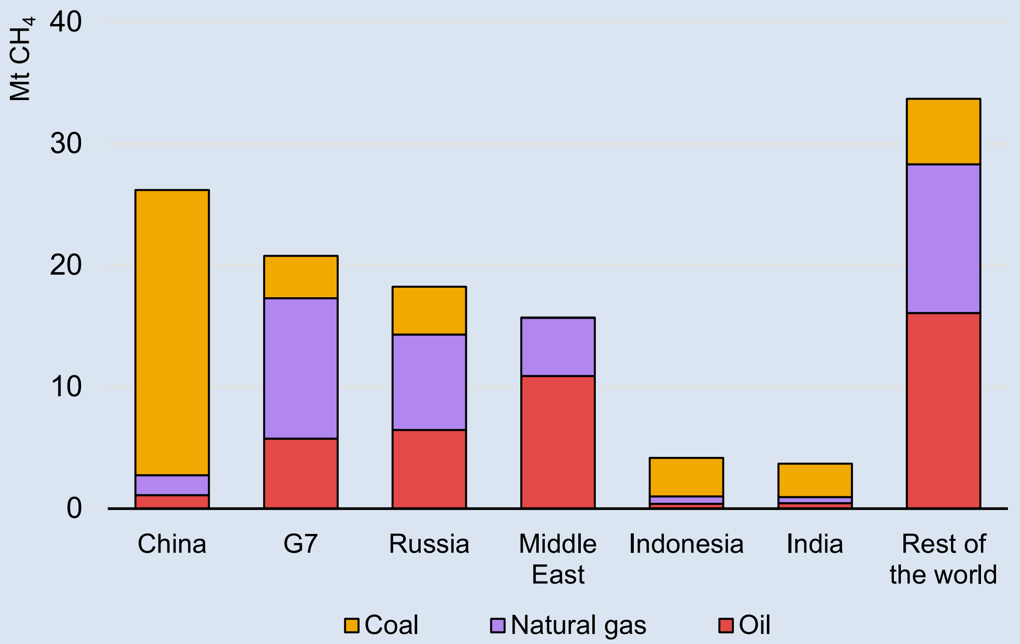
Box 1.1 Indirect emissions from fossil fuel supply

Today, the provision of the fossil fuels used by heavy industries leads to substantial quantities of indirect emissions, owing to the extraction, mining, refining, transportation, flaring and leakage that takes place along the supply chain. On a global average basis, fossil fuel supply emissions amount to around 0.37 tonnes of CO_2 equivalent (CO_2e) per tonne of coal equivalent (13 kt of CO_2e/petajoule [PJ]), 0.60 tonnes of CO_2e per thousand cubic metres of natural gas supply (16 kt CO_2e/PJ) and 0.11 tonnes of CO_2e per barrel of oil equivalent (19 kt CO_2e/PJ). Based on these average values, the amounts of fuels used in industry as a whole today leads to a total of about 1.6 Gt of CO_2e in indirect emissions. This is just under 20% of direct emissions from the industry sector. When indirect emissions from fossil fuel supply as well as from electricity and off-site heat generation are included, industry total emissions increase from about 9 to nearly 18 Gt of CO_2e.

Methane (CH_4) emissions are a major contributor to indirect fossil fuel supply emissions. Oil, natural gas and coal supply account for almost one-third of anthropogenic methane emissions and more than 90% of methane sources from the energy sector. Tackling methane emissions from fossil fuel operations represents one of the best near-term opportunities for limiting the worse effects of climate change because of its short-lived nature in the atmosphere and the large scope for cost-effective abatement. The Global Methane Pledge, led by the United States and the European Commission at the COP 26 summit in Glasgow last year, invites participants to agree to take voluntary actions to contribute to a collective effort to reduce global methane emissions at least 30 percent from 2020 levels by 2030.

According to IEA estimates, in 2021 fossil fuel operations released over 120 Mt of CH_4 to the atmosphere, equivalent to almost 3.7 Gt of CO_2,[6] around 10% of global energy-related CO_2 emissions. Coal, oil and natural gas account for similar shares of methane emissions, but this varies by region. Almost 90% of methane emissions in China are from coal supply, whereas leaks along the natural gas supply chain drive over half of related emissions in the United States.

Methane emissions from fossil fuel operations in key regions, 2021



[6] Methane global warming potential is considered at 30 over 100 years based on the latest values from the IPCC.

In the context of the Net Zero Emissions by 2050 Scenario, three-quarters of methane emissions from fossil fuel supply are abated by 2030, using existing technologies. Much of this methane abatement – particularly for oil and gas – can be done at relatively low cost, because the value of the captured methane is sufficient to cover the costs of the abatement measure. For CO_2 emissions from the extraction, processing and transport of fossil fuels, these also see substantial reductions the Net Zero Emissions by 2050 Scenario, as the transport, refining and mining sectors decarbonise their operations.

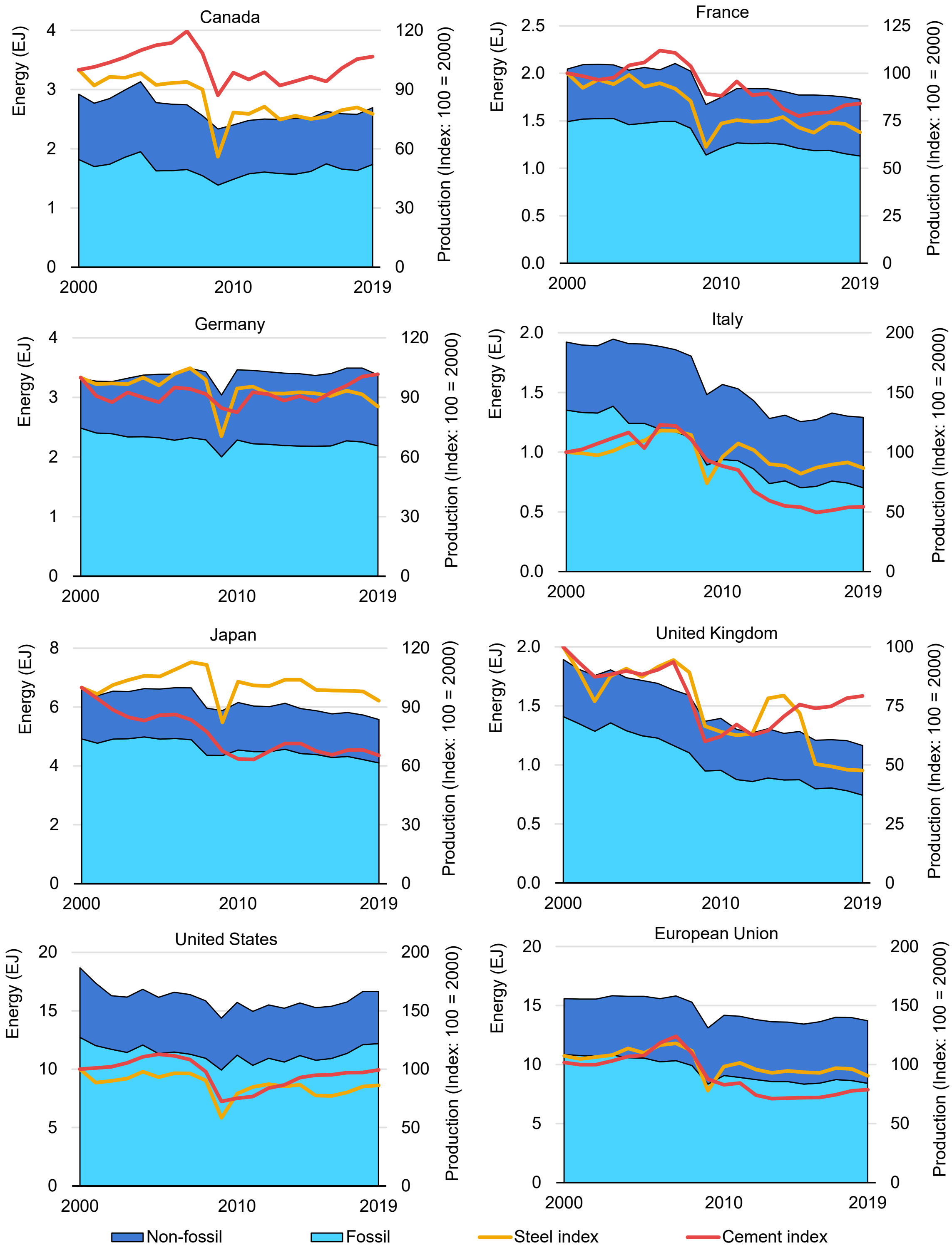
The G7 as a bloc is the second-largest contributor to global direct CO_2 emissions from these sectors, with 14% of emissions (0.9 Gt of CO_2). It is second only to China, which accounts for just over half of the global total (3.1 Gt of CO_2). India follows with 8% of emissions (0.5 Gt of CO_2). Over time, the G7's share of global emissions has declined, mainly because of reductions in its share of total global production. Just 20 years ago, the G7 accounted for about 35% of global heavy industry emissions (1.1 Gt of CO_2).

Most heavy industries in most G7 members have seen a decline in final energy consumption in industry over the course of the past two decades, and a stable share of fossil fuel use within that. This is again largely driven by stable or declining activity in heavy industries over that period, and further energy efficiency improvements through the adoption of current best available technologies and process integration strategies that minimise energy waste.

Each G7 member faces different circumstances when it comes to domestic materials demand, access to raw materials and the cost of energy. This is in part reflected in the distribution of production routes for steel and cement across regions. In the case of steel, steelmaking with oxygen-blown converters (typically the BF-BOF route) accounts for most of the primary production. In the G7, the share of oxygen-blown converter output in total steel production (55%) is slightly lower than the global average of 70%. This is due, at least in part, to the fact that G7 members' economies are mature, which leads to a proportionally larger amount of end-of-life scrap becoming available from the larger stock of steel in society. This leads to a larger share of electric furnace production.

There are also many other factors at play. For example, countries with high demand for steel grades that currently cannot easily be provided using electric furnaces and scrap alone – such as some products used in the automotive sector – may have higher shares of primary production to meet these needs, which

Figure 1.3 Industrial energy demand and production of steel and cement of G7 members

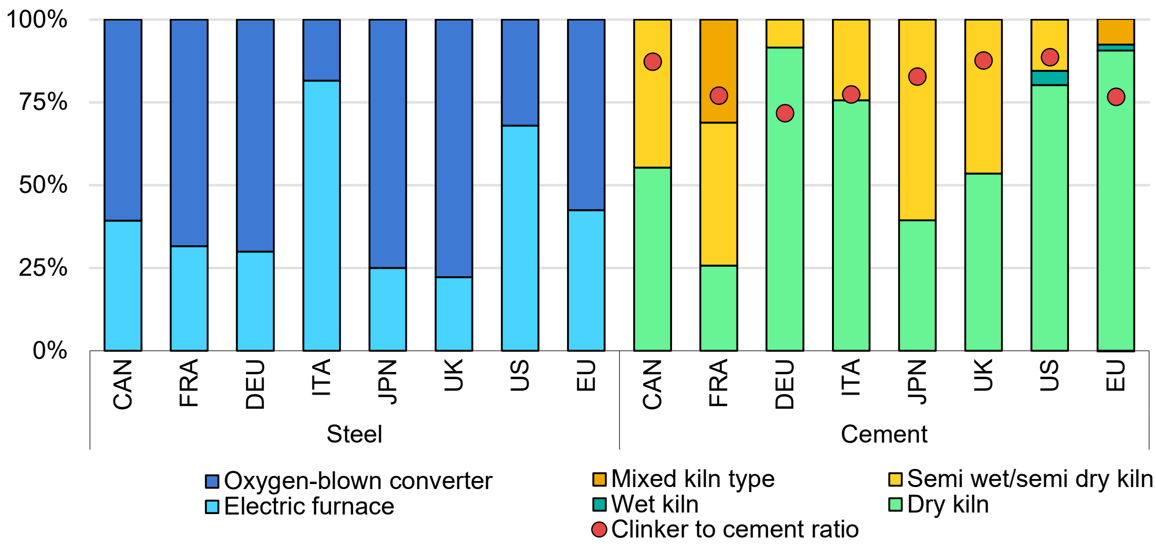


Notes: Energy data from the IEA World Energy Balances; steel production data from worldsteel; cement production data from USGS. Industrial energy consumption includes total final consumption by the industry sector, chemical and petrochemical feedstock non-energy use and energy consumed by blast furnaces and coke ovens in the transformation sector.

is the case in Germany, for example. An export-oriented approach may also lead to a higher share of primary production, as is the case in Japan, servicing a variety of steel product markets. Meanwhile, countries with access to low-cost natural gas can see higher deployment of the direct reduced iron-electric arc furnace (DRI-EAF) route, which increases the electric furnace share. In the United States, direct reduced iron is deployed in conjunction with many scrap-based "mini-mills," for instance, which explains the high share of production via electric furnaces.

In the case of cement, energy-efficient dry, or semi-dry kilns account for most of the production fleet across the G7. Clinker is the main precursor of cement, and its production is the most emissions-intensive step in cement manufacturing. The amount of clinker use per tonne of cement is minimised by integrating alternative cement constituents such as ground granulated blast furnace slag or coal fly ash in blended cements. Some regions require cement to have a higher clinker ratio (resulting in higher strength), owing to specific requirements of a given environment (e.g. earthquake resistant structures built in Japan). The average clinker-to-cement ratio in the G7 is 10% higher than the global average, mainly because of more stringent specifications or demands from the market for construction materials, relative to those of other markets.

Figure 1.4 Steel and cement production by process route in G7 members today



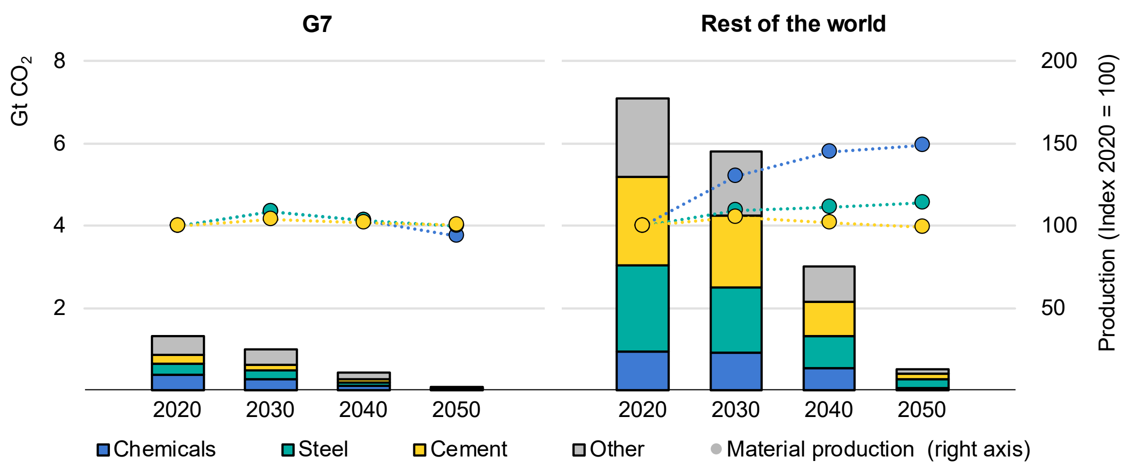
Note: CAN = Canada; FRA = France; DEU = Germany; ITA = Italy; JPN = Japan; UK = United Kingdom; US = United States; EU = European Union. Steel data are 2018 values from worldsteel. Cement data are 2019 values from GCCA; for Japan, country-level data are not available in GNR and thus the Asia regional value is used.

A pathway toward net zero heavy industry sectors

In the Net Zero Emissions by 2050 Scenario, global direct CO_2 emissions from heavy industries fall rapidly, declining by more than 90% by 2050, relative to current levels. The remaining emissions – just over 0.4 Gt of CO_2 on net, after taking in account bioenergy with carbon capture and storage (BECCS) within these sectors – are offset using carbon-removal technologies in other sectors of the energy system, primarily BECCS in power and fuels transformation applications and direct air capture (DAC). This offsetting occurs due to the challenges and costs associated with eliminating all emissions from heavy industries.

The G7 moves even faster than the global average under the scenario, achieving emissions reductions of 27% by 2030 (compared to 18% for the rest of the world), 70% by 2040 (compared to 58% for the rest of the world) and 95% by 2050 (compared to 92% for the rest of the world). As advanced economies, the G7 members are among the first movers to apply a comprehensive approach to accelerate innovation, early deployment of near zero emission technologies, infrastructure build-out, material efficiency improvements and policy development to achieve earlier and faster emissions reductions.

Figure 1.5 CO_2 emissions from industry and material production by sub-sector in the Net Zero Emissions by 2050 Scenario



Note: Other includes the production of aluminium, paper, other non-metallic minerals and other non-ferrous metals, and a series of light industries.

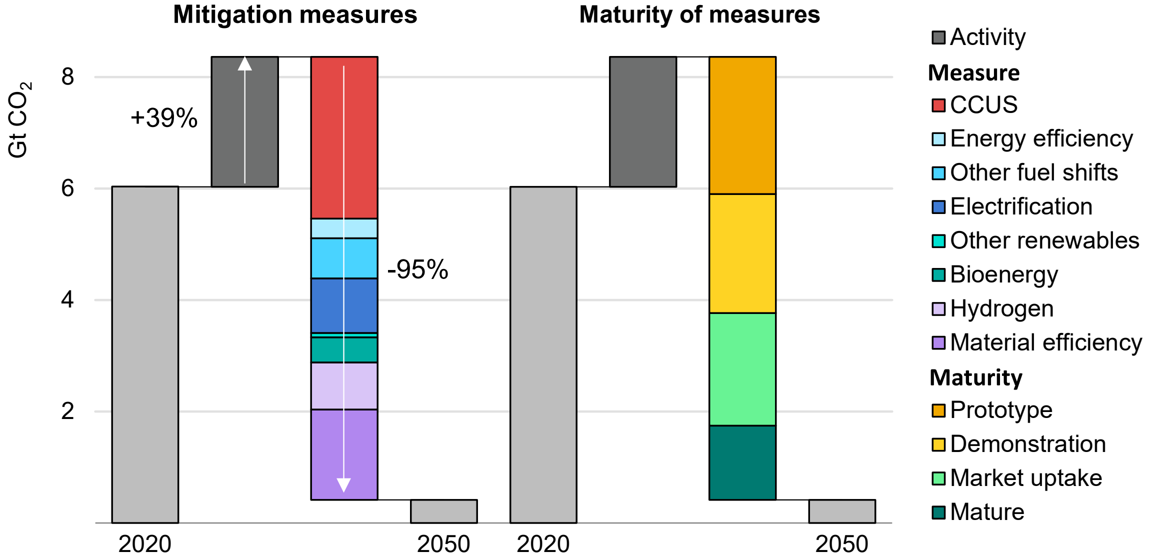
The outlook for global materials demand in the Net Zero Emissions by 2050 Scenario is one of plateaus and small increases. In G7 economies, there are small increases in production in the short term, but by 2025-30 the outputs from heavy industries plateau. In the rest of the world, cement production peaks by 2030 and then enters a gradual decline, while the production of primary chemicals – and to a lesser extent, steel – continue to increase.

Growth in demand in both the G7 and the rest of the world is moderated through ambitious pursuit of strategies to improve material efficiency across value chains, including circular economy schemes. Globally, these approaches account for around one-fifth (around 1.5 Gt of CO_2) of the emissions reductions in the Net Zero Emissions by 2050 Scenario through to 2050. These strategies include the renovation (as opposed to reconstruction) of buildings to extend their lifetimes; modal shifts in transport to reduce the need for new vehicles and infrastructure; changes to more efficient design and manufacturing methods; substitution of materials leading to lower lifecycle emissions; and increased end-of-life reuse and recycling of materials. While certain segments of materials demand increase rapidly to support the required expansion of energy-related infrastructure – notably renewable electricity generation and transport infrastructure – these increases are outweighed by the reductions achieved through enhanced material efficiency.

In addition to material efficiency, optimising the operational energy efficiency of equipment and adopting the best available technology (BAT) for new capacity additions play an important role in reducing emissions. However, there are limits to how much emissions reduction can be achieved by these measures with the technologies available at commercial scale today. Almost 60% of global emissions reductions in 2050 in the Net Zero Emissions by 2050 Scenario are attained using technologies that are still under development (at prototype or demonstration scale). These technologies must be brought to market readiness by the mid- to late- 2020s for initial deployment before 2030 and rapid subsequent diffusion from 2030 onwards.

The hydrogen and CCUS technology families comprise a range of specific applications for reducing emissions from heavy industries, most of which are not currently available in the market at commercial scale. Combined, these technologies contribute around half the emissions reductions in heavy industries through to 2050 under the Net Zero Emissions by 2050 Scenario. These technologies enable the provision of large volumes of high-temperature heat with substantially lower emissions. They also address industrial process emissions from the chemical reactions that are inherent to some conventional industrial production processes (e.g. the calcination reaction that takes place during the production of clinker from limestone for cement). Sustainable bioenergy also makes a moderate contribution in various industrial applications, being a source of heat, chemical feedstock and carbon removal (BECCS), the latter when bioenergy is deployed in conjunction with CCS. However, bioenergy use is constrained by limits to supplies of sustainable bioenergy and competing demands from other parts of the energy system. Direct electrification also contributes to some degree, although for high-temperature applications, this tends to be in earlier stages of development relative to hydrogen and CCUS-based technologies.

Figure 1.6 Global direct CO_2 emissions reductions in heavy industries by mitigation measure and current technology maturity category in the Net Zero Emissions by 2050 Scenario



Note: Technology maturity categories are as follows: Mature = technologies that have reached market stability, and the number of new purchases or installations are constant or even declining in some environments as newer technologies start to compete with the stock of existing assets; Market uptake = technologies that are being deployed in a number of markets. including the sub-categories "early adoption" for technologies that have a cost and performance gap with established technologies and "steady scale-up" for technologies that are competitive but barriers to reaching their full market potential remain, such as integration with existing infrastructure or consumer preference; Demonstration = technologies where the first examples of a new technology are being introduced at the size of a full-scale commercial unit; Prototype = technology types for which prototypes are being developed at a considerable size, as in pilot plants, technology types for which designs are being developed into lab-scale prototypes. For more information on which technologies are classified under the different maturity categories, please see the IEA's Clean Energy Technology Guide.

Sector-specific considerations

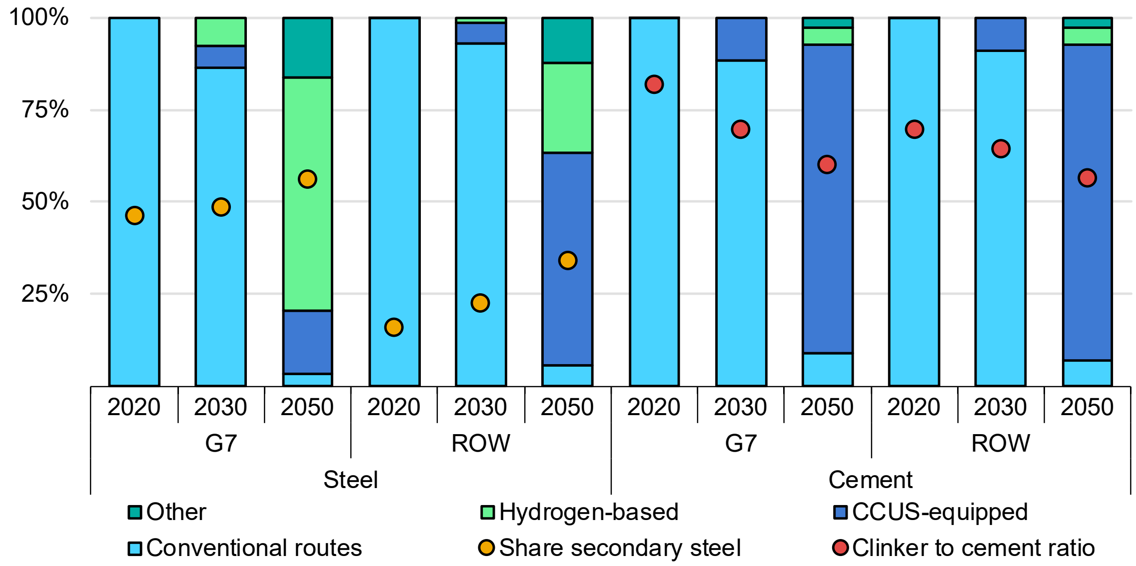
The technology pathways followed in each heavy industry sector vary according to their unique characteristics and the technologies that are currently under development in each. For the **steel sector**, both hydrogen- and CCUS-based pathways present promising options. Direct reduced iron (DRI) fuelled by electrolytic hydrogen continues to gain momentum. It is currently at the large prototype stage, with multiple projects in Europe, North America and Asia, targeting full or partial hydrogen substitution of fossil fuel inputs (see IEA's Clean Energy Technology Guide for more examples of innovation projects).

Various CCUS-based routes are also being pursued. The first commercial plant employing natural gas-based DRI with CCUS is operating in the United Arab Emirates. A number of projects are piloting technologies to apply CCUS to blast furnaces, including in a retrofit arrangement, such as the 3D project in France, the COURSE 50 project in Japan and a pilot scale blast furnace gas project in India. CCUS has also been explored on smelting reduction furnaces in the Netherlands, although the HIsarna project has recently been put on hold, with a shift in strategy toward hydrogen technology. While still in the earlier prototype stage, direct iron ore electrolysis (IOE) technologies are also under development in the EU and the United States.

By 2050 in the Net Zero Emissions by 2050 Scenario, around 65% of primary steel production in the G7 is via the hydrogen (H_2) DRI-EAF route, 15% via CCUS-based technologies and more than 15% via IOE. The H_2 DRI-EAF route is fed with hydrogen generated by electrolysers, using a combination of on-site renewable energy generation and the electricity grid, which is fully decarbonised at that time. These shares for the G7 differ from the global shares where, for instance, CCUS-equipped routes account for around half of primary steel production by 2050, reflecting the regional circumstances of G7 members (see Figure 1.7). This is particularly the case for the EU and the UK, where policy is providing considerable support for hydrogen, and hydrogen-based steelmaking has gained traction as the favoured near zero emission steelmaking route. Other G7 members see greater reliance on CCUS-based routes in 2050, due to a combination of favourable geology, low fossil fuel prices, existing policy support for CCUS-based routes and in some regional settings, lower potential for low-cost renewable electricity generation.

Scrap-based secondary steel production today has a direct CO_2 emissions intensity that is, on average, more than 95% lower than for primary production. The scrap EAF route plays an important role in the Net Zero Emissions by 2050 Scenario, accounting for about 55% of crude steel production in G7 members in 2050, compared to about 45% today. Under the scenario, ambitious efforts are made to maximise secondary production, including increases in scrap collection and reducing impurities through improved product design and scrap sorting. This enables steel from secondary production processes to be used in a wider range of end-use applications. Still, scrap availability is insufficient to meet all of steel demand with secondary production, thus primary still plays an important role. Additionally, a portion of scrap is used in primary routes, where scrap normally makes up as much as 15-25% of metallic inputs.

Figure 1.7 Production of primary steel and cement by production route in the G7 and the rest of world in the Net Zero Emissions by 2050 Scenario



Note: ROW = rest of world. Steel refers to primary steel production. Cement refers to clinker production. "Other" includes direct electrification and routes where bioenergy is the primary means of emissions reduction.

In the **cement sector**, CCUS technologies are critical for achieving substantial emissions reductions, given that process emissions from clinker calcination account for two-thirds of emissions. Alternative cement constituents – which reduce the need for clinker in cement – are an important strategy but cannot eliminate clinker altogether. A diversity of CO_2 capture technologies are currently under development in the cement sector, including chemical absorption, calcium looping, direct separation, novel physical adsorption, and oxyfuelling. The most advanced are at demonstration stage, including in Norway and Italy, while others are still being piloted, including in Canada and Germany.

Developments are also underway, including in the UK and Sweden, to use electricity and/or hydrogen, perhaps in combination with biomass, to provide the high-temperature heat required by cement kilns. However, these alternative heating methods are currently at the early prototype stage, and would not avoid the need for CCUS, if the process emissions are to be addressed. Bioenergy – including biogenic waste – is already used commercially today, and in the Net Zero Emissions by 2050 Scenario its use scales up considerably from 13% of thermal energy requirements on average in G7 members today to around 40% in 2050. This provides a source of carbon removal for kilns in which CCS is applied to both process and energy emissions. Meanwhile, use of non-renewable waste declines.

In the Net Zero Emissions by 2050 Scenario, about 90% of cement production in G7 members is via innovative technologies in 2050 (including CCUS). This level is just slightly below that observed at the global level, due to a higher share of bioenergy used in the G7 in both conventional and innovative routes, enabling the G7 to achieve a lower average emissions intensity of cement production with slightly lower CCUS deployment. Material efficiency plays a crucial role for cement in the Net Zero Emissions by 2050 Scenario. More efficient use of cement as a component of concrete, and of concrete in the construction industry, through modified design and construction practices, help to reduce total demand for cement. Use of blended cements also increases such that the average clinker-to-cement ratio in G7 members decreases from just over 0.80 today to 0.60 in 2050.

Limestone and calcined clay are the main alternative materials used in blended cements by 2050, as availability of leading conventional alternative materials – ground granulated blast furnace slag and fly ash from coal plants – declines in the context of a decarbonising energy system. A clinker-to-cement ratio of around 0.50 is likely the lowest technically achievable for most major applications (cements with over 90% granulated blast furnace slag have been used but only for very limited applications), so reducing clinker in cement alone is not sufficient to decarbonise the sector.

There may well be a role for new types of cements and concretes in the future, based on alternative binding materials that limit or avoid the generation of process emissions, and even enable CO_2 capture during the curing process. However, those that would achieve near zero emission production are still in the early stages of technological development (e.g. magnesium oxides derived from magnesium silicates) or can only be used for specific applications due to their technical properties (e.g. carbonation of calcium silicates, alkali-activated binders).

In the **chemicals sector**, near zero emission technologies based on CCUS, hydrogen and direct electrification all play a meaningful role. CCUS technologies are already applied today at commercial scale in ammonia and methanol production, and are being demonstrated for high-value chemicals production. Additionally, electrolytic hydrogen is at the large-scale demonstration stage for ammonia and methanol. In the Net Zero Emissions by 2050 Scenario, CCUS plays the largest role given that it is already the most advanced technology path, being applied to about 60% of primary chemicals production in G7 members in 2050. To achieve permanent emissions reductions, most of the CO_2 captured through CCUS in the chemicals sector in the Net Zero Emissions by 2050 Scenario is destined for permanent storage, rather than being used to produce other chemicals like urea and methanol, since the latter would lead to the CO_2 being re-released to the atmosphere when the product is used or disposed of after use.

Under the Net Zero Scenario, hydrogen that is derived from either electrolysis or pyrolysis (the latter a method that uses electricity to separate natural gas into hydrogen and solid carbon) contributes to about 25% of production through its role in ammonia and methanol production. Bioenergy accounts for about 10% of production through its provision of feedstock for high value chemicals production. Increasing the sorting and collection of waste plastic leads to a major increase in recycled plastic production, reaching almost 50% by 2050, relative to around 15% today for the G7 as an aggregate. Reductions in the use of single-use plastics also leads to lower total demand for chemicals.

