**Technology Executive Committee**

05 September 2023

**Twenty-seventh meeting**

**19-21 September and 22 September 2023 (TEC-CTCN Joint session)**

# Draft paper on mapping existing initiatives for transformative industry to identify areas where the TEC could add value

## I. Introduction

### A. Background

1. As per activity C.3.1 of the rolling workplan for 2023-2027, the TEC is to prepare a mapping of existing initiatives for transformative industry to identify areas where the TEC could add value.

2. At TEC 26 the TEC considered a draft concept note, prepared by the secretariat, in consultation with UNIDO, on mapping existing initiatives for transformative industry and provided guidance for further work on this matter, which included taking into account relevant existing and new mandates from the COP and the CMA, incorporating relevant insights from previous work of the TEC and the CTCN, building on available information and credible publications, and avoiding duplication of efforts.

3. At TEC 26 the TEC agreed to prepare a paper on mapping existing initiatives to identify areas where the TEC could add value, for its consideration at TEC 27 meeting. The TEC welcomed with appreciation the support of UNIDO and the Government of Japan for this activity and the work of the Technology Mechanism in general.

### B. Scope of the note

4. The annex to this note contains a draft paper on mapping of existing initiatives for transformative industry to identify areas where the TEC could add value.

### C. Possible action by the Technology Executive Committee

5. The TEC will be invited to consider the draft paper and provide guidance to the activity group for further work on this matter.

# Annex

## Draft paper on mapping existing initiatives for transformative industry to identify areas where the TEC could add value

# Assessment of Climate Action for Transformative Industry

This draft paper refers to the activity C.3.1. of the Rolling work plan of the Technology Executive Committee for 2023–2027 “Mapping of existing initiatives to identify areas where the TEC could add value.”

***The mapping of existing initiatives in transformative industry has been funded by UNIDO and financed by the Ministry of Economy, Trade and Industry (METI), Japan.***

***5 September, 2023***

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# EXECUTIVE SUMMARY

To be drafted in a final version of this report.

# ACRONYMS AND ABBREVIATIONS

## Acronyms and Abbreviations

| | |
|---|---|
| $ | Dollar |
| °C | Celsius |
| AAC | Autoclaved Aerated Concrete |
| AF | Alternative Fuels |
| AI | Artificial Intelligence |
| APS | Paris Agreement Scenario |
| BaU | Business-As-Usual |
| BECCS | Carbon Capture, Utilization And Storage Including Bioenergy |
| BF | Blast Furnace |
| BOF | Basic (Blasick) Oxygen Furnace |
| BPD | By-Pass Dust |
| BR | Biennial Report |
| BTX | Benzene, Toluene, And Xylenes |
| BUR | Biennial Update Report |
| CANACEM | National Cement Chamber |
| CBMI | Chamber Of Building Materials Industries / Cement Industry Division |
| CCS | Carbon Capture And Storage |
| CCUS | Carbon Capture, Utilization And Storage |
| CEMBUREAU | European Cement Association |
| CERFLOR | A Separate National Certification Scheme |
| CKD | Cement Kiln Dust |
| CM | Clinker To Cement |
| CM1 | Unconditional Reduction |
| CM2 | Conditional Reduction |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| $CO_{2eq}$ | Carbon Dioxide Equivalent |
| COP26 | Conference Of The Parties 26 |

## Acronyms and Abbreviations

| | |
|---|---|
| COP27 | Conference Of The Parties 27 |
| CSI | Cement Sustainability Initiative |
| CTCN | Climate Technology Centre and Network |
| DRI | Direct Reduced Iron |
| e.g. | Exempli Gratia |
| EAACA | European Autoclaved Aerated Concrete Association |
| EAF | Electric Arc Furnace |
| EBRD | European Bank for Reconstruction And Development |
| ECRA | European Cement Research Academy |
| EE | Energy Efficiency |
| EEAA | Egyptian Environmental Affairs Agency |
| EFR | European Ferrous Recovery |
| HER | Energy Heat Recvery |
| EOR | Enhanced Oil Recovery |
| ESCerts | Energy Saving Certificates |
| ETS | Emission Trading System |
| EU | European Union |
| EU ULCOS | European Union Ultra-Low $CO_2$ Steelmaking |
| Fe | Iron Metal |
| FICEM | Inter-American Cement Federation |
| FMC | First Movers’ Coalition |
| GBC | Green Building Council |
| GCCA | Global Cement and Concrete Association |
| GDP | Gross Domestic Product |
| GEF | Global Environment Facility |
| GHG | Greenhouse Gas |
| GJ | Giga Joule |
| GO | Guarantee Of Origin |
| GoV | Government Of Vietnam |

## Acronyms and Abbreviations

| | |
|---|---|
| Gt | Giga tonne |
| GW | Giga Watt |
| $H_2$ | Hydrogen |
| $H_2O$ | Water Vapor |
| HAI | Hard to Abate |
| HCl | Hydrogen Chloride |
| HF | Hydrogen Fluoride |
| I&S | Iron And Steel |
| ICLEI | Non-Governmental Organization |
| IDDI | Industrial Deep Decarbonization Initiative |
| IEA | International Energy Agency |
| IF | Induction Furnaces |
| IPPU | Industrial Processes and Product Use |
| ISI | Iron And Steel Industry |
| ISRI | Institute Of Scrap Recycling Industries |
| JEF | Young European Federalists |
| JISF | Japan Iron and Steel Federation |
| Kg | Kilogram |
| kWh | Kilo Watt Hour |
| LC3 | Limestone Calcined Clay Cement |
| LCI | Life Cycle Inventory |
| LeadIT | Leadership Group for the Industry Transition |
| LLC | Limited Liability Company in US |
| LT-LEDS | Long-term Low Emissions Development Strategy |
| LULUCF | Land Use, Land-Use Change and Forestry |
| MBIs | Market-Based Instruments |
| MENA | Middle East/North Africa |
| MJ | Mega Joule |
| MOC | Ministry Of Construction (Vietnam) |

## Acronyms and Abbreviations

| | |
|---|---|
| MRV | Measurement, Reporting, And Verification |
| MSW | Municipal Solid Waste |
| MT | Metric-Million Ton |
| MTI | Ministry Of Trade and Industry |
| MTOE | Million Ton of Oil Equivalent |
| MWh | Mega Watt Hour |
| NAMA | Nationally Appropriate Mitigation Actions |
| NDC | Nationally Determined Contributions |
| NDF | Nordic Development Fund |
| NG | Natural Gas |
| NGOs | Non-Governmental Organizations |
| NMEEE | National Mission for Enhanced Energy Efficiency |
| NOx | Nitrogen Oxides |
| NZCE | Net-Zero Carbon Emissions |
| NZE | Net-Zero Emissions |
| PA | Paris Agreement |
| PAT | Perform, Achieve, and Trade |
| PCA | Portland Cement Association |
| PDOs | Project Development Objectives |
| PM | Particulate Matter |
| PMU | Project Management Unit |
| PPP | Public-Private Partnership |
| R&D | Research And Development |
| RD&D | Research, Development and Demonstration |
| RE | Renewable Energy |
| SALCOS | Salzgitter Low $CO_2$ Steelmaking |
| SBTi | Science Based Targets Initiatives |
| SDA | Sectoral Decarbonization Approach |
| SDS | Sustainable Development Scenario |

## Acronyms and Abbreviations

| | |
|---|---|
| SITRA | Finnish: Suomen itsenäisyyden juhlarahasto, the Finnish Innovation Fund |
| $SO_2$ | Sulphur Dioxide |
| STEPS | Stated Policies Scenario |
| T | Tonne |
| T/tcs | Tonnes Per Tonne of Crude Steel |
| tcs | Tonne of Crude Steel |
| TNA | Technology Needs Assessment |
| TRL | Technology Readiness Level |
| UAE | United Arab Emirates |
| UK | United Kingdom |
| UNDP | United Nations Development Program |
| UNIDO | United Nation Industrial Development Organization |
| US | United States |
| USD | United States Dollar |
| VDZ | German Cement Works Association |
| VGGS | Vietnam Green Growth Strategy |
| VNEEP | Vietnam National Energy Efficiency Program |
| VOCs | Volatile Organic Compounds |
| WBCSD | World Business Council for Sustainable Development |
| WHR | Waste Heat Recovery |
| WSA | World Steel Association |
| Y/N | Yes/No |
| yr | Year |

# 1 INTRODUCTION

## 1.1 Background

Addressing climate change is an urgent and formidable challenge that the global community has collectively acknowledged and prioritized. Central to this effort is the unwavering commitment to the Paris Agreement (PA) target. This ambitious goal aims to maintain the rise in global temperatures well below 2 ºC, with a further aspiration to limit it to below 1.5 ºC when measured against pre-industrial levels. Achieving this target necessitates immediate and widespread international actions to curtail greenhouse gas (GHG) emissions. Consequently, there is an increasing recognition of the imperative to adopt transformative zero-emission solutions across various sectors worldwide[1].

While the world experienced a temporary dip in global emissions during the COVID-19 pandemic lockdown in 2019 and 2020, the subsequent rebound in 2021 was concerning. The International Energy Agency (IEA) reported an unprecedented annual rise of over 6% in emissions, primarily attributed to the resurgence in the utilization of coal, oil, and gas as economies recovered. This dramatic increase underscored the persistent challenge of rapidly rising GHG emissions, notably in sectors crucial to economic development[2]. The global emissions then reported a continuous, though less intense, increase with a rise of 0.9% in global emissions for 2022 relative to the previous year levels[3].

The industrial sector stands out as a significant contributor to the global economy, accounting for approximately 21.8% of the Global Gross Domestic Product (GDP) in 2021. This sector's core constituents are manufacturing, contributing to 77.7% of industrial value addition, and the mining and utilities sector, responsible for the remaining 23.3%[4]. Paradoxically, this same sector also represents a substantial portion of the problem, contributing directly to nearly 24% of global $CO_{2eq}$ emissions in 2019, and indirectly to 10% of the global $CO_{2eq}$ emissions, thereby positioning it as a major driver of climate change[5].

However, there is a glimmer of hope on the horizon. According to both the International Energy Agency's Net Zero by 2050 Roadmap report and the UNIDO Industrial Statistics Yearbook 2022, the adoption of best available techniques and industrial energy efficiency measures holds the potential to reduce CO2 emissions from all heavy industries by a staggering 2 billion tons by the year 2030. This represents a substantial 20% reduction in emissions from the sector[6] [7].

Between 1970 and 1990, emissions directly linked to industrial combustion showed modest growth. In the subsequent decade, from 1990 to 2000, they even shifted to a slowly declining trend, gradually reducing

[1] United Nations Framework Convention on Climate Change (UNFCCC), The Paris Agreement: What is the Paris Agreement?
[2] International Energy Agency. Global Energy Review 2022. Available at: https://www.iea.org. 2023
[3] International Energy Agency. CO2 emissions in 2022. Available at: https://www.iea.org. 2023
[4] United Nations Industrial Development Organization. International Year Book of Industrial Statistics 2022. Available at: https://stat.unido.org. Vienna, 2022
[5] Dhakal, S., J.C. Minx, F.L. Toth, A. Abdel-Aziz, M.J. Figueroa Meza, K. Hubacek, I.G.C. Jonckheere, Yong-Gun Kim, G.F. Nemet, S. Pachauri, X.C. Tan, T. Wiedmann, 2022: Emissions Trends and Drivers. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.004
[6] United Nations Industrial Development Organization. International Year Book of Industrial Statistics 2022. Available at: https://stat.unido.org. Vienna, 2022
[7] International Energy Agency. Net Zero by 2050 A Roadmap for the Global Energy Sector. Available at: https://www.iea.org. 2021

their portion of overall industrial emissions. This trend underwent a notable shift at the onset of the 21st century. Total emissions experienced a significant increase, ranging from 60% to 68%, depending on the metric used, marking the most rapid growth ever recorded. Notably, from 2000 to 2019, emissions from iron, steel, and cement production surged more than in any previous period in history. While emissions temporarily plateaued from 2014 to 2016, partly influenced by the financial crisis, they resumed their upward trajectory from 2017 to 2019, as illustrated in Figure 1-1.[8]

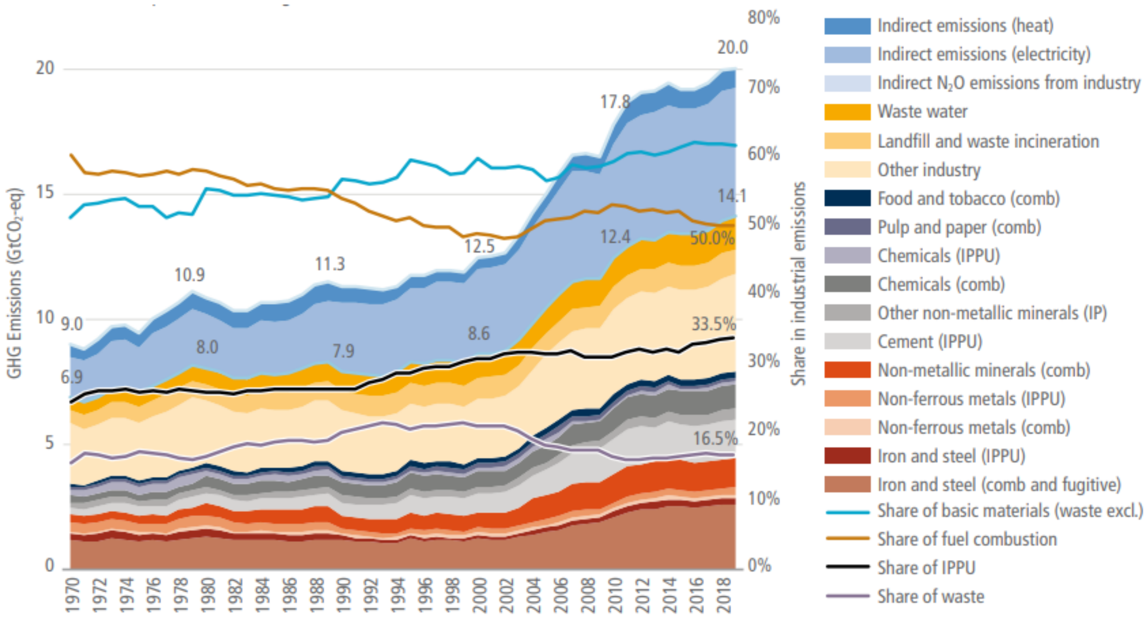



**Figure 1-1: Emissions from industrial sources, depicted on the left scale, are categorized into two main components: "Comb" represents direct emissions stemming from fuel combustion, while "IPPU" indicates emissions resulting from industrial processes and product use. Additionally, the chart illustrates indirect emissions originating from electricity and heat generation, positioned at the top. On the right side, the shares specifically pertain to direct emissions. (Adapted for IPCC AR6)**

In a surprising departure from the trends observed in global emissions in 2022, emissions from industrial processes recorded a 1.7% decrease compared to the previous year. The global reduction was primarily influenced by a significant decrease of 161 million tons of $CO_2$ emissions in China's industrial sector. This reduction was mainly due to a 10% decrease in cement production and a 2% decline in steel manufacturing[9].

Notably, three primary sectors – cement, chemicals & petrochemicals, and steel industries – collectively referred to as "Hard to Abate Industries (HAI)," are pivotal in this context. These sectors are responsible for nearly 60% of total industrial energy consumption and contribute to around 70% of industrial CO2 emissions.[10] Consequently, they are the primary focus of this assessment.

While it is essential to acknowledge the historical growth in global demand for steel (by 2.1 times), cement (by 2.4 times), and plastics (key products within the chemical sector, by 1.9 times) over the past two decades, the Net Zero Energy roadmap underscores the pressing need to either maintain or even decrease

[8] Bashmakov, I.A., L.J. Nilsson, A. Acquaye, C. Bataille, J.M. Cullen, S. de la Rue du Can, M. Fischedick, Y. Geng, K. Tanaka, 2022: Industry. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.013
[9] International Energy Agency. CO2 emissions in 2022. Available at: https://www.iea.org. 2023
[10] International Energy Agency. Net Zero by 2050 A Roadmap for the Global Energy Sector. Available at: https://www.iea.org. 2021

current production levels [11]. To achieve this, the implementation of comprehensive emissions mitigation measures, along with the adoption of transformative zero-emission technologies, is nothing short of imperative. Without this shift, the goals set forth in the Paris Agreement remain unattainable, underscoring the paramount importance of these transformative solutions in bending the emissions curve and securing a sustainable, zero-carbon future.

## 1.2 Objectives

The overall objective of this paper is to promote low and near zero emission production and product (e.g. steel, cement) through the support of innovation, enabling environments, sustainable purchasing commitments, and financing in order to inform NDC planning and implementation.

To support this objective, the Technology Executive Committee (TEC) will map existing initiatives in the above-mentioned Hard to Abate Industries (HAI) sectors. This effort is firmly aligned with the overarching aim of the Technology Framework, as outlined in the Katowice Rule Book, where Paragraph 65 underscores the critical role of enhancing climate technology development and transfer for implementing both mitigation and adaptation measures under the Paris Agreement. Given that these HAI sectors collectively account for over 30% of global emissions, their active engagement in implementing mitigation measures is paramount to achieving the ambitious targets of the Paris Agreement.

Additionally, reducing emissions from HAI sectors is not easy, and requires overcoming many challenges. These challenges (reflected in detail in chapter 5) include: maturity level of each technology, lack of financial support, difficulty of replacing existing assets, potential impact on the product's use, public acceptance of changing product composition/ design, risk of market share loss for private sector, and CCS-related challenges including transport infrastructure and liability.

Moreover, some technologies are facing technical challenges, for example using alternative raw materials for clinker production in cement have some limitations including high concentrations of incompatible elements, and electrifying cement kilns has been challenging because of their high temperature needs. Also, utilizing slag in steel construction faces the barrier of having high content of free lime. In addition, incorporating $CO_2$ as a one-carbon building block in chemical synthesis is difficult due to the high thermodynamic stability and kinetic inertness of carbon dioxide ($CO_2$) pose another challenge.

Furthermore, reductions in emissions would require large changes in investment patterns. A necessity for implementing cross-sectoral mitigation strategies for reducing emissions could be way more cost effective than focusing on individual technologies. The success of technology transfer of HAI sectors may involve not only the provision of finance and information, but also strengthening policy and regulatory environments and capacities to absorb, employ and improve technologies to achieving the ambitious targets of the Paris Agreement successfully.

This made mapping HAI sectors to be a foundational step towards implementing mitigation measures by identifying and analyzing existing initiatives within these sectors, we can pinpoint areas where the TEC can add substantial value. This mapping exercise will not only provide guidance but also furnish valuable insights and information necessary to facilitate the effective implementation of transformative technologies

[11] International Energy Agency. Net Zero by 2050 A Roadmap for the Global Energy Sector. Available at: https://www.iea.org. 2021

through the Climate Technology Centre and Network (CTCN). Furthermore, this comprehensive map will establish a solid foundation for preparing the anticipated outputs and deliverables in the rolling work plan of the TEC for 2023-2027, scheduled for the years 2024, 2025, and 2026.

## 1.3 Scope of Mapping

The scope of the work presented is to map the relevant data on the HAI sectors: cement, steel and chemicals & petrochemicals. The undertaken work includes assessment and mapping of emission reporting, climate technologies, their suggested relative priority of implementation, enabling policies and implementation cost estimation in global studies, roadmaps and initiatives on HAI. The work also analyzes the status of inclusion of HAI sectors and climate technology needs in nationally determined contributions (NDCs), biennial reports (BRs), biennial update reports (BURs), technology needs assessment (TNAs), and long--term low emissions development strategies (LT-LEDS), as well as the requirement on technologies to be promoted to reach PA targets.

Additionally, data is assessed on selected countries including the current situation of the HAI in these countries, the future plans regarding emissions mitigation, the technologies implemented and technology needs, as well as any other gaps required for meeting the identified mitigation ambitions. Ten countries were selected for an in-depth assessment together with the global-level analysis. The selection process focused on achieving a diversity in terms of the geographical location, size of economy, and technological advancement. The selected countries also represent a significant contribution to the GHG emissions from the HAI sectors.

Finally, the document provides an analysis of challenges, trends and promising policies for mitigation of GHGs in transformative industries, in addition to the impact of the implementation of response measures. It also provides an overview of implemented success stories and recommendations towards a sustainable transformation.

# 2 MAPPING AND ASSESSMENT OF GLOBAL INTIATIVES IN HAI

This section provides an overview about sectoral emissions and indicators for the sectors of cement, steel, and chemicals & petrochemicals. It also provides an assessment and mapping of the global studies, roadmaps, and initiatives relevant to HAI sectors.

## 2.1 Sectoral Emissions and Indicators

To act as a global on look about GHG emissions and their current inclusion in submitted NDCs, the latest 2022 NDC synthesis report mentioned that the submitted reports covered 193 parties with a share of 52.6 Giga tonnes $CO_2$ equivalent (Gt $CO_2$eq) without Land Use, Land-Use Change and Forestry (LULUCF) which is around 94.9% of the total global emissions. The implementation of the mitigation measures represented by the parties in the NDCs project that the global emissions would reach 53.4 (51.8 – 55) Gt $CO_2$eq in 2025 and 52.4 (49.1 – 55.7) Gt $CO_2$eq in 2030[12].

These figures indicate a higher possibility of emissions peaking before 2030 given the full implementation of the measures which depends on the provision of support in the areas of finance, technical assistance, knowledge transfer and capacity building. However, it's crucial to underscore that these figures, while representing a step in the right direction, do not, on their own, guarantee achievement of the ambitious Paris Agreement targets. The pathways outlined in these reports are, by no means, sufficient to align with the goals of the Paris Agreement. To effectively address the challenge of achieving a net-zero future, it is imperative to implement additional policies that encompass elevated pricing mechanisms on emissions. Simultaneously, a noticeable transformation in investment patterns must be embraced[13]. Furthermore, fostering international cooperation is essential to collectively work towards the shared goal of achieving net-zero emissions[14].

The industrial sector was mentioned as a mitigation option by 47% of the parties[15]. These findings underscore the urgent requirement for comprehensive transformation and the adoption of zero-emission pathways across all sectors, particularly the Hard to Abate Industries (HAI) sectors. Achieving the Paris Agreement targets demands nothing less than a sweeping, systemic shift towards a sustainable, zero-emission future.

The following sub-sections include the emission data and their trends in the HAI sectors.

[12] UNFCCC, 2022 NDC Synthesis Report. (available at: https://unfccc.int/ndc-synthesis-report-2022)
[13] Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, and M.V. Vilariño, 2018: Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 93-174, doi:10.1017/9781009157940.004.
[14] U. N. Environment, “Emissions Gap Report 2022,” UNEP - UN Environment Programme, Oct. 21, 2022. http://www.unep.org/resources/emissions-gap-report-2022 (accessed Aug. 25, 2023).
[15] ibid

### 2.1.1 Cement Sector

Global cement production was reported to be 4.3 billion tons in 2021[16], with total emissions of 1.672 Gt $CO_{2eq}$ in the same year[17]. This made the cement sector became the third-largest industrial energy consumer and the second-largest industrial $CO_2$ emitter globally. with a share of 7% of global energy emissions, after steel with 8%, followed by other industries with 6% and chemicals with 4%[18]. Under a scenario that considers announced carbon mitigation commitments and energy efficiency targets by countries, the cement sector would increase its direct $CO_2$ emissions by just 4% globally by 2050, for an expected growth of 12% in cement production over the same period[19].

As shown in Figure 2-1 below, the largest increase in demand for cement is not expected to be in developed economies such as the US and Europe, but rather in the rapidly growing and urbanizing economies, which are still going through major construction activities. While the US and Europe account for only 13% of global cement production, China's annual 2.5 billion tons currently account for 60% of such production. By contrast, cement production in India and Africa is likely to be more than tripled over the next 35 years as urbanization and infrastructure needs drive huge demand for concrete[20].

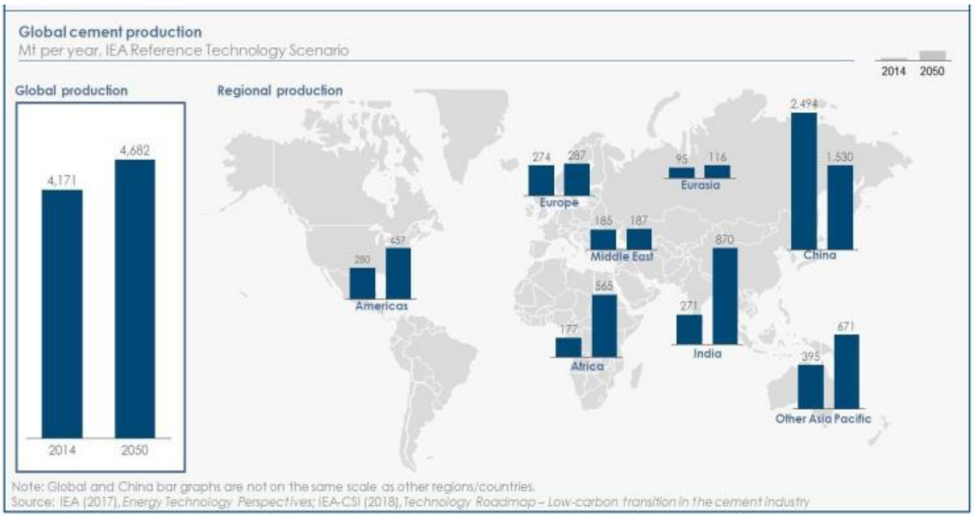



**Figure 2-1: Global cement production by 2050 according to IEA's Reference Technology Scenario[21]**

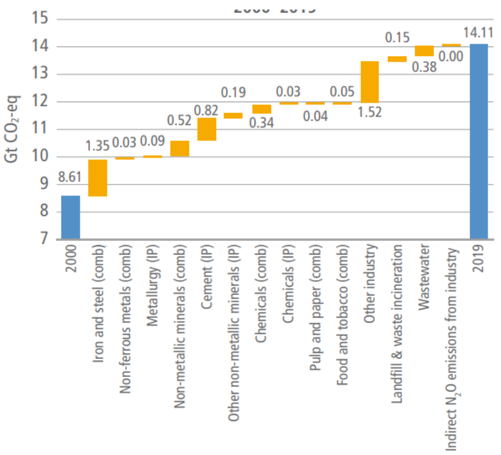
Hence, unless there is a major shift to use substitute materials for buildings material**,** total global cement production will continue to grow rapidly. However, demand growth impact could be slowed down via greater implementation of decarbonization technologies**.**

### 2.1.2 Steel Sector

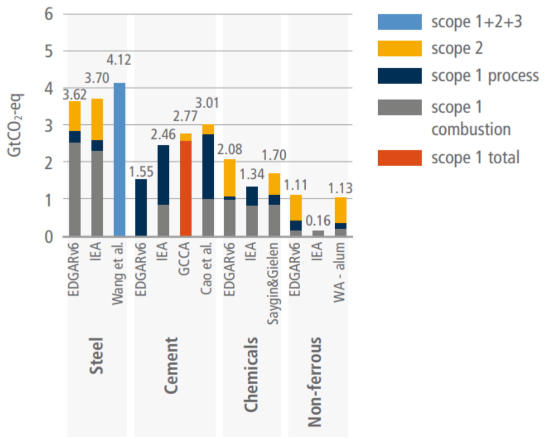
Demand for steel was estimated to have declined by 5% in 2020 relative to 2019. However, steel global demand is likely to grow by more than a third by 2050. The iron and steel sub-sector is considered the 2nd largest share of energy consumption and the largest source of emissions (about 2.6 Gt $CO_2$ annually) of the

16 https://www.iea.org/data-and-statistics/charts/global-cement-production-in-the-net-zero-scenario-2010-2030-5260
17 https://ourworldindata.org/grapher/annual-co2-cement?tab=table&facet=none
18 https://www.researchgate.net/figure/Cement-productions-share-of-global-CO-2-emissions-adapted-from-Czigler-et-al-2020_fig1_354873215
19 https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry
20 https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Cement_final.pdf
21 https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Cement_final.pdf

industrial sector, which represents about one quarter of the industrial $CO_2$ emissions among heavy industries (including process emissions)[22]. As per the IPCC document “Climate Change 2022: Mitigation of Climate Change”, increments of GHG emissions from iron and steel (direct emissions only) during 2000 till 2019 were recorded to be 1.35 Gt $CO_2$-eq.[23]




Increments of GHG emissions by sources (direct emissions only) 2000-2019




2019–2020 emissions by major basic materials production

**Figure 2-2:Industrial sector direct global greenhouse gas (GHG) emissions.**

Source: calculated based on emissions data from Crippa et al. (2021) and Minx et al. (2021). Indirect emissions were assessed using IEA (2021b). For (e): Cao et al. (2020); IEA (2020b, 2021a); GCCA (2021a); International Aluminum Institute (2021a); and Wang et al. (2021).

The table below shows the dynamics and structure of iron and steel industry greenhouse gas (GHG) emissions.

**Table 2-1:Dynamics and structure of iron and steel industry greenhouse gas (GHG) emissions[24]**

| Source | Average annual growth rate from 2011-2019 | Share in total industrial sector emissions in 2019 | 2019 emissions Mt$CO_2$-eq |
|---|---|---|---|
| **Direct $CO_2$ emissions from fuel combustion** | 2.28% | 12.4% | 2481 |
| **Industrial processes $CO_2$ - Metallurgy** | 3.10% | 2.0% | 391 |

Steel sector is currently responsible for about 8% of global final energy demand and 7% of energy sector $CO_2$ emissions.[25]

The IEA’s roadmap for the iron and steel and the driving energy efficiency in heavy industries article, as shown in Figure 2-3 the policies announced by countries in the Stated Policies Scenario (STEPS), it is projected that the GHG emissions will slightly increase in 2050 compared to 2019 despite the expected large rise in production. This is attributed to increasing the reliance on using scrap, and the more uptake of the Direct Reduced Iron in the Electric Arc Furnace (DRI-EAF) route. There is a potential for GHG emission reduction in the steel sector via maximizing the implementation of energy efficiency measures. According to a global benchmarking project in 2018, it was found that the G20 countries on average almost consume double the energy amounts compared to the benchmark[26]. As shown in Figure 2-3, employing

[22] https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf
[23] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf
[24] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf
[25] https://www.iea.org/reports/iron-and-steel-technology-roadmap
[26] https://www.iea.org/articles/driving-energy-efficiency-in-heavy-industries

more ambitious low-carbon solutions following the Sustainable Development Scenario (SDS) can result in almost 50% reduction in GHG emissions compared to the STEPS scenario. In addition, the emissions intensity of steel production can be dramatically reduced under the SDS scenario compared to the STEPS one. Hence, through innovation, low-carbon technology deployment and resource efficiency, iron and steel producers have a major opportunity to reduce energy consumption and greenhouse gas emissions, develop more sustainable products and enhance their competitiveness.[27]

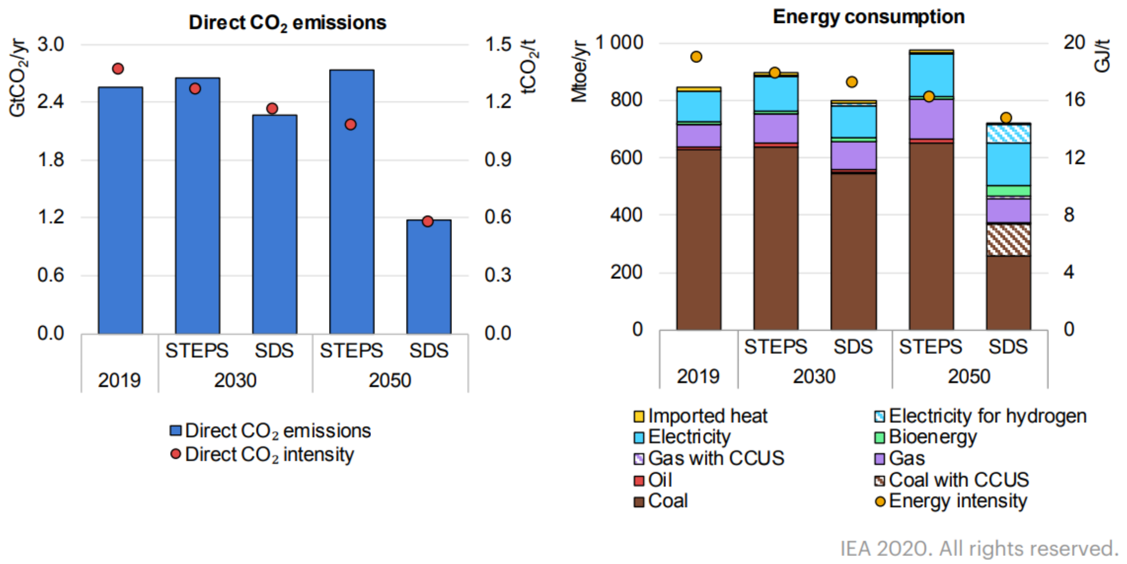



**Figure 2-3: Direct $CO_2$ emissions and energy consumption in the iron and steel sector by scenario (STEPS: Stated Policies Scenario, SDS: Sustainable Development Scenario)[28]**

### 2.1.3 Chemicals and Petrochemicals Sector

The chemical sector is a significant contributor to the global economy, directly accounting for over 1% of the world's GDP. It stands as the largest industrial consumer of energy, consuming 30% of total industrial energy use. However, it emits less $CO_2$ emissions compared to the steel and cement sectors, making up approximately 16% of total direct industrial emissions in 2019[29],[30].

Globally, the chemical industry contributed approximately 0.977 Gt $CO_{2eq}$ from Direct $CO_2$ emissions from fuel consumption in 2019, representing around 4.9% of the total industrial sector emissions, in addition to 0.720 Gt $CO_{2eq}$ from Industrial processes $CO_2$ emissions representing around 3.6% of the total industrial sector emissions in 2019.[31]

The carbon footprint in this industry primarily arises from two main sources: energy-related emissions and process-related emissions. Energy-related emissions amount to almost 85% of the total emissions[32]. These

[27] https://www.iea.org/reports/iron-and-steel-technology-roadmap
[28] https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf
[29] IEA (2020), Energy Technology Perspectives 2020, IEA, Paris https://www.iea.org/reports/energy-technology-perspectives-2020, License: CC BY 4.0
[30] "World Greenhouse Gas Emissions: 2019," World Resources Institute. https://www.wri.org/data/world-greenhouse-gas-emissions-2019 (accessed Jul. 24, 2023).
[31] Bashmakov, I.A., L.J. Nilsson, A. Acquaye, C. Bataille, J.M. Cullen, S. de la Rue du Can, M. Fischedick, Y. Geng, K. Tanaka, 2022: Industry. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.013
[32] ibid

emissions result from the combustion of fuels. A significant portion of the chemical sector's energy inputs is utilized as feedstock, leading to a substantial amount of carbon being incorporated into the final product rather than released during production. Despite this advantage, the sector still faces challenges in reducing $CO_2$ emissions. On the other hand, process emissions arise when feedstock carbon content exceeds product requirements, and they contribute to about 15% of total chemical sector emissions [33].

Figure 2-4 illustrates that the Asia Pacific region stands as the largest emitter of direct $CO_2$ emissions from chemical industries, with a contribution of around 500 $MtCO_2$/year, as of 2017 data, in comparison to other regions, such as North America and Europe which contribute about 90 $MtCO_2$/year each, and less for other regions [34].

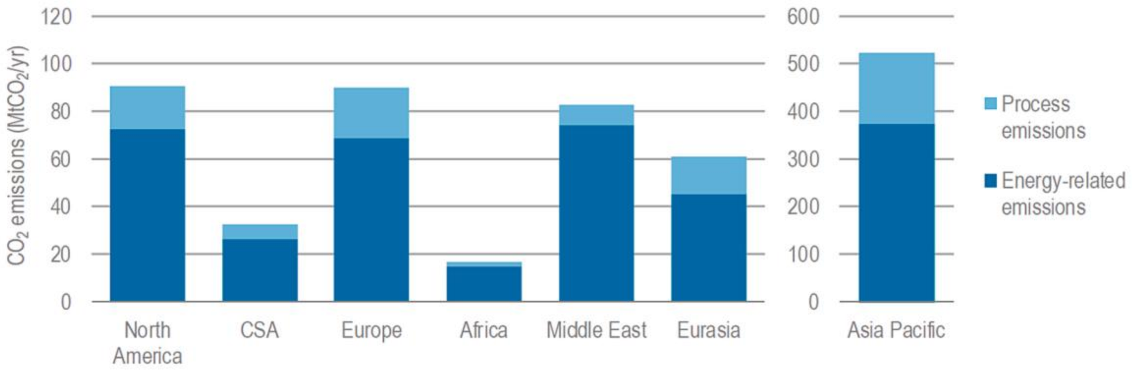



**Figure 2-4: Direct $CO_2$ emission of primary chemicals by region in 2017.[35]**
**Note: CSA = Central and South America, Asia-Pacific region include China, India, Japan, Korea, the Association of Southeast Asian Nations, Australia, New Zealand, and other Asian economies.**

Hydrocarbons, mainly derived from oil and natural gas, are the primary feedstocks for chemical production, with coal also playing a lower role, and constitutes around 85% of the sector's energy use. Chemical production accounted for about 14% of global oil demand and 9% of global gas demand, in 2019. The chemical sector produces a wide array of products, including primary chemicals, plastics, fertilizers, pharmaceuticals, and explosives. The energy intensity of production varies between products, with primary chemicals being particularly energy intensive. These primary chemicals, such as ammonia, methanol, and others, are the building blocks for most chemical products, accounting for about two-thirds of the sector's total energy consumption and feedstock needs [36].

According to the IEA's Reference Technology scenario mentioned in The Future of Petrochemicals report[37], the global demand for chemicals is projected to increase alongside economic growth, particularly in emerging economies, additional production capacity will be required. This scenario is founded on cost-optimized decisions regarding industrial equipment and operations, considering energy prices, chemical demand, and established policies. It aligns with the International Energy Agency's New Policies Scenario (IEA, 2017), which reflects current policy intentions, implemented measures, and official targets worldwide in the energy sector. For example, the use of fertilizers and agrochemicals is closely linked to agricultural

[33] ibid
[34] C. Chung, J. Kim, B. K. Sovacool, S. Griffiths, M. Bazilian, and M. Yang, "Decarbonizing the chemical industry: A systematic review of sociotechnical systems, technological innovations, and policy options," Energy Research & Social Science, vol. 96, p. 102955, Feb. 2023, doi: 10.1016/j.erss.2023.102955.
[35] ibid
[36] IEA (2020), Energy Technology Perspectives 2020, IEA, Paris https://www.iea.org/reports/energy-technology-perspectives-2020, License: CC BY 4.0
[37] IEA (2018), The Future of Petrochemicals, IEA, Paris https://www.iea.org/reports/the-future-of-petrochemicals, License: CC BY 4.0

output, which must expand to meet the needs of a growing population and increasing food demand. Figure 2-5 shows the projection for the global chemicals production until 2050 [38].