Table 1.1 Key milestones for heavy industry sectors of G7 members in the Net Zero Emissions by 2050 Scenario

Milestones by sub-sector	2020	2030	2050
Steel			
Recycling, re-use: scrap as share of input	53%	54%	60%
On-site hydrogen production (Mt H_2)	0.3	2	8
with on-site electrolyser capacity (GW)	0	14	61
Share of primary steel production: *hydrogen-based DRI-EAF*	0%	8%	63%
iron ore electrolysis	0%	0%	16%
CCUS-equipped processes	0%	6%	17%
CO_2 captured (Mt CO_2)	0	11	26
Cement			
Clinker-to-cement ratio	0.82	0.70	0.60
Pure hydrogen blending (Mt H_2)	0	0	1
Share of production via innovative routes	0%	12%	91%
CO_2 captured (Mt CO_2)	0	23	113
Chemicals			
Share of recycling: *share of waste plastic collected for recycling*	25%	35%	62%
share of secondary plastic production in total	15%	21%	49%
On-site hydrogen production (Mt H_2)	8	10	11
with on-site electrolyser capacity (GW)	0	8	34
Share of production via innovative routes	1%	18%	94%
CO_2 captured (Mt CO_2)	2	23	78

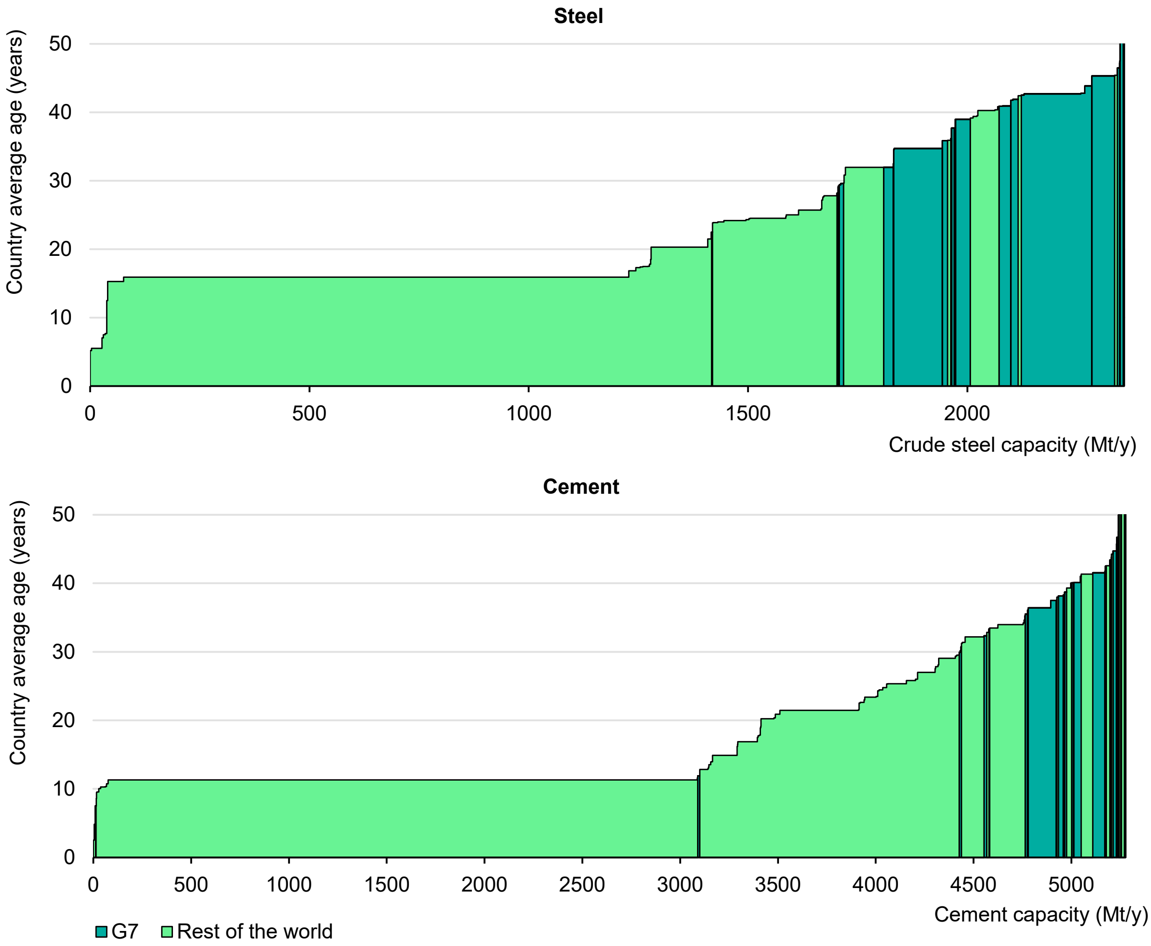
Notes: DRI-EAF = direct reduction of iron-electric arc furnace.

Investment cycles

An important element of the transition for the heavy industry sectors is timing. Given the long lifetimes and expense of key pieces of emissions-intensive equipment used in these sectors, the year 2050 is just **one investment cycle** away. Global average lifetimes of assets such as blast furnaces and cement kilns are around 40 years. However, after about 20-25 years of operation, plants often undergo a major refurbishment to extend their lifetimes, with associated investment costs of the same order of magnitude as a new-build plant (e.g. the relining of a blast furnace).

In the G7, many industrial plants are relatively old and will face a major investment decision in the coming decade. An estimated 90% of steelmaking and 80% of cement production capacity in the EU is more than 20 years old; the figures are similar for the US at around 80% and 75% respectively. This leaves a window of opportunity to address existing assets and avoiding locking in high-emitting plants for several more decades. This older capacity relative to that in emerging and developing economies can be a chance for G7 countries to show leadership by making the first investment in near zero emission technologies to retrofit or replace maturing plants.

Figure 1.8 Average age and regional distribution of key emissions-intensive assets in the steel and cement industries



Notes: Capacity and average age data estimated from a range of the latest available data. For cement, capacity data is from the United States Geological Survey and the Global Cement Directory, clinker-to-cementitious material ratios are from the Global Cement and Concrete Association and average ages of assets are based on the Global Infrastructure Emission Database. For steel, capacity data are from the OECD Steelmaking Capacity Database and average ages of assets are based on the Global Infrastructure Emission Database.

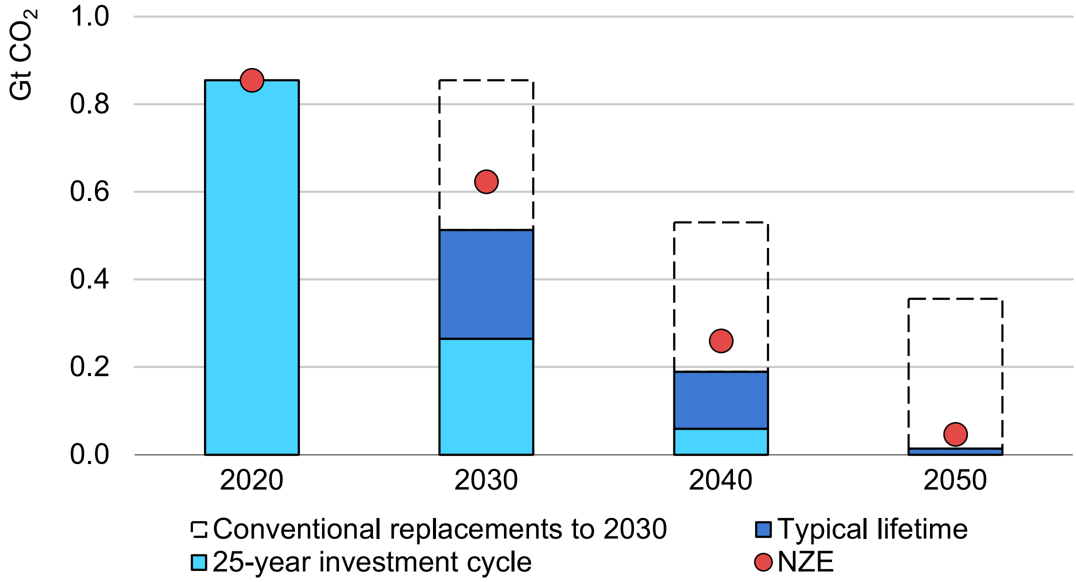
The nature of investment cycles also implies that there should be a clear time limit on investments in conventional capacity, especially units that are not able to be retrofitted. In the Net Zero Emissions by 2050 Scenario, from 2030 onwards, all investments in both new and existing industrial capacity in G7 members is in plants that are either near zero emission from the start or have clearly demonstrated a path to soon achieving near zero emission production. Any new plants built before 2030 also have the space and technical requirements to later incorporate near zero emission technologies.

To take advantage of the window of opportunity presented by investment cycles in heavy industries, it will be important for G7 members to ensure that innovative near zero emission industrial technologies that are at the large prototype and demonstration stage today are brought through to commercial-scale deployment as soon as possible. This is so that aging plants can be replaced by innovative technologies with substantially lower emissions intensities of production. It will also be important for the necessary enabling policy environment and supporting infrastructure to be put in place within the next few years, in order to facilitate the choice of near zero emission technologies over conventional ones.

Until near zero emission technologies are available in the market, renewal of existing assets requires careful consideration. Replacing them with plants that have the technical and space requirements to enable future retrofits that incorporate near zero emission technologies and fuels is a suitable interim solution. To do otherwise would negatively impact the pace of emissions reductions (as it would lock in emissions in future years) or otherwise risk stranded assets further down the line.

The scale of the opportunity should not be underestimated: if all existing plants in the G7 were retrofitted or replaced with near zero emission technologies at the end of the current investment cycle, this could reduce projected cumulative emissions from existing assets in heavy industry sectors by around 50%. Furthermore, action in the next decade is imperative, such that plants reaching an investment decision or end of life are replaced or retrofitted in a manner that would enable incorporation of near zero emission technologies when they are available. If capacity requiring a refurbishment or replacement between now and 2030 were replaced by the same technology and not later retrofitted, heavy industry emissions among G7 members would considerably exceed those of the Net Zero Emissions by 2050 Scenario, even before considering any capacity additions to meet modestly growing demand. In 2050, heavy industry emissions would still be about 0.35 Gt, implying a reduction of only 60% relative to today's emissions rather than the 95% reduction required in the Net Zero Emissions by 2050 Scenario. As such, the aging heavy industry fleet makes near-term retrofit-ready replacements for existing capacity particularly important for G7 members.

Figure 1.9 CO_2 emissions from existing heavy industrial assets in G7 members under different assumptions



Notes: NZE = Net Zero Emissions by 2050 Scenario. "Typical lifetime" and "25-year investment cycle" series represent projections of emissions from heavy industries were the underlying assets to be operated as they have in the past; this is not the case for the Net Zero Emissions by 2050 Scenario. Typical lifetimes of 30-40 years are assumed for chemical, steel and cement sector assets. "Conventional replacements to 2030" series represents projections of emissions from heavy industries if capacity reaching end of life this decade is not converted to lower emissions technologies and instead refurbished or replaced using conventional technologies.

Moving to implementation

Despite the enormity and urgency of the challenge facing heavy industries, emissions continue to rise. In 2021, global industrial emissions rebounded to their 2019 levels following a modest dip in 2020 due to the Covid-19 crisis. This contrasts with the 3% average annual decline required from now to 2030 in the Net Zero Emissions by 2050 Scenario. Moreover, most governments – including the G7 members – do not yet have in place sufficient supportive policy measures and stringent legislation that together would constitute a comprehensive plan to address the major challenges of the industry transition – and thus put heavy industry on a pathway compatible with their broader energy and climate goals. The vision has been established. The 2020s must be the decade for concerted implementation, and key decisions and steps already need to be taken within the next couple of years.

The remainder of this report addresses two key areas where governments – catalysed by the leadership potential of the G7 – can accelerate action in the implementation phase, regardless of the specific technology pathway chosen. First, there is a real need to establish ambitious, stable and well-designed policy frameworks that address the complexity of the net zero transition in heavy industries, to create a business case for near zero emission technologies and material efficiency strategies, and to ensure that the necessary enabling conditions are in place. Chapter 2 therefore proposes a toolbox of policy and finance mechanisms that governments may choose from to facilitate the transition toward net zero heavy industries. Second, a common need for robust policy frameworks is clarity on the emissions savings that can come with individual technology pathways. Chapter 3 proposes common definitions for near zero emission steel and cement production, which will be instrumental operationalising many components of the policy toolbox described in Chapter 2. The report provides a set of specific, actionable recommendations for G7 members to consider as they navigate the complex challenges ahead.

Chapter 2: Enabling net zero heavy industry sectors

Highlights

- Governments hold the pen in enabling net zero heavy industries: ambitious, stable and well-designed policy frameworks are vital for creating the conditions for a rapid transition. Many governments already have relevant policies in place, but the sector is still not on track for net zero by 2050 – and the window of opportunity is narrowing. The next few years are critical to develop and strengthen policy frameworks. Leadership from G7 members can provide valuable impetus for global acceleration.
- This chapter presents a “toolbox” of policy options that G7 members and other governments may draw upon to advance the industry transition. There is no silver bullet. Each region needs to tailor a complete and robust portfolio of measures, including policies that target technology progress, material efficiency, infrastructure development and other enabling conditions. Broader planning, policies and finance mechanisms are also required to establish a long-term investment case for reducing emissions.
- Both supply “push” and demand “pull” policies will be critical to support development and deployment of near zero emission and material-efficient technologies. Public finance mechanisms must lower the risks to mobilise private investment in full-scale demonstrations and early deployment. They must also accelerate the build-out of supporting infrastructure related to low emission hydrogen and electricity provision, CO_2 transport and storage, and recycling. Carbon contracts for difference, public procurement and near zero materials mandates can create differentiated markets for near zero emission materials production, which will initially be more costly than incumbents.
- Definitions of low and near zero emission production are vital to both push and pull mechanisms, setting the bar for which production should qualify for different levels of support and for meeting mandated requirements. By providing clear definitions, governments can guide the industry as well as investors on their decarbonisation targets.
- International competitiveness and collaboration are two sides of the same coin for the industry transition. Governments need to create a level playing field for low emission materials production within competitive international markets. Cooperation can facilitate more ambitious global policies while reducing the competitiveness challenge posed by policy unevenness. An international Industry Decarbonisation Alliance could help by enhancing coordination.

Introduction

Governments have a vital role to play in enabling and accelerating the transition to net zero heavy industries. While policy mixes and designs may vary, one key factor is common across all jurisdictions: the transition will not happen at the required speed and scale without government policy.

This chapter analyses different government policy options to accelerate the transition of heavy industries. The analysis is relevant for all countries, including G7 members and beyond. References are made to the potential role of first movers, where G7 members can play an important leadership role, together with other willing countries.

In the first section, a policy framework for accelerating industrial emissions reductions is outlined. The options presented represent a diverse policy "toolbox" that G7 members – but also other governments – may use to address key challenges of the transition. There is no "silver bullet" solution: a robust policy framework requires government measures that address each of these challenges. Many governments already have policies in place for industry, or are in the process of developing them. Illustrative examples are provided, focusing on those of G7 members but also including examples from other major industrial producers. Despite the important progress that has been made to date, the industrial sector is still not on track with a net zero by 2050 pathway. Governments will therefore need to more fully develop their policy frameworks and increase the breadth, scope and ambition of existing measures.

The second section delves more deeply into three categories of policy that will be critical in accelerating the roll-out of near zero emission industrial production technologies: supply, or "push" policies, demand, or "pull" measures, and international collaboration. Government action in these areas during the current decade is imperative for laying the foundation of the long-term transition. The chapter concludes with a discussion of the potential role of an intergovernmental Industrial Decarbonisation Alliance for encouraging more ambitious policy and enhancing government coordination.

Box 2.1 IEA high-level workshop on policy and finance

To inform this work, the IEA, in co-operation with the German Federal Ministry for Economic Affairs and Climate Action, hosted a virtual high-level workshop entitled "Achieving Net Zero Heavy Industry Sectors in G7 Members: Policy and financing mechanisms" on 17 February 2022. The workshop brought together G7 member governments – alongside country representatives from China, India and Indonesia – as well as stakeholders from the private sector and leading sectoral initiatives to discuss how governments can accelerate the transition to net zero emission heavy industries.

Focusing in particular on steel and cement, the discussion addressed challenges and opportunities for first movers in the industry transition. It also took a deeper look at the roles of push (e.g. finance mechanisms), pull (e.g. procurement policies) and international cooperation (e.g. capacity building) measures. The objective was to understand multiple perspectives and how a range of policies in the toolbox can be used by governments.

Some clear areas of agreement were identified among the stakeholders present:

- *"Push" and "pull":* The need for mechanisms that support both supply and demand for near zero emission materials production.
- *Collaboration:* International cooperation is important for the industry transition.
- *Definitions:* Developing definitions will be valuable for having a common understanding of what to support.
- *Urgency:* Policy support is needed in the current decade to enable the post-2030 transformation.

Conversely, the workshop highlighted areas where open questions remain:

- *"Push" and "pull":* What are the policy options that can finance production and create demand? How should these policies be designed? What level of support is needed?
- *Collaboration and competitiveness:* How could a sectoral approach best help advance the industry transition? What could be the role of an international industry alliance? How can concerns about carbon leakage be addressed?
- *Urgency:* How can governments balance support for near-term gradual changes and for medium-term transformational changes?

These takeaways from the workshop – along with many other insights – were instrumental in developing the core content and recommendations contained in this document.

Policy frameworks for the industry transition

Many governments are implementing policies to help advance the net zero transition in the industrial sector. Industry is also taking significant important steps toward the transition (see Box 2.2). However, despite this important progress, heavy industries are not yet on track to achieve net zero emissions by 2050. Large gaps remain between rhetoric and action and faster progress is needed, globally, to change course. Time is of the essence: we are now just one investment cycle away from the 2050 target for drastically lower CO_2 emissions for industry. The transition cannot happen overnight, which is why the present decade – from now until 2030 – is a critical window to lay the groundwork for long-term success. This includes seizing near-term opportunities for incremental emissions reductions within existing technologies and taking the first steps in deploying innovative near zero emission technologies as well as the required supporting infrastructure.

Here, governments hold the pen: ambitious, stable and well-designed policy frameworks are needed to create the conditions for industry to make a rapid transition. Collaboration among multiple stakeholders along value chains will be fundamental, and initiatives led by the private sector and by non-governmental organisations can make important contributions. But without strong government-led policies providing the needed enabling environment the transition is unlikely to happen at the scale and pace required.

There are many policies available in the toolbox that governments can use to help accelerate the industry transition. No silver bullet exists – no one policy must be adopted everywhere, nor can a single measure sufficiently address the full suite of challenges that industry faces. Instead, a robust and comprehensive framework of multiple policies is needed, as shown in the figure below. Each country can choose its own policy tools tailored to its individual circumstances, although all countries would do well to consider a multi-faceted approach that adequately addresses all aspects of the challenge.

This section outlines the various policies available and provides examples of how they are already being implemented by national governments in some G7 members and other major industrial-producing countries. These examples are illustrative and not intended to be a comprehensive list of all G7 member policies that could aid the industry transition. Furthermore, while the focus here is on national policies, policies by sub-national governments can also play an important role and actions from the private sector will also be imperative. While the examples discussed show important progress, global industry emissions continue to rise – underscoring the fact that accelerated action from governments and all stakeholders is urgently needed.

The overarching driver of change for the industry transition lies in setting **long-term plans and establishing a clear, strong, predictable long-term policy signal for emission reductions** early on. This is critical for industry planning and decision-making given the long lifetimes of industrial assets, and helps provide confidence that high-cost, high-risk innovation efforts on near zero emission industry technologies will pay off. This is where government plans, roadmaps and targets can set the direction and pace of the transition. They should be underpinned by mandatory CO_2 reduction policies that increase in stringency over time, such as emissions trading schemes, carbon taxes or tradeable CO_2 performance standards.

Figure 2.1 A policy toolbox for accelerating the transition to net zero heavy industries

Driving force: stakeholder collaboration

- Leading role: governments, producers and associations
- Supporting role: intermediate and final material users, financial institutions and investors, technology suppliers, startups, trade unions, researchers, non-governmental organisations

Framework fundamentals

Establishing plans and policy for long-term CO_2 emission reductions

- Roadmaps, plans and targets addressing multiple levels (e.g. industry, sub-sectors, companies, national, regional)
- Legislated policy: emissions trading systems, carbon taxes, tradeable emissions standards
- Just transition planning and support mechanisms, skills redevelopment and training

Mobilising finance and investment

- Direct public funding (e.g. grants)
- Public financing mechanisms to mobilise private investment (e.g. low-interest and concessional loans, blended finance)
- International finance supporting the global transition, including development aid
- Sustainable investment schemes and taxonomies, including for transition finance

Targeted actions for specific technologies and strategies

Production technologies

Managing existing assets and near-term investment

- Requirements for retrofit-ready builds and refurbishments
- Tradeable energy efficiency schemes
- Differentiated policy for existing plants
- Sunset clauses
- Incentives to reduce excess capacity

Creating a market for near zero emission materials production

- Carbon contracts for difference
- Sustainable public procurement
- Promoting and incentivising private procurement
- Near zero emission material mandates, minimum content regulations
- Certification and product stewardship initiatives

Developing technologies

- R&D and demonstration funding, including targeting large-scale demonstration
- Public-private partnerships
- Programs and networks for innovation knowledge sharing and co-ordination

Demand & recycling

Accelerating material efficiency and circularity

- Modified design regulations focused on life-cycle emissions, recyclability, and performance-based rather than prescriptive requirements
- Incentives for extended end-use lifetimes, demolition fees
- Training programs for engineers, architects, construction workers

Necessary enabling conditions

International co-operation and a level playing field

- International carbon markets, sectoral agreements, carbon border adjustments, climate clubs/alliances, consumption-based emissions policy
- International technology co-development, capacity building, best practice sharing

Infrastructure planning and development

- Co-ordinated planning and public financing for CO_2 transport and storage; low emissions electricity and hydrogen production and distribution; and end-of-life materials collection, sorting and recycling
- Streamlined and accessible permitting

Tracking progress and improved data

- Increased data collection and reporting
- Standards, definitions, certification and labelling for low and near zero emission materials production
- Work towards common international methodologies

Governments that have already developed decarbonisation roadmaps for industry overall as well as for several industrial subsectors include the United Kingdom, Japan, and France. Carbon pricing is in place through an emissions trading system (ETS) in the EU, for which prices exceeded EUR 60 (USD 70) per tonne of CO_2 in the latter half of 2021 and the overall carbon cap will be reduced by 43% by 2030 compared to 2005 levels. The United Kingdom's ETS replaces its previous coverage by the EU ETS and has a similar design to enable continuity. Canada has an output-based carbon price system that in practice works quite similarly to an ETS with free allocation of permits; the carbon price is CAN 40 (USD 32) per tonne as of 2021 and is set to rise gradually to CAN 170 (USD 135) per tonne by 2030. China has in place an ETS for the power sector currently, and there are plans to expand coverage to industry. It is anticipated that at least a few industrial sectors will be added within the next year or two, but that carbon prices in the near term will be relatively low. Energy-related taxes and regulatory policies also lead to considerable implicit carbon pricing in some countries, such as Japan.

An important aspect of overall transition planning and policies will be ensuring a just transition for workers and communities. In the industry sector, this may include training workers to operate new technologies within industrial plants, or to work in new areas (e.g. operating CO_2 transport and storage networks, increased work related to material efficiency and circular economy such as expanded material re-use and recycling networks). Governments will need to develop strategies, implement training programmes and in some cases provide funding support to affected communities. Consultation with the public, companies and sub-national governments in affected regions will be important to develop these strategies. Many governments are already taking steps in this direction. For example, the European Union has developed a Just Transition Mechanism to provide support to communities affected by the transition, while Canada has launched a public consultation to guide its development of just transition strategies and activities.

In addition to broad policy and planning, **finance** will need to be mobilised for the industry transition, shifting away from incumbent technologies and toward R&D, demonstration and deployment of near zero emission technologies at existing and new plants, and in supporting infrastructure. The public sector has a key role to play in de-risking projects in order to mobilise private finance, including through public-private partnerships, as well as providing some direct public funds in specific areas such as R&D and demonstration. The public sector can also play an important role in developing guidelines for transition and sustainable finance, which can serve as a crucial reference point for industries in their transition.

In this area, the EU has developed a taxonomy that defines sustainable activities to provide guidance for investment, while Japan has developed a set of Guidelines for Transition Finance to assist industry in investing in technologies that help move along the pathway to low emissions. In the EU, the InvestEU Programme has been established to blend public and private funds in order to de-risk investment, including for green recovery measures. Some non-exhaustive examples of finance provided include: the UK Industrial Decarbonisation Challenge's GBP 171 million (USD 210 million) in funding for industrial cluster decarbonisation projects; the UK Industrial Energy Transformation Fund's GBP 315 million (USD 390 million) of general funding for industry; Canada's investment of CAD 319 million (USD 250 million) into R&D and demonstration to advance the commercial viability of CCUS technologies; France's recent commitment of EUR 5.6 billion (USD 5.8 billion) for decarbonising industry; and Japan's Green Innovation Fund of JPY 2 trillion (USD 15.5 billion) for R&D for innovative technologies (including but not exclusively for industry), along with efforts to mobilise transition finance from the private sector of JPY 300 billion (USD 2.3 billion).

Policies targeted to particular technology areas and strategies will be needed to complement and reinforce broader CO_2 reduction policy. One such area is **management of existing and near-term assets**. Energy performance schemes can encourage industrial plants to improve their operational efficiency and adopt energy saving add-ons such as waste heat recovery. A balance needs to be struck, however, between investing in incremental improvements for high-emitting conventional plants in the near term, and the need to shift to near zero emission production in the medium term. Some investments in incremental improvements may not be compatible with a net zero pathway (if they are not a step within a series of retrofits that could eventually transition a plant to achieve near zero emission production) and thus may become a stranded investment. Governments might consider differentiated energy and emissions performance requirements for existing and new plants to ease the financial burden for companies that demonstrate commitment to medium-term, near zero emission technology shifts.

India's Perform, Achieve, Trade (PAT) Scheme is a major industrial energy efficiency policy, currently resembling a cap and trade system for energy savings credits (although India has communicated its intention to reform it to trade carbon savings credits instead of energy). Japan has a suite of measures to promote energy efficiency, including its Energy Conservation Law, which sets a target for companies to reduce energy consumption by 1% per year. The law includes a benchmarking system that requires companies to report energy consumption in order to understand best performance in each sector. Additionally, China has a top energy-consuming enterprises programme,[1] and Indonesia has an energy conservation regulation (Regulation 70/2009), both of which promote energy savings among industrial producers.

Meanwhile, sunset clauses – which specify a date beyond which high-emitting plants must be retrofitted or close – can set the timeline for shifts to near zero emission technologies. Where feasible, this can include adapting, rather than closing, existing plants, such as through CCUS retrofits or shifting to the use of low emission fuels including hydrogen and biofuels. Since first commercial-scale near zero emission facilities will not be deployed until around 2025, retrofit-ready requirements for near-term new-builds can smooth the transition.

Addressing excess capacity will also be important. Excess capacity negatively affects profit margins, which makes it harder for industrial producers to invest in low emission technologies and other measures needed for the transition. Over-building capacity could also lead to stranded assets, if newly built capacity relies on conventional technologies. Global cooperation on reducing excess capacity will thus be valuable, such as through the Berlin Principles developed by the Global Forum on Steel Excess Capacity.

Table 2.1 Examples of key national government policies, programmes and activities toward net zero heavy industries in G7 members and selected other major economies, including adopted, developing and announced policies*

Country or region	Establishing plans and policy for long-term CO_2 reductions	Mobilising finance and investment	Managing existing assets and near-term investment	Creating a market for near zero emission production	Developing near zero emission technologies
Canada	Output-based carbon price; A Healthy Environment and a Healthy Economy		Energy Star for Industry certification and performance indicators	Member of CEM IDDI	EIP; PERD; Strategic Innovation Fund and Net Zero Accelerator initiative; Clean Growth Program
European Union	Emissions Trading System; European Research Area (ERA) industrial technology roadmap for low-carbon technologies; 2050 long-term strategy	Taxonomy for sustainable activities; Invest EU; IPCEI hydrogen framework; Climate, Energy and Environmental Aid Guidelines	Mandatory compliance with energy audit proposals to receive compensation under ETS	Big Buyers for Climate and Environment initiative; (Carbon contracts for difference)	Innovation Fund; Horizon Europe; Processes 4 Planet; EERA; ZEP; Member of MI NZIM; Research Fund for Coal and Steel; Clean Steel Partnership; EIB-Innovfin

[1] Referred to as the Top 10 000 Program in the 12th Five-Year Plan and the 100, 1 000, 10 000 Program in the 13th Five-Year Plan; program inclusion and design for the 14th Five-Year Plan may be forthcoming in more specific five-year plans that follow the release of the outline plan.