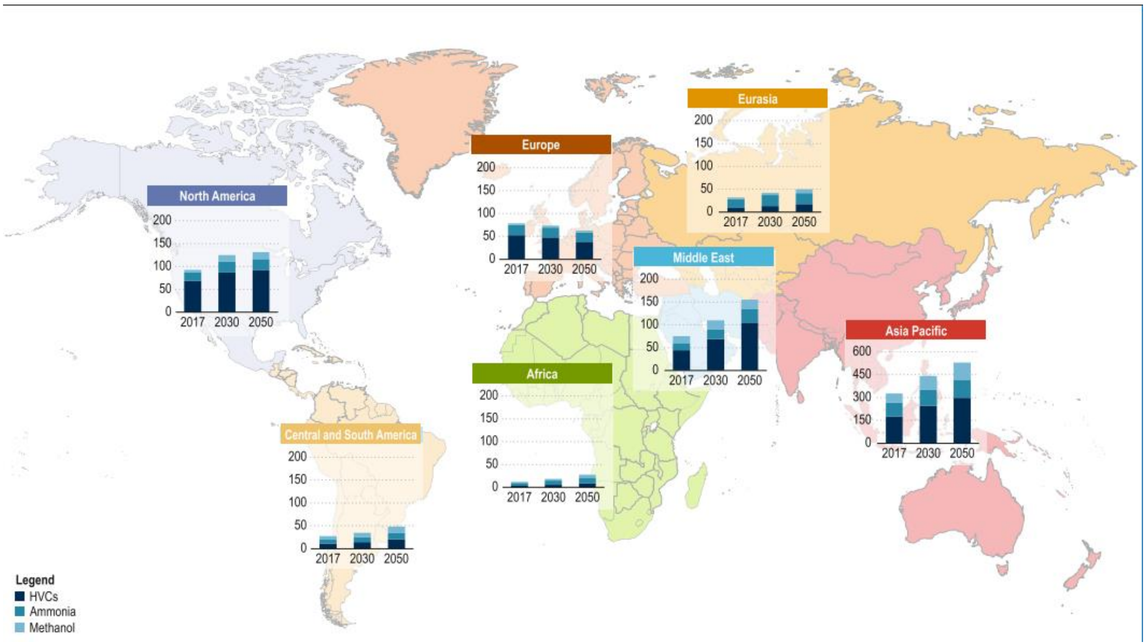



**Figure 2-5: Regional production of primary chemicals in the Reference Technology Scenario[39]**

In the Reference Technology Scenario as referenced in the IEA's The Future of Petrochemicals, $CO_2$ emissions from the chemical sector is expected to experience a significant rise of over 30% by the year 2050. Most of this increase, nearly two-thirds, occurs before 2030, with emissions continuing to grow at a slower pace from 2030 to 2050, reaching just under 2 Giga tonnes of carbon dioxide per year ($GtCO_2/y$). Emissions in 2050 are almost at the same level as those observed in 2030. The driving force behind this emission growth is the substantial increase in primary chemical demand, which rises by 32% by 2030 and 56% by 2050 in comparison to 2017[40].

Despite a temporary drop in demand due to the COVID-19 crisis, there is no sustained saturation in global demand for plastics and other chemical products. Some chemical products, like personal protective equipment, have even experienced a surge in demand. However, there is increasing interest in curbing plastic use due to environmental concerns. Several countries have initiated policies to phase out single-use plastics, responding to their detrimental impact on oceans, human health, and wildlife. Addressing $CO_2$ emissions in the chemical sector is challenging for several reasons. Moreover, long-lived capital assets, such as steam crackers, make early retirement economically challenging due to significant initial investments. International trade considerations also hinder the adoption of climate measures without a global consensus, as chemical supply chains often span multiple countries [41].

To overcome these obstacles, the chemical sector must invest in innovative technologies and cooperate internationally to transition towards more sustainable practices. Efforts to improve plastic waste

[38] IEA (2018), The Future of Petrochemicals, IEA, Paris https://www.iea.org/reports/the-future-of-petrochemicals, License: CC BY 4.0
[39] IEA (2018), The Future of Petrochemicals, IEA, Paris https://www.iea.org/reports/the-future-of-petrochemicals, License: CC BY 4.0
[40] ibid
[41] IEA (2020), Energy Technology Perspectives 2020, IEA, Paris https://www.iea.org/reports/energy-technology-perspectives-2020, License: CC BY 4.0

management, increase efficiency, and identify alternatives for specific end uses are crucial for mitigating the sector's environmental impact.

## 2.2 Roadmaps and Initiatives

### 2.2.1 Global Industrial Roadmaps and Initiatives

Roadmaps and initiatives play a key role to organize efforts related to achieving deep-decarbonization of global industries, which is a part of governments' support for research and development (R&D). National governments spend roughly $15 billion annually on R&D for clean energy technologies[42], which played important roles in the development of countless technologies in recent decades. Increased R&D funding on industrial decarbonization is essential for developing the corresponding mitigation technologies. This subsection includes an overview of the global roadmaps and initiatives, summarized in Table 2-2 below.

The roadmaps have several key findings that can be considered as cross-cutting to the achievement of the reduction goals, including the need for policy drivers, the importance of collaborations, technology transfer as well as the importance of investing in R&D as a main driver of low-carbon technology implementation on the different levels.

This section focuses on the sectoral cross cutting roadmaps, and the sector specific roadmaps will be discussed in the subsequent section.

**Table 2-2: Global industrial roadmaps and initiatives**

| Issuing Entity | Year of Issuing | Name of Publication |
|---|---|---|
| **Global roadmaps** | | |
| The Energy Transitions Commission | 2018 | Mission Possible Roadmap: Reaching net-zero carbon emissions from harder-to-abate sectors |
| SITRA (Finnish Innovation Fund) | 2018 | The Circular Economy Roadmap: A Powerful Force for Climate Mitigation Transformative innovation for prosperous and low-carbon industry |
| Fondazione Eni Enrico Mattei (FEEM) and the Sustainable Development Solutions Network (SDSN) | 2019 | Roadmap to 2050: A Manual for Nations to Decarbonize by Mid-Century: |
| IEA | 2021 | Net Zero by 2050 A Roadmap for the Global Energy Sector |
| IEA | 2022 | Achieving Net Zero Heavy Industry Sectors in G7 Members |
| World Resources Institute | 2022 | State of Climate Action 2022 |
| **Global initiatives** | | |
| UNIDO and the Clean Energy Ministerial | 2021 | The Industrial Deep Decarbonization Initiative (IDDI) |
| Mission Innovation Ministerial | 2022 | The Net-Zero Industries Mission Initiative |
| The World Economic Forum | 2021 | The First Movers' Coalition (FMC) Initiative |
| Science Based Targets | 2015 | Science Based Targets |
| Leadership Group for the Industry Transition (LeadIT) | 2019 | Leadership Group for the Industry Transition (LeadIT) |

#### 2.2.1.1 Global Roadmaps

[42] https://cdrlaw.org/wp-content/uploads/2020/09/ICEF_Roadmap_201912.pdf

#### 2.2.1.1.1 Mission Possible Roadmap: Reaching net-zero carbon emissions from harder-to-abate sectors[43]

The "Mission Possible" is a roadmap which was developed in 2018 by the Energy Transitions Commission with contributions from over 200 industry experts, that outlines the possible routes to fully decarbonize cement, steel, plastics, trucking, shipping and aviation. These industries represent 30% of global energy emissions today and could increase to 60% by mid-century as other sectors decrease their emissions. The roadmap shows that full decarbonization is technically feasible with technologies that already exist, by following three main routes (as shown in Figure 2-6 below): reduce demand for carbon intensive products & services, improving energy efficiency and deploying decarbonization technologies across all sectors.

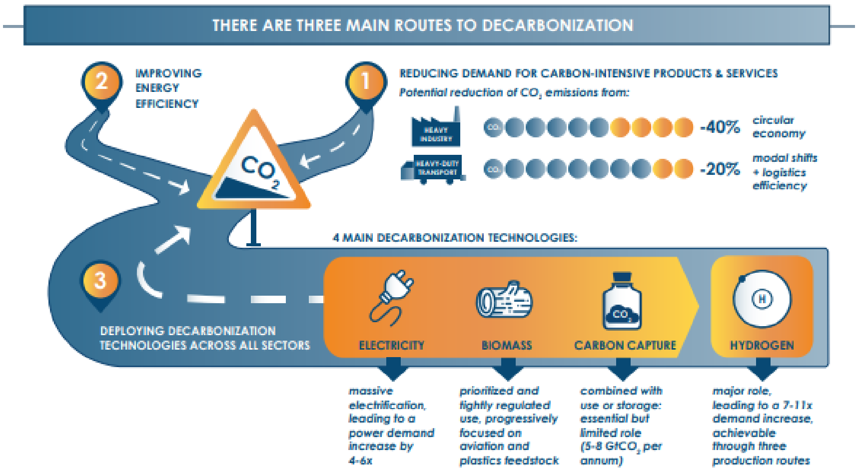



**Figure 2-6: Routes to Decarbonization According to Mission Possible roadmap[44]**

Key policy levers to accelerate the decarbonization of harder-to-abate sectors according to mission impossible roadmap include:

- Focusing on carbon-intensity mandates on industrial processes, heavy-duty transport and the carbon content of consumer products
- Introducing adequate carbon pricing, by pursuing a comprehensive pricing systems
- Encouraging the shift to a circular economy by applying materials efficiency regulation
- Investing in the green industry, through R&D support, and deployment support
- Accelerating public-private collaboration to build necessary energy and transport infrastructure

#### 2.2.1.1.2 The Circular Economy Roadmap: A Powerful Force for Climate Mitigation Transformative innovation for prosperous and low-carbon industry[45]

This roadmap prepared by the Finnish Innovation Fund (SITRA) in 2018, investigates how a more circular economy can contribute to cutting $CO_2$ emissions. It focuses on making better use of the materials that already exist in the economy, which can take industry halfway towards net-zero emissions.

This roadmap believes that a more circular economy can cut emissions from heavy industry by 56% by 2050, as shown in Figure 2-7. The "Circular Economy" Roadmap explores a broad range of opportunities

[43] https://www.energy-transitions.org/publications/mission-possible/#download-form,%20https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Cement_final.pdf
[44] https://www.energy-transitions.org/publications/mission-possible/#download-form,%20https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Cement_final.pdf
[45] https://www.sitra.fi/app/uploads/2018/06/the-circular-economy-a-powerful-force-for-climate-mitigation.pdf

for the four largest materials in terms of emissions (steel, plastics, aluminum, and cement). The key conclusion from this roadmap is that a circular economy can make deep cuts to emissions from heavy industry, as much as 296 Mt $CO_2$ per year in the EU by 2050, out of 530 in total. It suggests three circular strategies to work together to cut industrial emissions. This includes materials recirculation, more material-efficient products and new circular business models which encourages that buildings and transportation vehicles are utilized more efficiently.

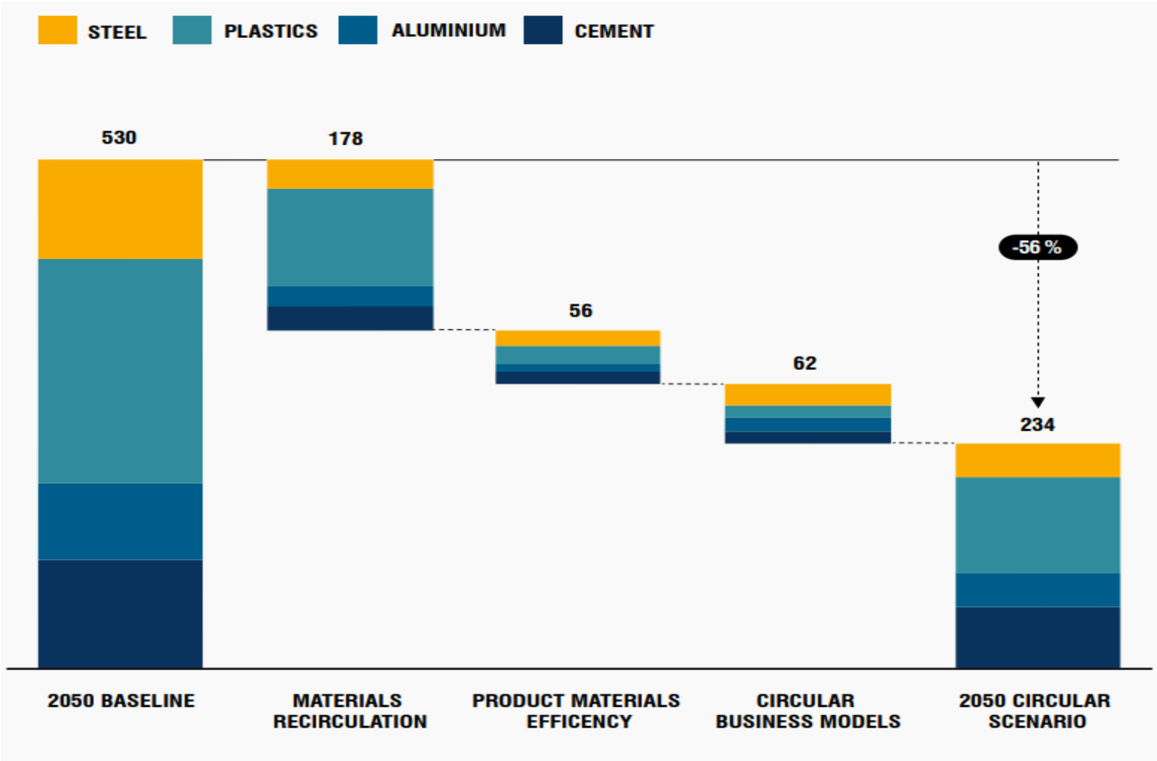



Figure 2-7: EU Emissions Reductions Potential From A Circular Economy roadmap in 2050 (Mt Of Carbon Dioxide Per Year)[46]

### 2.2.1.1.3 Roadmap to 2050: A Manual for Nations to Decarbonize by Mid-Century[47]

The roadmap which was published in 2019, offers a comprehensive blueprint for countries to achieve a fair and just transition to zero emissions by 2050. It is built based on four key principles as follows:

- Cooperation and coordination in policy design and implementation, especially in developing or low-income regions. This includes utilizing diverse resources, technologies, and processes to ensure inclusivity and socioeconomic development.
- Recognizing the unique geographical and social contexts of each country. The roadmap emphasizes the importance of meeting both societal needs and environmental goals.
- Having regulatory frameworks that encourage innovation and can adapt to changing circumstances.
- Allocating consistent investments for R&D.

The roadmap also stresses the need for transparency and accessibility as crucial principles, and accordingly ensuring that planning data and design assumptions are transparent to stakeholders.

[46] https://www.sitra.fi/app/uploads/2018/06/the-circular-economy-a-powerful-force-for-climate-mitigation.pdf
[47] SDSN and FEEM, Roadmap to 2050 A Manual for Nations to Decarbonize by Mid-Century, 2019 (Available at: https://roadmap2050.report/static/files/roadmap-to-2050.pdf)

The roadmap emphasizes the importance of achieving zero net emissions of greenhouse gases (GHGs) by 2050 and negative emissions without providing certain milestones for the transition. It also incorporates feedback from experts across various sectors, including international agencies, academia, research centers, think tanks, NGOs, public institutions, and the private sector. Additionally, technology recommendations from expert engineers are provided, adding further depth and expertise to the roadmap. The roadmap identified six decarbonization pillars; four of which are related to HAI; namely, zero-carbon electricity generation, improved materials efficiency, electrification of technologies, in addition to deployment and use of green synthetic fuels.

The roadmap also provides several recommendations for the decarbonization of the industrial sectors with a focus on the cement, iron and steel and the petrochemicals sector (mainly plastics, solvents, and industrial chemicals). These recommendations include:

- Integrated approach: Decarbonization should be implemented in an integrated manner, rather than in sector-based silos. This means that different industry sectors should work together and consider the interdependencies between them when implementing decarbonization strategies.
- Leadership and political will: Achieving net zero carbon emissions by 2050 requires strong leadership, political will, and courage. Industry leaders and policymakers need to take proactive steps to drive the transition to renewable resources and support the adoption of sensitive options such as carbon capture.
- Pathways design: Scientists, engineers, and technical experts play a crucial role in designing decarbonization pathways for energy-intensive sectors such as power, heavy industry, transport, and buildings. These pathways should consider the specific requirements and challenges of each sector.
- Displacing fossil fuel-based energy inputs: To reduce emissions, industry sectors need to replace fossil fuel-based energy inputs with low- to zero-emission electricity. This can be achieved through the use of renewable energy sources and improved heat integration and energy efficiency.
- Multidimensional approach: Fully decarbonizing complex and integrated industrial environments requires a multidimensional approach. This includes reducing demand for carbon-intensive products and services, improving energy efficiency in current production processes, and deploying decarbonization technologies across all industries.
- Supply-side decarbonization routes: The roadmap identifies four supply-side decarbonization routes for industries: electrification, use of biomass, use of hydrogen and synthetic fuels, and use of carbon capture technology. These routes can help industries transition to low-carbon energy sources and reduce emissions.

By following these recommendations, the industrial sector should be able contribute to the overall decarbonization efforts and help achieve the goal of net zero carbon emissions by 2050. In summary, the roadmap serves as a valuable guide for countries in formulating comprehensive climate policies and strategies to achieve decarbonization by 2050. It underscores the importance of considering specific contexts, fostering cooperation and coordination, and embracing innovation and transparency in the pursuit of a sustainable and low-emission future.

##### 2.2.1.1.4 IEA's Net Zero by 2050 A Roadmap for the Global Energy Sector[48]

The Net Zero by 2050 roadmap was prepared by IEA in 2021, and highlights that despite the current gap between rhetoric and reality on emissions, the roadmap demonstrates that there are still pathways to achieve net zero emissions by 2050. The pathway set out in this roadmap is designed to ensure the technical feasibility, cost-effectiveness, in addition to being socially acceptable. However, it is important to note that this pathway remains narrow and extremely challenging, requiring the involvement of all stakeholders, and the immediate and wide implementation of clean and energy efficient technologies in this decade via strengthening the relevant national policies. The roadmap sets the milestones for the transition by 2030: newest clean technologies have been demonstrated at a scale, and production of 150 Mt of low carbon hydrogen. By 2035: All industrial electric motor sales are best in class and capturing 4 Gt of $CO_2$. By 2040: 90% of existing capacity in heavy industry reaches the end of investment cycle. By 2045: production of 435 Mt of low carbon hydrogen. By 2050: 90% of the heavy industry production is low emissions and capturing 7.6 Gt of $CO_2$ as shown in Figure 2-9.

The roadmap also highlights the following:

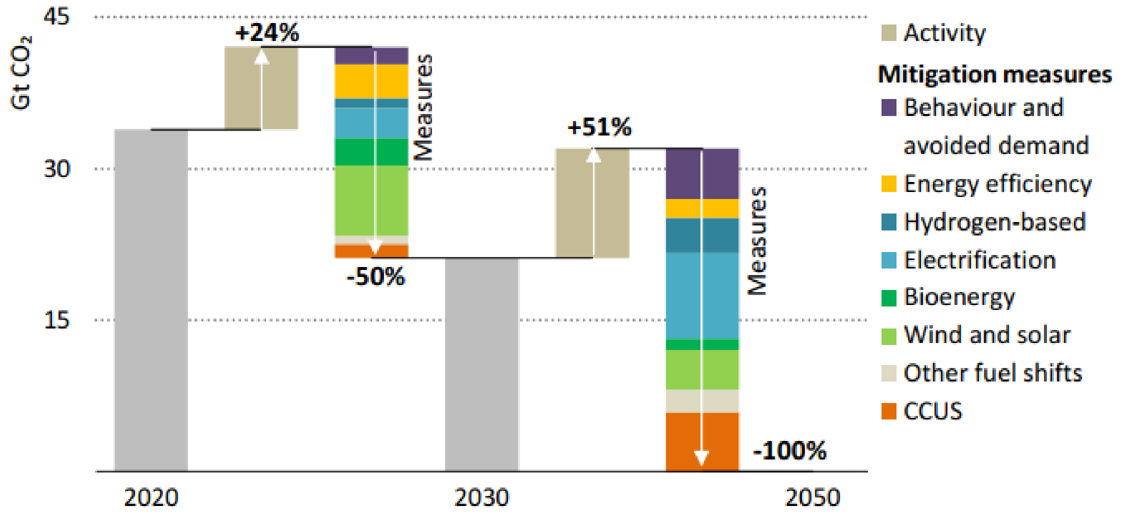
- The criticality of increasing the R&D spending on the key decarbonization technologies. Around USD 90 billion needs to be mobilized to complete the required portfolio of demonstration decarbonization projects.
- The need for long-term policy frameworks with clear step by step plans to facilitate an orderly transition and allow all branches of government and stakeholders to plan for change.
- The importance of international cooperation, innovation, and investment in achieving the net-zero pathway.
- The importance of behavioral changes since the transition to net zero is not just about technology and policies; it is also about people.
- There is no need for investment in new fossil fuel supply in the net-zero pathway.

The roadmap mentions that emissions from industry are expected to fall by around 20% over the next decade. The pace of emissions reductions in the industry sector is expected to accelerate during the 2030s as the roll-out of low-emissions fuels and other emissions reduction options is scaled up. However, it also acknowledges that there are areas in transport and industry, such as aviation and heavy industry, where it is difficult to eliminate emissions entirely. These sectors are projected to have residual emissions in 2050, which are offset with applications of Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Capture and Carbon Capture and Storage (DACCS).

To successfully achieve the net-zero pathway, it is essential for governments, businesses, investors, and citizens to act consistently. The roadmap sets out clear milestones, spanning all sectors and technologies, for the transformation of the global economy from one dominated by fossil fuels to one powered predominantly by renewable energy sources like solar and wind. This transformation requires significant investment, innovation, skillful policy design and implementation, technology deployment, infrastructure building, international cooperation, and efforts across many other areas.

[48] IEA, Net Zero by 2050 A Roadmap for the Global Energy Sector, 2021 (Available at: 'https://unfccc.int/sites/default/files/resource/IEA_net_zero_by_2050.pdf)

To achieve a swift reduction in $CO_2$ emissions over the next 30 years in the Net-Zero Emissions (NZE) scenario, a diverse set of policy measures and technologies is necessary (see Figure 2-8). The primary drivers for decarbonizing the global energy system include enhancing energy efficiency, promoting changes in behavior, electrification, expanding the use of renewables, advancing hydrogen and hydrogen-based fuels, harnessing bioenergy, and implementing carbon capture, utilization, and storage (CCUS).






*Solar, wind and energy efficiency deliver around half of emissions reductions to 2030 in the NZE, while electrification, CCUS and hydrogen ramp up thereafter*

Notes: Activity = energy service demand changes from economic and population growth. Behaviour = energy service demand changes from user decisions, e.g. changing heating temperatures. Avoided demand = energy service demand changes from technology developments, e.g. digitalisation. Other fuel shifts = switching from coal and oil to natural gas, nuclear, hydropower, geothermal, concentrating solar power or marine.

**Figure 2-8: IEA Emissions reductions by mitigation measure in the NZE, 2020-2050[49]**

It is worth noting that IEA has published a new roadmap for the members of the G7 for achieving NetZero in the heavy industry sectors, discussed in the subsequent section as a mean to transit quickly to zero emission industries and stop investing in technologies reliant on fossil fuels.

Overall, the roadmap provides a comprehensive plan for achieving net-zero emissions by 2050, highlighting the challenges, implications, and necessary actions for governments and stakeholders at various levels, these actions included:

- Making the 2020s the decade of massive clean energy expansion.
- Preparing for the next phase of the transition by boosting innovation.
- Knowing that clean energy jobs will grow strongly but must be spread widely.
- Setting near-term milestones to get on track for long-term targets.
- Driving a historic surge in clean energy investment.
- Addressing emerging energy security risks now.
- Taking international cooperation to new levels.

[49] ibid

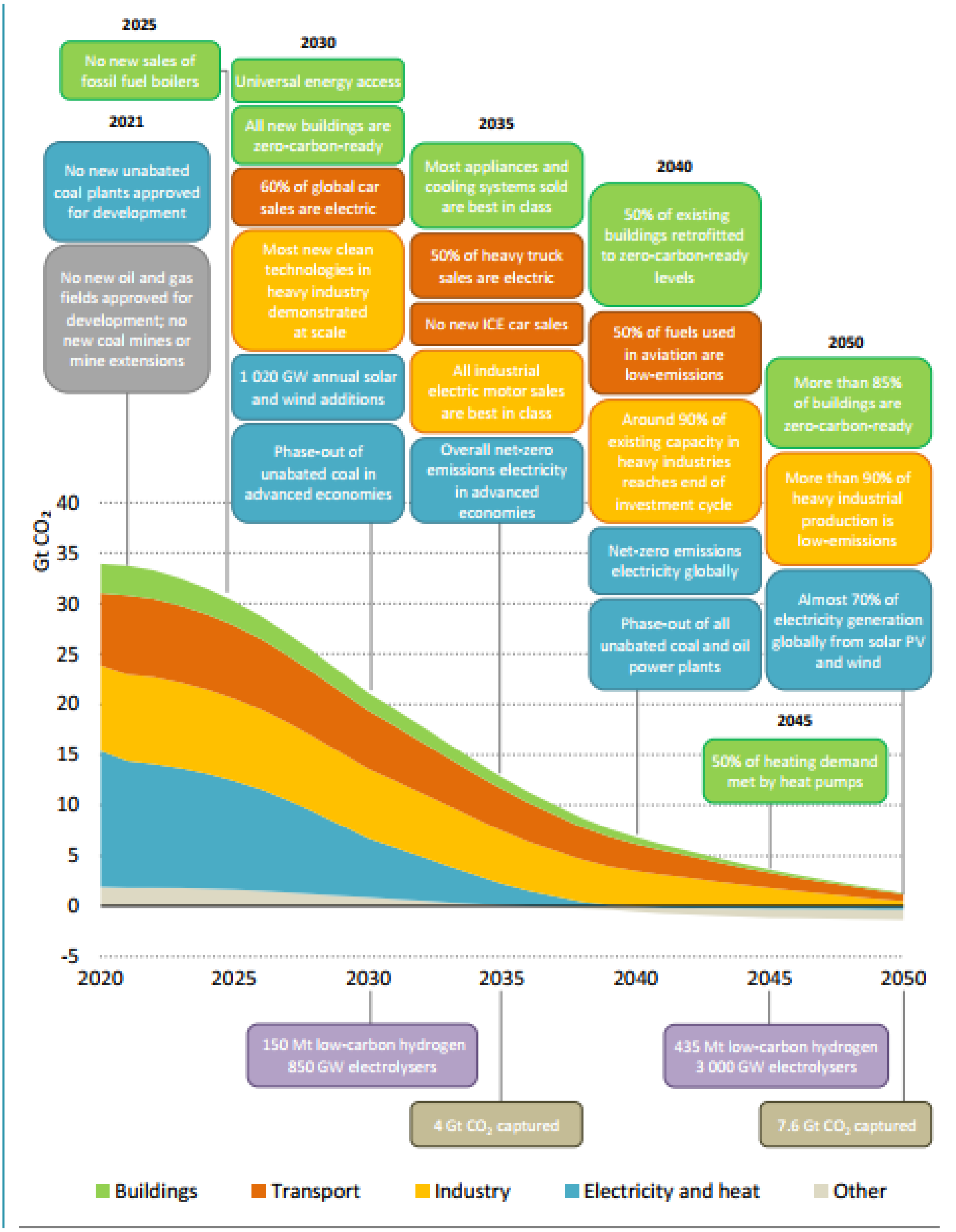



**Figure 2-9: IEA Key milestones in the pathway to net zero[50].**

### 2.2.1.1.5 WRI's State of Climate Action 2022

The report assesses global progress in addressing the climate crisis. It focuses on system-wide transformations across various sectors such as power, buildings, industry, transport, forests and land, food, and agriculture, and the scale-up of carbon dioxide removal technologies and climate finance. The report's methodology includes the selection of systems, targets, indicators, datasets, and enabling conditions which

[50] ibid

are compiled from the previously discussed roadmaps. Although there are no new milestones or target developed in the report, the report acts as a guide to decision-makers in government, companies, investing firms, and funding institutions dedicated to accelerating climate action.[51]

#### 2.2.1.1.6 Achieving Net Zero Heavy Industry Sectors in G7 Members[52]

Achieving Net Zero Heavy Industry Sectors in G7 Members is a new roadmap by IEA that focuses on the implementation of policies aimed at drastically lowering $CO_2$ emissions from heavy industries in the G7. This focuses on two key areas for achieving net zero heavy industry sectors in G7 members (Canada, France, Germany, Italy, Japan, the United Kingdom, the United States plus the European Union). The first is a toolbox of policies and financing mechanisms to initiate and sustain the industry sector transition. The second is a series of standards and definitions that are critical to form the basis for differentiating markets for products and establishing green public procurement protocols. This is followed by a review of existing efforts to establish near zero emission steel and cement production.

The figure below reflects the global direct CO2 emissions reductions in heavy industries by mitigation measure in 2050 net zero scenario by Achieving Net Zero roadmap. According to this roadmap, the G7moves 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). 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.

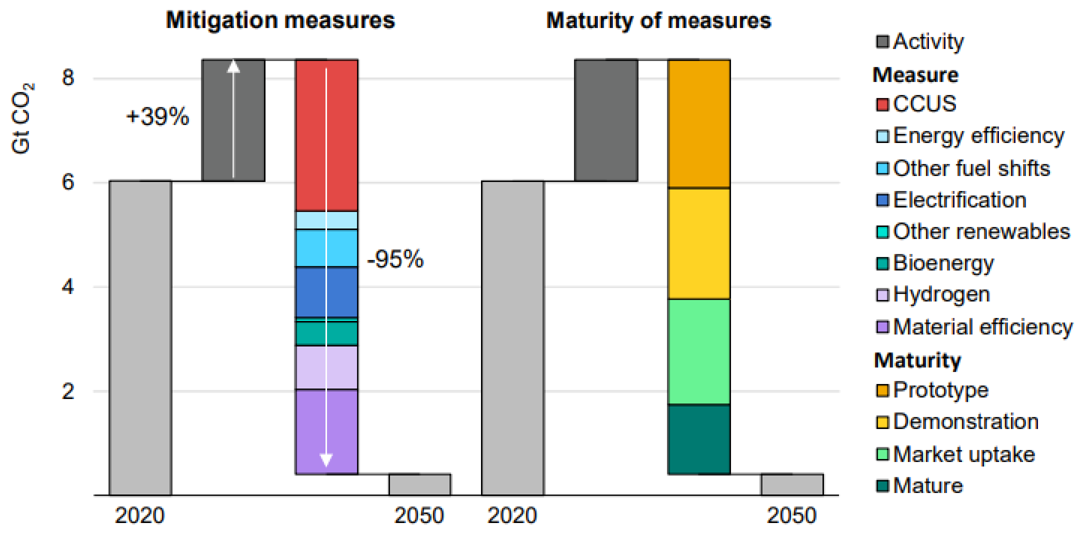





**Figure 2-10: Global direct $CO_2$ emissions reductions in heavy industries by mitigation measure and technology in the net zero scenario by 2050 in G7 Members** [53]

[51] S. Boehm et al., "State of Climate Action 2022," Oct. 2022, Accessed: Aug. 27, 2023. [Online]. Available: https://www.wri.org/research/state-climate-action-2022
[52] IEA, https://iea.blob.core.windows.net/assets/c4d96342-f626-4aea-8dac-df1d1e567135/AchievingNetZeroHeavyIndustrySectorsinG7Members.pdf
[53] IEA, https://iea.blob.core.windows.net/assets/c4d96342-f626-4aea-8dac-df1d1e567135/AchievingNetZeroHeavyIndustrySectorsinG7Members.pdf

Achieving Net Zero Heavy Industry Sectors in G7 Members roadmap carries a set of recommendations including:

- Develop sustainable transition plans for industry that are supported by policy
- Finance a portfolio of demonstration projects for near zero emission industrial production technologies
- Develop finance mechanisms to support deployment of near zero emission industrial technologies and associated infrastructure
- Create differentiated markets for near zero emission material production
- Explore a non-binding intergovernmental international industry decarbonization alliance in support of the industry transition
- Establish a cement sectoral Breakthrough at COP27
- Consolidate existing work on measurement standards, ensure their fitness for purpose, and avoid the development of duplicate standards and protocols
- Value interim steps taken to substantially lower emissions intensity, without compromising the stringency of the thresholds for near zero emission production
- Extend the reach of work on definitions down existing supply chains, and into new ones.

### 2.2.1.2 Global Initiatives

#### 2.2.1.2.1 The Industrial Deep Decarbonization Initiative (IDDI) [54]

The Clean Energy Industrial Deep Decarbonization Initiative (IDDI) as a country led initiative which is working to stimulate demand for low-carbon industrial materials that started since 2010 and still growing. In collaboration with public and private organizations, IDDI works to standardize carbon accounting standards, establish ambitious public and private sector procurement targets, incentivize investment into low-carbon product development and design industry guidelines. While being coordinated by UNIDO and the Clean Energy Ministerial in 2021, IDDI is co-led by the UK and India and current members include Canada, Germany, Japan, Saudi Arabia, Sweden, United Arab Emirates (UAE), the United States of America (US), and Brazil.

The initiative brings together a strong coalition of related initiatives and organizations including the Mission Possible Platform, the Climate Group, the Leadership Group for the Industry Transition (LeadIT) the World Economic Forum, Responsible Steel, First Movers Coalition as well as industry associations, particularly, WorldSteel and GCCA, to tackle carbon intensive construction materials such as steel and cement. Within the next three years, IDDI expects to have encouraged a minimum of 10 governments to make public procurement commitments for low-carbon steel and cement.

#### 2.2.1.2.2 The Net-Zero Industries Mission Initiative[55]

The “Net-Zero Industries Mission” Initiative is a global initiative launched by Mission Innovation Ministerial in 2022 to catalyze the development and demonstration of cost competitive solutions for the efficient decarbonization of hard-to-abate energy intensive industries worldwide by 2030.

[54] https://www.cleanenergyministerial.org/initiatives-campaigns/industrial-deep-decarbonisation-initiative/#:~:text=Overview,for%20low%2Dcarbon%20industrial%20materials.%20https://www.unido.org/IDDI
[55] https://explore.mission-innovation.net/mission/net-zero-industries/

This initiative is concerned with heavy industries like steel, cement, and chemicals, as these sectors also encounter high investment costs for process equipment with long payback periods and a lifetime of more than 20 years. The initiative focuses on unlocking emissions reductions at the end of their next refurbishment cycles, as it believes that this would prevent nearly 60 Gt $CO_2$ by 2050 and help put industrial sectors on a pathway to net zero emissions by 2050. This is by focusing on three pillars: underpinning R&D to fast-track new and radical breakthrough technologies, overcoming technical and non-technological barriers and technology demonstrations by realizing a portfolio of at least 50 large-scale demonstration projects in energy intensive industry.

#### 2.2.1.2.3 The First Movers' Coalition (FMC) Initiative[56][57]

This initiative is a result of public-private partnership that was launched by the World Economic Forum in 2021 to invest in innovative green technologies. The idea of the initiative is to have a collation of large companies who have a considerable purchasing power, which is a strong enough to ensure that the innovative low-carbon technologies are available for scale-up by 2030 and make a critical contribution to achieving net-zero emissions by 2050. Since it was launched at COP26, the First Movers Coalition has brought together global companies with supply chains across carbon-intensive sectors. They range from major consumer goods firms that ship, truck and fly their products, to renewable energy companies that use steel to build wind turbines.

So far, 65 companies, (whose collective market value exceeds $8 trillion across five continents) have committed $12 billion in 2030 purchase commitments for green technologies to decarbonize various HAI sectors including cement and concrete industry, steel, aluminum, shipping, trucking, and aviation. This group is also championing negative emissions through advanced carbon dioxide removal technologies.

Members of the FMC commit to purchasing near zero-emissions cement satisfying the following criteria[58]:

- Cement with embodied carbon below 184 kg $CO_2$eq/ton
- Concrete that meets embodied carbon limits below:

**Table 2-3: Embodied carbon limits for concrete by the First Movers' Coalition (FMC) Initiative**

| Specified compressive strength (f'c* in pounds per square inch (psi)) | Embodied carbon (kg $CO_2e/m^3$) |
|---|---|
| 0 - 2500 psi | 70 |
| 2501 - 3000 psi | 78 |
| 3001 - 4000 psi | 96 |
| 4001 - 5000 psi | 117 |
| 5001 - 6000 psi | 124 |
| 6001 - 8000 psi | 144 |

*Definition: f'c is the specified compressive strength of concrete using standard cylinders of six inches' diameter and twelve inches' height.

They also commit to purchase near zero-emissions steel satisfying the following criteria[59]:

- Crude steel from near-zero $CO_2$ technology production facilities

[56] https://www.weforum.org/first-movers-coalition/partners
[57] https://www.weforum.org/first-movers-coalition
[58] https://www3.weforum.org/docs/WEF_FMC_Cement_Concrete_Commitment.pdf
[59] https://www3.weforum.org/docs/WEF_FMC_Steel_2022.pdf

- Emitting <0.4 t (with 0% scrap inputs) to <0.1 t (with 100% scrap inputs) of $CO_2$ per tonne of crude steel produced

#### 2.2.1.2.4 Science Based Targets Initiative

The Science Based Targets initiative (SBTi) is a partnership between CDP, the United Nations Global Compact, World Resources Institute (WRI), and the World Wide Fund for Nature (WWF)[60]. The SBTi was established in 2015 to help companies set emission reduction targets in line with climate science and Paris Agreement goals[61]. The initiative defines and promotes best practice in emissions reductions and net-zero targets in line with climate science, provides technical assistance and expert resources to companies who set science-based targets in line with the latest climate science, and brings together a team of experts to provide companies with independent assessment and validation of targets[62]. Over 1,000 organizations worldwide are leading the zero-carbon transformation by setting emissions reduction targets grounded in climate science through the SBTi[63].

## 2.2.2 Sectoral Roadmaps and Initiatives

The R&D efforts support the expansion of decarbonization options in all industry sectors. In order for the industries to encourage the implementation of emerging technologies in the sector, several sector specific HAI roadmaps and initiatives were initiated, as will be discussed in the following sub-sections.

### 2.2.2.1 Cement Sector Roadmaps

The following section includes the roadmaps and initiatives related to cement sector, and Table 2-4 includes a summary of the cement sector roadmaps showing the mitigation targets, technology focus to reach such targets as well as the suggested enabling policies highlighted by each roadmap.