Country or region	Establishing plans and policy for long-term CO_2 reductions	Mobilising finance and investment	Managing existing assets and near-term investment	Creating a market for near zero emission production	Developing near zero emission technologies
France	Covered by EU ETS; Industry decarbonisation roadmap, roadmaps for metals, cement, chemicals, steel plan	France 2030 investment		Embodied carbon targets in RE2020 buildings regulation; (Carbon contracts for difference)	Programme for investments of the future
Germany	Covered by EU ETS; Federal climate protection law and sectoral targets	Decarbonisation of Industry funding programme; Sustainable Finance Strategy; Green and Sustainable Finance Cluster	Energy efficiency strategy 2050 ; KfW energy efficiency financing for industry	Member of CEM IDDI; [Carbon contracts for difference]	Member of MI NZIM; Competence Centre on Climate Change Mitigation in Energy-Intensive Industries; support via the Federal Agency for Disruptive Innovation
Italy	Covered by EU ETS				
Japan	Green Growth Strategy Through Achieving Carbon Neutrality in 2050 ; Carbon neutral action plan for 2030; Technology roadmaps for cement and steel	Basic Guidelines on Climate Transition Finance; Technology Roadmap for "Transition Finance" in Iron and Steel Sector	Energy benchmark system; Energy conservation law	GX League	COURSE 50 Programme; Green Innovation Fund for R&D through demonstrations to social implementation of innovation technologies
United Kingdom	Emissions Trading System; Industrial decarbonisation strategy, Decarbonisation roadmaps for steel, cement, chemicals	Industrial Energy Transformation Fund; Industrial Decarbonisation Challenge		Member of CEM IDDI	Net Zero Innovation Portfolio
United States			Energy star guides for industry	Launched the First Movers Coalition; Buy Clean Executive Order and Taskforce	ARPA-E; AMO cost-sharing; innovation funding under the Infrastructure Investment and Jobs Act; Initiative for Interdisciplinary Industrial Decarbonization Research and Industrial Technology Innovation Advisory Committee

Country or region	Establishing plans and policy for long-term CO_2 reductions	Mobilising finance and investment	Managing existing assets and near-term investment	Creating a market for near zero emission production	Developing near zero emission technologies
China	14th five-year plan for industrial green development [ETS to be extended to industry]		Top 100/ 1 000/10 000 Enterprises Program; Capacity replacement measures to restrict the addition BF-BOF and encourage scrap-EAF development		National Key Technologies R&D Program; Member of MI NZIM
India			Perform, Achieve, Trade Scheme	Member of CEM IDDI	R&D funding for Iron & Steel Sector
Indonesia	(ETS to be extended to industry)		Green Industry Programme; Energy conservation regulation		

Country or region	Accelerating material efficiency	Enhancing international co-operation and creating a level playing field	Planning and developing infrastructure	Tracking progress and improving data
Canada		(Carbon border adjustments)	Hydrogen strategy; [CCUS strategy; Tax credit for CCUS]	Member of CEM IDDI
European Union	Circular Economy Action Plan; Ecodesign directive; [Sustainable products initiative]; [Ecodesign for Sustainable Products Regulation]	Free allocation of allowances in the EU ETS; [Carbon border adjustment mechanism]; (US-EU joint statement on steel and aluminium)	Hydrogen strategy; Connecting Europe Facility (CEF) - Energy; TEN-E Regulation for Energy Infrastructure	
France	Law against waste and for a circular economy; Circular Economy Roadmap; Embodied carbon targets in RE2020 buildings regulation		Hydrogen strategy	Assessing low-Carbon Transition initiative
Germany	Circular Economy Roadmap	[Initiated proposal for an international Climate Club]	Hydrogen strategy; H2Global initiative; Renewable Energy Sources Act	Member of CEM IDDI
Italy	Circular Economy Strategy		[Hydrogen strategy]	

Country or region	Accelerating material efficiency	Enhancing international co-operation and creating a level playing field	Planning and developing infrastructure	Tracking progress and improving data
Japan	Fundamental Plan for Establishing a Sound Material-Cycle Society Circular Economy Vision 2020	International Technology Transfer Program; (US-Japan joint statement on steel and aluminium)	Hydrogen roadmap; Asia CCUS Network	
United Kingdom	Circular Economy Policy Statement	(US-UK joint statement on steel and aluminium)	Hydrogen strategy	Member of CEM IDDI
United States		(Carbon border adjustments; joint statements on steel and aluminium with the EU, Japan and UK)	Section 45Q tax credit for CCUS; hydrogen and CCUS infrastructure funding under the Infrastructure Investment and Jobs Act; adjustments to reporting and review procedures to facilitate CCUS	
China	14th Five-Year Circular economy development plan; removal of import ban on scrap metal to promote recycled production		Hydrogen medium to long-term plan	
India	Steel Scrap Recycling Policy			Member of CEM IDDI
Indonesia				

* Policies that are not yet adopted, but are in the active planning and development stages, are shown in square brackets. Policies that a country has announced intent to pursue, but little information is publicly available on active planning, are shown in round brackets.

Note: This table is not necessarily comprehensive of all policies that may influence industrial emissions, but rather highlights a number of examples of key policies. Policies of subnational/regional governments are not included.

Given that near zero emission production processes for most heavy industries have not yet been demonstrated at full scale, government support to accelerate innovation will be crucial. Increased **government funding for research, development and demonstration of near zero emission industrial technologies** will be important to mitigate investment risks and leverage private sector efforts to scale these innovations and accelerate learnings so that they soon become ready to deploy en masse. Governments can also help with coordinating and stimulating knowledge sharing and innovation efforts among relevant actors.

Many countries are providing such funding, for example: Canada, through its Strategic Innovation fund; the EU, through the Horizon Europe fund supporting earlier stage R&D and the Innovation Fund supporting demonstration projects, including a funding specifically for projects in energy-intensive industries; Japan, through its COURSE50 program for steel supported by the Green Innovation Fund; and the US, through the Infrastructure Investment and Jobs Act. Still, additional funding would help accelerate innovation on key technologies. At the international level, a Net-Zero Industries Mission is under development under the Mission Innovation platform, led by Austria and Australia and currently supported by a core membership including Germany, China, the United Kingdom and the European Commission.

Once near zero emission technologies reach commercial scale, they will likely still be higher risk initially, and face increased costs relative to high-emitting conventional technologies. **Demand-pull policies** can help create certainty on markets for near zero emission material production. Mechanisms that may be useful here include carbon contracts for difference (CCfDs), sustainable public procurement, near zero emission materials mandates and life cycle-based product emissions standards.

There is growing interest in using procurement to drive demand. This includes through the Industrial Deep Decarbonisation Initiative (IDDI), launched in June 2021. It is housed within the Clean Energy Ministerial and coordinated by UNIDO, with current membership from UK (co-lead), India (co-lead) Germany and Canada. The central objective is to stimulate demand for low emission industrial materials, particularly steel and cement, through procurement targets and work on data, standards and certification to identify low emission steel and cement. The US has launched a Buy Clean Task Force, intended to coordinate public procurement of low-carbon materials. The EU has the Big Buyers for Climate and Environment initiative through which public purchasing organisations from across Europe, such as local and regional governments, share best practices and market engagement to help drive demand for low-carbon and recycled construction materials. The US also launched the First Movers Coalition, along with the World Economic Forum, which aims to generate early private sector demand for emerging technologies needed to achieve net zero in hard-to-abate sectors through sectoral commitments. The initial set of sectoral commitments includes a commitment for purchasers of steel to purchase at least 10% near zero emission steel per year by 2030; commitment for concrete chemicals will follow (see Box 3.2 in Chapter 3 for more information on this initiative). Aside from procurement, several governments are considering adopting CCfDs: Germany has released a call for expressions of interest, while France and the EU have mentioned them as possible tools them may use.

Another important lever for reducing industry emissions is **greater material efficiency**, which involves reduced material use and increased re-use as well as recycling (sometimes referred to as "circularity"). Policy can help overcome various barriers related to cost, delivery times, coordination, lack of awareness and the regulatory environment. Regulations that consider lifecycle emissions can help incentivise material savings all along value chains and promote durable end-use products with maximised lifetimes. Modifying design regulations, including building codes, to focus on performance rather than prescriptive requirements can facilitate leaner construction and manufacturing and use of less emission-intensive materials. Policies such as demolition fees and building refurbishment incentives can target longer lifetimes of products and structures. Governments can also help coordinate improved channels for end-of-life material collection, sorting, re-use and recycling. Additionally, design policies should consider the future suitability for re-manufacturing, refurbishment, materials reuse and ultimately materials recyclability, the latter including promotion of design to reduce contamination and enable high quality recycled material. In the case of steel, copper contamination can lead to lower quality steel that cannot be used for all applications – governments can help fund R&D and provide incentives to promote recycling methods that lead to reduced contamination and thus higher quality scrap-based production. To enable mainstreaming of material efficiency considerations, governments should promote curriculum revisions and skills upgrading programmes for architects, civil engineers and construction firm managers.

Several governments have developed circular economy strategies, including the EU, France, Germany, Italy and Japan. France has developed embodied carbon targets in its RE2020 buildings regulation, which should help promote efficient use of materials in buildings construction. The EU is developing the Sustainable Products Initiative, a revision of its Ecodesign Directive, to promote more durable, reusable, repairable and recyclable products.

Beyond support for specific technologies and strategies, policies need to cultivate conditions that facilitate change. A **level playing field** is needed for producers shifting to higher-cost, near zero emission technologies since many industrial products are traded in highly competitive global markets. Policy interventions in this area can help avoid carbon leakage and enable competitiveness of lower-emission production. Aligning global policy goals through a common carbon price or global sectoral agreements could resolve this, but it may be very difficult to achieve. Other options that could help include special provisions in emission regulations, carbon-based border adjustments, consumption-based regulations, and mechanisms to create differentiated markets for near zero emission materials.

International cooperation, technology co-development and best practice sharing could help better align the policy goals of different countries. An international climate alliance with industry as a focus might be helpful for these objectives. Sequencing of approaches may also be important, in that a near-term focus on voluntary measures and cooperation on common methods – including for measurement and reporting of embedded carbon – could build the foundation for medium-term broader agreement on and implementation of binding approaches. Whatever the measures chosen may be, it will be important to use careful design to ensure compatibility with international trade law.

The EU is in the process of developing a carbon border adjustment mechanism to create a level playing field and address the risk of carbon "leakage" in the context of rising carbon prices. Other governments have said they are considering carbon border adjustments, including Canada and the US. Additionally, the US has recently made joint statements on trade in steel and aluminium with each of the EU, Japan and UK that make reference to future work related to carbon intensity. (In the case of the EU, the statement references "a shared commitment to joint action… including through a new arrangement to discourage trade in high-carbon steel and aluminium," while the UK and Japan statements say each country pair "will confer on entering into discussions on global steel and aluminium arrangements to address both non-market excess capacity as well as the carbon intensity of the steel and aluminium industries.") Further details are not publicly available, so the future outcomes of such discussions and their potential to help create a level playing field for low emission production is yet to be seen. Additionally, the World Trade Organisation's Trade and Environmental Sustainability Structured Discussions (TESSD) platform includes discussion on trade-related climate measures, and thus could prove helpful as countries consider adopting measures to level the playing field for industry.

With regards to international cooperation, several government-led initiatives are underway. At COP26 in November 2021, the Breakthrough Agenda was launched to advance international cooperation for accelerating clean technologies, led by the UK and endorsed by 45 states. The agenda includes a Glasgow Breakthrough on steel, with the goal to advance international cooperation such that "near zero emission steel is the preferred choice in global markets, with efficient use and near zero emission steel production established and growing in every region by 2030." There are also breakthroughs for hydrogen and power, which will support industry decarbonisation. While there are currently no breakthroughs specifically for other industrial subsectors such as cement, these may be added in the future. In 2021, the UK G7 presidency and the US initiated the G7 Industrial Decarbonisation Agenda (IDA), to enhance collaboration among G7 members, including on regulation, standards, investment, procurements and joint research related to industrial decarbonisation. The work is being taken forward by this year's German G7 presidency. The Leadership Group for Industry Transition (LeadIT) was launched in autumn 2019 by the governments of Sweden and India with support from the World Economic Forum, with the aim to provide a platform for public-private collaboration and learning within and across sectors to help reach net zero emissions in industry by 2050.

International finance will also play an important role in helping advance the transition in emerging market and developing economies, including through multilateral funds and programmes and various mechanisms including blended finance. Key funds and programmes of potential relevance for industry include: the Clean Technology Fund under the Climate Investment Funds framework, covering low-carbon technologies and the CIF Industry Decarbonisation program focused on high-emitting hard-to-abate industries; the High Impact Programme for the Corporate Sector under the Paris Agreement Green Climate Fund, which targets uptake of low-carbon technologies in industry; and the Global Environment Facility, which assists developing and economies in transition to meet international environmental convention objectives, including those of the United Nations Framework Convention on Climate Change. The OECD's Clean Energy Finance and Investment Mobilisation programme is helping emerging economies strengthen their domestic enabling conditions to attract finance and investment in clean technologies, including for industry.

Many innovative technologies that will be key for deep emission reductions in the heavy industries will require secure and resilient **supporting infrastructure**. This includes CO_2 transport and storage, low-emission hydrogen production and distribution, and low-emission electricity generation and transmission. Since in many cases this infrastructure will be shared by multiple users, governments have an integral role to play in coordinating, planning and providing a suitable regulatory environment for infrastructure development, as well as in some instances using finance mechanisms to de-risk private sector investment. It will be important to prioritise the planning and build out of infrastructure in the coming years, so that infrastructure will be ready in time to support the initial deployment of innovative near zero emission technologies from the mid-2020s and beyond 2030. International cooperation can be valuable to share knowledge and since some infrastructure may cross borders.

Multiple governments have developed hydrogen strategies, including Canada, the EU, France, Germany, Italy, Japan, and the UK. Strategies are less common for CCUS, although are under development in some countries including Canada.

Various incentives are in place to promote hydrogen-related developments, such as the US's Hydrogen Shot initiative aiming to accelerate the deployment and reduce the costs of clean hydrogen. With regards to CCUS, the United States is providing support through a tax credit under the Internal Revenue Code Section 45Q, ranging from USD 20 to USD 50 per tonne of CO_2 stored, depending on the year (the credit increases over time) and whether the project involves EOR or dedicated geological storage. Canada has also proposed an investment tax credit for CCUS that once approved would come into effect later in 2022, amounting to 50% of investment in equipment to capture CO_2 (60% for direct air capture) and 37.5% of investment in equipment for CO_2 transport, storage and use. Additionally, in the area of related international cooperation, Germany is aiming to establish an international hydrogen pact to enable global supply chains for clean hydrogen. On CCUS, in 2021, Japan announced the launch of the "Asia CCUS Network", which is an international industry-academia-government platform aiming at knowledge sharing and improvement of the business environment for utilisation of CCUS throughout the Asia region.

Additionally, **improved data and classification systems** will be important for tracking progress, supporting decision making and enabling key policy measures. Tracking progress can provide transparency and enable governments to modify their policy strategies in areas that are falling short. Definitions and certifications for low and near zero emission production can facilitate purchasing decisions, policy implementation, and investor finance choices. Here, governments can encourage industrial actors to report energy and CO_2 data to existing data reporting schemes, or develop new schemes as needed, including through providing incentives and technical assistance for data reporting. They can also help coordinate and agree on common definitions, certification and labelling schemes that differentiate low and near zero emission materials production.

As an example, France in partnership with CDP has developed the Assessing low-Carbon Transition (ACT) initiative, which develops sector-specific methodologies to assess company readiness for the transition to the low-carbon economy. The resulting assessment reports can help with climate-related reporting, communication and dialogue with shareholders. A methodology for the cement sector was released in 2021, while a methodology for the steel sector is being pilot tested without the final version due for release in spring 2022.

Box 2.2 Efforts by private sector and other non-governmental actors

The private sector and non-governmental actors are also making important efforts toward the industry transition. This includes the following (specific examples outlined in table below):

- ***Industrial producers*** are developing transition roadmaps, setting emissions targets and undertaking projects to commercialise low and near zero emission technologies.
- ***Industry associations*** are also developing roadmaps, setting targets and initiating programmes to aid members in the transition. This includes programmes focused on energy efficiency improvements, innovation knowledge sharing and the overall transition to net zero.
- ***Materials users,*** including construction companies and vehicle manufacturers, are setting targets to reduce lifecycle emissions (including upstream or "Scope 3" emissions), which implies a need to source low emission materials. Some are also entering into direct partnerships with producers to procure and support development of low emission materials.
- ***Non-governmental organisations*** are developing initiatives to mobilise private sector action, including net zero roadmap development and implementation and procurement of low emission materials.
- ***The financial sector*** has several initiatives working to align investments and finance with climate objectives.

Private sector and non-governmental industrial emissions reductions efforts

Action category	Examples relevant to steel and cement (non-exhaustive list)
Roadmaps	**Cement:** Global Cement and Concrete Association (GCCA) 2050 Net Zero Roadmap, CEMBUREAU, US Portland Cement Association, national roadmaps for India and Brazil (collaborators included World Business Council for Sustainable Development, International Finance Corporation, IEA) **Steel:** Eurofer, Japan Iron and Steel Federation, The Energy and Resources Institute in India, Canadian Steel Producers Association, Mission Possible Partnership
Net zero targets (by 2050, or earlier as stated)	**Cement:** GCCA member companies (covering 40% of global cement production and 80% outside of China) **Steel:** Baowu Steel, ArcelorMittal Europe, HBIS, Nippon Steel, POSCO, Tata Steel Europe, JFE Steel Group, Hyundai Steel, China Baotou Steel, China Steel Corporation, JSW Steel, United States Steel Corporation, thyssenkrupp, voestalpine, Canadian Steel Producers Association, SSAB (2030), Liberty Steel Group (2030)

Action category	Examples relevant to steel and cement (non-exhaustive list)
Private sector net zero mobilisation initiatives	**Cement:** Mission Possible Partnership Concrete Action for Climate, GCCA 2050 Net Zero Roadmap Accelerator Program; SBTi's cement initiative **Steel:** Mission Possible Partnership Net-Zero Steel Initiative, SBTi's steel initiative
Energy efficiency programmes	**Cement:** World Cement Association's Plant Evaluation, Gap Analysis and Support Service (PEGASUS) Programme, Global Cement and Concrete Association's GNR reporting database for use in benchmarking **Steel:** World Steel Association "step up" programme,
Low emission technology innovation projects	A diversity of demonstration, pilot and prototype projects
Innovation knowledge sharing programmes	**Cement:** GCCA's Innovandi initiatives **Steel:** World Steel Association's Global Technology Innovation Expert Group, China Baowu Steel Group's Global Low-Carbon Metallurgical Innovation Alliance, Prometia Metnet network
Lifecycle/Scope 3 net zero (by 2050, or earlier as stated) and other targets	**Construction:** Lendlease (2040), Balfour Beatty (2040), Skanska (2045), Bouygues Construction (reduce by 30% by 2030), **Vehicles:** Daimler (2039), Volvo Cars (2040), Hyundai (2045), Toyota, Ford, Nissan, BMW, Renault (for European sales); GM (50% "sustainable"' material content by 2035), BMW (reduce by at least 20% per vehicle by 2030)
Procurement initiatives, partnerships and direct investment	**Steel:** SteelZero initiative; First Movers Coalition (public-private partnership), IDDI (public-private partnership) **Cement:** forthcoming ConcreteZero initiative; forthcoming First Movers Coalition targets (public-private partnership); IDDI (public-private partnership) **Vehicles:** fossil free steel partnerships with SSAB (Volvo Cars, AB Volvo, Cargotec, Daimler, Peab, and Polestar), BMW venture capital investment in Boston Metal, Scania investment in H2 Green Steel
Clean finance initiatives and venture capital funding	Task Force on Climate-related Financial Disclosures (TCFD), Glasgow Financial Alliance for Net Zero (GFANZ), UN Net-Zero Banking Alliance, RMI's Steel Climate-Aligned Finance Working Group, ISO's standard for green bonds (ISO 14030), Climate Action 100+ Steel sector strategy, Climate Bonds Initiative standards and certification, World Economic Forum's Financing the Transition to a Net Zero Future initiative, Breakthrough Energy Ventures
Data reporting, standards, definitions and certification schemes	**Steel:** CO_2 and energy reporting under worldsteel Sustainability Charter, ISO 20915, ResponsibleSteel **Cement:** CO_2 and energy reporting under GCCA Sustainability Charter, Concrete Sustainability Council

Accelerating progress

Building on the overview of policies available in the toolbox, this section will delve more deeply into three key areas of government policy that will be critical during the present decade to accelerate the transition toward net zero heavy industries – areas where G7 members could make a particularly valuable contribution: 1) supply "push" policies, 2) demand "pull" policies, and 3) international cooperation and competitiveness measures. These policy areas will be particularly important for enabling near zero emission materials production, but also for enabling interim, partial emission reductions and material efficiency strategies.

With respect to near zero emission materials production, the challenge is significant, but so is the opportunity for first movers: following the pathway laid out in the IEA's Net Zero Emissions by 2050 Scenario would imply a global market for near zero emission production in 2030 of around 100 Mt for primary steel and 250 Mt for clinker used in cement. Assuming G7 members tap into this opportunity rapidly, and in a coordinated manner, they could in aggregate account for around 25 Mt of this output for each material by 2030 (or around 10-15% of the G7's combined output today). Across the G7 membership, this would require the construction or retrofit of around a dozen commercial-scale near zero emission steel plants, and two dozen cement plants in total.

The three areas discussed in this section draw on several of the policy components in the framework above. They are discussed in turn, although some overlap exists among them. Push and pull measures go hand-in-hand to support the development, deployment and operational aspects of near zero emission materials production technologies and the plants that employ them. They also enable greater material efficiency. Various mechanisms – including push and pull measures – can help to make near zero emission production more competitive on international markets. International cooperation is also crucial for accelerating the industry transition globally.

Push mechanisms

Targeted policy measures are needed to enable supply of near zero emission materials production as well as the technologies and infrastructure for improved material efficiency. We refer to such measures as "push" mechanisms and they include support for the following:

- **R&D and demonstration:** Technology R&D and demonstration require large investments with considerable risk, given the inherent uncertainty about the performance of technologies that are still under development and for which market demand has not yet been clearly established. In many cases, broad schemes like carbon pricing or demand (pull) mechanisms provide insufficient incentives for technology development on their own.

- **Early deployment:** Massive capital investment is needed for commercial deployment of near zero emission technologies – and for the first several plants that employ a new technology, these investments involve greater risk. Without access to de-risked finance, plants will not be built or retrofitted at the pace required.
- **Enabling infrastructure:** Often infrastructure will be used by multiple companies and industries. The massive amount of capital investment required and need to coordinate among multiple stakeholders could likely result in a slow rollout without government planning and support.

As further elaborated below, push mechanisms help address these challenges directly in ways that other broader policies do not. Definitions of low and near zero emission production are a critical element of push mechanisms, since they can be used to set the bar for which investments are eligible for different levels of support at various stages of the transition. (See Chapter 3 for further discussion of such definitions).

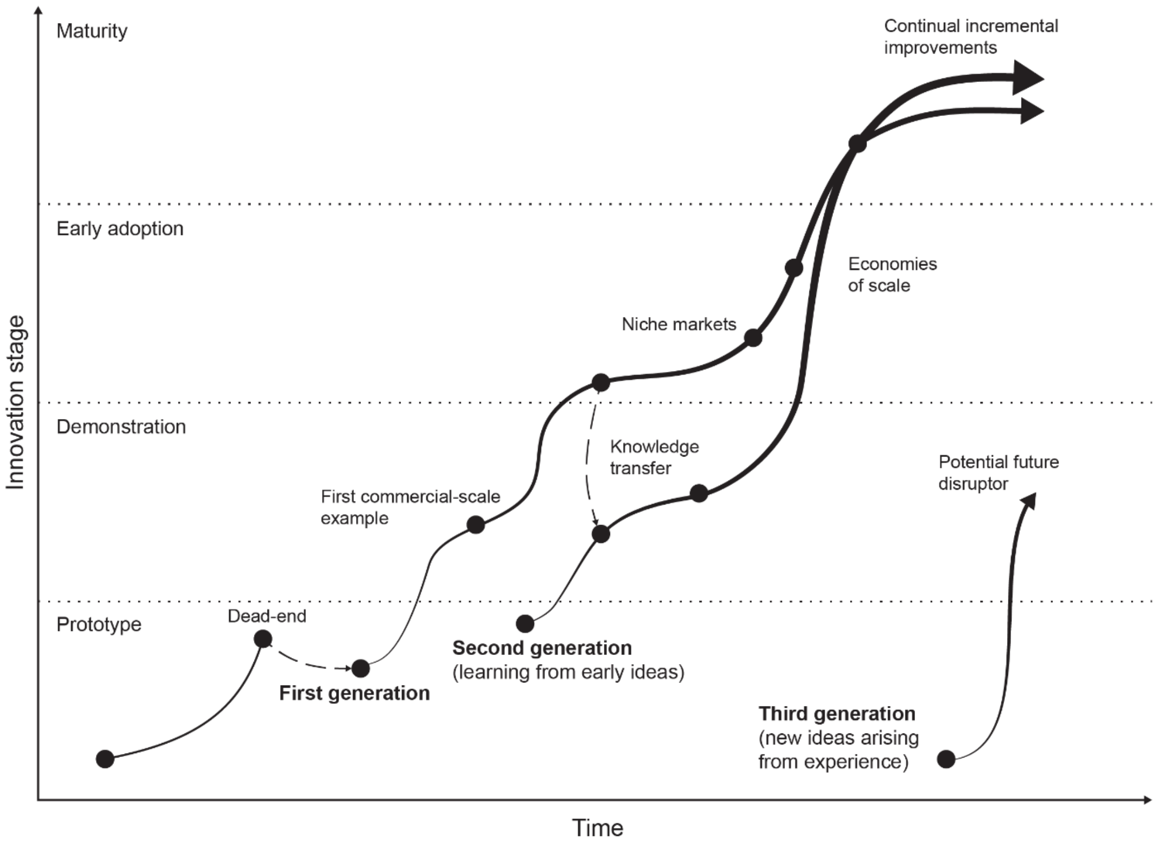
Table 2.2 Table Overview of “push” mechanisms for the industry transition

Policy measure	Purpose	Benefits	Challenges
Funding for demonstration projects	Overcome high costs and risks of innovation to bring near zero emission technologies, as well as technologies that enable more efficient use of materials, already at pilot and demonstration stages to full scale	Can enable accelerated innovation, helping technologies become available sooner and helping lower technology costs	Support needs to be sufficient, targeted and coordinated internationally to quickly bring a portfolio of technologies to market across key industry sub-sectors
Funding for earlier stage technology innovation	Overcome high costs and risks of innovation in additional near zero emission technologies, as well as technologies that enable more efficient use of materials, currently at prototype stage	Potential to expand the portfolio of available near zero emission technologies and material efficiency strategies, which may be particularly useful in certain regional contexts	Need to balance innovation support for earlier stage technologies with technologies that are closer to commercial scale, ensuring sufficient priority for technologies with highest potential
Finance for technology deployment	Overcome higher capital costs and risks of initially deploying near zero emission technologies, as well as technologies that enable more efficient use of materials	Can enable faster roll-out of near zero emission technologies and material efficiency strategies	Need to carefully use public funds to leverage private finance, as public finance cannot cover the full bill

Policy measure	Purpose	Benefits	Challenges
International finance	Address more limited access to finance in some emerging and developing economy contexts	The global community, including G7 members, can help accelerate progress in parts of the world that might otherwise face more challenges in deploying near zero emission technologies and material efficiency strategies	Mobilising and coordinating sufficient funds to support the global transition can be difficult; to make most efficient use of funds, finance needs to be targeted at projects that achieve major emissions reductions (those that are at or demonstrably on a path to near zero emission production) or make a step change in improving material efficiency
Planning and funding for supporting infrastructure	Infrastructure for CO_2 transport and storage, provision of low-emission hydrogen and electricity, and improved end-of-life material collection, sorting and recycling will likely be shared and thus require coordinating and potentially public finance	Public support can help ensure sufficient infrastructure is available in time and in the locations it will be needed, to facilitate rapid roll-out of near zero emission production and improved circularity	Long timeframes for infrastructure planning, permitting, and development will require early initiative in this area; considerable coordination likely needed to develop strategic approach that considers interactions with other part so the energy system and leads to well-sited industrial hubs for shared infrastructure
Taxonomies and definitions	Can help set the threshold for what technologies and projects should receive investment support from the public sector at different points in time, as well as providing guidance to private sector investors	Clear definitions provide a common understanding among multiple stakeholders of expectations for investment with regards to emissions implications	Developing robust, common definitions requires agreement and acceptance among a diversity of stakeholders; should be designed in a technology-neutral manner to avoid excluding particular options
Transition finance	Overcome higher capital costs for investment in technologies that will enable near-term partial emission reductions, as plants transition to near zero emission production in the medium to long term	Until near zero emission technologies are fully ready to deploy, support for interim measures can help achieve immediate emission reductions while moving plants progressing toward near zero emission production	A careful balance needs to be struck between investment in near-term measures and the long-term objective of near zero emission production. Public finance for technologies that partially reduce emissions should be carefully designed to ensure that those technologies are part of a pathway to reach achieve near zero emission production and would not lead to stranded assets
Retrofit-ready requirements	Ensure that capacity additions and investments in major plant refurbishments in the near-term enable later incorporating near zero emission technologies when they become available	Avoid becoming locked into high emissions technologies in the coming years while near zero emission technologies are still under development	Policymakers will need to pre-define what constitutes sufficient readiness in terms of space and technical requirements in plants with potentially varying characteristics

Technologies for near zero emission material production are already known – and in several cases they are already well advanced, having reached the large prototype or demonstration stages. Still, the demonstration stage can be a significant hurdle, since commercial-scale trials are capital intensive and may also require some minimum enabling infrastructure. A sustained scale-up pace throughout the early commercial deployment phase is essential to keep costs low enough for the technology to survive the critical "valley of death" – the period between the prototype phase and early market uptake. The case of photovoltaic technology is an illustrative example: although the first demonstrations of solar PV cells took place in the 1950s, it took more than 50 years of innovation for the technology to be deployed at the gigawatt scale, in the 2000s. To follow a pathway in line with net zero emissions by 2050, a faster pace of innovation will be required. Near zero industrial technologies will need to be successfully demonstrated at scale, and in different configurations and regional contexts, within the next few years to ensure they are ready for mass deployment by the late 2020s.

Figure 2.2 The four stages of technology innovation and the feedbacks and spillovers that improve successive generations of designs



Source: IEA (2020), Energy Technology Perspectives 2020: Special Report on Clean Energy Innovation.

Public **funding for demonstration projects** is therefore crucial for the industry transition. This funding could take different forms, including direct grants, public-private partnerships and low-interest loans. Given different regional circumstances – variations in raw material quality and energy sources, for example – demonstration projects would ideally be funded in several different regional contexts and in different configurations. Given the pace at which this needs to happen to reach net zero emissions by 2050, demonstrations will likely need to take place in parallel, rather than consecutively (which is the more normal practice). International cooperation and coordination will be fundamental to facilitating effective sharing of lessons learned among demonstration projects to make sure that knowledge advances collectively and that needed technologies can be rapidly brought to market. The G7 and other first movers could play a critical role in ensuring that sufficient funding is available for a portfolio of projects.

Given the time pressure, and the possibility of setbacks and delays in the innovation process, it is important that governments hedge their bets by collectively supporting multiple different technology options in parallel for each material. This means, for example, continuing to support both hydrogen and CCUS-based steel production, as well as multiple carbon capture technologies for cement production. This would provide increased security in the event that one technology encounters greater difficulties than anticipated. Additionally, in the not-unlikely event that several technologies are brought to market, it would provide the option to select the technology that is most suitable in a given regional context and thus reduce costs. In this same vein, **support for earlier stage technologies** still at the lab or pilot phase must also continue, such as for electrified production of steel and cement, and alternative binding agents to clinker.

In addition to technologies for near zero emission materials production, innovative technologies and methods for improving material efficiency will be important for the industry transition. This includes, for example, new methods for designing buildings and recycling techniques that reduce contamination from trace metals. Governments should consider allocating a portion of R&D and demonstration funding to improved material efficiency and circularity.

Once innovative technologies have been scaled and are ready for deployment, government **finance mechanisms** are needed to support timely roll-out. For near zero emission production technologies, this includes funding for capacity additions as well as retrofits to existing facilities, where feasible. For early commercial deployment, where investment risks may be considered high, some direct government support may be warranted through grants or other direct funding. Even more importantly, private sector finance will be critical, and here governments have a role to play in mobilising this resource – either through finance mechanisms and public-private partnerships that take on some of the financial risk of early projects or by providing other incentives for investment. Such mechanisms may include concessional and subordinated loans, debt guarantees, early-stage equity investment, tax incentives. In this way, public sector mechanisms will give a push to investing in near zero emission production capacity and other technologies that enable the industry transition. Of course, government policies signalling the need to reduce emissions are also critical in mobilising finance, as they establish the investment case for low and near zero emission material production and circularity-enhancing technologies.