The details of the roadmaps and initiatives identified for the cement sector are discussed after the summary table. These roadmaps and initiatives are essential to accelerate the decarbonization of the cement industry, as the emergence of innovative technologies are not commercially ready compared to other industrial sectors.

[60] Science Based Targets initiative - Wikipedia. https://en.wikipedia.org/wiki/Science_Based_Targets_initiative.
[61] Ambitious corporate climate action - Science Based Targets. https://sciencebasedtargets.org/.
[62] ibid
[63] About Us - Science Based Targets. https://sciencebasedtargets.org/about-us/.

**Table 2-4: Cement Sector Roadmaps Summary**

| Roadmap | Mitigation target and timeframe | Technology focus for target achievement | Enabling Policies |
|---|---|---|---|
| The GCCA 2050 Cement and Concrete Industry Roadmap | Net zero by 2050 | • Efficiency in design & construction (22%)<br>• Efficiency in concrete Production (11%)<br>• Savings in cement & binders (9%)<br>• Savings in clinker production (11%)<br>• Carbon capture and utilization/ storage (CCUS) (36%)<br>• De-carbonization of electricity (5%)<br>• $CO_2$ sink: recarbonation (6%) | **$CO_2$ reductions will be accelerated through the following actions:**<br>• Promoting the investments in low-carbon cement manufacturing.<br>• Stimulate demand for low-carbon concrete products, and<br>• Create the infrastructure needed for a circular and net zero manufacturing environment.<br>• Increased clinker substitution – including fly ash, calcined clays, ground granulated blast-furnace slag (ggbs), and ground limestone.<br>• Fossil fuel reductions and increased use of alternative fuels<br>• Improved efficiency in concrete production<br>• Improved efficiency in the design of concrete projects and use of concrete during construction, including recycling<br>• Investment in technology and innovation<br>• CCUS technology and infrastructure development<br>• Collaborate in establishing a policy framework to achieve net zero concrete. |
| The Technology Roadmap: Low-Carbon Transition in the Cement Industry | The equivalent of almost 90% of today's direct global industrial $CO_2$ emissions by 2050 | • Thermal energy efficiency (3%)<br>• Fuel switching (12%)<br>• Reduction of clinker-to cement ratio (37%)<br>• Innovative technologies (ind.carbon capture) (48%) | **The following policies are highlighted to be applied by governments:**<br>• Eliminate energy price subsidies, which can act as a barrier to the use of energy efficient technologies.<br>• Develop and reinforce waste management regulations, encompassing waste avoidance, collection, sorting and treatment.<br>• Promote the use of blended cements in sourcing and public procurement policies.<br>• Reward clean energy investments.<br>• Provision of flexibility to local energy grids – for example fiscal incentives for Energy Heat Recovery (EHR)<br>• Develop plant- or sector-level energy efficiency improvement target-setting programmes.<br>• Governments to co-ordinate identification and demonstration of $CO_2$ transport networks at regional, national and international levels, to optimize infrastructure development and to lower costs by collaborating with industry, to investigate linkages into existing or integrated networks and opportunities for cluster activities in industrial zones. |
| The Role of Cement in the 2050 Low Carbon Economy Roadmap | 80% reduction in emissions by 2050 | Multiple paths to emissions reduction:<br>• Kiln efficiency and fuel mix (136 Mt $CO_2$)<br>• Clinker substitution and Novel cements (125 Mt $CO_2$)<br>• Transport efficiency (123 Mt $CO_2$)<br>• Non $CO_2$ GHG (123 Mt $CO_2$eq)<br>• Decarbonization power (113 Mt $CO_2$)<br>• Breakthrough technologies (34 Mt $CO_2$) | • Provide access to R&D funds to stimulate breakthrough technologies. For example, making grinding more efficient.<br>• Integrate access to and development of public and private financing mechanisms in all policy initiatives allowing a faster market delivery of existing and new technologies.<br>• Ensure industries have access to electricity at fair and affordable price levels (including taxes and fees), which means a liberalized electricity market is crucial.<br>• Research and development on all aspects related to CCS need to be supported and funded to accelerate greenhouse gas reduction in cement manufacture.<br>• Finance for new research to develop alternative ways to use the captured carbon emissions. |

| Roadmap | Mitigation target and timeframe | Technology focus for target achievement | Enabling Policies |
|---|---|---|---|
| | | | • Storage sites would need to be identified and developed with transport solutions, such as a dedicated pipeline network, put in place. |
| Cementing the European Green Deal: reaching climate neutrality along the cement and concrete value chain by 2050 | By 2050, net zero. | 783 kg$CO_2$/t reduction of emissions of cement:<br>• 280 CCS/CCU<br>• 160 Clinker (decarbonated raw material 27, biomass fuels 71. Low carbon clinker 17, $H_2$ & electrification 19)<br>• 117 cement (clinker substitution 72, electrical efficiency and re electricity 35, carbon natural transport 10)<br>• 116 emissions<br>• 59 concrete (concrete mix 52, carbon natural transport 7)<br>• Construction carbonation 51 (concrete in use 89 $CO_2$ capture in built environment 51) | • Policies should facilitate waste shipment between countries, discourage landfill and prohibit exports of waste.<br>• Sufficient access to biomass and non-recyclable waste should be guaranteed for co-processing in cement kilns, as the most ecological solution for the majority of materials.<br>• Energy-intensive industries, including cement, will need sufficient infrastructure to transport, re-use and store the $CO_2$ it captures.<br>• Developing a Pan-European $CO_2$ transportation network that responds to the industry's needs. Continued support for CCUS technologies, as well as measures to support the business case of this technology (such as State Aid), are urgently needed.<br>• Access to public funding for innovation, $CO_2$ pipeline infrastructure, access to renewable electricity, high $CO_2$ price, ability to pass on $CO_2$ costs.<br>• Access to funding for research, take-up of low carbon products efficient revision of standards. |
| The Roadmap to Carbon Neutrality: A More Sustainable World Is Shaped by Concrete | By 2050, net zero | • NEAR-TERM: Replace raw materials with recycled materials, produce low-carbon cement blends, optimize designs for the lowest life cycle emissions<br>• MID-TERM: Increase the use of alternative fuels and use renewable energy<br>• LONG-TERM: Carbon capture and introduce new cement blends | • Accelerated research, funding, and investment in manufacturing, material innovation, and CCUS technologies and associated infrastructure.<br>• Streamlined regulation, siting, and permitting practices for facility and infrastructure modernization.<br>• Recognition and credit for industry reduction levers.<br>• Community acceptance of CCRs, alternative fuels, CCUS, and other manufacturing technologies.<br>• Consideration of a market-based carbon price – preferably a cap-and-trade mechanism<br>• Market acceptance of low-carbon alternative cements and concrete.<br>• Adoption of performance-based standards for building materials.<br>• Consideration of the full product, material, and building life cycle in procurement standards and policy. |
| The Net-Zero Roadmap for Autoclaved Aerated Concrete | By 2050, net zero | • Low carbon cement and lime (69%)<br>• Optimizing factories and switching fuel sources (13%)<br>• Optimizing assembly and end-of-life disposal (7%)<br>• Low emissions transport (3%)<br>• Switching to renewable electricity (3%) | **Energy policy that supports the availability of renewable electricity and hydrogen for Europe's industrial sector. And Policies that capture the full life-cycle emissions for buildings and construction products to:**<br>• Allow for recarbonation to be accounted for $CO_2$ abatement<br>• Take into account the benefits of properties such as thermal mass in avoiding emissions for heating and cooling buildings<br>• Support the development of industry-wide approaches to circularity<br>• Acknowledge that $CO_2$ emissions from the manufacturing phase account for only a minor share of the total GHG emissions in the life cycle of a building. The largest contribution to $CO_2$ emissions comes from the use phase. |

| Roadmap | Mitigation target and timeframe | Technology focus for target achievement | Enabling Policies |
|---|---|---|---|
| | | | • Switching to low-carbon cement and lime binders that are used as raw materials in the manufacture of Autoclaved Aerated Concrete (AAC).<br>• Switching to renewable energy sources together with efficiency improvements within factories that manufacture AAC.<br>• Switching to cement-based products such as AAC absorb $CO_2$ during their lifespan. |
| **Note: MPP will publish a concrete and cement sector transition strategy in 2023** | | | |

#### 2.2.2.1.1 The GCCA 2050 Cement and Concrete Industry Roadmap

In 2020, member companies of the Global Cement and Concrete Association came together as leaders in the sector to commit to producing carbon neutral concrete by 2050, in line with global climate targets. [64] Their 2050 Net Zero Roadmap 2022 sets out in detail how collectively, in collaboration with built environment stakeholders and policymakers, to fully decarbonize the cement and concrete industry and provide net zero concrete for the world.

This roadmap outlines a proportionate reduction in $CO_2$ emissions of 25% associated with concrete by 2030 as a key milestone on the way to achieving full decarbonization by the mid-century. As shown in Figure 2-11 below, the proposed roadmap actions between 2020 and 2030 will prevent almost 5 billion tons of $CO_2$ emissions in total from entering the atmosphere compared to a business-as-usual scenario.

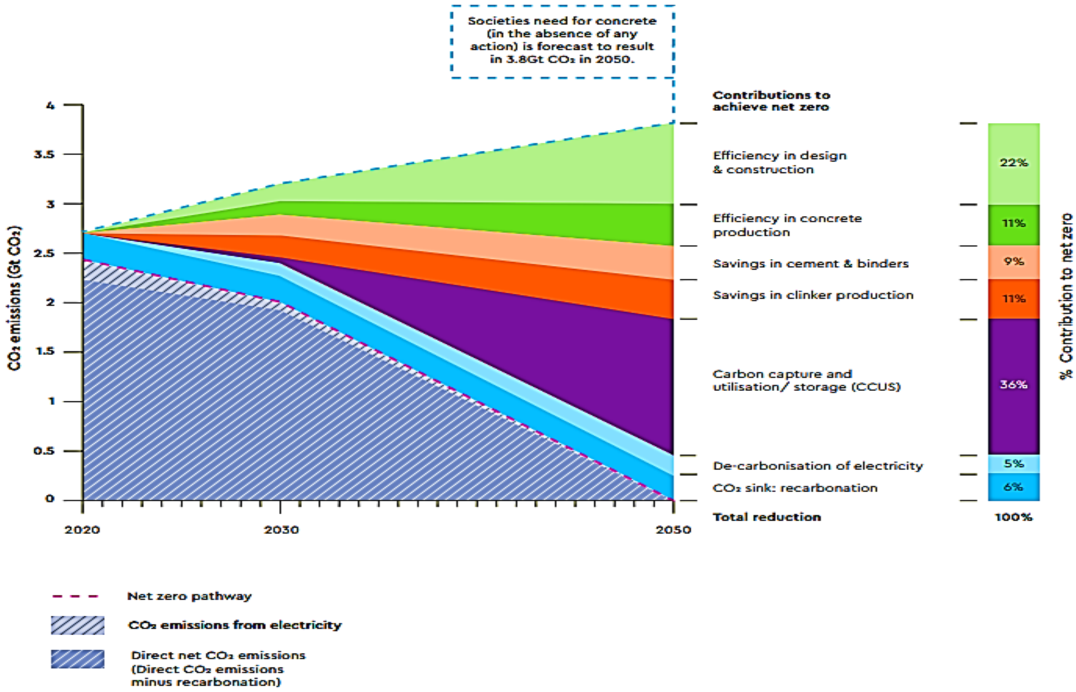



Figure 2-11: The net zero pathway according to the GCCA 2050 Cement and Concrete Industry Roadmap[65]

#### 2.2.2.1.2 The Technology Roadmap: Low-Carbon Transition in the Cement Industry

This Technology Roadmap builds on the long-standing collaboration of the IEA with the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD)[66]. Developed in 2018, the roadmap outlines a detailed action plan for specific stakeholders till 2050 as a reference and a source of inspiration for international and national policy makers to support evidence-based decisions and regulations.

It sets a strategy for the cement sector to achieve the decoupling of cement production growth from related direct $CO_2$ emissions through improving energy efficiency, switching to fuels that are less carbon intensive, reducing the clinker to cement ratio, and implementing emerging and innovative technologies such as carbon capture and storage.

64 https://gccassociation.org/concretefuture/wp-content/uploads/2022/10/GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf
65 https://gccassociation.org/concretefuture/wp-content/uploads/2022/10/GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf
66 https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry

### 2.2.2.1.3 The Role of Cement in the 2050 Low Carbon Economy Roadmap

This roadmap was developed in 2018 by the European Cement Association (CEMBUREAU) and focus on what can be done to reduce $CO_2$ in cement production using today's technology and speculate on what could be achieved by 2050[67]. It highlights innovative application and concrete products to allow the contribution of the industry to the low carbon economy of 2050. This roadmap is the result of open discussion within the industry and with external stakeholders, including NGOs, policymakers and international agencies. This roadmap focused on five routes to achieve these objectives, three of which are considered to be 'under the sector's control' (as shown in Figure 2-12 below).

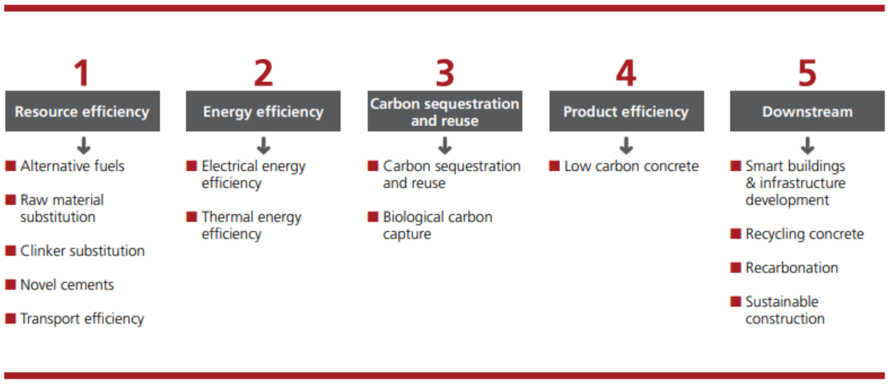



**Figure 2-12: The five routes to achieve carbon neutrality according to the Role of Cement in the 2050 Low Carbon Economy Roadmap[68]**

### 2.2.2.1.4 Cementing the European Green Deal: reaching climate neutrality along the cement and concrete value chain by 2050

This was developed in 2020 by The European Cement Association (CEMBUREAU) [69], and it outlines the path towards carbon neutrality along the entire value chain. It looks at how carbon emissions reduction can be done at each step of the cement and concrete value chain in order to align their 2050 roadmap with the European Green Deal's objectives and deliver carbon neutrality. In this roadmap they considered two scenarios first is to reduce a 40% gross reduction compared to the 1990 $CO_2$ emissions by 2030 (equal to 472 kg $CO_2$/t of cement) and second is to reach net zero by 2050 (equal to 783 kg $CO_2$/t of cement). This involves measurements related to clinker reduction, concrete mix, decarbonated raw material, and carbon capture.

### 2.2.2.1.5 The Roadmap to Carbon Neutrality: A More Sustainable World Is Shaped by Concrete

This roadmap was developed by the Portland Cement Association (PCA) in 2021 and aims at guiding the industry on the most ambitious journey to carbon neutrality[70]. It focuses on the entire value chain beginning at the cement plant and ending with the buildings and roads. Their approach to carbon neutrality leverages relationships at each step of the value chain, demonstrating to the world that this industry can address climate change. The five links in the value chain include the production of clinker, the manufacture and shipment of cement, the manufacture of concrete, the construction of the built environment, and the capture of carbon dioxide using concrete as a carbon sink.

[67] https://lowcarboneconomy.cembureau.eu/wp-content/uploads/2018/09/cembureau-full-report.pdf
[68] https://lowcarboneconomy.cembureau.eu/wp-content/uploads/2018/09/cembureau-full-report.pdf
[69] https://cembureau.eu/media/cpvoin5t/cembureau_2050roadmap_lowcarboneconomy_2013-09-01.pdf
[70] https://www.cement.org/docs/default-source/membership-2020/pca_roadmap-to-carbon-neutrality_jan-2022.pdf?sfvrsn=9b26febf_2

#### 2.2.2.1.6 The Net-Zero Roadmap for Autoclaved Aerated Concrete

This roadmap developed in 2022 sets out a pathway for Autoclaved Aerated Concrete (AAC) products to reach net-zero emissions by 2050 with the potential to become carbon negative[71]. The roadmap aligns the European Autoclaved Aerated Concrete Association (EAACA) and its members with the objectives of the Paris Agreement to limit global warming to 1.5°C and supports policies to decarbonize Europe's buildings and construction sectors. The roadmap sets out the main levers that must be applied to achieve this. The Net-zero target was based on a life-cycle analysis provided by an independently verified Environmental Product Declaration.

### 2.2.2.2 Cement Sector Initiatives

#### 2.2.2.2.1 The Concrete Zero initiative

The Concrete Zero, launched in 2022, is a partnership with WBCSD and World GBC. The initiative includes corporate partnerships with 22 companies committed to using low- and net-zero emission concrete — and effectively cement, as its key ingredient[72]. Concrete Zero sends a strong demand signal to shift global markets, investment and policies towards the sustainable production and sourcing of concrete. Businesses that join Concrete Zero commit to using 100% net zero concrete by 2050, with two ambitious interim targets of using 30% low emission concrete by 2025 and 50% by 2030.

#### 2.2.2.2.2 The Innovandi Global Cement and Concrete Research Network

Launched in 2020, by GGCA, the Innovandi Global Cement and Concrete Research Network is an association between 40 global institutions representing academia and 34 cement and concrete manufacturers, and technology suppliers representing industry. This association aim to gather efforts on research, in areas such as energy efficiency, clinker production, CCUS/technologies, new materials, and low carbon and recycling technologies[73].

#### 2.2.2.2.3 The Innovandi Open Challenge

The Open Challenge, launched in 2021, is a global program for start-ups with GCCA members. This program aims at supporting cement decarbonizing technologies[74]. The scope includes carbon capture technologies, calcination technologies for heating materials during the concrete manufacturing process, carbon use in the construction supply chain and improved recycling of concrete. The start-ups receive guidance from the GCCA through the program to develop new technologies and/or define new business cases[75], as well as extending their reach beyond their own R&D boundaries to help in securing a net zero future.

### 2.2.2.3 Steel Sector Roadmaps

The following section contains the steel sector specific roadmaps that aim at mitigating the GHG emissions from the sector. Although a number of country level and company level roadmaps were identified for the steel sector, for example the European Union and other countries, the global roadmaps were more scarce and are represented by the IEA Iron and Steel technology roadmap. A summary of the identified roadmaps

[71] https://eaaca.org/wp-content/uploads/2022/08/EAACA_Net-Zero-Roadmap-for-AAC_2022-08-12.pdf
[72] https://www.theclimategroup.org/concretezero
[73] https://gccassociation.org/innovandi/gccrn/
[74] https://gccassociation.org/concretefuture/wp-content/uploads/2022/10/GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf
[75] https://gccassociation.org/innovandi/openchallenge/oc2023/

is presented in Table 2-5 together with the mitigation targets, the technologies identified as a driver and enabling policies.

The details of the roadmaps and initiatives identified for the iron and steel sector are discussed after the summary table.