On top of funding and finance mechanisms within countries, there is also a critical need for **international finance**. This can help enable a timely transition in emerging markets and developing economies, as well as in other countries where sufficient affordable public or private sector finance is not accessible. Here, G7 members will likely have a disproportional role to play. Finance support could take various forms, including contributions to funds administered by multilateral institutions and development banks, bilateral agreements and official development aid. Using blended finance mechanisms could help maximise public funds in mobilising private finance. While a number of funds that could finance industry projects already exist – such as the CIF Industry Decarbonisation programme, announced in 2021 – a successful global transition will require advanced economies to scale up donor support substantially in order to make a significant impact on emerging economy transitions. There is also a need to better coordinate the activity of multilateral development banks, philanthropies, donor and recipient countries, to ensure funds are put to best use. The Energy Transition Council pioneered a model for this type of coordination for the power sector, which could be replicated for other sectors, including industry.

One area where a "push" from governments may be particularly critical is in terms of **planning and funding for secure and resilient supporting infrastructure** for the industry transition. Infrastructure to support near zero emission production includes capabilities for CO_2 transport and storage, low-emission hydrogen production and distribution, and low-emission electricity generation and distribution. Infrastructure to support material efficiency and increased circularity – such as improved networks and facilities for end-of-life materials collection, sorting, re-use and recycling – will also be important. While in some cases it may be possible for an individual plant or company to build its own supporting infrastructure (such as in the case of on-site smaller scale hydrogen and electricity generation), in many cases it is more efficient and makes more economic sense to build large-scale infrastructure that will be used by multiple users. Often, the high cost and shared nature of such infrastructure pose a considerable barrier for individual companies.

Government support and coordination will be important here, particularly given the scale of infrastructure needed, which will likely include cross-country and cross-border projects (e.g. electricity grids, CO_2 and hydrogen transport pipelines) and in some cases, large requirements for land (e.g. renewable electricity generation). Through planning, easier and faster permitting, and coordination, governments can help ensure that sufficient infrastructure is built out in time, and in the places where it will be needed. Planning for industrial clusters can help facilitate this.

Additionally, government finance will likely be needed. Until CO_2 emissions reductions requirements have reached very high levels – and in the absence of other government supports – the business case will likely be weak for private companies to invest in high-cost infrastructure. Different models of infrastructure ownership are possible, including government ownership through public utilities, new companies formed focused specifically on infrastructure, shared ownership among existing industrial companies, or shared public-private partnerships (PPPs). In the cases where governments are not full or part owner, funding through grants and financing support will likely be needed, at least in the shorter-term. Given the time needed for planning, permitting and build-out, infrastructure coordination should be a near-term priority to ensure that the infrastructure to support near zero emission production is ready by the time innovative production technologies are ready to deploy – and in the case of infrastructure for improved circularity, as soon as possible to maximise near-term emissions reductions.

An important aspect of supply push mechanisms will be determining which technologies to support. Here, **taxonomies and definitions** for low and near zero emission production developed by governments will be critical. (See Chapter 3 for more details.) Such definitions are needed to provide guidance about which technologies are deemed acceptable for investment at various points in time. They can be used directly by the public sector or they can serve as guidance to the private sector.

In the near term, governments could define emissions performance thresholds and emissions reduction planning requirements for **transition finance** eligibility. Such finance could apply to investments that result in a considerable reduction in emissions, even if they do not yet achieve near zero emission production. Governments might provide some degree of transition finance support themselves, but also can play a role in defining transition finance guidelines for private sector investment. Different levels of finance might be provided or recommended depending on whether the plant has clearly demonstrated a plan to eventually bring its emissions to near zero, versus if the plant would only ever be able to achieve a partial reduction in emissions.

Similarly, governments should consider setting restrictions on new-build plants and on investments in major plant refurbishments in the near term before near zero emission technologies are available**. Retrofit-ready requirements** in permitting or financing applications, for example, could require plants to demonstrate that they have the space and technical capacity to incorporate near zero emission technologies down the road. As discussed in Chapter 1, such retrofit-ready requirements will be particularly important in the near-term in G7 members given the advanced age of a large portion of industrial capacity. If existing aging plants that require an investment decision between now and 2030 are not retrofitted or replaced in a manner that enables a transition to near zero emission production in the future, there would be a substantial risk of stranded investments.

For alignment with the net zero by 2050 pathway, all new capacity additions from 2030 onwards should be constrained to plants that will already achieve near zero emission production once built or have clearly demonstrated a pathway to reach near zero soon. Commonly agreed definitions of what constitutes near zero emission would be helpful, as discussed in the next chapter of this report. Based on such definitions, governments can, for example, set deadlines for phasing out public finance and permits (e.g. permits for construction, operation or land use) for new material production plants that do not adopt near zero emission technologies or have not demonstrated a clear pathway to soon do so. Such requirements should be defined well in advance of the deadline to send a clear signal to industry to plan accordingly.

Pull mechanisms

In addition to “push” instruments, policies will be needed that create demand for near zero emission materials production and materially efficient products, which we refer to here as “pull” mechanisms. A business case for deploying near zero emission technologies requires a high certainty that there will be a buyer for the materials they produce. In most cases, the cost of producing materials with near zero emission technologies will be higher than production with conventional technologies, which poses a challenge in a competitive marketplace. These higher production costs are to be expected, at least in the initial stages of deployment until technology learning reduces costs – though they may persist over the longer term. The cost of materials production depends on capital expenditures as well as operating expenditures – the latter including costs for energy, for raw materials and for transporting and storing CO_2, if applicable. Even if the cost of capital is less than for conventional technologies – or if it can be subsidised by governments – high operating costs could still leave near zero emission technologies at a competitive disadvantage. Similarly, the business case for material efficiency and circularity also requires some form of "pull" to justify the additional labour, procedural changes and, in some cases, investment required to maximise these strategies.

Table 2.3 Overview of "pull" mechanisms for the industry transition

Policy measure	Purpose	Benefits	Challenges
Carbon contracts for difference	Directly addresses the potentially higher capital and operating costs of near zero emission production by guaranteeing to funding the carbon abatement cost for a guaranteed quantity of production and a fixed period	Provides producers with high confidence in the economic viability of investing in near zero emission production, given it is a long-term contract	Relies on direct public subsidy and so may become costly for governments if supporting more than the first few near zero emission plants
Sustainable public procurement	Provides a potential market for low and near zero emission production despite likely higher production costs, as well as can provide an incentive for material efficiency	Can provide producers with confidence in the economic viability of investing in near zero emission production, particularly if procurement takes the form of a long-term purchase agreement or if multiple governments pool commitments; can drive improved material efficiency	Depending on the form the procurement commitment takes, there may be lower confidence of a stable, long-term market for near zero emission production of a particular material compared to a policy like carbon contracts for difference
Near zero emission materials production mandates	Creates a growing niche in the market that must be met with near zero emission production	Provides producers with confidence in investing in near zero emission production, as the domestic market will need to adjust to accommodate the legal requirement for near zero emission production, and does not require any direct public subsidy	Producers would need to directly pass through higher costs to purchasers, which may be possible within the regulated domestic market but more challenging for exports

Policy measure	Purpose	Benefits	Challenges
Revised product and building design regulations	Modifies design regulations, such as building codes and products standards, in a way that promotes or requires reductions in life cycle/embodied emissions, enhances durability and circularity, and removes barriers to using low emission materials	Can provide a pull for both more efficient use of materials and low or near zero emission materials; a potential method to require – rather than only incentivise – end-use manufacturers to reduce embodied emissions and thus potentially procure low emission materials	Calculating life cycle and embodied emissions can be complex given the multitude of materials used in products and uncertainty around how the product will be used in future; needs to appropriately factor in trade-offs between reduced initial embodied emissions and durability; the incentive for using near zero emission materials may be relatively weak until requirements reach sufficient stringency
Incentives or charges to promote extended lifetimes and circularity	Encourages changes in decision-making at end-of-life, such as through refurbishment incentives or demolition and landfill taxes	Can provide a pull for material-efficient choices, such as refurbishing and using products and structures longer, and maximising opportunities to reuse and recycle materials	Given the large number of actors involved (product users, construction and demolition companies, recycling companies), careful design would be needed to provide sufficient and efficient incentives
Promotion of private sector procurement	Encourages the private sector to create a market for near zero emission production despite likely higher production costs, and to procure material efficiency and circular products	Can provide producers with confidence in the economic viability of investing in near zero emission production, particularly if it is a pooled commitment; this also helps grow demand for the large part of the market that is outside direct public control; can drive improved material efficiency	As with public procurement, private procurement may provide lower confidence to a stable, long-term market relative to other options; efforts to promote private procurement are voluntary and thus do not guarantee the extent of private sector participation
Carbon pricing and tradeable production emissions standards	Adjusts the economic equation such that high-emitting production becomes more costly or sets mandated requirements to reduce average emissions intensity, thus opening a space for lower-emission production to compete	Is an economically efficient and technology neutral policy to drive least-cost emissions reductions; in the case of carbon pricing, can incentivise material efficiency and raises revenue that could be used to fund aspects of the transition such as innovation	Policy must be sufficiently stringent to drive technology shifts; on its own, carbon pricing or emission standards would be unlikely to provide sufficient incentives to invest in early deployment of innovative technologies; carbon pricing could be politically challenging to adopt in some regional contexts
Labelling and certification schemes	Provides information to purchasers on the emissions performance of production	Provides the necessary information to purchasers wanting to support low and near zero emission production, and may encourage increasing support for low and near zero emission production	Information alone does not guarantee what purchasers will choose, and it may be quite complicated to develop systems to track emissions of materials throughout complex global supply chains

Policy measure	Purpose	Benefits	Challenges
Definitions	Can help set the threshold for what technologies and projects should be eligible for demand support at different points in time	Clear definitions provide a common understanding among multiple stakeholders of expectations for demand support with regards to emissions implications	Developing robust, common definitions requires agreement and acceptance among a diversity of stakeholders

Push and pull mechanisms are complementary: push mechanisms help to ensure there is sufficient capital available to invest, while pull mechanisms help to secure the business case for investment and operation. As with push mechanisms, definitions of low and near zero emission production are a critical element of pull mechanisms, setting the threshold that production must meet to be eligible. (See Chapter 3 for further discussion on such definitions.)

Several different mechanisms could be used to help create a differentiated market for near zero emission materials production. Particularly for the first-few-of-a-kind plants where risk and cost are highest, mechanisms providing a higher degree of certainty would be useful. An example of such a mechanism is **carbon contracts for difference** (CCfDs). Under such a policy, governments tender for low or near zero emission production of a material and agree to fund the carbon abatement cost for a guaranteed quantity of production. The typical duration of such a contract would normally be about 15 to 20 years, which would be a sufficient guarantee for most emissions-intensive industries, but this could be adjusted for each sector.

In a region where carbon pricing is in place, the carbon-abatement cost could be hedged against the market price for carbon, so that funding is structured to make up the difference between actual carbon avoidance costs and the existing carbon price. Alternatively or in addition, the contract could hedge against not only changes in the carbon prices but also changes in the price of inputs and enabling conditions such as energy (especially hydrogen and/or electricity), raw materials, and CO_2 transport and storage. In the long term, such costs may have the most substantial impact on production costs, and so a CCfD that also hedges against these costs would provide considerably more certainty to industry to invest in new technologies. Other formulations may be possible, particularly in regions where carbon pricing is not in place and thus cannot be hedged against, such as funding the difference between actual production costs and the market price for the material.

Regardless of the exact formulation, the objective of CCfDs would be to guarantee a price sufficient for low or near zero emission production to become competitive with conventional production and thus economically viable. Since the amount of funding at a given point in time is calculated based on actual costs and prices – with the possibility to incorporate regular updates to the costs used in calculating the funding amount – the actual level of support would likely decline along with production costs over time as technology learning deepens and as the carbon price rises. In this way, governments can be assured that public funds are not subsidising production by more than is needed. The certainty provided by a CCfD could present a considerable advantage over other instruments that may provide only short-term, less certain and more fragmented demand pull. Again, G7 members and other first movers could play a key role in supporting the roll-out of the first few industrial plants, which could have the added positive spillover of reducing costs for subsequent plants through learning-by-doing.

Sustainable public procurement is another mechanism governments could use to create a market for near zero emission materials and promote material efficiency. This may require capacity-building within government agencies to include sustainability considerations in procurement rather than basing decisions on the lowest cost. The design of the public procurement policy will also be important. Possible tools within procurement policies include setting targets for embodied carbon, shadow carbon prices and targets for shares of near zero emission materials.

In order to provide a level of certainty for near zero emission material demand comparable to a CCfD, a government would need to make an advance market commitment – a long-term guarantee of a viable market – with a plant producing near zero emission materials. Such a fixed contract could be particularly useful when a technology is just starting to be deployed. Requirements related to competitive bidding processes might make it difficult in some instances for governments to enter a long-term procurement contract with a particular supplier, which might make CCfDs a preferable policy to support initial deployment. For the roll-out of additional plants beyond the first few, broader sustainable public procurement policies could provide sufficient certainty, given that risks and technology costs would hopefully be declining. This would especially be the case if first-mover governments, including G7 members, made coordinated commitments, thus ensuring a larger combined potential market.

Still, the target of the procurement policy will impact the degree of certainty and support for near zero emission production. A procurement policy targeting the reduction of embodied emissions at the project level – for example, at the level of a building – could be a good way to support material efficiency improvements. However, it may still not create enough demand pull for near zero emission steel or cement if the targets are insufficiently stringent, since such targets could be met through less costly methods (e.g. using different materials, using materials more efficiently, or using steel and cement with incrementally lower – but not near zero – emissions).

While incentivising material efficiency is an important policy objective, material efficiency will not be able to eliminate the need for producing steel and cement. In the case of steel, this includes the need for primary steel production, as scrap availability will be insufficient to meet all of steel demand with recycled production for the next several decades at least – in particular given projections for economic growth in emerging market and developing economies. In the case of cement, the material is very difficult to recycle and alternative binding agents that could wholly substitute clinker are either in very early stages of development or can only be used in particular applications. Thus the need for new clinker production will remain. Furthermore, considerable hurdles remain to developing the required technologies, building out production plants and building up supply chains for near zero emission cement and primary steel production.

For these reasons, the most effective public procurement policies would need to either have very high stringency at the project level, or they would have to specifically designate that at least some portion of their cement and steel come from near zero emission sources, providing greater certainty and targeted demand pull. Demand pull could be solidified through legislated requirements for a minimum share of near zero emission materials in publicly funded projects for a fixed period (for example, for the next decade), which could later be phased out as the overall stringency of project-level requirements increases. Such mandates could be implemented through lists of preferred materials or products in procurement bidding processes, where specific minimum requirements for near zero emission steel or cement could be set and would need to be followed by all bidders.

Procurement from the private sector can also provide an important source of demand pull. Governments can help facilitate this. Founding and promoting coalitions, as in the case of the First Movers Coalition announced at COP26, as well as SteelZero under the Climate Group, can help generate momentum and collective buy-in. Governments might even consider supporting participation in such coalitions through incentives, such as tax reductions, or through a public-private blended approach that sets targets for both public and private procurement. An advantage is that a pooled purchases commitment from multiple buyers provides greater certainty to material producers than an individual company pledging to buy near zero emission materials or reduce its embodied emissions. Additionally, governments might play a role in developing and promoting **labelling and certification schemes** for low and near zero emission production and for the embodied or lifecycle emissions of products, which can provide an important signal to interested private sector buyers.

Regulatory measures could be another method for governments to create demand pull. Comparable to a renewable portfolio standard or a zero emission vehicle mandate, a **near zero emission material production mandate or quota** could set a growing minimum market share for near zero emission steel, cement and other materials production, thus establishing a lead market through regulation. The regulation could be complemented with a tradeable certificates scheme, such that the requirement is met on average throughout the market, while individual producers or purchasers who do not meet the requirement could purchase certificates from those who exceed the requirement (like an emissions trading system). This could help minimise costs of the policy. Such regulations could be formulated in a way that requires increasing performance over time – for example, requiring shares of low emission production at various performance levels in the near term, and gradually phasing in requirements for near zero emission production. (See Chapter 3 for discussion of definitions for low and near zero emission production that could be used in such a phased approach.)

The regulation could be applied either on the production side, requiring producers to sell a growing share of near zero emission production, or on the consumption side, requiring product manufacturers in key demand sectors (e.g. automobiles, construction) to purchase a growing share of near zero emission production. (The latter formulation is sometimes referred to as a minimum content regulation.) A potential advantage of applying such regulations on the consumption side is that product manufacturers should be able to more easily pass on the cost to end-users. This is because end-users may be less exposed to international competition (at least in the case of construction) and because the cost of materials tends to make up only a small portion of the total cost of end uses such automobiles or houses, so the cost increase in percentage terms for end-users would be considerably smaller than that of the materials themselves. One disadvantage of such a policy would be some degree of added administrative complexity, particularly if it is applied on the consumption side since it creates a need for tracking of near zero emission production. However, experience of similar policies in other sectors suggests the administrative burden is not insurmountable.

Applying **CO_2 regulations or taxes to the embodied emissions of end-use products** could be another way to generate demand for near zero emission material production and assist with cost pass-through, as well as create incentives for material efficiency. This could take the form of life cycle or embodied emission requirements within design regulations or carbon-added taxes. At lower levels of stringency, the demand-pull signal specifically for near zero emission materials would be weaker compared to regulatory measures targeting a minimum market share of such materials – in the same way that procurement focused on project-level emissions provides a weaker signal than targeted procurement. However, they could still create a good incentive for a various material efficiency strategies, including leaner design and substitution in favour of lower emission materials. Since fully accounting for embodied or lifecycle emissions can have many complexities, simplified methodologies may be required to reduce the regulatory burden.

On top of adding embodied CO_2 considerations, it would be helpful for governments to **adapt design regulations** to incorporate performance-based rather than prescriptive standards. In some cases, existing prescriptive design standards can prevent the incorporation of newer low emission materials. Modifying requirements to focus on performance can better enable the incorporation of low emission materials while still ensuring that robust standards for safety and product quality are met. Additionally, design regulations should be reviewed to incorporate considerations that promote durability, longer lifetimes, and future ease of refurbishment as well as materials recycling.

Additionally, **incentives and charges** can be used to create demand pull for extended product and building lifetimes and circularity. This could include, for example, tax breaks for repurposing older buildings and taxes applied to demolition or disposing of materials in landfills. Such policies can encourage decisions to extend lifetimes through refurbishment, and to reuse or recycle materials to the greatest extent possible.

In the longer term, there may be less need for targeted demand pull policies, as near zero emission production and materially efficient design become increasingly widespread, and the number of buyers increases. Earlier-stage regulations could eventually be phased out and broader policies like **carbon pricing, tradeable emissions performance standards,** or **bans on high-emitting technologies** could take over as the primary driver of continued deployment of near zero emission technology and implementation of material efficiency strategies. They would need to be sufficiently stringent in the case of carbon pricing and standards, which may be more feasible once near zero emission technologies are available on the market. These policies would provide continued pull by either increasing the costs of high-emitting technologies – or prohibiting them outright – thus opening a space for low and near zero emission technologies to compete and for the prioritisation of material efficiency. But targeted demand pull policies will be critical in the short to medium-term to get the transition rolling.

As in the case of push mechanisms, **definitions** of low and near zero emission materials production will be important to identify what kinds of production to support. Policies like CCfDs, procurement and mandates aimed at near zero emission production will require a clear and commonly accepted definition of what constitutes "near zero emission" production. Some policies, such as public procurement, may wish to recognise interim measures, and here definitions of low emission material production will also be useful. Backing by robust measurement standards, certification and labelling schemes, as well as tracking systems, will facilitate stakeholders in using these definitions.

International competitiveness and collaboration

The transition for heavy industry is an international challenge – due the global nature of both climate change and the competitive markets on which such products are traded. International cooperation will enable a faster transition by encouraging more ambitious policies, providing mutual support and facilitating cooperative learning.

The issue of competitiveness is key. Industrial materials and products are traded in highly competitive global markets and producers' margins tend to be thin. In many cases, using lower emission technologies raises production costs, exacerbating the competitive challenge in conventional markets. When emissions reduction policies are unevenly stringent in different countries, producers may simply relocate to the least-restrictive jurisdictions. This can not only result in socio-economic losses for countries with stricter regulations, but it also undermines policy effectiveness, since the emissions would simply move elsewhere. This is referred to as "carbon leakage." Measures are therefore needed to create a level playing field for low and near zero emission industrial production.

Various policy measures may be beneficial to promote international cooperation and enable the competitiveness of low and near zero emission materials production. The options chosen by different countries may vary, and some measures may be used in tandem to maximise benefits.

Table 2.4 Overview of international cooperation and competitiveness mechanisms for the industry transition

Policy measure	Purpose	Benefits	Challenges
International finance, capacity building and technology co-development	Support the global industrial transition, particularly in emerging and developing economies	Can help increase global ambition, thus helping to reduce the competitiveness challenges caused by differences in the speed of the transition among countries	Sufficient support needs to be mobilised; on its own this strategy is unlikely to fully eliminate differences in the speed of the transition and therefore will not fully eliminate competitiveness challenges for first movers
Provisions for industry in climate policy	Help maintain competitiveness of production traded on global markets when applying domestic climate policy	Provides a way for a government to protect its industry, without requiring agreement with other governments or adopting trade measures	Special provisions may not be able to sufficiently protect competitiveness while also ramping up emissions reduction requirements
Differentiated markets for near zero emission materials	Provide a market where near zero emission production can compete despite its higher costs relative to conventional production	Can help shield near zero emission production from international competition, thus providing producers with confidence to invest in near zero emission technologies when there is a cost gap relative to conventional production (support can be reduced as production costs fall with increasing deployment)	It may be difficult to create a differentiated market that is large enough to fully eliminate the competitiveness challenge posed by uneven climate policies across countries
International carbon market with common carbon pricing or carbon price floor	Provide a common emissions reduction signal across the global economy, or parts of it such as the industrial sector	If adopted and depending on design details, the approach could be a technically simple and economically efficient way to remove the competitiveness challenge for industry caused by uneven emissions reductions requirements in different countries	In practice, the likelihood of achieving such an agreement in the timescale needed is low, given country-specific preferences and circumstance; the common price is unlikely to be high enough to drive initial investment in innovative near zero emission technologies; if applying a common carbon price, complementary support measures would likely be needed to aid emerging and developing economies, or if a carbon price floor is used then this would not fully eliminate the challenge of policy unevenness among countries; allowing inclusion of implicit carbon prices would require complex methods to calculate equivalency

Policy measure	Purpose	Benefits	Challenges
Industrial sector agreement	Help overcome the first-mover challenge through countries acting together to increase the ambition of their emissions reductions measures for industry	Could help reduce the unevenness in policy stringency across countries, thus reducing international competitiveness challenges	Could be difficult to reach a sufficiently ambitious agreement given country-specific preferences and circumstances, particularly if a large number of countries were involved; if only a small number of countries were involved, it would likely be insufficient to address the international competitiveness challenge
Carbon-based border adjustments	Helps prevent carbon leakage and ensure the environmental integrity of emissions reduction policies while adopting increasingly stringent requirements	Provides a mechanism to secure competitiveness of lower emission industries without requiring third countries to agree to similarly ambitious policies; also could provide a significant revenue stream to support near zero emission production	Poses a risk of creating trade tensions and retaliatory measures; measures might also be needed to protect competitiveness of exports, such as refunding carbon price payments; requires emissions tracking throughout complex global supply chains or use of estimated default values; careful design needed to ensure compliance with international trade law
Consumption-based policies	Applies the same emissions performance requirements to materials consumption, regardless of whether they are produced domestically or imported	Provides a mechanism to protect competitiveness without requiring third countries to agree to similarly ambitious policies; facilitates cost pass-through as the requirement applies to the material consumer	Likely to be complicated to implement, requiring detailed emissions tracking throughout complex global supply chains and regulation of a large number of purchasers; would not protect the competitiveness of exports without complementary measures
Climate contributions	Applies the same climate contribution requirement to domestically produced and imported materials, while generating a considerable revenue stream to support near zero emission production	Helps create a level playing field for near zero emission production, without straining government budgets and without requiring carbon accounting for imports; provides an incentive to improve material efficiency	Poses a risk of creating trade tensions and retaliatory measures; domestic producers may also resist; would not protect the competitiveness of exports without complementary measures

International finance, technology co-development and capacity building can take many forms, including: bilateral finance mechanisms; disbursing contributions through multi-lateral development banks; technical cooperation and sharing knowledge for the demonstration and deployment of new technologies; as well as sharing best practices on policy development. It will be important for advanced economies, including the G7 members, to support emerging and developing economies in accelerating the pace of the transition, particularly since much of future industrial capacity additions will be built in emerging and developing economies. Additionally, first movers can share valuable lessons with others seeking to follow a similarly ambitious path. To be sure, international finance and assistance will be crucial to the global industry transition. But they will probably not be sufficient to eliminate competitiveness concerns, since countries are still likely move at different paces. Other complementary measures will therefore be needed.

In the shorter term and at lower levels of policy stringency, creating **special provisions for industry within domestic climate policy** can help alleviate competitiveness challenges. An example would be the free allocation of permits for emissions below a benchmark intensity in an emissions trading system – which in principle should maintain the marginal incentive to reduce emissions above the benchmark. A carbon tax applied only above a given emission intensity threshold would have a similar impact. The advantages of such special provisions are that they can be adopted unilaterally, they are likely to be welcomed by domestic industry, and they are unlikely to spark international controversy. As a country's policies become more stringent, challenges can arise, however. Maintaining special provisions makes it harder to effectively incentivise deeper emissions reductions, but removing those provisions may end up hurting competitiveness. Meanwhile, at higher levels of stringency, the special provisions may be insufficient to protect competitiveness. Again, other measures will likely be needed. International coordination on phasing out of special provisions could help smooth the transition.

Alternative policy choices – such as a regulatory approach – can produce an effect similar to special provisions in carbon pricing systems. For example, a tradeable emission intensity standard does not involve levying any direct carbon charges and only implies costs in terms of either investing in technologies to reduce emissions or purchasing permits – only for the emissions above the standard – via an emissions permit trading market. As such, the impact on competitiveness would be mitigated in a similar way as an emissions pricing-based trading system with free allocation of permits. Again, at increasing levels of stringency the competitiveness challenge would grow and other measures would be needed.

Demand pull measures that create **differentiated markets** can help low and near zero emission materials and products compete. As discussed in the previous sections, such measures range from sustainable public procurement to carbon contracts for difference. Such measures can be adopted unilaterally and could be relatively effective in helping support the first few near zero emission plants, particularly in the case of carbon contracts for difference. In the case of procurement where one government might not have sufficient demand to purchase a plant's entire output, coordination with other countries would considerably increase effectiveness. These measures are much less likely to be challenged than direct trade measures would be. While they can be a good option in the short term, in the medium to long term they may be insufficient to facilitate the full transition. Governments will be challenged to support a full switch to near zero emission production, in that their procurement represents only a portion of total demand, and directly covering the cost differential of near zero emission production for all domestic production would likely be too large of a financial ask to taxpayers. In the longer term, other policies will likely be needed to support the full roll-out of near zero emission production.

When moving, in the medium term, toward more ambitious emissions reductions for industry, the available measures range from those that require substantial international alignment to those that can be adopted unilaterally without any international agreement. On one end of the spectrum are strategies such as an **international carbon market with common carbon pricing or a common carbon price floor**. This has long been a topic of discussion in climate policy circles, and it is regarded by some as the ideal policy solution. In principle, the simplicity and economic efficiency of a carbon pricing scheme that covers all emissions is appealing. Competitiveness concerns for industry from uneven climate policies across countries would also be eliminated if all producers faced the same carbon price. But in the real world, this appeal can quickly unravel. The challenge of bringing all countries onboard with a common agreement is complicated by country-specific preferences and circumstances, including the particular challenges of emerging market and developing economies. Furthermore, agreeing to a carbon price that is sufficiently high to drive deep emissions reductions in industry would be an even greater challenge. Thus the likelihood of achieving such an accord within the necessary timeframe is low.

By making certain adjustments or narrowing its scope, it might be possible to bring such an agreement more within reach. For example, the common carbon price could be applied to only specific portions of emissions – perhaps just to the industrial sector. Or the requirement could be modified so that the objective is comparably ambitious policy, rather than carbon pricing specifically. In place of explicit carbon pricing policies like carbon taxes or emissions trading systems, other regulations lead to "implicit" carbon prices. In an **industrial sectoral agreement**, countries might agree to common policy goals for industry that could be implemented through various instruments. There could also be provisions for common but differentiated aims: for example, countries could agree to accelerating the transition but acknowledge that the pace may differ by country depending on its circumstances. The agreement might include supports for emerging market and developing economies to aid them in accelerating the transition.

Furthermore, rather than aiming for broad agreements among all countries, an option could be to develop an agreement among a smaller number of countries, which might include some combination of the most ambitious countries and/or the largest producers. Here, first movers like the G7 members could play an important role. The smaller number of countries involved would likely make it less complicated to reach an agreement, but the effectiveness in terms of both achieving considerable global emissions reductions and preventing carbon leakage would depend on whether a substantial portion of global production is covered by the agreement. And even among a smaller group of countries, reaching an agreement may not be straightforward.

On the other end of the spectrum would be unilateral adoption of trade measures. **Carbon-based border adjustments** would involve adding a tax on imports based on their CO_2 footprint, so that domestic and imported products would face comparable CO_2 performance requirements. Such a system could also consider carbon pricing in the country of origin when calculating the tax, thus helping encourage the development of carbon pricing systems in other countries. Adoption of carbon-based border adjustments could be a useful tool for countries aiming to ramp up emissions reduction requirements more quickly than others, and it avoids the need to reach an international agreement. The policy could also put pressure on trading partners to adopt more ambitious policies so that they can continue to export to the country applying the carbon border adjustments.

However, there are challenges involved. Carbon-based adjustments would need to be backed by robust accounting, tracking and verification systems on the carbon intensity of products. This could be logistically very challenging given the complexity of global supply chains. Default carbon intensity estimates may need to be used as an alternative.

Border adjustments would need to be carefully designed to ensure compliance with international trade law, particularly World Trade Organisation requirements. Even so, they could face external challenges and create tensions with trading partners. The extra costs of border adjustments could especially pose challenges for producers in developing and emerging economies, who already may face difficulties in accessing finance for the transition. To maintain a collaborative spirit in the event that carbon-based border adjustments are implemented, it will be important for countries within the protected "carbon bloc" to communicate and support a clear onramp for countries that intend to put policies of equivalent stringency in place. This could include technical assistance for those countries, particularly in the case of emerging and developing economies, to build the institutional and policy infrastructure for domestic carbon pricing or equivalent regulations and adjustments at the border. It might also include finance and technology co-development support to help other countries move forward with the transition.

It is also important to note that carbon-based border adjustments on imports do not address the potential for low and near zero emission domestic production to be face a competitive disadvantage on export markets. Complementary measures could help, such as carbon price rebates upon export, although any such measures would need to be designed in a way that complies with international trade law. Moreover, in the case of steel, the dynamics of primary and secondary production could complicate policy effectiveness. Since secondary production is considerably less emissions-intensive than primary, trading partners might respond to carbon border adjustments by increasing secondary production exports – which would face a considerably less costly carbon border tariff – in place of primary production exports. Therefore, the level playing field challenge for domestic low emission primary production would not be fully resolved, as imported conventional secondary production with only a small carbon charge might be more competitive. It would be important for governments to monitor the outcomes of such policies and introduce additional safeguards if needed. This would need to be done in a way that complies with international trade law.

Alternatives to carbon-based border adjustments could be used to create a level playing field. **Consumption-based policies** would place emissions taxes or emissions reduction requirements on intermediate or final material consumption – that is, materials going into end-use products – rather than on the production of the materials. Since the policy is applied to materials use, domestic and imported materials production would face the same carbon requirements. This policy approach would reduce the burden on materials producers by facilitating cost pass-through: product manufacturers would need to pay for the additional cost of lower-emission production and could pass that cost on to the end-user. As with carbon-based border adjustments, however, a major challenge of this approach would be developing systems for tracing the carbon content of materials, and the approach would address only competitiveness for imports, not exports.

Another approach that has been proposed is referred to as **climate contributions**, in which both domestic and imported production is liable to pay a contribution per weight of material, regardless of its CO_2 intensity. This additional cost could be passed along the value chain, creating incentives for more efficient use of materials. The revenue collected from climate contributions would be used to finance carbon contracts for difference to support near zero emission materials production, thus providing an incentive for lower-CO_2 intensity production. Such a policy would help create a level playing field for near zero emission material production without straining government budgets and without requiring complex carbon footprint accounting systems for imports. It could still encounter resistance from domestic producers being required to pay the contribution, however, as well as pushback from trading partners. The policy would need to be designed in a way that ensures compliance with international trade law. Additionally, careful analysis would be needed to determine if the revenues collected would be large enough to provide sufficient support for the transition to near zero emission production.

When evaluating ways to level the playing field, there are **various factors to consider**, including: the implications for domestic and international emissions reduction ambition; the effectiveness in protecting industry competitiveness; the need to comply with international trade law; the risk of trade tensions; and the feasibility of actual implementation.

Aiming for a broader consensus generally results in agreeing to weaker objectives, since it reflects only what the least ambitious parties are willing to accept. Although the negotiation process could put pressure on less ambitious countries to do more, it would still probably fall short of what the most ambitious parties are seeking. And it would likely be a long and difficult process to reach an agreement. An advantage of universal agreement – were it to be achieved – could be avoiding the need to apply carbon border adjustments and thus avoiding potential trade tensions and challenges related to compliance with international trade law. An agreement that maintains room for common but differentiated policy stringency might prove easier to reach. But since it would be less effective at protecting the competitiveness in more ambitious countries, border adjustments could still be needed.

Meanwhile, a country or bloc with stringent domestic emissions reductions that applies mechanisms to level the playing field on its own might be able to adequately protect its industry's competitiveness and achieve more ambitious domestic climate objectives. However, this approach could lead to trade tensions, would need careful design to ensure compliance with international trade law and would likely make a more limited contribution to increasing policy objectives globally. The impact of unilateral action will depend partially on the share of industrial production and trade that a country or bloc represents: a larger share would result in more pressure on other countries to also implement policies to achieve increased emissions reduction objectives, since it would be more difficult for them to avoid economic consequences of the protective policies.

Potential role of an intergovernmental industry decarbonisation alliance

Several recent proposals have suggested the formation of an international climate alliance, or club, in which a group of countries comes together to help accelerate climate action. Such proposals are being discussed within international organisations and fora such as the Germany G7 presidency, the OECD and the IMF. They have also been the subject of several recent analyses by climate think tanks (for example, Agora Energiewende and E3G). Some proposals see an alliance as a possible way to avoid the need for carbon-based border adjustments, while others see it as a complementary approach focused on increasing climate policy ambition and enhancing international cooperation, particularly for the industrial sector given international trade considerations.

Here we focus in on the potential role of an intergovernmental industry sectoral alliance, given the focus of this report on industry, and on the role of the G7 in particular. Industry is an area where collective ambition-raising and collaboration could be particularly beneficial. Given that industrial products are traded internationally, coordinated efforts to raise global ambition and provide mutual support would reduce unevenness in the pace of transition. It would also help to defuse trade tensions related to climate policy rather than create new ones. The global nature of the market also means that it would be valuable to align standards, definitions and – to the extent possible – principles for developing climate-related trade policies. Efforts on technology innovation, infrastructure development and policy design would also benefit from coordination and knowledge sharing among countries.

To add value, an intergovernmental industry alliance would need to have a function that enhances, rather than duplicates, the roles of the many existing international initiatives in the industrial space. As outlined above, some existing initiatives, such as Lead-It, focus broadly on dialogue and exchange to encourage increased action on the industry transition. Others aim to address specific parts of the industry challenge, such as IDDI's focus on public procurement and Missions Innovation's focus on new technologies. Meanwhile the Breakthrough Agenda is helping coordinate among the various initiatives and identify areas for further progress. However, one remaining gap in the landscape is a platform for governments to collectively raise ambition for the industry transition and commit to those larger aspirations. Of course governments can include targets for industry in their Nationally Determined Contributions under the UNFCCC, but there is no requirement to include industry targets and no forum for focused discussion of industrial policies.

Here, members of the G7 could provide a leadership role, considering their solid foundation for being first movers in the industrial transition. The G7 Industrial Decarbonisation Agenda (IDA) is already taking positive steps in this direction, including through dialogue, knowledge exchange and coordination on specific aspects such as definitions and innovation. There is an opportunity for the IDA to raise the bar, by transforming into an institutionalised Industry Decarbonisation Alliance. Benefits of this approach include bringing all members into key conversations, regardless of which other multilateral initiatives they may have already joined, and ensuring the continuity of underlying work and objectives even with an annually rotating G7 presidency.

Three key transformations could mark the founding of the alliance: 1) a shift to include a comprehensive suite of concrete commitments; 2) opening the doors to members beyond the G7; and 3) housing the alliance within a permanent secretariat. Here we discuss the potential objectives and logistics of such an alliance.

The type of alliance: non-binding versus binding

A range of possibilities exist for the purpose and design of an intergovernmental industry alliance, mirroring possible designs for a broader climate club. Depending on the chosen objectives, an alliance could range from a "non-binding" collaboration focused on voluntary commitments to increased ambition and coordinated implementation mechanisms, to a "binding" alliance with stringent membership requirements and possibly sanctions toward non-members.

A **non-binding alliance** could effectively contribute to advancing the industry transition and would likely be more conducive to reaching agreement compared to binding commitments. Signed accords within the alliance could foster commitment and collective diplomatic pressure, even in the absence of legally binding requirements. An example of a successful intergovernmental sectoral agreement formed along similar lines is the commitment of the International Maritime Organisation (IMO) to reduce emissions from international shipping by 50% by 2050 from 2008 levels. Engagement with key private sector stakeholders, particularly international industry associations, in the process of establishing commitments could help provide a solid foundation for such commitments.

Potential objectives of a non-binding alliance could include the following:

- Collaborative pledges, setting milestones and creating roadmaps for increased industry emissions reduction ambition, including absolute and/or intensity-based CO_2 emissions objectives, striving toward aligned commitment to the extent possible but taking region-specific circumstances into account
- Sharing of best practices and building capacity on industrial emissions reduction policy design and planning
- R&D and demonstration funding pledges, coordination, and knowledge sharing (supply push), including collaboration via existing initiatives such as the Mission Innovation Net Zero Industries Mission
- Jointly timed market creation (demand pull), including increased engagement in existing initiatives such as IDDI
- Jointly agreed standards, definitions, certification and labelling systems for low and near zero emission materials production
- Jointly agreed commitments and knowledge sharing on developing supporting infrastructure, including for CO_2 transport and storage, and low-emission hydrogen and electricity provision
- Collaborative increased support for the transition in emerging and developing economies, including capacity building, technology co-development and access to finance
- Discussion on principles for designing carbon pricing systems and carbon-based border adjustments, including compliance with international trade law
- Discussion on strategies to ensure a just transition for workers and communities

On the other end of the spectrum, a **binding industry alliance** would set specific membership requirements backed by consequences for non-compliance. This may be in addition to working on some of the potential objectives listed above for a non-binding alliance. It is likely that the requirements for such an alliance to be binding would involve minimum policy equivalency covering the industry sector, focused on explicit and implicit carbon pricing, the latter involving other regulatory policies that result in a comparable requirement to reduce emissions. Such an alliance would need to agree to a robust methodology for determining policy equivalency, which can be quite complex including with respect to implicit carbon prices. A period of negotiation would likely be needed to determine the minimum requirement, and the alliance could set a date beyond which membership is contingent on meeting the policy requirement.

Binding commitments would provide more robust protection from carbon leakage for members relative to non-binding commitments, but they are also likely to be more challenging to agree to. Binding requirements might lead to a smaller number of members, or less ambitious requirements among a larger number of members. Too great a focus on binding commitments could also risk diverting attention from other useful collaborative objectives. One way to overcome the challenges with binding commitments is to start with cooperative mechanisms and incorporate binding commitments later if they are still deemed necessary. Alternatively, binding aspects can be separated into an elective sub-group that is distinct from the main work of the alliance.

Given the potential challenges of a binding alliance, an evolution of the IDA into an Industrial Decarbonisation Alliance might be best suited to take the form of a non-binding alliance. One primary objective would be to collectively raise policy ambition through commitments, aided by coordination and knowledge exchange. This would include commitments on general targets for industrial emissions reductions, domestic policies, and increased participation and more aspirational goals within existing multilateral initiatives. Increased coordination and knowledge exchange would facilitate meeting the commitments. Discussion on trade aspects, such as principles for carbon-based border adjustment design and trade in near zero emission materials and products, could take place in an optional sub-group.

The logistics of an intergovernmental alliance: membership and administration

Beyond the objectives of the alliance, there are several practical aspects to consider. With regards to **membership**, an alliance among G7 members could be useful in advancing the industrial transition for members and could have positive spillover effects for the transition outside of the G7. However, an alliance open to participation of major emerging and developing economies would maximise effectiveness in advancing the global industrial transition, given that these countries account for a large share of industrial production. To illustrate, an alliance composed of G7 members only would cover about 17% of global steel production and 8% of cement production. Adding China and India alone would expand coverage to over 70% of current production of both steel and cement. Including a handful of additional major producers could quickly bring the total to 80%.

There are trade-offs between broad versus narrow membership. Broad membership would enable larger coverage of global production (including future production considering the likelihood of expanded production in developing countries) and could facilitate more direct collaboration with developing economies. Meanwhile, a smaller membership base could facilitate more effective negotiation and lead to faster implementation, while preventing the lowering of climate ambitions to satisfy a broad membership base. Perhaps the G7 could first pursue collaboration with a handful of the largest industrial producers outside of the G7, while leaving the door open for continued expansion in the future.

Additionally, even for a non-binding alliance, membership would likely have some form of climate ambition requirement. This could simply be along the lines of a clear willingness to contribute to the alliance's objectives and accelerate the transition, as demonstrated by emissions reduction pledges that are ambitious while taking into consideration region-specific circumstances. The requirement should be designed in such a way that it would not exclude key players unnecessarily. It would however be helpful for assuring that all members come to the negotiating table in good faith and with the intention to collaborate, rather than stall progress.

Another consideration would be **where to house and how to administer** such an alliance. Housing the alliance in a permanent secretariat would have advantages over administration by a changing G7 presidency, in terms of continuity on objectives and administration. This is particularly important given the long-term nature of industrial decarbonisation and the rather detailed tracking and coordination required. Additionally, a secretariat outside the G7 could signal more openness to collaboration beyond the bloc. While the G7 would be an important catalyst for founding the alliance, and could remain deeply engaged in its work, help from another body for administration purposes would likely prove valuable. To avoid creating an entirely new body from scratch, the secretariat might best be housed by an existing international organisation such as the IEA, OECD or UNIDO that meets the need of institutional longevity and stability to support the long-term endeavour effectively. Various formulations are possible of course; the relevant point is the longevity of the institution.

The alliance would likely require regularly scheduled general meetings, and technical subgroups working on particular topics. International industry associations could be included in some of these meetings and consulted on a regular basis. Annual progress reports could summarise steps taken and ensure the alliance is making a meaningful contribution to accelerating progress.

Chapter 3: Defining “near zero emission” materials production

Highlights

- Definitions and standards can help in building consensus on the way forward for heavy industries – both in the medium and long term. The core components of the policy toolbox explored in Chapter 2 require common definitions to be agreed as a pre-requisite: on the “demand pull” side (e.g. differentiating markets for products, establishing green public procurement protocols), on the “supply push” side (e.g. evaluating direct financial support for demonstration projects), and to facilitate international cooperation.
- Heavy industries and their supply chains use thousands of measurement standards and thresholds to specify product grades, content requirements, colours, strength and various aspects of product safety. Measurement standards for evaluating the emissions intensity already exist or are under development for steel (e.g. ISO 14404, ISO 20915, World Steel Association Benchmarking System) and cement (e.g. ISO 19694-3, GCCA Cement CO_2 and Energy Protocol). However, these measurement standards generally do not specify normative thresholds or target levels for emissions intensities.
- Stable, absolute and ambitious thresholds for near zero emission materials production are proposed, which take account of sector-specific nuances. The thresholds for “near zero emission” production aim for levels of emissions intensity that are compatible with a trajectory for heavy industries in a pathway that reaches net zero emissions from the global energy system by mid-century, as defined in the IEA’s *Net Zero by 2050* roadmap.
- The thresholds proposed for near zero emission steel and cement production are stipulated on a sliding scale that depends on steel scrap use and the clinker-to-cement ratio, respectively. The threshold value for steel production with zero scrap use is 400 kg of CO_2 equivalent per tonne ($kgCO_2e/t$) of crude steel, decreasing to 50 $kgCO_2e/t$ for production using 100% scrap. The equivalent values for cement production are 125 $kgCO_2e/t$ for a clinker-to-cement ratio of 1.00 and 40 $kgCO_2e/t$ for a ratio of zero. Unlike steel production, these extremes are rarely applied in practice, but they set the gradient for more commonly realised ratios (0.50-0.95).
- Complementary – but distinct – definitions are proposed for “low emissions” production which recognise the important interim steps taken to reduce emissions intensity. These are evaluated on a continuous scale; the low emission output is proportional to the emissions intensity reduction achieved.

Introduction

Standards and definitions will be critical to all efforts to achieve net zero heavy industries in the G7 and beyond. Many of the policy tools explored in Chapter 2 require common definitions as a pre-requisite. Common definitions can form the basis for differentiating markets for products, establishing green public procurement protocols and other elements of the “demand pull” side of the policy equation. Conversely, on the “push” side, definitions make it possible to evaluate whether a given innovative technology or interim emissions-reduction measure deserves financial support, and if so, to what extent, and for how long. More broadly, definitions can help establish a common view of the way forward for heavy industries, both in the medium and long term.

This chapter begins with an overview of the key attributes of measurement standards and thresholds. This is followed by a review of existing efforts to establish definitions, and components thereof, for near zero emission (or similarly defined) steel and cement production. Building on this literature, the IEA proposes its own definition of “near zero emission” production– terminology which was chosen for its precision and neutrality. The definition is not intended to imply the use of a specific technology (e.g. “green steel” that uses “green hydrogen”), nor to exclude a specific technology (e.g. emissions mitigation via CCUS), denote a specific carbon content (e.g. “low carbon steel”) or to rule out any process that leaves residual emissions (e.g. “net zero” or “zero emissions” steel). We also propose a complementary – but distinct – definition of “low emission production” aimed recognising interim steps on the way to the eventual goal of achieving net zero heavy industries.

Background on standards and definitions

It is important to establish what is meant by “standards” and “definitions” in the context of this work. A *standard* is a measure, norm, or model used in comparative evaluations. A standard can contain a definition corresponding to a certain threshold, quantity or set of criteria, measured as specified by the standard. Thus, in common usage, the word standard can refer to both the measurement routine and a normative threshold. In this publication, we make a distinction between measurement standards and normative standards, which define a specific threshold that may be reached using the measurement standard. A definition of near zero emission steel or cement production requires both an agreed threshold and a common measurement standard.

Measurement standards and thresholds enable comparative evaluation

Today, heavy industries and their supply chains use thousands of measurement standards and thresholds. Buyers and sellers use measurement standards and thresholds in contracts to specify product grades, content requirements, colours and many other qualities at each step in the supply chain. Regulators use them to specify various aspects of product safety, such as toxicity, strength and operating conditions. Consumers use them to inform their purchasing decisions. Measurement standards and thresholds are nothing new, and without them, heavy industries could not carry out their core operations.

In this publication, we are concerned with a specific subset among this wide array of measurement standards and thresholds used in heavy industries: those addressing the emissions from steel and cement *production*. In evaluating existing standards, we will also review standards that address the so-called embodied emissions of finished steel, cement and concrete products and projects, to the extent they are directly relevant to the production phase. Standards that address energy performance are indirectly relevant to emissions from production, but only insofar as the energy carriers used result in emissions. In the context of the IEA’s Net Zero Emissions by 2050 Scenario, these standards would become less relevant over time and so are only addressed peripherally here.

When designing or evaluating a measurement standard for the emissions associated with steel and cement production, there are four main components that warrant specific consideration:

- **Emissions scope:** A measurement standard may cover total greenhouse gas emissions or a subset thereof. By definition, direct emissions must be addressed in any measurement standard or threshold, but varying levels of indirect emissions may be included. “Full” indirect emissions coverage is not possible, as emissions can be allocated infinitely among sectors. Similarly, a measurement standard that includes indirect emissions should address the treatment of so-called negative emissions and emissions offsets. The inclusion of indirect emissions is generally preferable, but there must be clarity as to what is accounted for and the method for doing so.
- **Supply chain scope:** Emissions are incurred at every stage in the process of transforming raw materials into finished steel and cement products. Any measurement standard or threshold must specify the upstream and downstream boundaries of the supply chain that they cover.
- **Granularity of application:** Measurement standards and thresholds can be applied at the plant level, or to the evaluation of multiple plants – within a country or region, a company portfolio, or an industry sector or sub-sector. Evaluations at the product and project level can also involve accounting at different levels of granularity.

- **Measurement methodologies and data requirements:** Measurement standards will often specify the method by which emissions and other relevant quantities should be measured, calculated or modelled. Such methods could include physical readings from stacks, guidelines for calculations based on measured or estimated inputs and outputs, or a set of default factors for use in the absence of more granular data.

Like measurement standards, when designing or evaluating an emissions intensity threshold for steel and cement production, there are three key aspects that merit evaluation:

- **Absolute vs. relative reduction:** A threshold could be specified as an absolute value of emissions intensity, or a reduction in intensity relative to a pre-specified benchmark (e.g. a conventional process technology using best available technology). If the benchmark used in the relative reduction method is static and universal, then these two approaches are essentially the same.
- **Static vs. dynamic:** A threshold could be specified as a static value, or dynamically, in relation to a temporally or regionally varying reference point (e.g. a scenario for the future of the energy system).
- **Formulation:** A threshold could be specified as an emissions intensity, or a fixed quantity of emissions from a given plant, region or sector. An emissions intensity threshold could be specific to a particular material, sector or technology, or applied universally in the case of a relative reduction. Thresholds can also be established as a function of various technical factors, such as shares of certain input materials and other factors that have a significant impact on emissions.

There are no right or wrong ways of specifying any of the above components of a measurement standard or threshold, nor are there any universal scales for judging comprehensiveness or effectiveness. It is only fitness for purpose that can be judged – whether theoretically or empirically – and the purpose of the definition, as well as its components, must be clearly defined in order to do so. When proposing new standards, compatibility and continuity with existing standards is another important principle to consider, to avoid duplication and confusion among users.

Box 3.1 IEA high-level workshop on definitions

To inform this work, the IEA, in co-operation with the German Federal Ministry for Economic Affairs and Climate Action, hosted a virtual high-level workshop entitled "Defining a standard for near zero emission materials production" on 18 February

2022. The workshop brought together G7 member governments – alongside country representatives China, India and Indonesia – stakeholders from the private sector and leading sectoral initiatives to discuss standards and definitions for near zero emission materials production.

Focusing on steel and cement, the discussion addressed considerations, implementation logistics and data requirements associated with definitions of near zero emission production. The objective was to understand multiple perspectives and start building consensus toward a cross-jurisdictional definition of near zero emission steel and cement production.

Some clear areas of agreement could be identified among the stakeholders present:

- New protocols for measuring emissions should not be developed
- Definitions alone will not be able to address all the challenges facing the steel and cement industries
- A need for precision around the term “near zero emission” materials
- The need for technology neutrality

Conversely, the workshop highlighted areas where open questions remain:

- The extent of indirect emissions – such as from producing electricity or hydrogen – that should be included
- Whether definitions should be static or dependent on a given scenario parameter or regional context
- The extent to which interim measures that achieve substantial emissions reductions – but fall short of “near zero” – should be recognised

These takeaways from the workshop – along with many other insights – were instrumental in developing the core content and recommendations presented in this document.

Existing measurement standards

Steel and cement production

The World Steel Association (worldsteel) compiles data reported by its members on the CO_2 emissions intensity of steel production. They use a measurement standard in the form of their CO_2 Emissions Data Collection User Guide, which specifies in substantial detail the manner in which the CO_2 and production data must be collected and reported. The data itself is confidential, and participating members are granted access to the benchmarking analysis derived from the data on an anonymised basis.

The worldsteel measurement standard covers CO_2 emissions only, which accounts for most emissions from steel production within the boundary considered. The supply-chain boundary extends from iron ore agglomeration through to finished steel products. It does not include the emissions associated with raw materials extraction, sorting and transportation, nor does it incorporate upstream emissions from fossil fuel supply. The emissions boundary covers all direct CO_2 emissions from the iron and steel sector, along with indirect emissions from electricity generation and the production and use of lime fluxes. Emissions credits are applied when electricity and other energy carriers (like off-gases) are exported for use off-site. The standard is route-specific, with data collection methodologies provided for the blast furnace-basic oxygen furnace (BF-BOF), direct reduced iron-electric arc furnace (DRI-EAF) and scrap EAF processes. The measurement standard does not provide any guidance for route-specific considerations for innovative technologies, as there are very few such plants operating even at pilot scale today.

The Cement CO_2 and Energy Protocol was originally developed by the World Business Council for Sustainable Development (WBCSD) under the Cement Sustainability Initiative (CSI), with the first version – then, the Cement CO_2 Protocol – published in 2001. Last revised in 2013 (Version 3.1), this measurement standard is now hosted by the Global Cement and Concrete Association (GCCA), which was established in 2017. It lays out detailed instructions for energy and emissions accounting associated with cement production at the individual plant level. The standard draws a wide analytical boundary, covering both direct and indirect CO_2 emissions – including raw material supply, preparation of raw materials, fuels and additives and core operations (kilns, grinders, transport of materials). Emissions accounting conventions are established both on a gross and net basis, with the latter including various categories of offsets and credits for the use of alternative fuels (e.g. bioenergy and renewable waste), carbonation during curing and the utilisation of waste heat.

The International Organization for Standardization (ISO) produced its first standard in 1951 and has since become the internationally recognised body for standard setting in the making of products, managing processes, delivering services and supplying materials. ISO has a membership of 167 national standard bodies, more than 25 000 published standards, and more than 800 technical committees and subcommittees. The Japanese Industrial Standards Committee is the secretariat of the technical committee on steel, which has overseen the development of specific standards for measuring the emissions intensity of production. ISO 14404, entitled "Calculation method of carbon dioxide emissions intensity from iron and steel production," was first published in 2013. The ISO 14404 series is based on the worldsteel measurement standards described above and is very similar in its approach. Parts 1 to 3 contain route-specific guidance for calculation the greenhouse gas emission intensities of production for the BF-BOF, Scrap EAF and DRI-EAF routes. Part 4 contains guidance for using the series. Both direct and indirect emissions from steel production are covered, and the methodology is intended for evaluations at the site level with measured data. ISO 19694-3, a similar standard for cement production, is currently under development.

The European Committee for Standardization (CEN) drafts and maintains a series of European Norm (EN) standards, covering many of the same areas addressed by ISO standards. A subset of EN standards addresses methods and instruments for measuring of gas emissions, with the EN 19694 standard covering greenhouse gas emissions from energy-intensive industries. Part 2 is focused on the iron and steel industry and Part 3 on the cement industry. Aluminium and lime production are also covered within the series. As with ISO 14404 and the forthcoming ISO 19694-3 standard, EN 19694 provides a methodology for calculating the emissions intensity of steel and cement production, covering both direct and indirect emissions, together with guidance for comparing performance at the process unit level, to establish best practice.

A number of benchmarking protocols and initiatives establish measurement routines. The European Commission's Emission Trading Scheme uses benchmark emission intensities for a range of industrial commodities as part of its allocation of free allowances for trade-exposed industries. Emissions intensities of the top 10% of installations operating in the Commission's jurisdiction are used to set the benchmark values. These benchmark values are then also used in the EU Innovation Fund GHG Emission Avoidance calculations, where the calculations of emissions reductions require more detailed guidance (e.g. counterfactuals for carbon capture and utilisation technologies). The United Nations Industrial Development Organization and the IEA, among other institutions, perform energy efficiency benchmarking analyses for industrial products and sectors. The information produced can form the foundation of emissions intensity calculations for these industries.

Flannery and Mares of Resources for the Future, a research organisation, delineate a detailed emissions accounting framework for calculating the

Greenhouse Gas Index (GGI) for industrial products. The GGI is designed for use as part of a proposed border tax adjustment, to calculate export rebates and import charges for greenhouse gas-intensive products. The GGI can be applied to dozens of products across 46 energy intensity industrial sectors the authors identify, with specific examples provided to demonstrate the calculation.

Products, projects and portfolios

While the standards described above pertain specifically to the production of steel and cement, there are other standards, certification schemes and assessments used in these industries to appraise the sustainability of products, projects and specific assets and operations within company portfolios. Perhaps the most well-known entity operating in this area is the Forestry Stewardship Council, which provides standards, labels and certification schemes to actors along the supply chains of industries using products derived from forests (paper, timber etc.). There is no single organisation with as comprehensive coverage of the steel and cement supply chains, but there are several analogous efforts.

ISO 20915 specifies guidelines and requirements for conducting life cycle inventory studies for steel products. The guidance covers the whole supply chain, including the extraction of raw materials through to the production of steel products, as well as the treatment of steel scrap. Quantifying the environmental impact of the supply chain using the inventories for which it provides guidance is outside the scope of the document. Environmental product declarations (EPDs) and their associated product category rules (PCRs) follow a similar approach, using life cycle analysis ISO standards (e.g. ISO 14025 and ISO 14040) to establish measurements of environmental performance for specific products. Many EPDs have been developed for specific steel, cement and concrete products, with most being specific to a given country and product grade.

For cement and concrete, the GCCA requires its full members to attain compliance with its Sustainability Charter within five years of joining the organisation. The charter aims to document and incentivise improvements in the environmental performance of cement and concrete producers. Alongside health and safety and social responsibility, the charter requires companies to report publicly data on climate change and energy, including greenhouse gas emissions from the production phase of cement and concrete. Similarly, the worldsteel Sustainability Charter, signed by 39 of its members as of 2022, embodies nine principles covering the areas of environment, social, governance and economics. The first of these principles is climate action, with one of the criteria being that signatories must submit CO_2 or energy consumption data to worldsteel or national governments.

ResponsibleSteel, a global multi-stakeholder standard and certification programme, developed its first standard in 2019, covering a range of environmental, social and governance issues. The latest version of the standard (version 1.1) stipulates under Principle 8, that "greenhouse gas emissions are measured, reported and disclosed." The standard also recognises the EN 19694 and ISO 14404 series of measurement mechanisms as appropriate tools for doing so. ResponsibleSteel is also in the process of defining thresholds for near zero emission steel production (see below). The Concrete Sustainability Council hosts a certification system for appraising the environmental performance of companies producing cement, aggregates and concrete. Categories of sustainability (management, environment, social topics and economic topics) are appraised with different weightings and scores assigned to each, leading to an overall rating ranging from bronze to platinum. The rating of an individual entity in the cement supply chain depends in part on the ratings of the entities that supply and use its inputs and outputs, respectively.

The Building Research Establishment Environmental Assessment Method (BREEAM) provides a sustainability assessment method for buildings and infrastructure, covering all aspects of a building's life cycle that lead to environmental impacts. The organisation brings together technical standards addressing a variety of topics, including the sourcing of building materials like steel, cement and concrete. The aim of applying these standards is to assess emissions performance (and other aspects of sustainability) at the project level. BRE Group, the organisation that offers BREEAM, is based in the UK. A similar set of services are available as part of obtaining LEED certification (Leadership in Energy and Environmental Design), a scheme run by the U.S. Green Buildings Council. Both groups offer their services internationally. Other more specialised rating systems for buildings are supplied by Envision (United States), ÖGNI (Austria) and DGNB (Germany).

The Science Based Targets initiative (SBTi) works with companies to develop voluntary emissions reduction pathways that it considers compatible with goals of the Paris Agreement on climate change. After companies set their target – which can be done using a methodology derived from published mitigation scenario results (including those published by the IEA) – it is then evaluated by SBT. If the target is accepted, the company is then encouraged to report company-wide emissions and track progress against it. A number of other initiatives are now offering similar services and assessments to corporates across a range of sectors, including the Assessing Low Carbon Transition (ACT) and Low Carbon Emitting Technologies (LCET) initiatives. These initiatives tend to use the corporate emissions accounting framework developed by the Greenhouse Gas Protocol (see below).

System-level emissions accounting

It is important to note that there are long-established frameworks for collecting, estimating and compiling national and sectoral energy and emissions data that cover both the steel and cement industries. These frameworks provide detailed guidelines as to the boundaries around direct emissions from each sub-sector, default factors for estimating data in the absence of precise measurements, and inventories for compiling the data once it is collected and computed.

The Intergovernmental Panel on Climate Change (IPCC) publishes Guidelines for national greenhouse gas inventories for both energy and industrial process emissions, which cover both steel and cement production. The United Nations Framework Convention on Climate Change (UNFCCC) provides emissions inventories for the data collected and estimated by governments, using the IPCC guidelines. The IEA collects and computes energy balances for countries, which are in turn used to compute greenhouse gas emissions from the energy sector, using the IPCC's guidelines, and the energy and emissions intensity indicators (described above) derived from these data. There are various regional efforts to compile energy and emissions data from each of these (and other) sources that also cover the steel and cement industries, such as the European Union's Emissions Database for Global Atmospheric Research (EDGAR).