Table 2-5: Steel Sector Roadmaps summary

| Roadmap | Mitigation target and timeframe | Technology focus | Enabling Policies |
|---|---|---|---|
| **The Iron and Steel Technology Roadmap** | Decrease at least 50% by 2050<br>Continue towards net zero afterwards | • Efficient use of steel together with material efficiency measures (40% of $CO_2$ emissions savings) including:<br>○ Reducing material demands following Sustainable Development Scenario (SDS) of operation<br>○ Material replacement to lower GHG emitters<br>• Enhancing energy efficiency in existing facilities (20% of $CO_2$ emissions savings) including early closure or underutilization of existing facilities<br>• Developing advanced steel manufacturing processes (40% of $CO_2$ emissions savings):<br>○ Use of alternative energy sources such as hydrogen<br>○ Utilizing CCUS<br>○ Bioenergy and direct electrification | The polices could be summarized as follows:[76]<br>• Setting a long-term $CO_2$ emission reduction target.<br>• Managing the assets currently available and near-term investment.<br>• Enhance and encourage international cooperation.<br>• Support the R&D and technologies related to net-zero emission.<br>The following provides some initiatives by specific countries/organizations:[77]<br>• Some countries have implemented carbon pricing mechanism.<br>• The European Union aimed at avoiding drifting competitiveness and causing carbon leakage by reducing the provision of free emission trading system payments to non-trade-exposed industries. However, steel industry sustained to receive free allowances for emissions equivalent to production at a benchmark emission intensity.<br>• The European Union is currently working on proposals related to the mechanism of adjusting carbon border, which aims at providing an additional method to address the potential impact of the emissions trading system (ETS) on industrial competitiveness.<br>• The People’s Republic of China (“China”) has undefined plans with unspecified dates regarding steel industry.<br>• Japanese government has worked together with the Japanese Iron and Steel Federation on providing support and proficiency in sharing knowledge and technologies to improve the energy efficiency of steel plants in India and other Asian countries.<br>• German government has commenced a competence center related to climate mitigation measures in energy-intensive industries (KEI) to support emission reduction (IN4climate.NRW, 2020; KEI, 2020).<br>• Some of steel manufacturer and industry associations have set targets aiming at reducing emission and developing sustainable roadmaps.<br>• World Steel Association “step up” programme to collect and report standardized data related to $CO_2$ emissions.<br>• European Union is developing a system to classify environmental objectives including climate change mitigation |

[76] https://www.mdpi.com/2071-1050/13/22/12548
[77] https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

| Roadmap | Mitigation target and timeframe | Technology focus | Enabling Policies |
|---|---|---|---|
| **Clean Steel Partnership Roadmap** | **For the EU**<br>Achieve 50% reduction by 2030<br>Reach 80-95% reduction by 2050<br>Ultimately reaching carbon neutrality | • Enhancing circular economy and resources efficiency practices<br>• Smart use of carbon through process integration<br>• Carbon capture and use and storage<br>• Fuel substitution to avoid carbon intensive fuels via utilizing renewable energy e.g., replacing fossil fuels by hydrogen and electricity based metallurgy | • Encourage the corporation on clean steel in the Union programmes.<br>• Enable the utilization of resources outside the Union programmes, through an optimum combination of funding and financing schemes, from Member States and regions.<br>• Enable a regulatory framework for the potential impacts of the partnership to be delivered.<br>• Support the R&D and technologies related to net-zero emission<br>• Ensure the provision of appropriate and sustainable financing programme[78] |
| **Mission Possible Partnership Roadmap** | Reach net-zero emissions by 2050 | • Reduction in $CO_2$ emissions via circularity (estimated reduction 37% by 2050 and about 52% by 2100):<br>○ Increasing the recycling in steel production<br>○ Shifting to a more circular economy and reducing the total steel demand<br>• Energy efficiency improvement (estimated improvement to be 15-20% of present energy consumption on average globally)<br>• De-carbonization of ore-based steel production via:<br>○ Technology readiness<br>○ Cost trade-off | • Encourage R&D support<br>• Each government must set up its policy framework to encourage private sector actions<br>• Develop and set up codes which require efficiency in steel utilization and any other materials<br>• Carbon pricing and regulations on steel production seeking international agreement between all countries.<br>• Set up regional steel specifications |

[78] https://www.estep.eu/assets/Uploads/200715-CSP-Roadmap.pdf

#### 2.2.2.3.1 The Iron and Steel Technology Roadmap [79]

The IEA roadmap published in 2020 stated that the steel global demand is expected to increase by 2050 by more than one third. However, emissions from the steel industry must decrease by at least 50% by 2050 and continue decreasing towards zero emissions being pursued thereafter to meet global energy and climate goals.

The roadmap proposed by the International Energy Agency (IEA) and revised by the World Steel Association (WSA) regarding iron and steel technology, encouraged an approach for world steel's carbon emissions reduction through the following three steps:

- **Step 1:** improving the energy performance of existing equipment including improvements in operational efficiency and applying best available technologies. This shall contribute about 20% of $CO_2$ emissions savings in the Sustainable Development Scenario of IEA.
- **Step 2:** promoting more efficient use of steel together with the material efficiency measures along supply chains, e.g., improving manufacturing yields and increasing building lifetime, where the material efficiency strategies could contribute to emission reductions by 40%.
- **Step 3**: developing advanced steel manufacturing processes, such as using hydrogen, CCUS, bioenergy and direct electrification, accounting for about emission reduction by 40%.

According to IEA's estimate, if the above-mentioned measures are fully implemented, the $CO_2$ emission intensity of steel is expected to be reduced by more than 50%, from 1.4 t $CO_2$/tcs of today's level to 0.6 t $CO_2$/tcs by 2050.[80]

#### 2.2.2.3.2 Clean Steel Partnership Roadmap[81]

The Clean Steel Partnership Roadmap is developed by the European Union in 2020 to realize the EU goal of carbon neutrality. The roadmap sets the goal of reducing the emissions from the steel sector by 50% by the year 2030, and achieving an 85% - 90% reduction by 2050, ultimately reaching carbon neutrality.

The roadmap highlights a number of specific objectives to reach the targets set, starting with enabling policies and collaborations among the EU member states in order to successfully implement the highlighted operational objectives in developing countries as well as the developed countries.

The highlighted objectives started with actions on technology decarbonization from sources using circular economy and energy efficiency techniques, as well as carbon utilization and storage technologies to the use of alternative zero carbon emission fuels as an alternative to the conventional fossil fuels.

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[79] IEA, Iron and Steel Technology Roadmap, 2020 (available at: https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf )
[80] https://www.mdpi.com/2071-1050/13/22/12548
[81] ESTEP AISBL, Clean Steel Partnership Roadmap, 2020 (available at: https://www.estep.eu/assets/Uploads/200715-CSP-Roadmap.pdf)

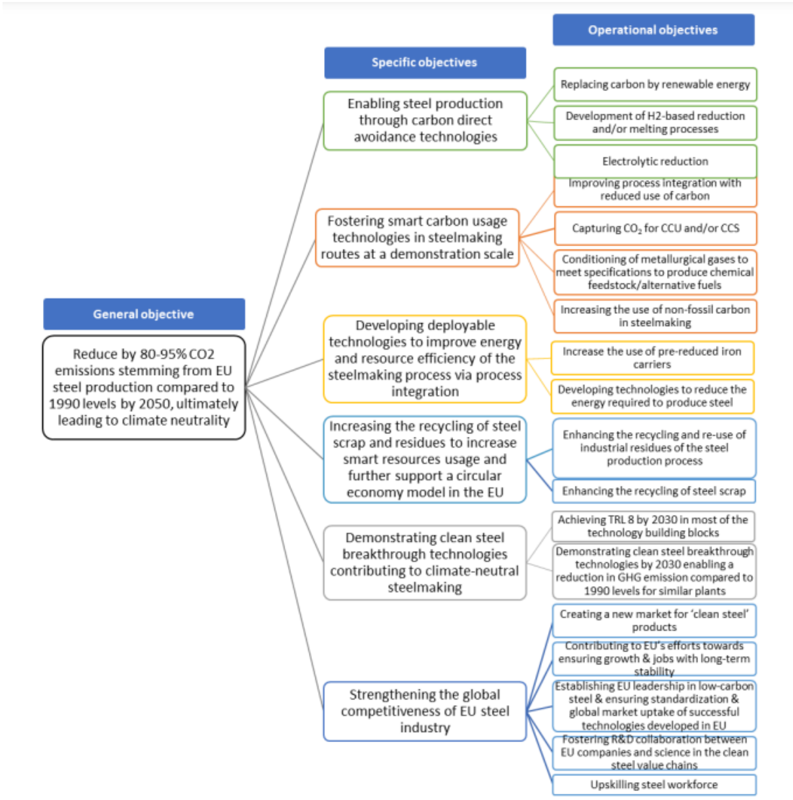


**Figure 2-13: The objectives tree as set by the clean steel partnership roadmap[82]**

### 2.2.2.3.3 Mission Possible Partnership Roadmap[83]

The "Mission Possible" is a roadmap which was developed in 2018 by the Energy Transitions Commission with contributions from over 200 industry experts, that outlines the possible routes to fully decarbonize steel industry as part of the HAI.

The innovation is to develop and pilot hydrogen based DRI and new technologies to reduce the carbon capture cost on BF-BOF, and enable higher quality and value of steel recycling.

Its recommended policies should include, but not limited to, the following:

- Agree on carbon tax on steel production as a sort of coalition of governments
- Develop regulations with regards to the embedded carbon intensity
- By 2040, ensure that 100% green steel are utilized in all infrastructure and buildings publicly funded.

[82] ibid
[83] https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Steel_final.pdf

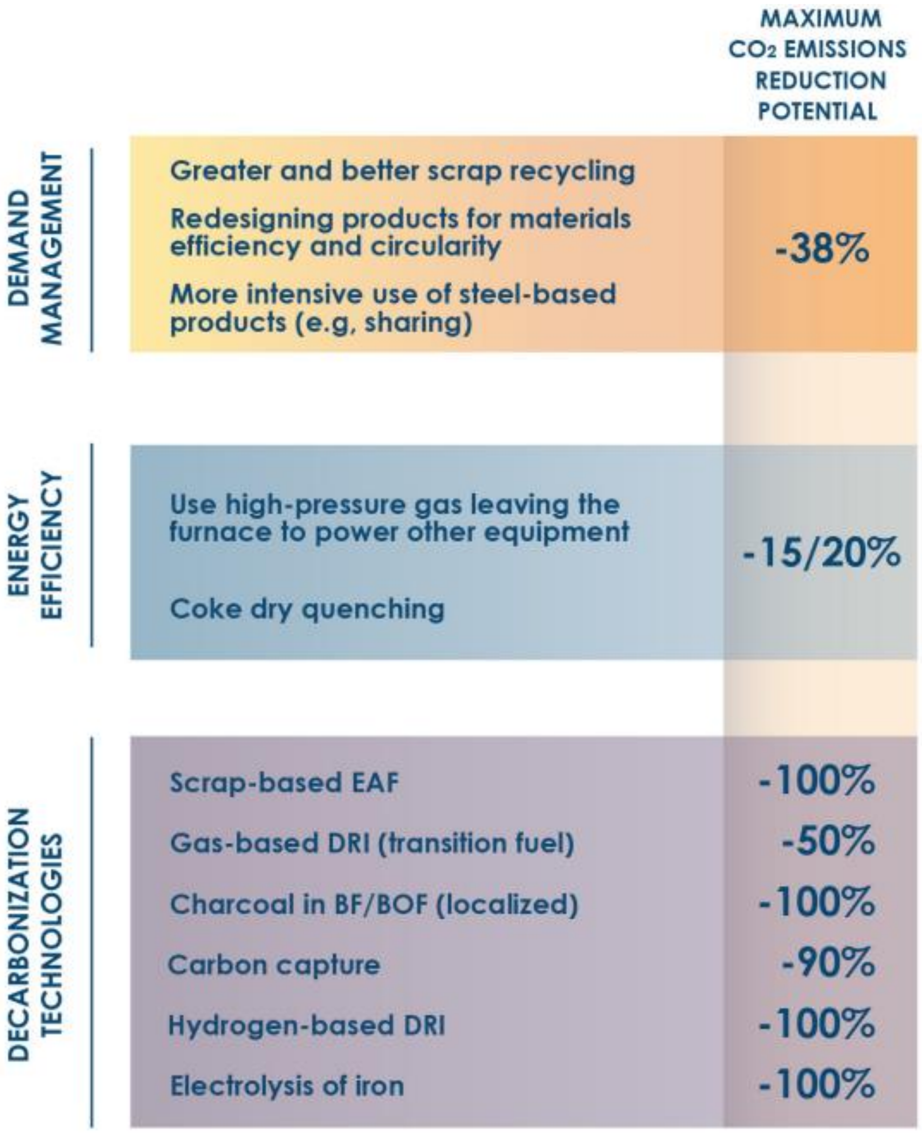


**Figure 2-14: The 3 significant routes to reaching Net-Zero $CO_2$ emissions as identified by MPP roadmap**

### 2.2.2.4 Steel Sector Initiatives[84] [85]

The following section includes the initiative related to steel sector, and Table 2-6 includes an overview of the steel sector initiatives direction, with the details mentioned afterwards.

**Table 2-6: Steel Sector Initiatives Overview**

| Initiative | Overview of General Direction |
|---|---|
| **Mission Innovation Initiative** | Aims at accelerating actions and investments in R&D making clean energy attractive, affordable and accessible for all to reach PA goals to net zero.<br><br>• Identifying goals and providing regulatory framework.<br>• Ensuring sufficient access to materials needed in the manufacturing process<br>• Reforming of electricity market design |

[84] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en
[85] https://www3.weforum.org/docs/WEF_FMC_Steel_2022.pdf

| Initiative | Overview of General Direction |
|---|---|
| **First Movers Coalition (FMC) Initiative** | Aims at reaching a target of at least 10% (by volume) of all steel purchased per year to be near-zero emissions by 2030 via achieving the following criteria:<br>• Utilizing crude steel from near-zero $CO_2$ technology production facilities<br>• $CO_2$ emissions to be <0.4 t to <0.1 t (with 0% scrap inputs) per tonne of crude steel production |
| **Industrial Deep Decarbonization Initiative (IDDI)** | The IDDI aims to motivate the call for low carbon materials through green public procurement (GPP) by:<br>• Global standardizing the definition of the low carbon steel, and how to calculate the embodied carbon.<br>• Develop and public disclose a global framework with accessible data that is easy to navigate.<br>• Setting up a worldwide standard goal for the public procurement of green steel. |
| **Science Based Targets Initiative (SBTi)** | Aims at achieving PA 1.5 ºC goal by motivating companies to set science-based targets and enhance their competitive advantage in the transformation to the net-zero economy.<br>• New pathways in SBTi's target-setting tool to be integrated<br>• Identification and assessment of the 1.5 °C goal modeling scenarios<br>• Integrate adjusted Sectoral Decarbonization Approach (SDA) calculation method for the steel industry.<br>• Road-testing of new target-setting resources<br>• Developing of a guidance for science-based target-setting in the steel sector. |
| **WorldSteel Climate Action: Policy and initiatives** | Aims at achieving PA goals by reducing $CO_2$ emission.<br>• Reducing emissions from the manufacturing process.<br>• Encouraging the reuse, remanufacturing and recycling processes.<br>• Developing advanced steel products to reach net zero carbon dioxide emissions. |

#### 2.2.2.4.1 Mission Innovation Initiative

Mission Innovation is a global initiative accelerating actions and investments in research, development, and demonstration by making clean energy attractive, affordable and accessible for all. This will accelerate progress to achieve the Paris Agreement goals and pathways to net zero.

- Net-Zero Industry Act: Identifying goals to achieve net-zero industrial capacity and provide a regulatory framework suitable for its quick deployment;
- Critical Raw Materials Act: Ensuring sufficient access to materials that are essential for manufacturing key technologies e.g., rare earth
- Reform of electricity market design: Helping beneficiaries from the lower costs of renewables

#### 2.2.2.4.2 First Movers Coalition (FMC) Initiative

Public-private partnership that was launched by the World Economic Forum to invest in innovative green technologies resulted in the First Movers Coalition (FMC) initiative [86]. Ambitious commitments for steel purchasing have been set by FMC to reach a target of at least 10% (by volume) of all steel purchased per year to be near-zero emissions by 2030 via achieving the following criteria:

- Utilizing crude steel from near-zero $CO_2$ technology production facilities
- $CO_2$ emissions to be <0.4 t to <0.1 t (with 0% scrap inputs) per tonne of crude steel production

[86] https://www3.weforum.org/docs/WEF_FMC_Steel_2022.pdf

#### 2.2.2.4.3 Industrial Deep Decarbonization Initiative (IDDI) [87] [88]

The IDDI aims to motivate the call for low carbon materials through green public procurement (GPP) by:

- Global standardizing the definition of the low carbon steel, and how to calculate the embodied carbon.
- Develop and public disclose a global framework with accessible data that is easy to navigate.
- Setting up a worldwide standard goal for the public procurement of green steel.

Additionally, the IDDI established three technical Working Groups (WGs), including government, private sector, civil society, intergovernmental organizations, trade associations, and leading experts from academia and research centers. These WGs are working together on: 1) data improvement and reporting procedures on embodied carbon, 2) standardizing low carbon products, and 3) exchanging best practices on green procurement policies (GPP).

Moreover, the IDDI is co-led by the UK and India. Currently, Canada, Germany, Japan, Saudi Arabia, Sweden, United Arab Emirates (UAE), the United States, and Brazil are members in the IDDI with more countries are willing to join. It is expected within the next three years to have encouraged a minimum of ten governments to make public procurement commitments for low-carbon steel. An estimated 90% of steel is produced in around ten key countries. Therefore, this will make a significant impact in terms of greenhouse gas emission reduction.

#### 2.2.2.4.4 Science Based Targets Initiative (SBTi)[89]

The SBTi aims at developing a set of science-based target-setting procedures, tools and guidance that will assist steel companies and other stakeholders understand the target-setting ambition, short-term and long-term targets, essential to meet the 1.5ºC goal of Paris Agreement.

The SBTi Steel Project procedures, tools and guidance includes:

- New pathways in SBTi's target-setting tool to be integrated
- Identification and assessment of the 1.5°C goals modeling scenarios
- Integrate adjusted SDA calculation method for the steel industry.
- Road-testing of new target-setting resources
- Developing of a guidance for science-based target-setting in the steel sector.

The SBTi Steel Project was mobilized in the end of November 2021 and the official launch and socialization of resources developed is expected by September 2023 via achieving the following criteria:

- Utilizing crude steel from near-zero $CO_2$ technology production facilities
- $CO_2$ emissions to be <0.4 t to <0.1 t (with 0% scrap inputs) per tonne of crude steel production

[87] https://www.industrialenergyaccelerator.org/areas-of-work/the-industrial-deep-decarbonization-initiative/
[88] https://www.cleanenergyministerial.org/initiatives-campaigns/industrial-deep-decarbonisation-initiative/
[89] https://sciencebasedtargets.org/resources/files/SBTi-Steel-Guidance.pdf

##### 2.2.2.4.5 WorldSteel Climate Action: Policy and Initiatives

WorldSteel Association members have set Climate Action: Policy and initiatives[90] aim is to reduce $CO_2$ emissions from steel industry and achieve the goals of the Paris Agreement. The main elements that were established to enable industrial and societal transformation are as follows:

- Reducing emissions from the production of iron and steel through reducing their own impact.
- Achieving efficiency and the circular economy by encouraging the reuse, remanufacturing and recycling, all key elements of the circular economy.
- Enable societal transformations by developing advanced steel products to reach net zero carbon dioxide emissions through zero-energy buildings, renewable energy infrastructures, electrification and more.

#### 2.2.2.5 Chemical Sector Roadmaps

Considering the chemicals sector has numerous products, one roadmap covering the whole sector is reviewed and presented while also covering a main line of action which is catalytic technology utilization. In order to better represent the sector, other roadmaps for the highest emission contributors in the sector are discussed, and therefore, specialized roadmaps for the ammonia industry and the plastics and fertilizers industry are discussed in the following section, while Table 2-7 a summary of the roadmaps findings.

[90] https://worldsteel.org/steel-topics/environment-and-climate-change/climate-action/#

Table 2-7: Chemicals Sector Roadmaps Summary

| Roadmap | Mitigation target and timeframe | Technology focus | Enabling Policies |
|---|---|---|---|
| **Technology Roadmap Energy and GHG Reductions in the Chemical Industry via Catalytic Processes (2013)** | 2025<br>2050<br>Limit long-term global average temperature rise to 2°C by achieving necessary emissions reductions by 2050. | • Catalyst and related process improvements offer a 20% to 40% reduction in energy intensity for chemical products by 2050, considering various scenarios.<br>DECHEMA Model<br>• energy savings potential approaching 13.2 exajoules (EJ) by 2050 and 1 Giga tonnes (Gt) of carbon dioxide equivalent ($CO_2$-eq) per year by 2050 versus a "business-as usual" scenario.<br>IEA Model:<br>• Energy efficiency improvements, closely linked to the catalysis roadmap, contribute to over 60% of projected emissions reduction in the IEA 2DS scenario.<br>• Other significant reductions come from Carbon Capture and Storage (CCS) at 25% and energy recovery at 8%.<br>• Fuel switching, specifically from coal to gas, accounts for only 4% or less of emissions reduction.<br>• By 2050, annual savings from these efforts amount to approximately 1.6 $GtCO_2$ in the Low-Demand Case and approximately 1.8 $GtCO_2$ in the High-Demand Case.<br>• Low-Demand Case:<br>○ Energy use in the chemicals sector is projected to increase from 42 EJ in 2010 to 85 EJ in 2050.<br>○ The 2DS Low-Demand Case expects energy consumption to rise only to 65 EJ in 2050 due to improved energy efficiency and increased recycling, reducing energy intensity.<br>○ The scenario also assumes a higher level of biomass and waste use, accounting for 4% of total chemical energy use by 2050.<br>• High-Demand Case:<br>○ Energy use in the chemicals sector could increase to 96 EJ in 2050, reflecting higher demand.<br>○ The emissions reduction potential is still significant, considering energy efficiency improvements and other measures outlined in the IEA 2DS scenario.<br>• The roadmap doesn't give a specific percentage for each technology, but these technology categories were discussed for the technology needs and mentioned the ROI of each one.<br>• Feedstock production efficiency: olefins<br>• Alternative means of fuel production: fuels<br>• Biomass as feedstock: ethanol/ethylene and aromatics<br>• Hydrogen production | • Stakeholder collaboration and public-private partnerships are crucial for success.<br>• Governments should create a favorable environment for energy efficiency gains and emission reductions.<br>• Industry must prioritize top opportunities, accelerate investments and R&D, and collaborate with academia.<br>• Policy support for R&D is essential.<br>• All stakeholders should contribute to innovation from training to industrial-scale R&D. |
| **The Future of Petrochemicals Towards more sustainable** | 2030<br>2050 | • Emissions reduced by 45% by 2050<br>• Plastic recycling:<br>○ Secondary plastic production volumes from recycled resins increase by 65% by 2030 and double by 2050.<br>• Feedstock changed. | • Implementation of effective regulatory actions to reduce $CO_2$ emissions and air pollution, and meet stringent air quality standards.<br>• Implementation of plant-level benchmarking schemes and incentivizing their adoption through fiscal incentives. |

| Roadmap | Mitigation target and timeframe | Technology focus | Enabling Policies |
|---|---|---|---|
| **plastics and fertilizers** | | ○ Oil feedstock demand for primary chemical production in the CTS is 5% lower in 2030 and 13% lower in 2050, relative to the RTS.<br>• CCUS:<br>• carbon capture and storage (CCS) deployment increases from almost 3 million tonnes per year ($MtCO_2$/yr) in 2017, to around 220 $MtCO_2$/yr in 2050. Around 3 Giga tonnes of carbon dioxide ($GtCO_2$) is captured cumulatively by 2050, 10% of which is captured before 2030.<br>• Coal to natural gas shifts<br>• For methanol and ammonia, an almost entire shift away from coal, to natural gas and coke oven gas, takes place in the CTS<br>• Energy Efficiency<br>○ Globally 50 Mt of HVCs is projected to be produced using naphtha catalytic cracking technology in 2050, compared with only 8 Mt in the RTS.<br>• Innovative low-$CO_2$ processes<br>• By 2050, nearly half of total ammonia and two-thirds of methanol is produced via electrolysis, whereas less than 10 $MtCO_2$/yr are captured from all primary chemical production. | |
| **Ammonia Technology Roadmap** | Net Zero 2050 Stated Policies Scenario (baseline analysis) and Sustainable Development Scenario (net-zero $CO_2$ emissions by 2070). | • CCS: 11%<br>• Electrolysis 75%<br>• Utilizing efficiency improvements,<br>• Developing supporting infrastructure,<br>• Accelerating RD&D in sustainable nitrogen fertilizer production. | • Implementation of strong supportive policy mechanisms to incentivize and support the adoption of sustainable and low-emission technologies in ammonia production.<br>• Policies to improve energy and use efficiency, reducing energy consumption in the ammonia production process.<br>• Support for the development of infrastructure, such as storage and transportation facilities, to facilitate the deployment and integration of innovative technologies.<br>• Policy support for research and development to revive catalysis R&D for high-volume, high-energy-consuming processes and encourage substantial infusion of capital resources over the long term from governments, academia, industry, equipment suppliers, and other stakeholders. |

#### 2.2.2.5.1 Technology Roadmap Energy and GHG Reductions in the Chemical Industry via Catalytic Processes [91]

Developed in 2013, the roadmap sets out milestones for the international community to measure progress and assess whether the chemical industry is on track to achieve the necessary emissions reductions by 2050. The ultimate goal is to limit the long-term global average temperature rise to 2°C. To achieve these emissions reductions, the roadmap suggests a range of actions for various stakeholders. The chemical industry is encouraged to identify top catalyst opportunities, collaborate with academia and government labs, share best practice policies for energy efficiency and greenhouse gas emissions reduction, and accelerate capital investments and R&D.

The roadmap also recommends long-term policies to encourage developments in emerging technologies and game changers, as well as feedstock choices such as biomass. It suggests accelerating permit approval for energy efficiency projects and supporting energy management systems like ISO 50001, which promote continuous improvement plans for energy. Staged incentives are proposed to encourage companies to deploy and improve best practices, reduce energy and environmental burden, and participate in long-term R&D to enhance processes.

The roadmap emphasizes the importance of stakeholder collaboration, including public-private partnerships. It highlights that concerted, long-term action by all stakeholders is critical to realizing the vision and impacts described. Governments are called upon to create a favorable environment that encourages additional gains in energy efficiency and lowers energy-related emissions. Industry is expected to provide focus on top opportunities, highlight priorities for support, accelerate capital investments and R&D, and foster collaborations with academia and research institutions.

Policy support for research and development is deemed essential for achieving the roadmap's aims. Reviving catalysis R&D for high-volume, high-energy consuming processes requires substantial infusion of capital resources over the long term. Governments, academia, industry, equipment suppliers, and other stakeholders are encouraged to contribute to the entire chain of innovation, from college-level training to industrial-scale R&D.

Overall, the roadmap serves as a guide for governments and industry to work together in achieving emissions reductions and promoting sustainable growth in the chemical industry. It emphasizes the need for collaboration, long-term planning, and policy support for research and development to realize the outlined goals.

#### 2.2.2.5.2 Ammonia Roadmap [92]

Developed in late 2021, the roadmap focuses on the future of ammonia production and its role in achieving the goals of the Paris Agreement and the United Nations Sustainable Development Agenda. It outlines different scenarios and pathways for the energy system, taking into account existing policies and commitments. One of the scenarios discussed is the Stated Policies Scenario, which projects current trends in the energy sector, considering the policies and contributions established under the Paris Agreement. While this scenario serves as a baseline for analysis, it is not the main focus of the roadmap.

[91] IEA (2013), Technology Roadmap - Energy and GHG Reductions in the Chemical Industry via Catalytic Processes, IEA, Paris https://www.iea.org/reports/technology-roadmap-energy-and-ghg-reductions-in-the-chemical-industry-via-catalytic-processes, License: CC BY 4.0

[92] IEA (2021), Ammonia Technology Roadmap, IEA, Paris https://www.iea.org/reports/ammonia-technology-roadmap, License: CC BY 4.0

The Sustainable Development Scenario, on the other hand, offers a pathway for the energy sector to achieve "net zero" $CO_2$ emissions for the global energy system by 2070. This scenario aligns with the goals of the Paris Agreement and addresses other key elements of the Sustainable Development Goals, such as universal access to modern energy and a reduction in energy-related air pollution. The roadmap also highlights the importance of accelerating progress and provides recommendations for achieving sustainable nitrogen fertilizer production. It emphasizes the need for integration efforts, prototyping, validation, and testing of technologies in order to reach commercial operation in relevant environments.

Several actions to accelerate progress towards sustainable nitrogen fertilizer production has been suggested. These recommendations include:

1. Establishing strong supportive policy mechanisms: It is crucial to implement policies that incentivize and support the adoption of sustainable and low-emission technologies in the ammonia production sector.
2. Taking action on energy and use efficiency: Improving energy efficiency and reducing energy consumption in the production process can contribute to reducing emissions and enhancing sustainability.
3. Developing supporting infrastructure: Investing in the development of infrastructure, such as storage and transportation facilities, can facilitate the deployment and integration of innovative technologies.
4. Accelerating RD&D: Increasing research, development, and deployment efforts is essential for advancing innovative technologies and strategies in ammonia production.

Furthermore, the roadmap emphasizes the significance of readiness levels in assessing the maturity of technologies. It provides a framework, known as the Technology Readiness Level (TRL) scale, which helps evaluate and compare the readiness of different technologies across sectors.

Overall, the roadmap aims to provide insights into the potential impacts and trade-offs of different pathways for the energy system. It offers information on the outlook for demand and production of ammonia, as well as the necessary actions and conditions for achieving sustainable and low-emission energy systems.

#### 2.2.2.5.3 The Future of Petrochemicals: Towards more sustainable plastics and fertilizers[93]

Developed in 2018, the report focuses on the analysis of the chemical sector and its development in relation to the UN SDGs. The report is focused in mapping the transition towards sustainability, and therefore is considered as a roadmap. It identifies two priority areas for a sustainable transition in the chemical sector and provides specific actions to be taken in each area.

The first priority area highlighted in the report is energy performance. The report emphasizes the importance of improving energy efficiency in the chemical sector to reduce energy consumption and greenhouse gas emissions. It suggests implementing plant-level benchmarking schemes and incentivizing their adoption through fiscal incentives. By improving energy performance, the sector can contribute to the overall goal of reducing carbon emissions and mitigating climate change.

The second priority area identified in the report is the adoption of clean technologies. The report discusses the feasibility of alternative feedstocks and the potential for using renewable energy sources in the production of chemicals. It emphasizes the need for effective regulatory actions to reduce $CO_2$ emissions

[93] IEA (2018), The Future of Petrochemicals, IEA, Paris https://www.iea.org/reports/the-future-of-petrochemicals, License: CC BY 4.0

and air pollution. The report also highlights the importance of meeting stringent air quality standards and developing and installing air pollution control technologies.

Overall, the report emphasizes the need for policymakers and industry stakeholders to prioritize energy efficiency, emissions reduction, and air quality improvement in the chemical sector. By implementing the suggested actions and policies, the sector can contribute to the broader goals of sustainable development, including ending poverty, protecting the planet, and ensuring prosperity for all.

#### 2.2.2.6 Chemical sector initiatives

The following section details the initiative observed for the chemical sector, with an overview

Table 2-8: Chemicals Sector Initiative overview

| Initiative | Overview of General Direction |
|---|---|
| **The Low-Carbon Emitting Technologies Initiative** | Put the global chemical sector on a path to reach net-zero emissions by 2050, through five main technologies:<br>• Biomass utilization as fuel and raw material from sustainably produced biomass from agricultural and forestry waste and by-products.<br>• Carbon capture and utilization (CCU) as raw material in valuable products or as an energy/hydrogen carrier. carbon capture and storage (CCS) can also be a valuable transition technology.<br>• Electrification: By utilizing low-carbon electricity generation, the substitution of fossil fuels with electrically heated chemical processes.<br>• Alternative hydrogen production from green hydrogen as it is judged to be more sustainable on the long term.<br>• Waste processing or recycling of plastic waste, thus reducing the reliance on fossil fuels.<br>The initiative recognized collaborative innovation approach as an accelerator of low-carbon emitting technologies in key chemical value chains. |

##### 2.2.2.6.1 The Low-Carbon Emitting Technologies initiative [94]

A collaborative innovation approach designed to accelerate the development and upscaling of low-carbon emitting technologies through the creation of pilot projects in key value chains. The initiative was established by major chemical sector companies and the World Economic Forum to put the global chemical sector on a path to reach net-zero by 2050. The initiative aims at enhancing the chemical industry's enabling role to achieve a net-zero future economy.

The Low-Carbon Emitting Technologies Initiative is a collaborative effort led by major chemical companies to accelerate the chemical industry's transition to net-zero emissions by 2050. The initiative revolves around five primary focus areas:

- Biomass utilization: The aim is to replace fossil fuels and feedstocks with sustainably produced biomass from agricultural and forestry waste and by-products. When combined with carbon capture, this can create a carbon sink, helping to reduce emissions.
- Carbon capture and utilization (CCU): CCU presents a valuable solution for emission reduction. It involves capturing $CO_2$ streams from industrial processes and utilizing the captured carbon as raw material in valuable products or as an energy/hydrogen carrier. While this initiative primarily focuses

[94] "Low-Carbon Emitting Technologies." https://initiatives.weforum.org/low-carbon-emitting-technologies-initiative/home (accessed Jul. 24, 2023).

on utilization, it recognizes that carbon capture and storage (CCS) can also be a valuable transition technology.

- Electrification: By utilizing low-carbon electricity generation, the substitution of fossil fuels with electrically heated chemical processes can significantly contribute to emissions reduction. However, the feasibility of electrification depends on the availability and affordability of low-carbon electricity.
- Alternative hydrogen production: Hydrogen has the potential to replace fossil fuels in various applications and thereby reduce emissions. For this to be effective, hydrogen must be produced in a low-carbon emitting manner. Blue hydrogen combines conventional production with carbon capture, while green hydrogen is produced through renewable electricity-driven electrolysis. In the long term, green hydrogen is preferred.
- Waste processing: The initiative emphasizes waste processing or recycling of plastic waste. This approach aims to reduce the reliance on fossil feedstock for plastic production and avoid emissions-intensive incineration of end-of-life products.

# 3 LOW EMISSIONS AND NET ZERO TECHNOLOGIES AND ENABLING POLICIES

This section includes an identification of innovative low emission and net zero technologies and enabling policies towards implementation of such technologies for each of the HAI: cement, steel and the most carbon intensive chemicals. A summary of all the technologies and the enabling policies is first presented, followed by the gaps identified towards the implementation of the technologies, and a discussion of the sectoral cross-cutting technologies.

## 3.1 Identified Technologies

The technologies as identified in the different roadmaps, and initiatives as well as other sources, and summarized in Table 3-1 to Table 3-3 for the cement, steel and chemical sectors respectively. The technologies are obtained by sector and divided according to the intervention type which are categorized as follows:

a. Circular economy practices for energy consumption reduction (includes material efficiency and Process Optimization and Efficiency Improvements)
b. Direct use of clean electricity from renewable sources
c. Direct use of use of renewable heat and biomass
d. Carbon Capture and Storage (CCS) and Carbon Capture, Utilization and Storage (CCUS)

For each of the technologies obtained, several factors are taken into account to further explain the technology and stand on the applicability of utilizing it in other countries that have not yet utilized it. The details obtained include:

1. The technology maturity and barriers to implementation.
2. Implementation cost estimate.
3. Expected implementation timeframe.
4. The potential enabling policies reported [95]
5. Whether the technology is considered cross-sectoral or not.

[95] More elaborate analysis of the recommended policies is presented in chapter 6.

### Table 3-1: Low Emissions and Net Zero Technologies for Cement Sector

| **Sector** | **Cement Sector** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technologies** | **Circular economy practices for energy consumption reduction** | | | **Energy Efficiency & Direct use of renewable heat and biomass** | | | **Carbon Capture and Storage (CCS)and Carbon Capture, Utilization and Storage (CCUS)** | |
| **Type** | Efficiency in design and construction (it includes buildings' design optimization, construction site efficiencies, concrete recycling) | Technologies related to enhancing concrete's efficiency of production (it includes technologies reducing cement proportion in concrete mix "e.g. using admixtures", in addition to increased industrialized manufacture of concrete) | Technologies related to savings in cement and binders (it includes technologies affecting clinker cement substitution, and clinker binder ratios). | The use of green hydrogen as a fuel | Enhancing the energy efficiency of clinker production | The use of waste-derived fuels, biomass and other alternative fuels in clinker production | Carbon Capture Utilization and Storage (CCUS) | **(**Re)carbonation/$CO_2$ sink (exposing the concrete in construction & demolition waste to air for $CO_2$ uptake) |
| **Maturity & Barriers** | Mature | Mature | Mature | Not mature | Mature | Mature | Not Mature | Not Mature |
| **Costs estimation** | No significant investment required | No significant investment required | Investments of 4 Euro per ton binder per year (Expert judgment). | Investments of about USD 6.25 per $m^3$ per year of Hydrogen (Expert Judgment)<br>The IEA analysis found that the cost of production from electricity could fall 30% by 2030. | This depends on the exact energy efficiency measure to be applied. | Estimated to be in the range of 11-50 $/GJ | Partial or full CCS (blue hydrogen) increases costs by 20-50% depending on the degree of decarbonization. | - |
| **Implementation timeframe** | According to GCCA roadmap, GHG emissions reductions from implementation will be 7% and 22% in 2030 and 2050, respectively compared to BAU scenario | According to GCCA roadmap, optimizing concrete production. Regarding binder utilization can result in reduction of binder demand<br>Emissions of 5% and 14% in 2030 and 2050, respectively compared to BAU scenario | According to GCCA roadmap, the current clinker ratio in cement is 0.63 on average, and it will reduce to 0.58 and 0.52 by 2030 and 2050, respectively. In addition, it is projected that the share of alternative cement type will be 1% and 5% of cement in 2030 and 2050, respectively contributing to 0.5% reduction in overall $CO_2$ emissions.". | According to GCCA roadmap, this would play a role from 2040 | Has improved tremendously over past decades and will keep improving since the new plants will be typically more energy efficient. | Average global use of alternative fuel use expected to increase from being currently at 6% to reach 22% by 2030 and 43% by 2050 | According to GCCA roadmap, the expected value of $CO_2$ captured and stored will be 1370 Mt $CO_2$ in 2050. It is needed to start developing CCUS at scale to reach net zero by 2050 | According to GCCA roadmap, the Global recarbonation is expected to be 318 and 242 Mt $CO_2$ in 2030 and 2050, respectively.<br>Reduction of $CO_2$ emissions from cement by 6% in 2050 |
| **Potential enabling policies reported** | Policies are needed to enforce the use of $CO_2$ emissions reduction methods as a design parameter in addition to the current parameters (e.g. design that ensures less concrete consumption). In addition, policies are | Policies are needed to incentivize the use of admixtures in concrete production and to reduce risk through piloting. In addition, policies are also needed to support the development of concrete industrial plants instead of | This will involve changes in codes and standards to allow for increased percentage of Portland cement alternatives; scaling up best-practice dissemination and support to make the use of novel products viable. | Adopting hydrogen strategies and technologies that support demand for industrial sector, as the majority of policies in place are focusing on demand creation in | Allowing for fast and efficient permitting of captive power plants based on waste heat recovery, appropriate tax policies and incentives for energy efficient plants, and | Policies regulating waste management and distribution, at both the local and international level. In | Policies needed to help develop, de-risk and deploy the technology and infrastructure over the time to help transform the industry worldwide. This includes financial incentives, such as carbon pricing mechanisms and | Innovative set of policies regarding treating crushed concrete as well as building waste This would enable recarbonation to reach its full potential. Also policies incentivizing the relevant R&D activities are required |

| Sector | Cement Sector | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technologies** | **Circular economy practices for energy consumption reduction** | | | **Energy Efficiency & Direct use of renewable heat and biomass** | | | **Carbon Capture and Storage (CCS)and Carbon Capture, Utilization and Storage (CCUS)** | |
| | needed to incentivize investments in concrete recycling. | production of concrete in project sites. | | transportation, even though it is accounting for most current demand. Also policies incentivizing the relevant R&D activities are required | revision of energy subsidy programmes. | addition, policies are required to incentivize investments in biomass full value chain | subsidies, as well as regulatory frameworks that support the development and deployment of CCS/CCUS technologies. In addition, it is recommended to develop incentives to transform enhanced oil recovery (EOR). Also policies incentivizing the relevant R&D activities are required | |
| **Cross sectoral technology (Y/N)** | N | N | N | Y | Y | Y | Y | Y |