The accounting systems above generally use the United Nations International Standard Industry Classification of All Economic Activities (ISIC) system, to sub-divide the myriad activities, operations and commodities the industry sector comprises. The classification system is periodically reviewed and revised, with the current version being Rev.4. The IEA's World Energy Balances specify the individual ISIC sector and activity codes to form the boundary around each of the 12 sub-sectors (13 including "industry not elsewhere specified") for which it collects data. The iron and steel sector corresponds to ISIC Rev. 4 Group 241 and Class 2431.[1] The non-metallic minerals sector (which includes cement production) corresponds to ISIC Rev. 4 Division 23. This taxonomy, established in the IEA's

[1] The IEA's energy balances account for the use of energy in blast furnaces and coke ovens separately in "Transformation." But for the purposes of IEA industry sector analysis, these are considered part of the iron and steel industry along with the energy accounted under "Total final consumption."

energy accounting, is used as the basis for establishing the direct emissions associated with each industrial sector. This ensures a robust and comprehensive accounting framework that avoids double counting.

Emissions from other sectors can be allocated to industry sub-sectors, to quantify indirect emissions. A common allocation is the emissions from electricity generation to the consuming sector. Industry sector emissions can then in turn be allocated to other sectors (e.g. “well to wheel” analyses in the transport sector). The Greenhouse Gas Protocol is a joint effort from two organisations (WBCSD and the World Resources Institute) representing private sector and civil society stakeholders that aims to establish a common method of emissions allocation between sectors and companies. The organisation produces a corporate standard, first published in 2001 and subsequently revised, defining different “scopes” of emissions associated with companies’ operations, and those of their supply chains. Scope 1 emissions are direct emissions from the assets owned by the company. These emissions can potentially span multiple energy end-use sectors (e.g. industry, transport, buildings, electricity generation), depending on the company or companies in question. Scope 2 emissions are indirect emissions from purchased electricity generation, allocated to the consuming entity. Scope 3 emissions are defined as “a consequence of the activities of the company but occur from sources not owned or controlled by the company” – a broad category, with an undefined extent and method of allocation.

Consolidation and compatibility

The review of measurement standards above is not exhaustive, but it identifies a range of detailed and robust protocols and components thereof. The next phase of implementing common emissions intensity definitions for the steel and cement industries will require some degree of consolidation. The Clean Energy Ministerial Industrial Deep Decarbonisation Initiative (see below) has this activity as a core objective of one of its work streams, and this report does not seek to pre-judge the outcome of efforts therein to establish interoperability between standards. We would highlight three key areas that should be considered in any effort to harmonise existing standards and those under development:

- **The duplication of existing measurement standards should be avoided**. If one aspect of an existing standard is not fit for purpose, the standard in question should be revised. Nearly all the standards described above have been periodically revised and processes, consultation frameworks and committees exist for doing so. Ideally, a single set of standards should be agreed upon for the evaluation of emissions intensities, prioritising the production phase of steel and cement.

- **The fitness for purpose of existing measurement standards should be appraised with respect to emerging near zero emission technologies and their components – in addition to conventional process technologies.** There are sector and technology-specific elements to examine here: the worldsteel benchmarking standard – and the ISO 14404 standard based on it – have route-specific guidance, for example. The consideration of new production pathways (e.g. hydrogen-based direct reduced iron production) is not explicitly considered as one of the potential process routes. There are also cross-cutting considerations: the treatment of emissions credits for exported electricity and other energy commodities, for instance, should ideally be the same in the steel and cement sectors. These credits should be evaluated in a manner that is compatible with an energy system that is moving toward net zero emissions. Using the global average emissions intensity of electricity generation today in the evaluation of these credits, would not necessarily be an appropriate consideration in the future.
- **Relevant international energy and emission accounting frameworks must be adhered to during the development and refinement of new and existing measurement standards.** Several existing measurement standards use the Greenhouse Gas Protocol as a derivative accounting framework, which intentionally double-counts emissions. The double-counting of Scope 2 emissions is limited to electricity generation (these are Scope 1 for a company producing the electricity and Scope 2 for the company consuming it). There is no limit to double-counting of Scope 3 emissions, as an unlimited number of companies may identify a given source of indirect emissions as a consequence of their activities. This double-counting of indirect emissions is helpful for incentivising holistic supply chain assessments, but it is essential that these quantities can be traced back to clearly defined sources of direct emissions, according to the international frameworks of emissions accounting described above. Otherwise, unintentional double-counting and dilution of responsibility can ensue.

Existing thresholds

Terminology

There are several terms in common usage to describe the emissions intensities of steel and cement production (and products) that are implicitly lower than the levels that can be achieved with conventional process technology. Until now, these terms have been qualitative and generally imprecise about the specific quantities or boundaries to which they refer:

- **Low carbon:** Like the terms "low carbon hydrogen" and "low carbon electricity," it implies a production phase with fewer emissions relative to an unspecified benchmark. This term can lead to confusion in the case of steel, as it is already used to describe a specific grade and carbon content that is physically present in the material (typically 0.05 to 0.3% by weight).

- **Low emissions:** Applied in the same way as “low carbon” but refers more precisely to emissions that are implicitly associated with production.
- **Carbon neutral:** Similar to “low emissions” but with specific reference to carbon, and implicitly CO_2.
- **Green/Sustainable/Clean:** These terms generally imply some degree of consideration beyond emissions, including other environmental impacts. The use of colours can imply production via a specific technology, as is the case with so-called green hydrogen, which generally refers to production using an electrolyser and renewable electricity. As with low-carbon steel, the term “clean steel” has a specific metallurgical meaning (e.g. the specification of low levels of impurities), which makes re-purposing or duplicating this terminology similarly problematic.
- **Net zero/Near zero emission:** “Net zero” implies that carbon removal technologies are used to offset residual emissions, so that zero emissions can be achieved *on a net basis*. “Near zero” acknowledges the presence of residual emissions which are technically difficult, expensive or impractical to eliminate on a gross basis.

In this report, we opt for the term “near zero emission” when proposing common definitions for steel and cement production, for its precision and neutrality. The definition is not intended to imply the use of a specific technology (e.g. green steel using green hydrogen), exclude a specific technology (e.g. mitigation via CCUS), denote a specific carbon content (e.g. low-carbon steel) or entirely rule out any residual emissions (e.g. net zero or zero emissions steel). “Near zero” intentionally implies that there is a non-zero value for thresholds developed as part of these definitions (which in turn implies inter-sector emissions offsets at the energy system level). However, it is not our intention to consider inter-sector emissions offsets within the analytical scope of the proposed definitions.

With respect to the quantitative thresholds to which these terms pertain, there are several efforts underway that are likely to yield definitions over the course of 2022-2023. One such initiative – that of the First Movers Coalition – has already been published (see Box 3.2).

Box 3.2 The First Movers Coalition

The First Movers Coalition (FMC) is a global initiative to accelerate the commercialisation of critical technologies across sectors whose emissions are hard to abate. G7 countries have played an integral role in advancing this platform.

Launched at COP26 by the United States and the European Commission, in partnership with the World Economic Forum, the First Movers Coalition has expanded to include more than 50 companies with a combined market capitalisation of over USD 10 trillion. The initiative has since been joined by several other governments, including Japan and Sweden.

Building early demand signals for goods and services delivered with substantially lower emissions footprints will be critical to deploying the next generation of clean energy technologies. Around half the emissions reductions in 2050 in the IEA's Net Zero Emissions by 2050 Scenario are achieved with technologies that are not yet available on the market – most of which are deployed in the heavy industry and long-distance transport sectors.

Advance market commitments have been used to dramatic effect to induce innovations in other fields, from lifesaving vaccines to commercial spaceflight. One key lesson is that purchasing commitments need to be carefully constructed so that they create early market demand for emerging technologies that otherwise cannot compete with conventional incumbents. To create these early demand signals in clean energy technologies, the FMC has defined near zero emission thresholds across five key sectors (steel, shipping, trucking, aviation, and carbon removal) with additional thresholds under development for aluminium, cement, and chemicals production. The near zero emission threshold for steel production is defined on a sliding scale as a function of the share of scrap used in production. Focusing specifically on CO_2, and on Scope 1 and Scope 2 emissions, the upper end of the threshold is established at 400 kgCO_2/t (zero scrap) and the lower end at 100 kgCO_2/t (100% scrap). This threshold was designed in coordination with the IEA, Climate Group, the Mission Possible Partnership and other organisations.

The standard was constructed to ensure that the demand signal clearly targets the innovative technologies needed for a net zero energy system. It is framed in a technology-neutral format to allow different solutions from hydrogen direct reduction to electrolysis to CCUS. Standards for near- or fully zero-carbon materials and durable carbon removal in other sectors covered by the FMC have been developed through similar collaborative pathways. The FMC standard is already having an impact: companies joining the FMC steel commitment have pledged that by 2030, 10% of their purchases of steel will be near zero emission steel, as defined by the FMC threshold.

Forthcoming thresholds

SteelZero – an initiative lead by Climate Group in partnership with ResponsibleSteel – is in the process of establishing quantitative thresholds for "Net Zero," "Near Zero" and "Lower Embodied Carbon" steel. The production phase for crude steel is the focus of the definition (in line with the First Movers

Coalition approach). The final draft of the definition is not yet published, as the framing will be based on the ResponsibleSteel Standard which is due to be formally ratified and published in June 2022. Current indications suggest the thresholds will cover all major greenhouse gas emissions (CO_2/CH_4/N_2O) – both direct and indirect – and account for the quantities of scrap and iron ore used in production. A threshold value for near zero steel of 400-500 $kgCO_2e$ per tonne of crude steel production for 100% iron-based production has been suggested, with a sliding scale down to 50-100 $kgCO_2e$ per tonne for 100% scrap-based production – defined on a Scope 1 + Scope 2 + upstream Scope 3 emissions basis. SteelZero is awaiting the finalisation of the ResponsibleSteel Standard and expects to align its thresholds with ResponsibleSteel performance levels when available.

ConcreteZero, a forthcoming sibling initiative of SteelZero, is led by Climate Group in partnership with WBCSD and WorldGBC. The initiative aims to substantially reduce emissions in the cement and concrete industries by bringing together a series of actors committed to using, procuring, or specifying net zero concrete. By requiring participants to publicly commit to agreed procurement targets, ConcreteZero aims to create a market for concrete produced with net zero emissions, whether using Portland cement or alternative binding agents. The initiative is scheduled to launch in June 2022, with the members having defined the minimum criteria to support best practice in materials assessment and work to improve data accuracy, transparency and accountability across the supply chain. With a focus on the CO_2 emissions intensity of concrete, the group is adopting the benchmark defined in the Low Carbon Concrete Group Routemap published by the Institution of Civil Engineers (ICE), from which it will decide on the ConcreteZero Low Embodied Carbon Threshold to support 2025 and 2030 carbon intensity targets. The commitment framework and benchmarks are also scheduled to be made public in June 2022.

The Industrial Deep Decarbonisation Initiative (IDDI) of the Clean Energy Ministerial (CEM) brings together a coalition of governments, think tanks and private sector actors to work on decarbonisation of the industry sector. The IEA hosts the CEM, and actively participates in certain elements of the IDDI work streams; the United Nations Industrial Development Organization (UNIDO) co-ordinates the work of the initiative. The substantive work of the initiative is divided into three working groups: WG1 (chaired by the UK) is exploring the topics of data and reporting; WG2 (chaired by Germany) is examining low carbon standards, including the interoperability of existing measurement standards; and WG3 (chaired by Canada) will look at green procurement. WG2 plans to produce definitions of green steel, cement and concrete later in 2022.

Toward common definitions

In this section we propose definitions for near zero emission steel and cement production. While we have identified a need to refine existing measurement standards (see above), it is not necessary to reinvent protocols for measuring the emissions intensity of steel and cement production. The thresholds proposed below are intended to be compatible with the principles of existing measurement routines (e.g. ISO standards) and internationally recognised emission accounting frameworks (e.g. IPCC emission inventory guidelines). However, some important modifications to existing measurement standards would be required to facilitate the inclusion of specific emissions categories that are generally outside their current scope (e.g. upstream fossil fuel supply emissions) but included in the thresholds we propose.

The definitions we develop are for "near zero emission material production" for crude steel and cement. The aim is not to establish product-focused definitions, whether intermediate (e.g. cold-rolled coil or precast floor slab) or final (e.g. a vehicle or a building) products. However, we envision the proposed definitions forming the basis for such product- or project-focused definitions established in future work.

The rationale for establishing the definitions in this report stems from the commitments of G7 members and other countries to achieving net zero emissions from their energy systems and economies. Definitions can form a basis for a common vision of a final destination for steel and cement production in a sustainable future for the energy system. The definitions are also tools for evaluating proposed technologies and strategies for how to get there. As such, we have aimed to provide as much detail as needed for the definitions to be used in practice, but no more prescription than is necessary to remain technology neutral. The definition is not intended to imply the use of a specific technology, exclude a specific technology, denote a specific carbon content or rule out any solutions that leave behind residual emissions. We have aimed to take note of existing efforts underway to develop definitions for near zero (or similarly defined) steel and cement production, targeting compatibility and common principles wherever possible.

Alongside these over-arching principles, we identify three core reasons for developing common definitions of near zero emission materials production:

- Forming a basis for differentiated product markets that enables producers to sell at a premium and build consumer trust

- Facilitating targeted policy support for specific near zero emission technologies and measures
- Tracking how much near zero steel and cement is produced in a given region or time period

The analytical basis for the quantitative thresholds emerges from the IEA's scenario analyses of the potential pathways to deliver on these goals, notably the IEA's Net Zero by 2050 Roadmap. The Net Zero Emissions by 2050 Scenario is *one* pathway to net zero – not necessarily *the* pathway. It is situated within the mainstream of the scientific literature with respect to its implications for CO_2 emissions from end-use sectors: they must fall drastically if net zero is to be reached, with residual emissions being offset by carbon removal technologies in electricity and fuel transformation sectors. Small quantities of hard-to-abate emissions – including those from heavy industry sectors – remain in 2050 under the Net Zero Emissions by 2050 Scenario. This is because the emissions intensities of the technologies used, based on what we know about them today, are non-zero. The emissions intensity threshold values we have proposed in this report for steel and cement production constitute the upper limit of what we evaluate as compatible with the long-term goals of this scenario context.

It is important to evaluate the definitions in line with what they are intended to achieve, and conversely, with what they are not. For instance, they are not intended to address all the challenges associated with transforming the emissions of today's intensive heavy industry sectors, into the net zero heavy industry sectors that we need for a more sustainable future. They will not form substitutes for policies that target or create incentives for incremental energy efficiency gains, say, or material efficiency and over-capacity – even if they are complementary to such efforts. Common definitions are just one – albeit very important – component of the broader policy approach that is needed (see Chapter 2).

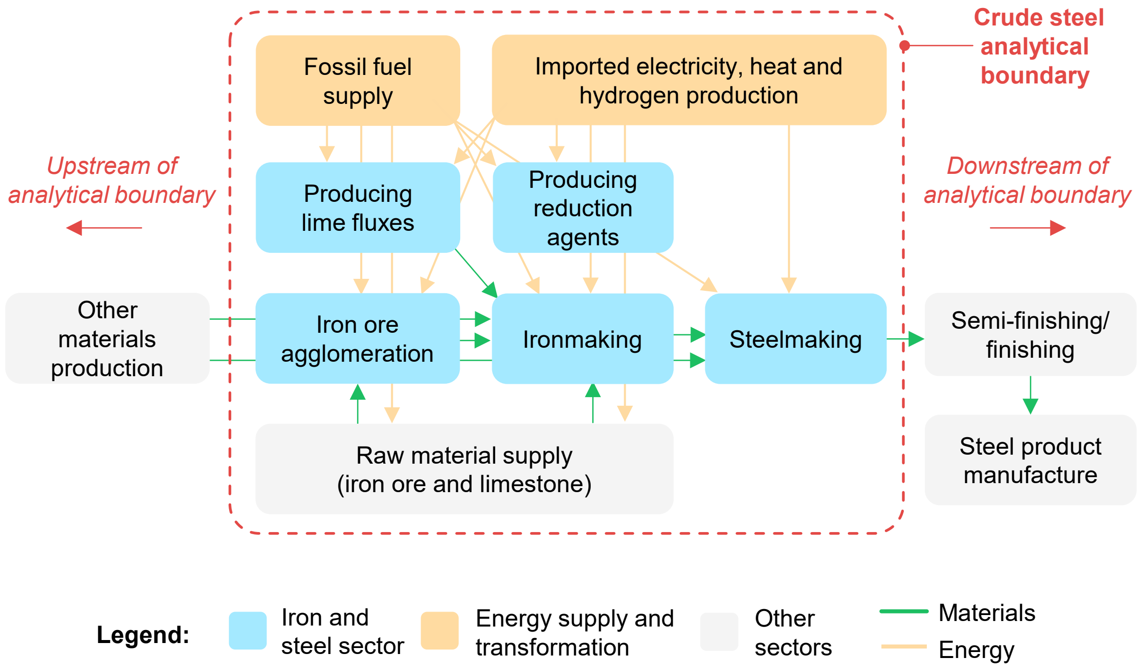
Near zero emission steel production

Analytical boundaries

There are two main components to the analytical boundaries adopted in establishing a definition of near zero emission steel production: the supply chain boundary and the emissions scope. There is no objective basis for drawing the supply chain boundary at a given point. If the supply chain boundary is drawn too narrowly around core process steps (e.g. ironmaking), there is a risk that factors that may differentiate the overall steel supply chain emissions using different technologies would be neglected. If the boundary is drawn too widely, it may dilute the focus on the most emissions-intensive process steps and/or become impractical to implement.

The upstream end of the supply chain boundary encompasses the supply and processing of the main raw material input to steelmaking: iron ore. Mining (including extraction, transportation and beneficiation) and agglomeration processes are both included within the scope. The sorting and transportation of steel scrap is not included, due to data constraints, nor are the production processes for other material inputs to the steelmaking process (e.g. producing refractory linings for furnaces, ferroalloy production). The supply of limestone (to produce lime fluxes) is included within the boundary, for consistency with the raw materials scope of the cement production definition (see below), although the quantities of limestone (and its derivatives) used in the steel industry are comparatively small.

Figure 3.1 Analytical boundary for defining near zero emission steel production



Notes: "Other materials production" refers to the production of material inputs to the iron and steel sector besides iron ore and limestone, including electrodes, alloying elements and refractory linings.

The boundary of the downstream end of the supply chain is set at crude steel production – including casting but excluding any further semi-finishing and finishing processes because the heterogeneity of processes at facilities producing different products. Our proposed definition of crude steel production could also form the basis for definitions of steel products (rebar, hot-rolled coil, stainless steel etc.) in combination with specific considerations for the additional processing steps required.

This supply chain boundary is wide enough to capture the main emissions-intensive steps of steel production – notably ironmaking – and narrow enough to avoid unwieldly data requirements and circular allocation in emissions accounting. The functional unit in our analysis – the denominator of the emissions intensity – is one tonne of crude steel production.

Both direct and indirect emissions from steel production are addressed in our proposed analytical boundaries. It is not possible to be entirely comprehensive in the consideration of indirect emissions, as an endless chain of emissions allocation can be established via the energy and material inputs (and outputs) to the sector, even when adhering to the supply chain boundaries described in Figure 3.1. These material and energy inputs in turn each have their own direct and indirect emissions, and so a cut-off must be made.

It would also be inappropriate to exclude indirect emissions from the definitions entirely. Several of the core process steps that result in direct emissions with conventional process technologies (e.g. producing coke using coal) may instead lead to indirect emissions with innovative technologies that can achieve a step change in emissions intensity (e.g. producing hydrogen using electricity).

The sources of direct CO_2 emissions covered by our emissions boundaries are a subset of the emissions stemming from the energy use within the iron and steel sub-sector (final energy consumption), as well as coke ovens and blast furnaces (primary energy transformation), as defined by the IEA World Energy Balances:

- **Fossil fuel use in iron ore agglomeration (direct energy-related CO_2 emissions)**, including any coke, coal and natural gas that are used in sintering and pelletising processes.
- **Fossil fuel use in ironmaking (direct energy-related CO_2 emissions[2])**, including the coke, coal and natural gas used in blast furnaces, DRI furnaces or in innovative ironmaking process units, including CCUS equipment. Carbon-containing off-gases generated during this step in the process are accounted for separately below.

[2] Emissions from ironmaking can be allocated across both energy-related and industrial process CO_2 emission categories, as the same fuels are used to generate heat and chemically reduce the iron ore. For simplicity, all emissions from ironmaking are classified as energy-related emissions.

- **Fossil fuel use in steelmaking (direct energy-related CO_2 emissions)**, including any coal, coke and natural gas that are introduced into oxygen blown converters and electric furnaces.
- **Producing reduction agents (direct energy-related CO_2 emissions)**, including the emissions generated during coke production with conventional routes today, and the emissions associated with any on-site hydrogen production for innovative process routes.

In addition to these direct energy-related emissions, a non-exhaustive series of industrial process emissions and indirect energy-related emissions are included, with the aim of striking a balance between comprehensiveness and practicality:

- **Lime fluxes and electrodes (direct industrial process CO_2 emissions)**, including the emissions associated with using lime fluxes that form slag and remove impurities, whether slaked lime, burnt lime, limestone or dolomite. The use of lime fluxes results in direct emissions when the calcination reaction takes place in a process unit within the iron and steel sector, and indirect emissions when this reaction takes place off-site, in the non-metallic minerals sector. Electrodes lead to small quantities of direct emissions during use in electric furnaces. For simplicity, these emissions are all classified as direct for the purposes of these definitions.
- **Off-gases (direct energy-related CO_2 emissions),** including coke oven gas, blast furnace gas and basic oxygen furnace gas, which result in direct emissions when the non-CO_2 components of these carbon-containing gases (mainly carbon monoxide) are combusted to generate heat on-site, and indirect emissions when they are used to produce electricity. For simplicity, these emissions are classified as direct for the purposes of these definitions. See the IEA’s Iron and Steel Technology Roadmap for more information on the energy accounting conventions for off-gases.
- **Imported electricity, heat and hydrogen (indirect energy-related CO_2 emissions)**, which includes the fossil fuel emissions associated with their production.
- **Fossil fuel supply (indirect energy-related CO_2 and CH_4 emissions)**, including the emissions associated with the production, processing and transportation of fossil fuels.
- **Raw materials supply (indirect energy-related CO_2 emissions)**, including the emissions associated with the extraction, beneficiation and transportation of iron ore and limestone.

Direct methane emissions and nitrous oxide emissions are not included within the analytical boundary due to lack of sufficient data, but they are estimated to be a minute fraction of the emissions covered by the categories above. Emissions associated with the production of other material inputs to the process of steelmaking, such as alloying elements, refractory linings, electrodes, de-oxidising – as well as their transport – are not included, due to a lack of sufficient data. Future efforts to build upon these definitions could opt to include these sources of emissions – in addition to others – while remaining compatible with the core analytical scope and thresholds proposed in this document, provided there is some foreseeable method for their mitigation. As discussed above, further work is needed to consolidate and refine existing measurement standards, such that a universal analytical boundary can be established for steel production. The emissions categories above are proposed as a starting point for these efforts.

While helpful for assigning varying levels of responsibility for emissions at the site or company level – and in widespread usage – we do not use the terminology of the (see above). We have chosen instead to be explicit about the sources themselves. To take emissions associated with pellet production as an example, these could be Scope 1 emissions at one site, and Scope 3 at another site with a different process arrangement (e.g. using purchased pellets, produced off-site), with both sites having the same overall emissions intensity of steel production. This notwithstanding, the analytical boundaries and emissions categories specified above can be evaluated using the GGP emissions categories and measurement standards based on them. The emissions categories proposed are also compatible with the IPCC's guidelines for compiling national emissions inventories. The explicit nature of the categories proposed facilitates cross-sector and cross-region accounting of emissions, where double counting must be avoided.

Near zero emission intensity thresholds

The near zero emission intensity threshold proposed for crude steel production is formulated as a function of the proportion of scrap use in the total metallic inputs. The more scrap that is used, the lower the threshold, as the use of scrap in steelmaking inherently reduces emissions intensity and its use is already well-incentivised. An alternative approach would be to neglect scrap entirely and focus on ironmaking, but this definition would leave roughly one-quarter of the world's crude steel production unaddressed. Users of the proposed thresholds may choose to specify a range of scrap use to distinguish between primary and secondary near zero emission crude steel production. No universally accepted threshold of scrap use has been identified for such a sub-division. We propose 30% scrap use as the cut-off below which primary near zero emission production could be explicitly recognised. The threshold values we propose would remain the same, regardless of where this cut-off is made.

The threshold is stipulated on a sliding scale between zero and 100% scrap use. For crude steel production with zero scrap use (iron ore provides all the metallic inputs) the proposed threshold is 400 kg of CO_2 equivalent per tonne ($kgCO_2e/t$) of crude steel (see Table 3.1). This compares to IEA reference values of 2 945 $kgCO_2e/t$ for a pulverised coal injection blast furnace-basic oxygen furnace (PCI BF-BOF) plant and 1 485 $kgCO_2e/t$ for a natural gas direct reduced iron-electric are furnace (NG DRI-EAF) plant, assuming best available technology (BAT) energy performance levels (see Box 3.3 for an explanation of the IEA reference values used in this document). The near zero emission production threshold is not derived as a function of these reference values, which are shown only for context and to clarify the analytical boundaries.

Table 3.1 Thresholds for near zero emission crude steel production with zero scrap use, relative to conventional process technology

<table>
<tr><th rowspan="2">Emissions source</th><th colspan="2">IEA reference values ($kgCO_2e/t$ crude steel)</th><th colspan="2">Near zero emission production thresholds ($kgCO_2e/t$ crude steel)</th></tr>
<tr><th>PCI BF-BOF</th><th>NG DRI-EAF</th><th>Direct</th><th>Direct + indirect</th></tr>
<tr><td>Fossil fuel use in iron ore agglomeration</td><td>235</td><td>40</td><td rowspan="6">400</td><td rowspan="9">400</td></tr>
<tr><td>Producing reduction agents</td><td>110</td><td rowspan="2">700</td></tr>
<tr><td>Fossil fuel use in ironmaking</td><td>590</td></tr>
<tr><td>Fossil fuel use in steelmaking</td><td>0</td><td>25</td></tr>
<tr><td>Lime fluxes and electrodes</td><td>70</td><td>50</td></tr>
<tr><td>Off-gases</td><td>1 320</td><td>0</td></tr>
<tr><td>Imported electricity, heat and hydrogen</td><td>105</td><td>375</td><td>N/A</td></tr>
<tr><td>Fossil fuel supply</td><td>435</td><td>210</td><td>N/A</td></tr>
<tr><td>Raw material supply</td><td>80</td><td>80</td><td>N/A</td></tr>
<tr><td>Total</td><td>2 945</td><td>1 485</td><td>400</td><td>400</td></tr>
</table>

Notes: PCI BF-BOF = blast furnace-basic oxygen furnace with pulverised coal injection; NG DRI-EAF = natural gas-based direct reduced iron-electric arc furnace. All values rounded to the nearest 5 $kgCO_2e/t$. See Box 3.3 for a description of the IEA reference values used in this document.

For crude steel production with 100% scrap inputs (zero iron ore use for metallic inputs), the proposed threshold value is 50 $kgCO_2e/t$ of crude steel (see Table 3.2). This compares to an IEA reference value of 285 $kgCO_2e/t$ for a Scrap

EAF plant, assuming BAT energy performance levels (see Box 3.3 for an explanation of the IEA reference values used in this document). As with the zero scrap use threshold value, the 100% scrap use value is not derived as a function of this reference, which is just shown to clarify the analytical boundaries and provide context.

The emissions boundaries to which the thresholds apply include both direct and indirect emissions. While this is beneficial to incentivise a holistic approach to reducing emissions along the supply chain, it is acknowledged that there is a distinction between which emissions a steel producer will have direct control over in most instances, and those where they will not. We split the threshold for steel production into two further sub-thresholds: "Near zero direct emissions" and "Near zero direct + indirect emissions." These two sub-thresholds have the same value, as the categories of indirect emissions included must trend toward near zero in the long term.

Table 3.2 Thresholds for 100% scrap-based near zero emission steel production relative to conventional process technology

<table>
<tr><th rowspan="2">Emissions source</th><th>IEA reference values (kgCO₂e/t crude steel)</th><th colspan="2">Near zero emission production thresholds (kgCO₂e/t crude steel)</th></tr>
<tr><th>Scrap EAF</th><th>Direct</th><th>Direct + indirect</th></tr>
<tr><td>Fossil fuel use in iron ore agglomeration</td><td>0</td><td rowspan="6">50</td><td rowspan="9">50</td></tr>
<tr><td>Producing reduction agents</td><td>0</td></tr>
<tr><td>Fossil fuel use in ironmaking</td><td>0</td></tr>
<tr><td>Fossil fuel use in steelmaking</td><td>30</td></tr>
<tr><td>Lime fluxes and electrodes</td><td>25</td></tr>
<tr><td>Off-gases</td><td>0</td></tr>
<tr><td>Imported electricity, heat and hydrogen</td><td>220</td><td>N/A</td></tr>
<tr><td>Fossil fuel supply</td><td>5</td><td>N/A</td></tr>
<tr><td>Raw material supply</td><td><5</td><td>N/A</td></tr>
<tr><td>Total</td><td>285</td><td>50</td><td>50</td></tr>
</table>

Notes: EAF = electric arc furnace. All values rounded to the nearest 5 $kgCO_2e/t$. See Box 3.3 for a description of the IEA reference values used in this document.

The sub-division of the near zero emission threshold means that efforts to address the emissions over which plant operators have most control are recognised in the absence – or in advance – of a full transition taking place for the energy system. Even in the IEA's Net Zero Emissions by 2050 Scenario, the electricity sector does not achieve net zero emissions until 2035 in advanced economies, and 2040 in emerging market and developing economies. For producers, countries and regions where electricity sector decarbonisation is already well-advanced or where rapid progress is made in the short and medium terms, the additional level of recognition is provided by the “Near zero direct + indirect emissions” category. In the longer term, all efforts should be targeting this sub-threshold.

Box 3.3 IEA reference values for process route characterisations

Throughout this report, emissions intensities of specific process routes for steel and cement production – referred to as “IEA reference values” – are used to provide illustrative quantities and clarify the boundaries associated with the thresholds proposed. It is important to note that the IEA reference values do not constitute the analytical basis for the thresholds (see above for an explanation of the rationale and analytical basis). Some components of these reference values (e.g. the CO_2 intensity of electricity generation) are subject to change over time and across regions. Global results from the IEA’s Net Zero Emissions by 2050 Scenario are therefore only used to illustrate the impact of these changes on the reference values, in the context of an energy system pathway toward net zero emissions.

Direct CO_2 emissions from fossil fuel combustion and industrial process emissions are calculated based on the IEA’s bottom-up modelling of the iron and steel and cement sectors. Best available technology energy performance levels are used for all relevant parameters. The underlying data for these parameters are gathered from a wide range of literature sources, and periodically reviewed by external experts, including for this publication. IEA bottom-up and sectoral estimates for emissions quantities are similar to those published by the global industry associations for the steel (worldsteel) and cement (GCCA) sectors, once adjusted for slight differences in boundary considerations. The modelling conducted at the IEA for these sectors has benefitted from many years of working level interaction, review and data comparisons carried out with these organisations, among others. It should be noted that the IEA values do not include emissions credits for exported energy products or site-specific counterfactuals where emissions may be avoided elsewhere.

Three categories of indirect emissions are included in the IEA reference values for emissions intensities used in this report: imported electricity, heat and hydrogen; fossil fuel supply; and raw material supply. For indirect emissions associated with imported electricity, heat and hydrogen, global average values from the IEA’s bottom-up electricity sector modelling for the Net Zero Emissions by 2050 Scenario are used for the IEA reference process characterisations. These indirect emissions will depend on the actual source of the electricity used on a given site, in a given region, over a given time period. The global average CO_2 intensity of electricity generation declines to around 140 gCO_2/kWh in 2030 and drops below zero around 2040 in the Net Zero Emissions by 2050 Scenario, relative to a value of around 440 gCO_2/kWh for 2020.

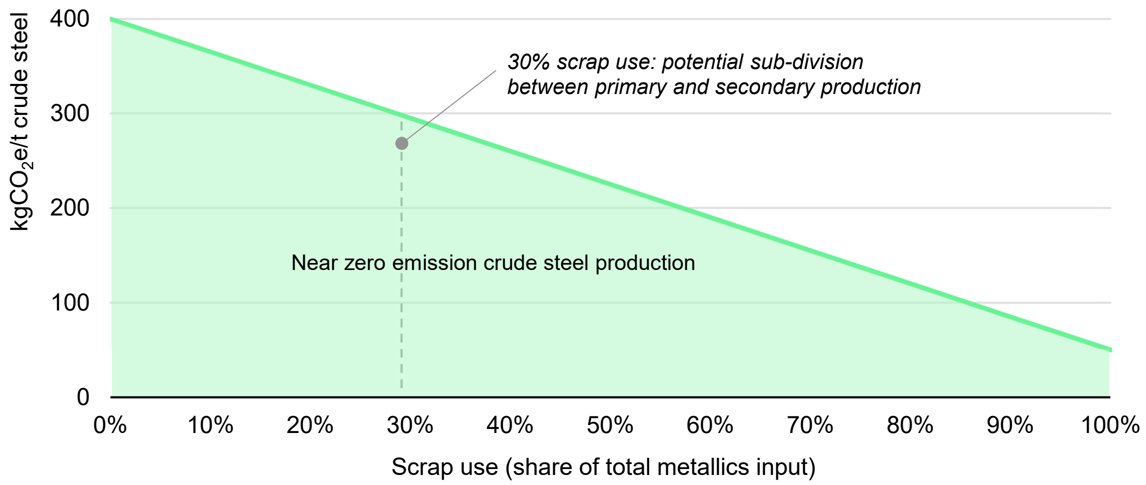
Indirect emissions from the supply of fossil fuels include emissions from the extraction, processing and transportation of coal, oil and natural gas, including methane emissions and flaring, are derived from IEA analysis (see Box 1.1). The latest values for methane emissions are summarised in the 2022 edition of the IEA’s Methane Tracker. Like those for electricity, the actual emissions intensities of a given unit of fossil fuel will depend on the source: there is huge variation between individual operations and countries. For the IEA reference values used in this report, global average emissions intensities (per unit of energy for each fuel) are computed and applied according to their trajectory in the Net Zero Emissions by 2050 Scenario.

Raw material supply emissions, specifically those associated with the mining, beneficiation and transportation of iron ore and limestone, are not currently disaggregated in the IEA’s bottom-up modelling of the sectors where they occur as direct emissions (the mining and quarrying sub-sector in the industry sector, the road, maritime and aviation modes in the transport sector). Current global average emissions intensity values (per tonne of iron ore and limestone) from external data sources – the worldsteel Life Cycle Inventory study report and the CRU Emissions Analysis Tool – are used for these values. As with the other indirect emissions categories, these quantities would vary from site to site, warranting in-depth analysis of individual supply chains. The quantities are projected forward using a function of the emissions trajectories of the sub-sectors above in the Net Zero Emissions by 2050 Scenario.

“Negative emissions,” generated using carbon removal technologies such as bioenergy with carbon capture utilisation and storage (BECCS) and direct air capture (DAC), are not allocated between sectors in the process route characterisations used in this report. In other words, the minimum emissions intensity of electricity, hydrogen or any other vector for allocating indirect emissions, is zero. Where these technologies are applied in the context of direct emissions (e.g. a BECCS or DAC technology used on-site in a steel or cement plant), the subtractive impact on emissions intensity *is* considered when computing the reference values.

Figure 3.2 summarises the near zero emission crude steel production threshold for the full spectrum of scrap use (zero to 100%). This simple graphical function is described explicitly in the Technical Annex. **The threshold is stable, absolute and ambitious.** It is **stable** because it is not dependent on a single scenario context that is subject to frequent revision, and it is compatible with the end goal of the Net Zero Emissions by 2050 Scenario as well as other IEA net zero energy system scenarios. It is **absolute** because there are no varying degrees of near zero; in other words, it is binary. Finally, it is **ambitious**: the intention is to send a clear signal of what needs to be achieved in the long term, in a sector where returns on investments take place over decades. A commercial-scale plant built in the coming few years that operates at or below this threshold will remain so in perpetuity, unless the threshold itself is revised. The threshold does not address the degrees of incremental progress that are made on the way to meeting them. For this purpose, we propose a separate evaluation for interim measures that result in meaningful emissions intensity reductions but fall short of the near zero emission threshold (see below).

Figure 3.2 Near zero emission crude production threshold as a function of scrap use



Notes: See the Technical Annex for the specific function used to formulate the series on the graph.

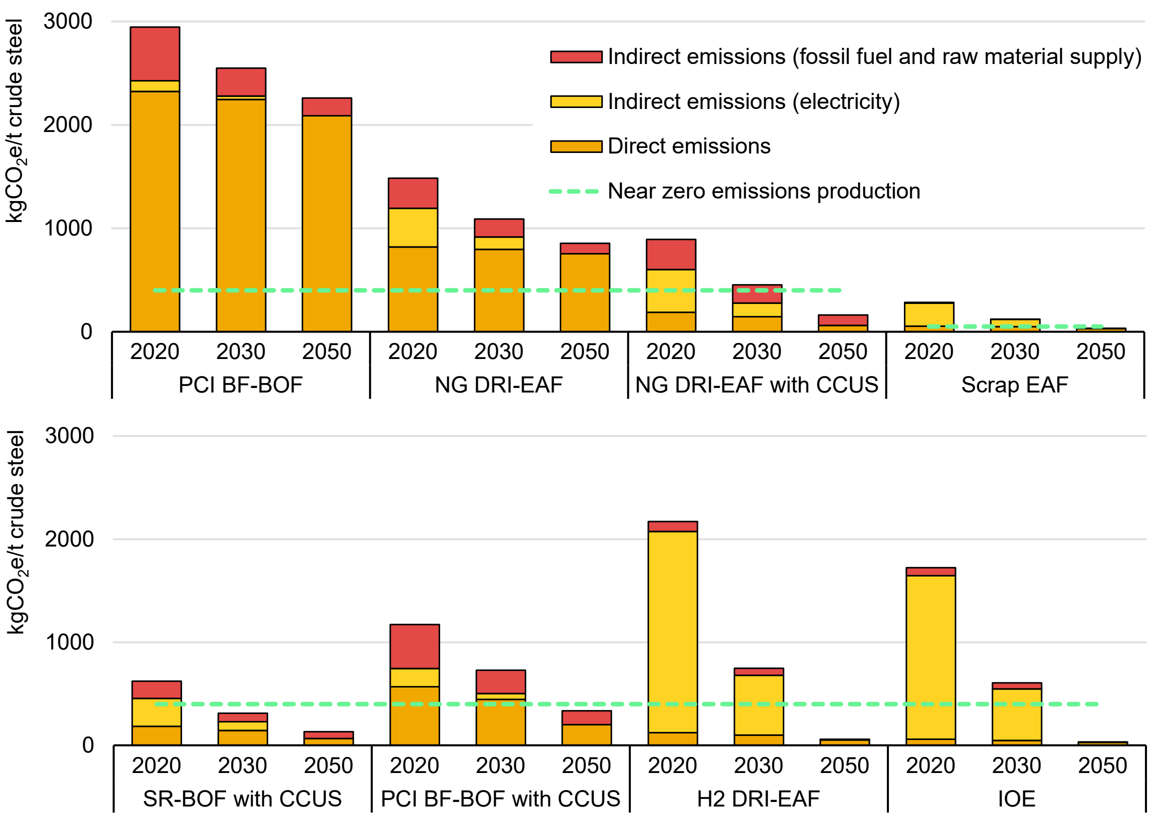
Applying the definitions

In this section we apply the near zero steel production definitions to a series of specific process route characterisations, using both conventional and innovative technologies. Global average values from the Net Zero Emissions by 2050 Scenario are used to illustrate the impact of parameters that vary over time and between geographies – the CO_2 intensity of electricity generation, changes in fuel inputs and the efficiency of key pieces of equipment like electrolysers and CO_2 capture processes. (See Box 3.3 for a description of the IEA reference values used in this document.)

The three major production pathways using conventional technology to produce steel today show very differing emissions intensity trajectories over the time horizon and scenario context examined. The emissions intensity of the PCI BF-BOF route declines by only 13% by 2030 and 23% by 2050, relative to its starting value of 2 945 kgCO_2e/t. The very small amount of imported electricity used in

BAT facilities of this type contributes marginal declines as the electricity sector decarbonises and the agglomeration processes switch over time to the use of low-emissions fuels (bioenergy and hydrogen partially displace the use of fossil fuels) in the Net Zero Emissions by 2050 Scenario. The result is that it falls well-short of reaching the near zero emission threshold. The other major route for primary production today – the natural gas-based DRI-EAF route – sees more substantial percentage reductions in emissions intensity over time, from a lower starting point today, of around 1 485 $kgCO_2e/t$. This is because electricity forms a larger share of the energy inputs relative to the BF-BOF route, particularly with respect to the steelmaking step, which proceeds via an electric furnace. Nonetheless, this route also falls short of reaching the near zero emission production threshold in the Net Zero Emissions by 2050 Scenario.

Figure 3.3 Global average direct and indirect emissions intensities of crude steel production via key pathways in the Net Zero Emissions by 2050 Scenario



Notes: PCI BF-BOF = blast furnace-basic oxygen furnace with pulverised coal injection; DRI-EAF = natural gas-based direct reduced iron-electric arc furnace; Scrap EAF = scrap-based electric arc furnace; SR-BOF = innovative smelting reduction-basic oxygen furnace; CCUS = carbon capture utilisation and storage; H2 = hydrogen-based; NG = natural gas-based; IOE = iron ore electrolysis. BAT energy intensities used for all process units. All process routes use zero scrap, apart from the Scrap EAF route, which uses 100% scrap. The near zero emission production thresholds are imposed on a direct + indirect emissions basis. See Box 3.3 for a description of the IEA reference values used in this document.

The scrap EAF route follows a different trajectory among the process routes utilising conventional technologies, as the majority of its energy inputs are in the form of electricity. Already in 2030, based on the global average emissions intensity trajectory of the Net Zero Emissions by 2050 Scenario, the pathway is operating quite close (120 $kgCO_2e/t$) to the near zero emission production threshold (50 $kgCO_2e/t$, with 100% scrap use) in absolute terms, compared with its reference value of 285 $kgCO_2e/t$ in 2020. By 2050, when the global electricity system is fully decarbonised under the Net Zero Emissions by 2050 Scenario, the scrap EAF route is well below the threshold. This emphasises the importance of progress being made in the power sector – or the use of captive low-emissions electricity generation – for this route, which would not decarbonise sufficiently on a global average basis to meet the threshold (assuming current trends and announced policies). In regions where the electricity grid is already decarbonised today, or where captive sources of renewable electricity generation are used, the scrap EAF route could already reach the near zero emission production threshold, if a small portion of the fossil fuel inputs were substituted with low-carbon fuels (e.g. bioenergy, hydrogen or additional electricity).

Two sub-categories among the innovative technologies – all of which fall under the near zero emission production threshold in the long term – can be identified: those retaining carbon as the primary means of chemically reducing iron ore, and those that do not. In the former category, the reductions in emissions intensity are achieved through capture of the CO_2 emissions generated using CCUS technologies. This results in large and immediate reductions in emissions intensity relative to their unabated counterparts in the Net Zero Emissions by 2050 Scenario: around 60% to 70% by 2030, and 80% to 85% by 2050. While most of the technical modifications needed to achieve these emissions reductions impact direct emissions, it should be noted that they are contingent upon a secure source of sequestration, including the CO_2 transport and storage infrastructure required. The NG DRI-EAF with CCUS route – a technology deployed at commercial scale today – could achieve the near zero emission production threshold, provided the indirect emissions from its electricity and fossil supplies were mitigated.

The innovative production pathways that replace the carbon-based reduction agents with hydrogen and electricity – the H2 DRI-EAF and IOE routes – achieve the lowest emissions intensities in the longer term, but take longer to reach the near zero emission threshold with the global average parameters used from the Net Zero Emissions by 2050 Scenario. This is because the emissions reductions mainly take place indirectly, and they require a substantially decarbonised electricity sector before their emissions intensities drop below those of the routes equipped with CO_2 capture, or even those of conventional routes today. As with the CO_2 capture-equipped process routes, the reductions in emissions intensity achieved via these two pathways necessitate substantial infrastructure development. In these cases, this is to enable low emission electricity and hydrogen production, together with the related transmission and distribution equipment if these energy carriers are sourced from centralised grids. A captive supply of low emission electricity and/or hydrogen along with any storage requirements – or a grid CO_2 intensity that declines faster than the global average – could yield lower emissions intensities of production for these routes much sooner than 2050.

Near zero emission cement production

Analytical boundaries

As with steel production, there are two main components to the analytical boundaries adopted for cement production: the supply chain boundary and the emissions boundary. The most emissions-intensive step of producing cement is clinker production. If the supply chain boundary is drawn too narrowly around clinker production, there is a risk that the emissions associated with producing substitutes may be neglected. If the boundary is drawn too widely, say around concrete, it may dilute the focus on the emissions from clinker production (see Box 3.4).

Box 3.4 Cement production vs. concrete products

Concrete is a composite material composed of cement, aggregates, water and various chemical additives. By weight, it is the most abundant synthetic material on earth today. The most emissions-intensive step – by far – in producing concrete is cement production, for which in turn the most emissions-intensive ingredient – by far – is clinker. Few market-ready near zero emission production pathways for cement exist today and these involve higher costs relative to incumbent technologies. There is a clear need for a definition addressing cement specifically, given its market size of more than 4 billion tonnes in 2020 (2.3 Gt direct CO_2 emissions) and the substantial volumes of production that are all but guaranteed for several years to come. Our analytical boundaries are therefore focused on cement production, taking specific note of the clinker content in the cement produced.

Concrete and concrete products are the final destination for virtually all cement. This extra step in the value chain could be included as part of the near zero production definition, thereby providing a holistic definition of "near zero emission concrete production." One key argument is that this extension in scope would take account of the CO_2 that is sequestered during the curing and use phase of concrete (reducing the overall emissions intensity of the value chain). Moreover, the wider analytical boundary could encompass the use of alternatives to cement in concrete, such as geopolymer materials.

Drawing a wider boundary comes with trade-offs, however. The amount of CO_2 sequestered in concrete during curing and use is highly dependent on the local conditions and techniques used. Attributing a standard emission – or sequestration – factor that applies cumulatively over the use-phase, and making their emissions (or reductions) fungible with those that take place instantaneously during the production-phase, risks becoming a distraction from clinker production – the main process that earns the cement industry its "hard to abate" designation. This is not to discount the increasingly recognised impact of carbonation over the lifetime of cement and concrete products, but rather to maintain a distinction between the production- and use-phase emissions associated with heavy industry sectors and their products.

Current proposals to substitute cement entirely face technical challenges. Some alternatives that achieve substantial reductions in the emissions intensity of production compared to ordinary clinker are at relatively early stages of technological development (e.g. magnesium oxides derived from magnesium silicates). The alternatives that are available today tend to face competition for supply of their raw materials, do not avoid emissions from clinker production entirely, and in some cases can only be used for specific applications (e.g. carbonation of calcium silicates, alkali-activated binders). Moreover, if a given cement alternative requires markedly different production processes and supply chain considerations, it merits its own production-phase definition of "near zero" similar to those we have developed for cement and crude steel.

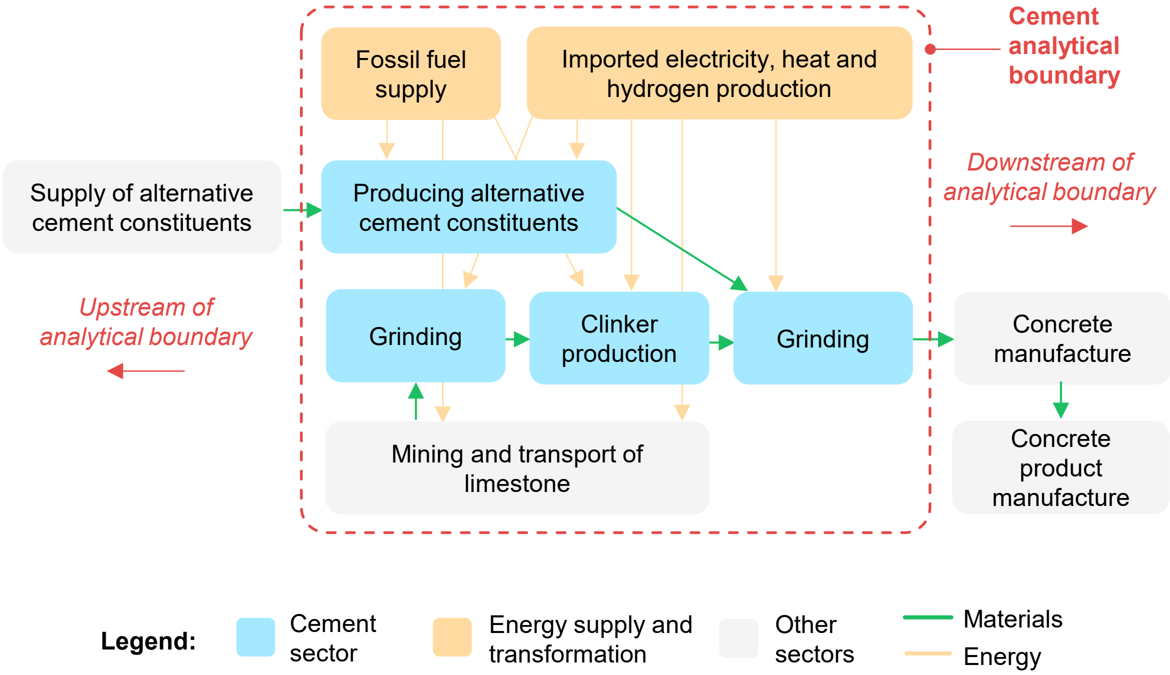
This is not to say that concrete product definitions should not continue to be developed. Such product definitions – and analogous definitions for products made from crude steel – will be integral to the creation of lead markets for final products with substantially decarbonised supply chains. The definitions developed for cement production in this report can form the basis for cement-containing product definitions. Similarly, the definitions for cement and crude steel could together be used as the basis for steel reinforced concrete product definitions.

The supply chain boundary encompasses clinker production, the production of alternative cement constituents, and the grinding that takes place before and after the kiln. The boundary also includes the emissions associated with the mining and transportation of the main raw material that goes into cement production:

limestone. The boundary excludes the emissions from producing alternative cement constituents if they are produced directly as a co-product of an industrial process (e.g. ground granulated blast furnace slag) or a power plant (e.g. fly ash).

At the downstream end of the boundary, concrete making and all concrete products manufacturing is also excluded. This supply chain boundary is wide enough to capture the main emissions-intensive steps of cement production – notably clinker production – and narrow enough to avoid unwieldy data requirements and circular allocation in emissions accounting. The functional unit in our analysis – the denominator of the emissions intensity – is one tonne of cement production.

Figure 3.4 Analytical boundary for defining near zero emission cement production



Both direct and indirect emissions from cement production are addressed in our proposed analytical boundaries. It is not possible to be comprehensive in the consideration of indirect emissions, as an endless chain of emissions allocation can be established via the sector's energy and materials inputs (and outputs), even when adhering to the supply chain boundaries described in Figure 3.4. Each of these materials and energy inputs in turn have their own direct and indirect emissions, and so a cut-off must be made.

As with the emissions boundaries for steel production, it would also be inappropriate to exclude indirect emissions from the definitions entirely. Several of the core steps that result in direct emissions with conventional process technologies (e.g. heating the cement kiln) may instead lead to indirect emissions with innovative technologies that can achieve a step change in emissions intensity (e.g. heating the kiln using electricity).

The sources of direct CO_2 emissions covered by our emissions boundaries include a subset of the emissions stemming from the energy use within the non-metallic minerals sub-sector (final energy consumption), as defined by the IEA World Energy Balances:

- **Fossil fuel use in clinker production (direct energy-related CO_2 emissions)**, including any coal, oil products, natural gas and non-renewable waste that are used to generate the heat required in cement kilns, including CCUS equipment.
- **Fossil fuel use in alternative cement constituent production (direct energy-related CO_2 emissions)**, including any coal, oil products and natural gas used directly in their production, except where they are produced as a by-product of another industrial process (e.g. ground granulated blast furnace slag).

In addition to these direct energy-related emissions, a non-exhaustive list of industrial process emissions and indirect energy-related emissions are included, with the aim of striking a balance between comprehensiveness and practicality:

- **Calcination (direct industrial process CO_2 emissions),** referring specifically to the portion of emissions generated within a kiln that arise from producing clinker from limestone.
- **Imported electricity, heat and hydrogen (indirect energy-related CO_2 emissions),** including the fossil fuel emissions associated with their production, whether used for thermal (e.g. kiln heating) or non-thermal (e.g. grinding) applications.
- **Fossil fuel supply (indirect energy-related CO_2 and CH_4 emissions)**, including the emissions associated with the production and distribution of fossil fuels, allocated on a global average basis.
- **Raw materials supply (indirect energy-related CO_2 emissions)**, including the emissions associated with the extraction, beneficiation and transportation of limestone.

Direct methane emissions and nitrous oxide emissions are not included within the analytical boundary due to lack of sufficient data collection, but they are estimated to be a minute fraction of the emissions covered by the categories above. Emissions associated with the production of other material inputs to the process of cement production – such as replacement components for kilns and other process units, as well as their transport – are not included, due to a lack of sufficient data. Future efforts to build upon these definitions could include these sources of emissions – in addition to others – while remaining compatible with the core analytical scope and thresholds proposed in this document, provided there is some foreseeable method for their mitigation. As discussed above, further work is needed to consolidate and refine existing measurement standards so that a universal analytical boundary can be established for cement production. The emissions categories above are proposed as a starting point for these efforts.

As with the boundaries established for steel production, we avoid the Scope 1/2/3 terminology of the Greenhouse Gas Protocol. While helpful for assigning varying levels of responsibility for emissions at the site level, these terms can lead to confusion about which specific sources of emissions are included (or not) in a given instance. The analytical boundaries and emissions categories specified above can be evaluated using the protocol and measurement standards on which it is based.

Near zero emission intensity thresholds

For cement production, the proposed near zero emission intensity threshold is formulated as a function of the proportion of clinker use. The more clinker that is used, the higher the threshold, similar to the adjustment applied to account for the percentage of scrap use in the near zero emission steel production threshold.

There are several reasons that justify varying the threshold based on the proportion of clinker use. Like scrap use in steel production, the use of alternative cement constituents inherently leads to lower emissions intensity, and their use is already well-incentivised by the high energy intensity and cost of clinker production. Supplies of major sources of alternative cement constituents, such as ground granulated blast furnace slag and fly ash, are currently limited. Both these alternative constituents would become even more limited within a net zero emissions energy system, although other sources such as calcined clay and limestone are more abundant. Nonetheless, these alternative sources cannot wholly replace clinker (the minimum clinker-to-cement ratio for most applications is thought to be around 0.50), so the higher emissions intensity of clinker merits consideration when establishing the threshold. Furthermore, the clinker content of cement is one of the primary factors impacting the strength that can be achieved – some product markets and applications require higher strength cement and concrete, which in some cases means that a higher clinker-to-cement ratio must be used.

This is not to say that alternative materials that avoid the use of clinker should not be pursued – on the contrary. Rather, the definition proposed here would not be suitable for evaluating materials with entirely different chemical composition and production processes, in the same way that the steel production definition we propose would not be appropriate for applying to, say, aluminium production.

The threshold proposed for near zero emission cement production using 100% clinker is 125 kg of CO_2 equivalent per tonne ($kgCO_2e/t$) of cement (see Table 3.3). This compares to an IEA reference value of 850 $kgCO_2e/t$ for a conventional dry kiln, assuming BAT energy performance levels (see Box 3.3 for an explanation of the IEA reference values used in this document). The threshold is not derived as a function of this reference, which is just shown to clarify the analytical boundaries and give a sense of the level of ambition embodied by the threshold.

The emissions boundaries to which the thresholds apply (see above) include both direct and indirect emissions. While this is beneficial to incentivise a holistic approach to reducing emissions along the supply chain, it is acknowledged that there is a distinction between the emissions that a cement producer will have direct control over in most instances, and those where they will not.

Following the same principle established for the near zero emission steel production definitions, we divide the threshold for cement production into two further sub-thresholds: "Near zero direct emissions" and "Near zero direct + indirect emissions." These two sub-thresholds have the same value, as the categories of indirect emissions included must tend toward zero in the long term. The sub-division of the near zero emission threshold provides a potential way for policy makers or tracking efforts to recognise producers' efforts to address the emissions over which they have the most control in the absence – or in advance of – a full transition of the energy system as a whole (e.g. decarbonisation of the electricity grid). Over the longer term, all efforts should be targeting the "Near zero direct + indirect emission" sub-threshold.

While cement production with close to 100% clinker inputs takes place today, it is not the global norm. Alternative cement constituents are used to reduce the clinker-to-cement ratio, which in turn reduces the energy intensity, emissions intensity and cost of cement production. According to the latest Getting the Numbers Right data gathered by the GCCA and estimates from the China Cement Association, the global average clinker-to-cement ratio is around 0.70.

Table 3.3 Thresholds for near zero emission cement production using 100% clinker shown relative to conventional process technology

Emissions source	IEA reference values ($kgCO_2e/t$ cement)	Near zero emission production thresholds ($kgCO_2e/t$ cement)	
	Dry kiln	Direct	Direct + indirect
Fossil fuel use in clinker production	250		
Fossil fuel use in alternative cement constituent production	0	125	
Calcination	520		125
Imported electricity, heat and hydrogen	30	N/A	
Fossil fuel supply	35	N/A	
Raw material supply	15	N/A	
Total	850	125	125

Notes: All values rounded to the nearest 5 $kgCO_2e/t$. See Box 3.3 for a description of the IEA reference values used in this document.

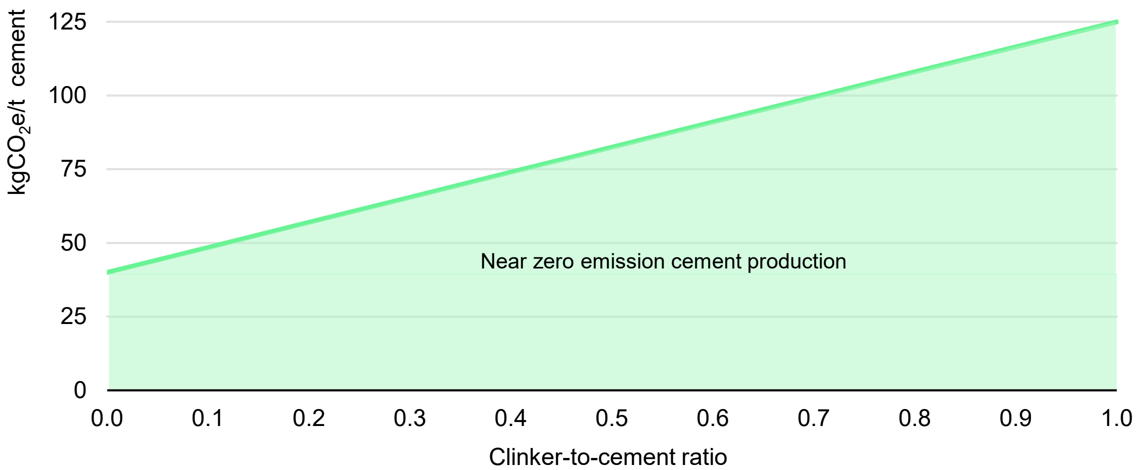
A range of different materials are used as alternative cement constituents today, including ground granulated blast furnace slag, fly ash, limestone, calcined clay and natural pozzolana. The main factors governing the cost of these alternatives are availability and proximity. In the context of the Net Zero Emissions by 2050 Scenario, the availability of ground granulated blast furnace slag and fly ash decreases over time, due to technology shifts in the steel and power sectors, respectively. While the availability of the raw materials required for calcined clay (raw clay) and limestone is constrained in some parts of the world, global reserves are thought to be more than adequate to meet projected demand this century.

Calcined clay is assumed as the most emissions-intensive, scalable alternative cement constituent in use today. We propose a threshold value of 40 $kgCO_2e/t$, which is of comparable ambition to the value established for pure clinker (125 $kgCO_2e/t$). This value is applied to all alternative cement constituents that could be used, which further incentivises the use of others that are less emissions-intensive to produce. This figure is analogous to the threshold of 100% scrap for near zero emission crude steel production, although it is unlikely that many cement plants will be able to avoid the use of clinker entirely in the coming years. (For most applications, the minimum practically achievable clinker content of cement for a wide range of applications is thought to be about 50%.) So while it may not be used in isolation, the figure is instrumental for determining the gradient of the emissions intensity threshold for varying clinker-to-cement ratios.

All else being equal, the lower the clinker-to-cement ratio, the lower the emissions intensity of cement production. Figure 3.5 presents a graphical summary of the near zero emission production thresholds for cement production for the full range of potential clinker-to-cement ratios. The equation associated with plotting this function is summarised in the Technical Annex.

As with those proposed for steel production, the threshold for near zero emission cement production is stable, absolute and ambitious. It is stable because it is not dependent on a single scenario context that is subject to frequent revision – and it is compatible with the end goal of the Net Zero Emissions by 2050 Scenario other IEA net zero energy system scenarios. It is absolute because there are no varying degrees of near zero; in other words, it is binary. And it is ambitious, signalling clearly what needs to be achieved long-term, in a sector where returns on investments take place over decades. A commercial-scale plant built in the coming few years that operates at, or below this threshold will remain so in perpetuity, unless the threshold itself is revised. The threshold does not address the degrees of incremental progress that are made on the way to meeting them. For this purpose, we propose a separate evaluation for interim measures that result in meaningful emissions intensity reductions, but which fall short of the near zero emission threshold (see below).

Figure 3.5 Near zero emission cement production threshold as a function of the clinker-to-cement ratio



Notes: See the Technical Annex for the formulation of the near zero emission cement production threshold.

Applying the definitions

In this section we apply the near zero emission cement production definition to a series of specific process routes, using both conventional and innovative technologies. To illustrate the impact of parameters that vary over time and between geographies – the CO_2 intensity of electricity generation, switches in fuel inputs and the efficiency of key pieces of equipment, like electrolysers and CO_2

capture processes – global average values from the Net Zero Emissions by 2050 Scenario are used (see Box 3.3 for a description of the IEA reference values used in this document).

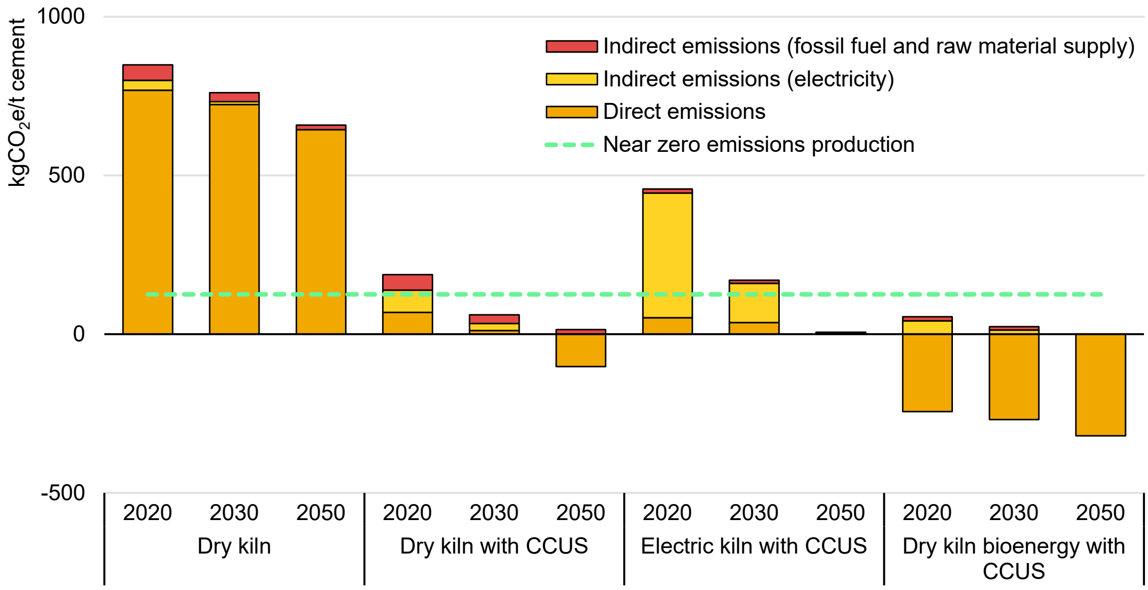
The emissions intensity of the reference dry kiln route without CCUS – the dominant production method today – declines by only 10% by 2030 and 22% by 2050, relative to its starting value of 850 kgCO_2e/t. Most of these reductions stem from the fact that the global average fuel mix for cement kilns varies over time in the Net Zero Emissions by 2050 Scenario, with 85% fossil fuels being used in 2020, 75% in 2030 and 50% in 2050. The global average share of bioenergy used in the dry kiln route (and the dry kiln with CCUS route, see below), increases from less than 5% in 2020 to nearly 30% in 2050 in this scenario. A very small amount of imported electricity used in BAT facilities of this type contributes marginal further declines as the electricity sector decarbonises in the Net Zero Emissions by 2050 Scenario. The result is that the reference route falls well short of reaching the near zero emission threshold.

Three innovative technologies are used to explore the path toward near zero emission cement production over time in the Net Zero Emissions by 2050 Scenario. As with the reference dry kiln route, the changes to the fuel mix over time contribute partially to the reductions achieved in the dry kiln with CCUS route. This emissions intensity of this route is more than 90% lower than its unabated counterpart by 2030 in the Net Zero Emissions by 2050 Scenario. Most of the decline in emissions intensity stems from the application of CCUS – which when combined with the increased share of bioenergy in the average thermal energy mix for kilns, results in a net negative intensity value of -90 kgCO_2e/t by 2050. The near zero threshold of +125 kgCO_2e/t may initially appear comparatively unambitious, but the nearly 30% average global share of bioenergy use in kilns in 2050 in this scenario is not a realistic proposition for every site. In cement producing regions where bioenergy resources may be scarcer (e.g. the Middle East), significant numbers of plants would still need to use natural gas to satisfy thermal energy inputs. These plants that would still be able to meet the near zero threshold if CCUS were applied with a 90% capture rate to both thermal energy-related emissions and those arising from calcination.

The two other innovative routes explored use alternative methods of providing the thermal energy inputs to the kiln. CCUS is still required to meet the near zero emission intensity thresholds, given that the calcination emissions (520 kgCO_2e/t) are unaddressed by these changes.

The electric kiln with CCUS route on average globally remains relatively emissions intensive in the short term, not dropping under the near zero threshold until after 2030, based on the global average CO_2 intensity of electricity production in the Net Zero Emissions by 2050 Scenario. In regional contexts where the grid is less emissions-intensive or where low emission captive electricity generation, this route could drop under the near zero threshold earlier than 2030. The breakeven point between the CO_2 intensity of electricity production and the near zero emission production threshold for this route is around 70 gCO_2/kWh, which is reached just before 2035 in the Net Zero Emissions by 2050 Scenario. It should be noted that under baseline assumptions, the global average CO_2 intensity of electricity production never reaches this breakeven value, emphasising the dependency of this route on strong progress being made in the power sector in parallel.

Figure 3.6 Global average direct and indirect emissions intensities of cement production via key pathways in the Net Zero Emissions by 2050 Scenario



Notes: CCUS = carbon capture utilisation and storage; Electric kiln = innovative kiln with electricity providing 100% of the thermal energy inputs; Dry kiln bioenergy = conventional dry kiln fuelled with bioenergy and renewable waste providing 100% of the thermal energy inputs. A clinker-to-cement ratio of 1.0 is used for illustrative purposes for all production pathways, with the near zero emission production threshold imposed on a direct + indirect emissions basis. See Box 3.3 for a description of the IEA reference values used in this document.

The dry kiln bioenergy with CCUS route would comfortably meet the near zero threshold today due to the strong carbon removal impact of using 100% bioenergy for thermal energy inputs in conjunction with carbon capture. The emissions intensity of this route drops to below -300 $kgCO_2e/t$ by 2050 in the Net Zero Emissions by 2050 Scenario, largely independent of the transition that takes place in the power sector. Sustainable bioenergy resources face considerable competition from other sources in this scenario context, so this arrangement is not a realistic prospect for all kilns.

Valuing interim measures to reduce emissions

The thresholds established for near zero emission steel and cement production described above are ambitious and absolute. The intention is to establish clear target thresholds for the technologies in these sectors, and to send clear and transparent signals to policy makers, investors and producers about the types of technologies and investments that are commensurate with the ambitions of the Net Zero Emissions by 2050 Scenario (a reduction in direct CO_2 emissions from heavy industry sectors of 90% to 95% by 2050).

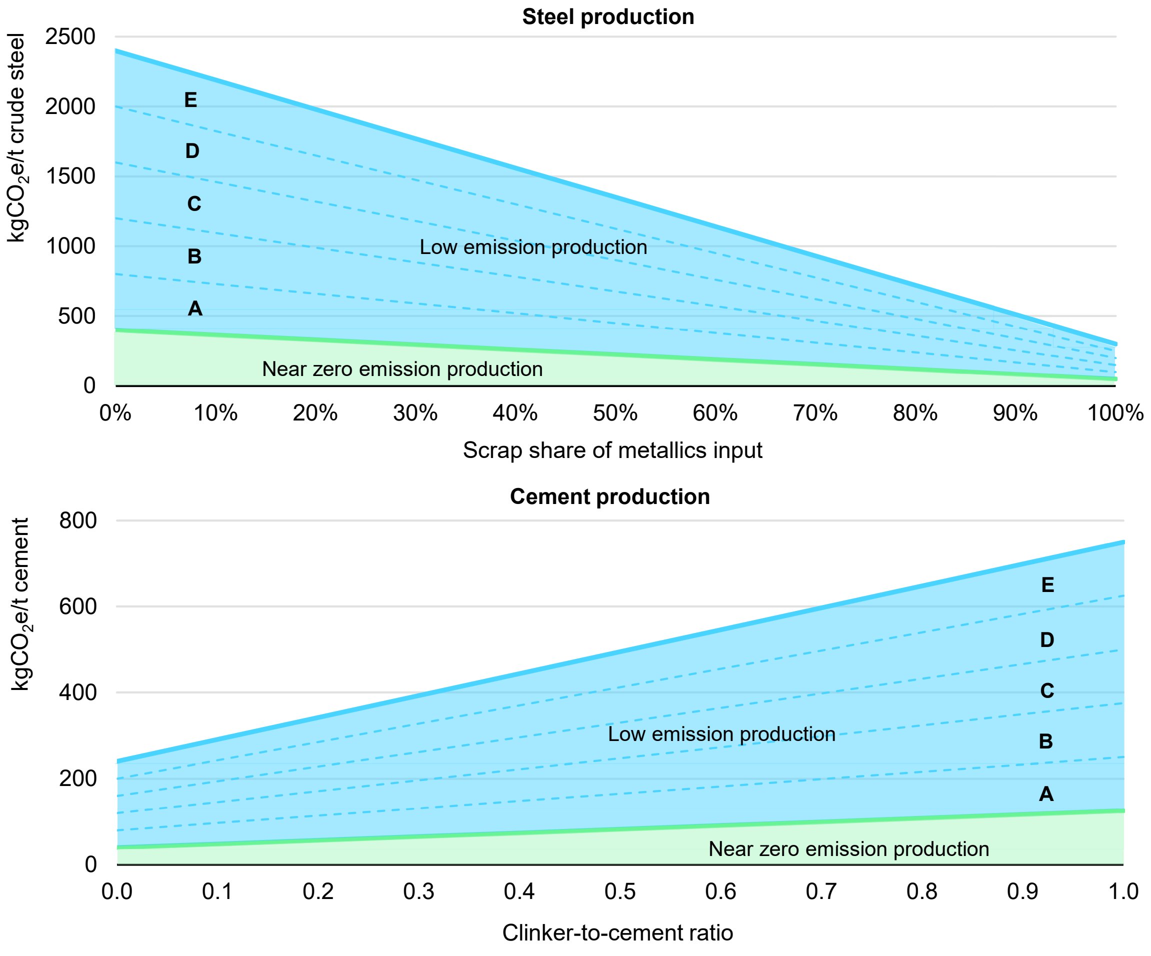
The disadvantage of setting an absolute threshold at a sufficiently ambitious level is that interim measures that can substantially reduce emissions – but which do not reach the near zero threshold – are not addressed or incentivised by the metric. Such measures are still important, however. Climate change is a cumulative problem, which means that each increment of emissions reduction matters. Therefore, the combined effects of innovation and regional circumstances require that interim steps be valued. It is for this purpose that we suggest a supplementary approach for recognising interim measures, with the aim of proposing key principles for doing so. The details of implementing such an approach would require international agreement were it to be established universally, taking note of individual country circumstances.

Low emission steel and cement production

Based on existing announcements, only a small fraction of the world’s steel and cement plants in operation or under construction can be designated in the short term as “near zero emission” using the thresholds proposed above – fewer still of those sites now operating at commercial scale. However, there are many efforts underway that will substantially reduce the emissions intensity of existing and new-build facilities, relative to today’s conventional production processes using BAT. Some of these measures will provide a stop-gap solution and extend the viable life of existing assets; some will lay the groundwork for achieving near zero emission production later. Examples include switching from coal (PCI BF-BOF) to natural gas (NG DRI-EAF) for primary steel production, and electrifying cement kilns without the application of CCUS. Reductions in emissions intensity associated with these measures are in the 40% to 50% range, relative to the dominant conventional process routes operating with BAT, compared with reductions of around 85% for the near zero emission thresholds.

As separate but complementary category of recognition for interim measures, we propose evaluating these interim measures, characterising them with the identical boundaries for emissions intensity measurement as the direct + indirect near zero emission production thresholds (see above). Figure 3.7 provides a graphical representation of the emissions intensity ranges within which a given plant, portfolio, region or sector would qualify as some degree of "low emission production." The maximum emissions intensity allowed to qualify as low emission production is set at six times the near zero emission threshold for steel and cement production.

Figure 3.7 Emissions intensity ranges for near zero and low emission steel and cement production



Notes: See the Technical Annex for the formulation of the low emission production thresholds.

The rationale for this multiple is that “low emission production” is intended to recognise efforts that make substantial improvements relative to the emissions intensities of the dominant conventional technologies. A multiple of six times the near zero emission thresholds places the low emission production threshold at around 10-20% below the emissions intensities of the dominant conventional process routes. This quantitative recognition is not designed to be a substitute for benchmarking efforts that compare plants operating at or close to BAT energy performance levels – something that is important to pursue in parallel. As with the near zero emission production thresholds, the low emission production thresholds vary according to the quantity of the main raw material inputs (scrap, iron ore, clinker and alternative cement constituents).

For a given volume of total production, a proportion would be deemed low emission production if the emissions intensity lies between the near zero and low emission production thresholds (the bold green and blue lines, respectively, in Figure 3.7). This share is inversely proportional to the emissions intensity of total production, and the formulation is summarised in the Technical Annex. As an example, a plant producing one tonne of material at an emissions intensity (measured using the same analytical boundaries explained above for each material) halfway between the near zero and low emission production thresholds would be deemed as achieving 0.5 tonnes of low emission material production. A plant operating at an emissions intensity above the low emission production threshold would not be considered as producing low emission output. A plant operating at or below the near zero emission intensity threshold would also not yield any low emission production, but all its output would be deemed near zero emission production. Thus, the low emission production is progressively recognised, whereas the near zero emission threshold is binary. As with the near zero emission production thresholds, the low emission thresholds are not derived from any particular reference value, but rather as multiples of the near zero emission thresholds.

The intensity range between low emission production and near zero emission production is divided into five increments, or “bands,” labelled A through E, as shown on Figure 3.7. These bands are intended as a tool for tailoring the quantification of low emission production to fit a given regional, temporal or other context. Interim measures should, after all, be temporary stops on the way to universal adherence to near zero emission thresholds.

A government, company or other actor could choose to restrict the recognition to a narrower set of bands than the default A to E formulation, thereby reducing the quantity of total production that is deemed low emission. The sliding scale of recognition in the calculation of low emission production would remain, regardless of the band range selected – thereby maintaining a consistent incentive to reduce emissions intensity. The formulation for the full use of the possible band ranges is summarised in the Technical Annex. As an example, a cement plant using 100% clinker with an emissions intensity of 250 $kgCO_2e/t$ operating in a jurisdiction using the band range A to E would be considered to produce 800 kg of low emission cement per tonne of total production. If that jurisdiction were ever to decide to shrink its band range to, say, A to C, the same plant would then be deemed as producing 666 kg of low emission cement.

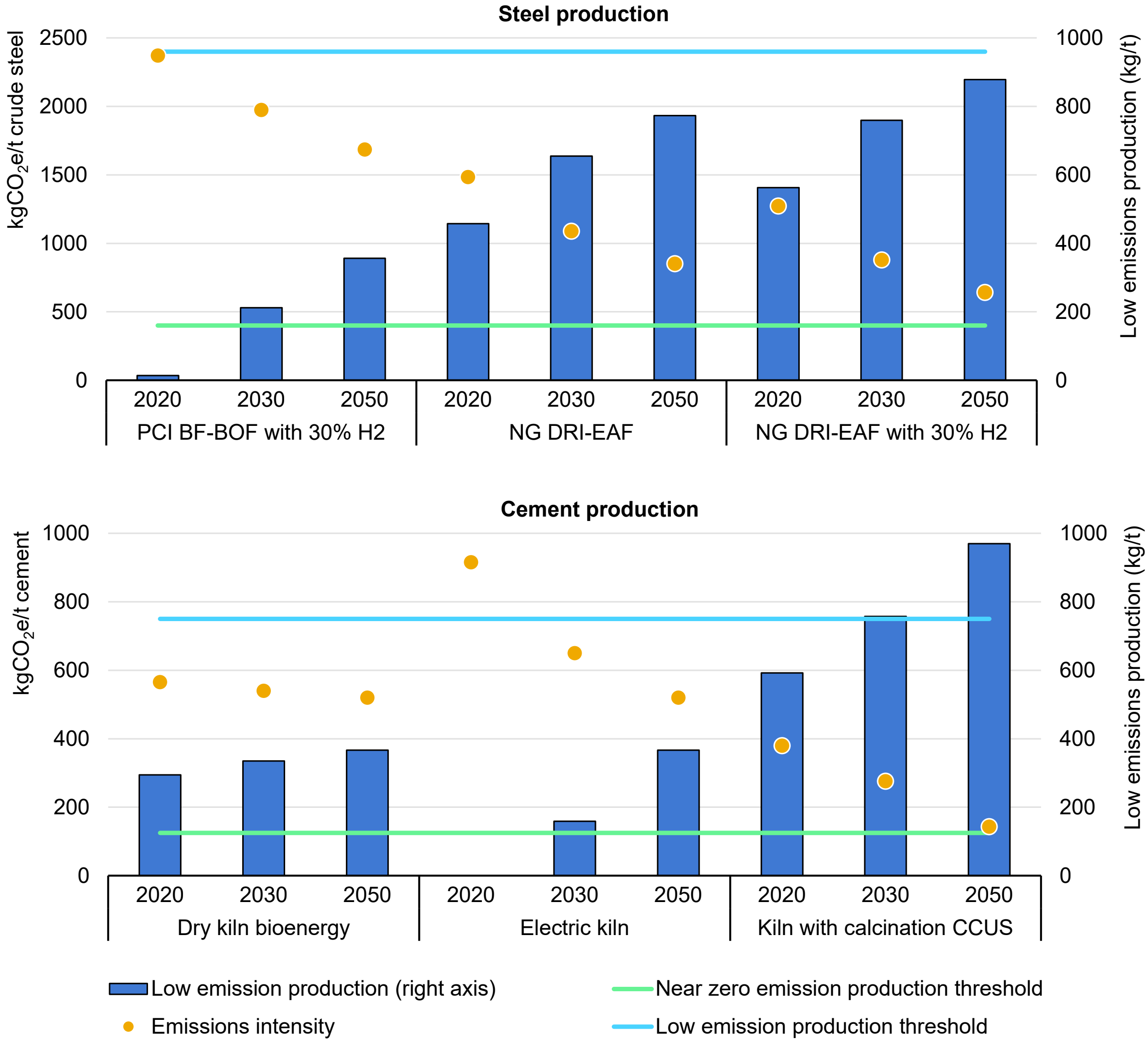
Applying the definitions

In this section we apply the low emission production definitions to a series of specific interim measures currently under consideration and in development that aim to substantially reduce emissions intensity in the steel and cement sectors:

- **PCI BF-BOF with 30% H_2** (Pulverised coal injection blast furnace-basic oxygen furnace plant with 30% hydrogen injection): The same conventional PCI BF-BOF process technology used today with 30% of the coal inputs substituted with electrolytic hydrogen.
- **NG DRI-EAF** (Natural gas-based direct reduced iron-electricity arc furnace): Today's conventional DRI-EAF process technology with 100% natural gas feed.
- **NG DRI-EAF with 30% H_2** (Natural gas-based direct reduced iron-electricity arc furnace with 30% hydrogen injection): Uses today's conventional process technology used today but with 30% of the natural gas inputs substituted with electrolytic hydrogen.
- **Dry kiln bioenergy** (Dry kiln heated with bioenergy): The same conventional dry kiln process used today but with 100% of the fossil fuel inputs substituted with bioenergy. Nothing done to address process emissions.
- **Electric kiln** (Dry kiln heated with electricity): Innovative electric kiln process technology with 100% of thermal energy needs met by electricity. Nothing done to address process emissions.
- **Kiln with calcination CCUS** (Kiln with CCUS applied to calcination emissions only): Innovative indirect heating kiln with CCUS applied to emissions from calcination. Nothing done to address energy-related emissions.

Global average values of the main scenario-dependent parameters from the Net Zero Emissions by 2050 Scenario for 2020, 2030 and 2050 are used for context to illustrate the quantities of low emission production using these technologies and interim measures. Such parameters include the CO_2 intensity of electricity generation, the average fuel mix of cement kilns and the efficiency of key pieces of equipment like electrolysers and CO_2 capture processes. (See Box 3.3 for a description of the IEA reference values used in this document.) For the calculation of low emission production, 0% scrap inputs is used for all steel production pathways, and the cement production pathways are modelled using a clinker-to-cement ratio of 1.00. The band range A to E is used in evaluating all the cases considered.

Figure 3.8 Quantifying low emission crude steel and cement production for specific examples of interim measures to reduce emissions



Notes: CCUS = carbon capture utilisation and storage; Electric kiln = innovative kiln with electricity providing 100% of the thermal energy inputs; Dry kiln bioenergy = conventional dry kiln fuelled with bioenergy and renewable waste providing 100% of the thermal energy inputs; Kiln with calcination CCUS = innovative indirect heating kiln with CCUS applied to emissions from calcination; PCI BF-BOF = Blast furnace-basic oxygen furnace with pulverised coal injection; DRI-EAF = Natural gas-based direct reduced iron-electric arc furnace; H2 = Hydrogen-based; NG = Natural gas-based. The steel near zero and low emission production thresholds shown are based on zero scrap use. A clinker-to-cement ratio of 1.00 is used for all cement production pathways. The near zero emission production thresholds are imposed on a direct + indirect emissions basis. A band range of A to E is used for calculating the quantity of low emission production for both steel and cement. See Box 3.3 for a description of the IEA reference values used in this document.

The interim measures explored for steel production achieve emissions intensities of 1 275 - 2 375 kgCO_2e/t today, 875 - 1 975 kgCO_2e/t in 2030 and 650 - 1 675 kgCO_2e/t in 2050. This results in low emission production of 25 to 575 kg per tonne of total crude steel production today, 200 - 750 kg in 2030 and 350 - 875 kg by 2050. All the production pathways use electricity – either directly or indirectly in the case of electrolytic hydrogen – as a means of mitigating emissions. This is because the global average CO_2 intensity of electricity generation falls from around 440 gCO_2/kWh in 2020 to 140 gCO_2/kWh in 2030, and to just below zero by around 2040. The NG DRI-EAF with 30% H2 route can be distinguished among those explored for steel, as with increased hydrogen blending over time, the emissions intensity could fall further and eventually reach the near zero threshold. For the BF-BOF with 30% H2 and the NG DRI-EAF routes, the potential to reduce emissions further is limited without a further fundamental technology or fuel switch.

The measures explored for cement production achieve emissions intensities of 375 - 925 kgCO_2e/t today, 275 - 650 kgCO_2e/t in 2030 and 150 - 525 kgCO_2e/t in 2050. This results in low emission production of zero to 600 kg per tonne of total cement production today, 150 - 750 kg in 2030 and 375 - 975 kg by 2050. The dry kiln bioenergy technology mitigates emissions from heating the kiln by substituting fossil fuels with bioenergy, resulting in immediate and sustained emissions reductions. Similarly, the dry kiln electric technology uses electricity to mitigate emissions from heating the kiln, but because electricity still leads to indirect emissions, the technology does not sufficiently reduce its emissions intensity to reach low emission production until after 2030. Even though these two measures achieve smaller reductions in emissions intensity than the partial CCUS arrangement, they are still compatible with further modifications to attain near zero emission production – namely by adding CO_2 capture to the remaining process emissions of CO_2. In the case of the dry kiln bioenergy approach, the combination of CCUS and bioenergy leads to net negative emissions, as shown in Figure 3.6.

Principles applicable to producing other materials

Combined, the steel and cement industries account for around 55% of direct industrial CO_2 emissions, making them a good place to start for defining near zero emission materials production. However, there are a plethora of other materials – whose production represents most of the remaining 45% of industrial emissions – that could be considered for such definitions. Processes and practices in the manufacturing, mining and construction sectors – which represent the remaining emissions from industry – would likely require a different approach, given the task- and site-specificities of these activities.

Many aspects of steel and cement production thresholds established in this report are also applicable to other bulk materials. The main principles for the near zero emission production thresholds – that they are static, absolute and ambitious – should be maintained in subsequent definitions developed for other materials. Recognising interim measures to reduce the emissions intensity of production, by using the low emission production thresholds, can also be useful elsewhere. There are other materials besides steel and cement where, in most cases, the most promising technologies for reducing emissions intensity are not yet available on the market (e.g. ammonia production from electrolytic hydrogen powered by variable renewable electricity). Even where near zero emission production methods are readily available at commercial scale for industrial processes (e.g. a manufacturing process with electrification for low-temperature heat using industrial heat pumps), the low emission production thresholds can still be used to evaluate and incentivise progress on indirect emissions.

The distinction between production and products when defining thresholds is another important principle established in this report. A clear boundary is drawn around the emissions and supply chain boundaries associated with steel and cement production – and the same should be done for any subsequent materials. Some product definitions can follow directly from production definitions – near zero emission crude steel from near zero emission crude steel production, for example. Other products, particularly those further down the supply chain, may require multiple near zero emission production definitions before the product definitions can follow. An example would be a vehicle, built from steel, aluminium, glass, plastic and rubber: a product definition would require production definitions for each of its component materials, together with thresholds established for their manufacturing processes. Some product definitions may warrant the inclusion of downstream emissions that are not as relevant for steel and cement (e.g. the oxidation during use or disposal of many chemical products). Product definitions are outside the scope of this analysis, but it is intended that this report – and any subsequent extensions of the work it contains – form a robust basis for such definitions.

When prioritising additional materials for further near zero emission production definitions, there are two key considerations: the total global emissions associated with their production, and the extent to which they, their derivatives or their pre-cursors are traded around the world. With these two considerations in mind, we would suggest that extensions of this work focus on ammonia, methanol, high value chemicals (as a group), and aluminium (primary and secondary) production as the next priorities. These materials are produced in large volumes, see significant levels of global trade (or trade in their derivatives/pre-cursors), and have manageable levels of supply chain complexity and data requirements. Pulp and paper, ferroalloys, other non-ferrous metals (e.g. copper and zinc) and other chemicals (e.g. carbon black and chlorine) could be tackled next, but each effort in these areas would address substantially smaller quantities of emissions.

Technical Annex

Near zero emission steel production formulation

The following equation characterises the emission intensity thresholds for near zero emission steel production:

$$E_{nz,s}(s) = 400 - 350s$$

Where $E_{nz,s}(s)$ is the near zero emission intensity threshold for steel production in $kgCO_2e$ per tonne of crude steel, and s is the scrap share of metallics input (zero to 100%). In the absence of information on the share of scrap use in a plant, country or region, the default value of zero scrap is to be used.

Near zero emission cement production formulation

The near zero emission cement production thresholds are adjusted on a sliding scale to account for the potential variability in this parameter, according to the following equation:

$$E_{nz,c}(c) = 85c + 40$$

Where $E_{nz,c}(c)$ is the near zero emission intensity threshold for cement production in $kgCO_2e$ per tonne of cement production, and c is the clinker-to-cement ratio (0.0 to 1.0). In the absence of information on the clinker-to-cement ratio in a plant, country or region, the default value of c = 1.0 is to be used.

Low emission steel and cement production formulation

The quantity of low emission steel production is calculated according to the following equation:

$$P_{l,s}(b,s) = \begin{cases} \dfrac{E_{l,s}(b) - E_{a,s}}{E_{l,s}(b) - E_{nz,s}(s)}, & E_{a,s} < E_{l,s}(b) \\ 0, & E_{a,s} \geq E_{l,s}(b) \end{cases}$$

Where $P_{l,s}(b,s)$ is the quantity of low emission steel production in tonnes per tonne of total steel production of the plant, portfolio, region or sector being considered, $E_{l,s}(b)$ is the low emission intensity threshold corresponding to the band range (see below) being considered in $kgCO_2e$ per tonne of crude steel, $E_{a,s}$ is the actual emissions intensity in $kgCO_2e$ per tonne of crude steel, and $E_{nz,s}(s)$ is the near zero emission intensity threshold for steel production in $kgCO_2e$ per tonne of crude steel.

The following equation characterises the emission intensity thresholds for low emission cement production:

$$P_{l,c}(b,c) = \begin{cases} \dfrac{E_{l,c}(b) - E_{a,c}}{E_{l,c}(b) - E_{nz,c}(c)}, & E_{a,c} < E_{l,c}(b) \\ 0, & E_{a,c} \geq E_{l,c}(b) \end{cases}$$

Where $P_{l,c}(b,c)$ is the quantity of low emission cement production in tonnes per tonne of total cement production from the plant, portfolio, region or sector being considered, $E_{l,c}(b)$ is the low emission intensity threshold corresponding to the band range (see below) being considered in $kgCO_2e$ per tonne of cement, $E_{a,c}$ is the actual emissions intensity in $kgCO_2e$ per tonne of cement, and $E_{nz,c}(c)$ is the near zero emission intensity threshold for cement production in $kgCO_2e$ per tonne of cement.

Table A.1 summarises the values of $E_{l,c}(b)$ and $E_{l,s}(b)$ for the possible band ranges that can be considered for the calculation of low emission cement and steel production.

Table A.1 Low emission production intensity thresholds corresponding to band ranges considered

Band range considered, b	$E_{l,s}(b)$ ($kgCO_2e$/t crude steel)	$E_{l,c}(b)$ ($kgCO_2e$/t cement)
A to E	2400	750
A to D	2000	625
A to C	1600	500
A to B	1200	375
A to A	800	250

Notes: See text above for explanation of terms used in the table.

Abbreviations and acronyms

ACT	Assessing Low Carbon Transition
BAT	best available technology
BECCS	bioenergy with carbon capture and storage
BF-BOF	blast furnace-basic oxygen furnace
BREEAM	Building Research Establishment Environmental Assessment Method
CAPEX	capital expenditure
CCS	carbon capture and storage
CCUS	carbon capture, utilisation and storage
CEM	Clean Energy Ministerial
CEN	European Committee for Standardization
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CSI	Cement Sustainability Initiative
DAC	direct air capture
DRI	direct reduction of iron
DRI-EAF	direct reduced iron-electric arc furnace
EAF	electric arc furnace
EDGAR	Emissions Database for Global Atmospheric Research
EN	European Norm
EPD	environmental product declaration
ETS	emissions trading system
FMC	First Movers Coalition
GCCA	Global Cement and Concrete Association
GHG	greenhouse gas
GGI	Greenhouse Gas Index
GGP	Greenhouse Gas Protocol
H_2	hydrogen
ICE	Institution of Civil Engineers
IDDI	Industrial Deep Decarbonisation Initiative
IOE	iron ore electrolysis
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification of All Economic Activities
ISO	International Organization for Standardization
JISC	Japanese Industrial Standards Committee
LCET	Low Carbon Emitting Technologies
LEED	Leadership in Energy and Environmental Design
NG	natural gas
N_2O	nitrous oxide
NZE	net zero emissions
OECD	Organisation for Economic Co-operation and Development

PCI	pulverised coal injection
PCR	product category rule
SBTi	Science Based Targets initiative
SR-BOF	smelting reduction-basic oxygen furnace
UNFCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
USGS	U.S. Geological Survey
WBCSD	World Business Council for Sustainable Development

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Typeset in France by IEA - May 2022

Cover design: IEA

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