**Table 3-2: Low Emissions and Net Zero Technologies for Steel Sector**

| Sector | Steel Sector | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technologies** | **Circular economy practices for energy consumption reduction** | | **Process Optimization and Efficiency Improvements** | **Direct use of clean electricity from renewable sources** | | **Direct use of use of renewable heat and biomass** | **Carbon Capture and Storage -CCS-, and Carbon Capture, Utilization and Storage - CCUS** | |
| **Type** | Steel industry co-products (slag)[96] | Scrap use in the steel industry[97] | Industrial Process GHGs reduction measures (e.g., energy management systems and recovery of energy throughout the steelmaking process)[98] | Electrolysis in ironmaking (iron ore)[99] | Hydrogen ($H_2$)-based ironmaking by replacing NG with $H_2$[100] | Biomass in steelmaking[101] | Carbon capture and storage (CCS)[102] | Carbon capture and use and storage (CCUS) [103] |
| **Maturity & Barriers** | Mature<br>About 97.5% worldwide of the material effciency rate was from the contribution of the recovery and use of steel industry co-products. | Mature<br>However, there is a delay in production time and availability for recycling. | Mature<br>Since 1960, energy efficiency has improved savings of about 60% in energy consumed to produce one tonne of crude steel | Not Mature | Not Mature | Mature (albeit at small replacement ratio) | Not Mature.<br>CCS has not yet been applied to blast furnace steel production beyond pilot-scale projects (the DRI unit at Emirates Steel in Abu Dhabi and the Netherlands, Tata Steel). | Not Mature.<br>CCUS (pilot $CO_2$ from Emirates Steel plant, is captured and injected into the Abu Dhabi National Oil Company's oil reservoirs, and also pilot in chemicals industry in New Zealand to convert waste gases from steel plant to ethanol replicated on commercial scale in China 2018). |
| **Costs estimation** | The slag cost ranges from few cents to about USD$ 120/ton or more.[104] | | Energy constitutes a significant portion of the cost of steel production, from 20% to 40%. The energy efficiency cost of steelmaking facilities varies depending on production route, type and quality of iron ore and coal used, the steel product mix, operation | Dependent on the availability of renewable energy (e.g., solar and wind) and electricity prices. | Investments of about USD 6.25 per $m^3$ per year of Hydrogen (Expert Judgment)<br>The IEA analysis found that the cost of producing hydrogen from renewable electricity by 2030 could fall 30% as a result of costs reduction of renewables and the | Quintupling the supply of biofuels by 2030 will require USD 124 billion annually. | The IEA found that innovative process (including CCS on the blast furnace, smelt reduction and gas-based DRI) is expected to cost 10-50% more than conventional technology within a given regional | Not all CCUS applications have the same cost. The source of $CO_2$ has direct impact on the cost as follows[105]:<br>- $CO_2$ from ISR cost range from about USD 380/t$CO_2$ – USD 500/t$CO_2$ |

[96] https://worldsteel.org/wp-content/uploads/Fact-sheet-Steel-industry-co-products.pdf
[97] https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf
[98] https://worldsteel.org/wp-content/uploads/Fact-sheet-energy-in-the-steel-industry-2021-1.pdf
[99] https://worldsteel.org/wp-content/uploads/Fact-sheet-Electrolysis-in-ironmaking.pdf
[100] https://worldsteel.org/wp-content/uploads/Fact-sheet-Hydrogen-H2-based-ironmaking.pdf
[101] https://worldsteel.org/wp-content/uploads/Biomass-in-steelmaking.pdf
[102] https://worldsteel.org/wp-content/uploads/Carbon-Capture-Storage_2023.pdf
[103] https://worldsteel.org/wp-content/uploads/Carbon-capture-use-and-storage-2023.pdf
[104] https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-iron-steel-slag.pdf
[105] https://www.iea.org/commentaries/is-carbon-capture-too-expensive

| **Sector** | **Steel Sector** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technologies** | **Circular economy practices for energy consumption reduction** | | **Process Optimization and Efficiency Improvements** | **Direct use of clean electricity from renewable sources** | | **Direct use of use of renewable heat and biomass** | **Carbon Capture and Storage -CCS-, and Carbon Capture, Utilization and Storage - CCUS** | |
| | | | control technology, and material efficiency. | | scaling up of hydrogen production. | | context, taking into account that this cost increase significantly exceeds profit margins from steel production today. Steel plants located in industrial zones in close proximity to other $CO_2$ emitters can share transport and storage infrastructure as an efficient and cost-effective way to meet climate targets. | - $CO_2$ from Gas DRI cost range from about USD 440/t$CO_2$ – USD 640/t$CO_2$. |
| **Implementation timeframe** | Already implemented where over the past 20 years and the average recovery rate for slag varies from 80% for steel manfacturing and almost 100% for iron manufacturing. | Steel scrap starts to reach the end of its life and it is expected to increase from the mid 2020s.<br>The global end of life scrap availability is expected to reach around 600 Mt in 2030 and around 900 Mt in 2050. | Energy efficiency measures in the steel industry has been implemented for more than 20 years. However, a goal has been set by the European Commission to improve energy efficiency by 20% by 2020 relative to 2005 (Eurostat, 2013). Moreover, renewable energy share should increase to 20%.[106] | IEA modelling suggesting that about 100 Mt of iron ore electrolysis could possibly be in operation by 2050. | Green hydrogen will be introduced as a primary reducing agent at a commercial scale in the mid-2030s under ‘Sustainable Development Scenario’ (SDS) as part of the IEA 2020 technology roadmap. Additionally, its use is expected to reach 12 Mt annually by 2050. The IEA’s modelling Suggests as well that by 2050 below 8% of total steel production will utilize electrolytic hydrogen as the primary reducing agent (or 14% of primary production). | For conventional biofuels, the implementation is dependent on the supply chain ability to meet the demand.<br>For bio-coal pilot in Brazil, it was found that not all biomass can be used according to their physical and chemical properties. Therefore, only improved biomass can be utilized, through torrefaction (bio-coal) or pyrolysis (charcoal). The large-scale demonstration is expected to reach zero emissions by 2025[107]. | Under the IEA’s core ‘Sustainable Development Scenario’ (SDS), by 2070 about 75% of all the $CO_2$ emission produced globally in iron and steel will be captured. | It is expected by 2030, 2050 and 2070 that CCUS contribution to $CO_2$ emission reductions reach 4%, 25% and 31%, respectively with a cumulative reduction of 25%.[108] |
| **Potential enabling policies reported** | Developing policies to extend the use of co-product in other industries (e.g., | In order to make best use of the expected growth in scrap | Allowing for fast and efficient permitting of captive power plants | Policies are needed for for iron electrolysis to become economically | Adopting hydrogen strategies and technologies that | Regulations and legislative frameworks should be developed to | Enabling policies for CCS/CCUS include financial | Enabling policies for CCS/CCUS include financial incentives, |

[106] https://www.diva-portal.org/smash/get/diva2:711353/FULLTEXT02.pdf
[107] https://www.iea.org/reports/iron-and-steel-technology-roadmap
[108] https://www.iea.org/reports/ccus-in-clean-energy-transitions/ccus-in-the-transition-to-net-zero-emissions

| **Sector** | **Steel Sector** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technologies** | **Circular economy practices for energy consumption reduction** | | **Process Optimization and Efficiency Improvements** | **Direct use of clean electricity from renewable sources** | | **Direct use of use of renewable heat and biomass** | **Carbon Capture and Storage -CCS-, and Carbon Capture, Utilization and Storage - CCUS** | |
| | cement, glass, fertilizer, etc.) to save natural resources and reduce the environmental impact by raising awarness such as modifying the public and political perception needs. | availability and use, it is recommended that the stakeholders could agree on a global classification given the international nature of scrap trade. Scrap global classification aims at agreeing on making best use of the expected high growth in scrap availability and use.[109] | based on waste heat recovery, appropriate tax policies and incentives for energy efficient plants, and revision of energy subsidy programmes. | feasible. This includes supporting technology innovation to solve engineering issues; e.g., in molten oxide electrolysis, a cheap and carbon-free inert anode resistant to the corrosive conditions has to be developed. | support demand for industrial sector, as the majority of policies in place are focusing on demand creation in transportation, even though it is accounting for most current demand. Also policies incentivizing the relevant R&D activities are required | ensure the good management of forests to ensure sustainable supply of wood. In addition, policies are required to incentivize investments in biomass full value chain | incentives, such as carbon pricing mechanisms and subsidies, as well as regulatory frameworks that support the development and deployment of CCS/CCUS technologies. In addition, it is recommended to develop incentives to transform enhanced oil recovery (EOR). Also policies incentivizing the relevant R&D activities are required. Finally, the IEA notes that ‘deployment strategies that shift the focus from large, stand-alone CCS/CCUS facilities to the development of industrial “hubs” with shared $CO_2$ transport and storage infrastructure are also opening up new investment opportunities’. | such as carbon pricing mechanisms and subsidies, as well as regulatory frameworks that support the development and deployment of CCS/CCUS technologies. In addition, it is recommended to develop incentives to transform enhanced oil recovery (EOR). Also policies incentivizing the relevant R&D activities are required. Finally, the IEAs notes that ‘deployment strategies that shift the focus from large, stand-alone CCS/CCUS facilities to the development of industrial “hubs” with shared $CO_2$ transport and storage infrastructure are also opening up new investment opportunities’. |
| **Cross sectoral technology (Y/N)** | N | N | Y | N | Y | Y | Y | Y |

[109] https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf

## Table 3-3: Low Emissions and Net Zero Technologies for Chemicals Sector

| **Sector** | **Chemicals Sector** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Category** | **Circular Economy Practices for Energy Consumption Reduction** | | **Industrial Process GHGs reduction measures** | | **Direct use of clean electricity from renewable sources** | | **Direct use of renewable heat and biomass** | **Carbon Capture, Utilization and Storage** |
| **Type** | Circular Economy Approaches | Sustainable Feedstock and Raw Material Substitution | Advanced Catalysis and Chemical Engineering (e.g. light alkane upgrading, and synthesis of aromatics from various sources) | Process Optimization and Efficiency Improvements | Hydrogen Production and Utilization | Renewable Energy Integration | Bioenergy | Carbon Capture, Utilization, and Storage (CCUS) |
| **Maturity & Barriers** | Fairly mature, but still in progress. | Not mature.<br>The use of sustainable feedstocks and raw material through the replacement of fossil-based raw materials with renewable or recycled alternatives, such as the use of bio-methanol directly or as a basis to produce olefins and aromatics. Additionally, increased recycling of plastics can also help reduce the demand for primary feedstocks in chemical production. | Not Mature. | Mature. | Not Mature. | Technology is Mature, but not widely implemented in chemicals sector yet. | The use of bioenergy in the chemical sector is still in the early stages of development | Not mature, but relatively advanced than other sectors.<br>The CCUS has been utilized often for the production of urea for example, and a pilot in Norway is studying producing ammonia that can be used as fuel. |
| **Costs estimation** | The costs of circular economy approaches depend on the specific techniques and technologies used. However, these approaches are generally considered to be cost-effective, as they can reduce the consumption of virgin materials and the generation of waste | The costs of sustainable feedstock and raw material substitution depend on the specific feedstocks and materials used. However, these measures are generally considered to be cost-competitive with fossil-based alternatives, and the costs of renewable and recycled materials have been declining in recent years | The costs of advanced catalysis and chemical engineering depend on the specific techniques and technologies used, and the maturity of the specific catalytic process (implemented or R&D stage). | The costs of process optimization and efficiency improvements depend on the specific techniques and technologies used. | Investments of about USD 6.25 per $m^3$ per year of Hydrogen (Expert Judgment)<br>The IEA analysis found that the cost of production from electricity could fall 30% by 2030. | The costs of renewable energy integration varied greatly depending on the type of industry. However, the cost is generally becoming more cost-competitive with fossil fuels. | The costs of bioenergy depend on the technology and feedstock used. | The CCUS is generally considered to be a costly technology, requiring significant investment in infrastructure and operation |
| **Implementation timeframe** | The implementation timeframe for circular economy projects can vary depending on the scale and complexity of the industry in which it is being applied.<br>"Net Zero by 2050 A Roadmap for the Global Energy Sector" targets 54% reuse in plastics collection | Not determined in the roadmaps | Not determined in the roadmaps | The implementation timeframe for process optimization and efficiency improvement projects can vary depending on the scale and complexity of the project. | "Net Zero by 2050 A Roadmap for the Global Energy Sector" targets 83 Mt $H_2$ production by 2050 with on-site electrolyser capacity of 210 GW | The integration of renewable energy into the chemical sector is expected to increase in the coming years, dependent on the products type. | Bioenergy depends on the maturity of the supply chain in the vicinity of the industries in which it can be utilized. | The implementation timeframe for CCUS is expected to be long, as large-scale projects may take several years to develop and become operational<br>"Net Zero by 2050 A Roadmap for the |

| Sector | Chemicals Sector | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Category** | **Circular Economy Practices for Energy Consumption Reduction** | | **Industrial Process GHGs reduction measures** | | **Direct use of clean electricity from renewable sources** | | **Direct use of renewable heat and biomass** | **Carbon Capture, Utilization and Storage** |
| | and 35% reuse in secondary production | | | | | | | Global Energy Sector" targets 540 Mt $CO_2$ reduction by 2050. |
| **Potential enabling policies reported** | Numerous countries are actively addressing plastic pollution, with over 60 nations implementing bans and levies on plastic packaging and single-use items. Notably, India is set to ban many single-use plastic items from 2022, while Canada has also announced a ban on several new items, effective in the same year[110]. Also policies incentivizing the relevant R&D activities are required | Enabling policies for sustainable feedstock and raw material substitution include and sustainability certification schemes for raw materials. Also policies incentivizing the relevant R&D activities are required | Encouraging more R&D efforts to produce more efficient catalytic agents might support the advancement of this field further in the industry. | Enabling policies include energy efficiency standards, financial incentives for energy audits and retrofits. In addition, allowing for fast and efficient permitting of captive power plants based on waste heat recovery, appropriate tax policies and incentives for energy efficient plants, and revision of energy subsidy programmes are required. | Adopting hydrogen strategies and technologies that support demand for industrial sector, as the majority of policies in place are focusing on demand creation in transportation, even though it is accounting for most current demand. Also policies incentivizing the relevant R&D activities are required | Enabling policies include feed-in tariffs, renewable portfolio standards, and tax incentives for renewable energy projects. | Enabling policies for bioenergy include feed-in tariffs, renewable energy incentives, and sustainability certification schemes for biomass feedstocks. | Enabling policies for CCUS include financial incentives, such as carbon pricing mechanisms and subsidies, as well as regulatory frameworks that support the development and deployment of CCUS technologies. In addition, it is recommended to develop incentives to transform enhanced oil recovery (EOR). Also policies incentivizing the relevant R&D activities are required. |
| | | | | . | | | Regulatory systems for the supply chain, as well as forestry preservation policies for coal substitution with bio-coal. In addition, policies are required to incentivize investments in biomass full value chain | |
| **Cross sectoral technology (Y/N)** | Y | N | N | Y | Y | Y | Y | Y |

[110] "Chemicals," IEA. https://www.iea.org/energy-system/industry/chemicals (accessed Jul. 20, 2023).

## 3.2 Sectoral Cross-cutting Technologies

### 3.2.1 Circular economy practices for energy consumption reduction

Slag is the main co-product from steel production. It is primarily used in cement production, reducing about 50% of $CO_2$ emissions. Also, it could be used in roads (substituting aggregates), as fertilizer (slag is rich in phosphate, silicate, magnesium, lime, manganese and iron), and in coastal marine blocks to facilitate coral growth and accordingly, improving the ocean environment. However, the steel decarbonization will reduce the amount of the slag produced.

### 3.2.2 Carbon Capture and Storage (CCS) and Carbon Capture, Utilizat ion and Storage (CCUS)

CCUS applications include oxygenated compounds (polycarbonate, urethane, etc.), biomass-derived chemicals, commodity chemicals (olefin, BTX, etc.), minerals such as concrete products, concrete structures, carbonate, etc.

### 3.2.3 Electrification

Electrification is a cross-cutting technology that presents a viable pathway for decarbonization across various industries. Electrifying of industrial processes, such as electric heating and the use of electric motors, not only reduces greenhouse gas emissions but also enhances energy efficiency and process flexibility. Additionally, electrification can synergize with renewable energy integration, creating opportunities for using renewable electricity in the industry. However, while electrification technologies are mature and already widely available, their broader implementation may require upgrading infrastructure, grid integration, and supportive policies to incentivize adoption [111].

### 3.2.4 Renewable Energy Integration

Renewable Energy Integration is a critical cross-sectoral technology that enables the industrial transition to low-carbon operations. By directly using clean electricity from renewable sources, such as solar, wind, and hydropower, the industry can significantly reduce its greenhouse gas emissions and decrease its dependency on fossil fuels. Renewable energy integration can be applied to power various energy-intensive processes, including electrolysis for hydrogen production and electric arc furnaces for steelmaking. The implementation of this technology requires supportive policies like feed-in tariffs, renewable energy targets, and incentives to encourage the deployment of renewable energy technologies. While renewable energy integration is already a mature technology in the power sector, its expansion into industry is still in the early stages but holds enormous potential for decarbonization [112].

### 3.2.5 Hydrogen Production and Utilization

Hydrogen Production and Utilization is another cross-cutting technology with immense potential to decarbonization. Hydrogen can be produced from renewable energy sources through electrolysis (green hydrogen) or from natural gas with carbon capture and storage (blue hydrogen). When used as a clean energy carrier and feedstock, hydrogen offers an alternative to fossil fuels, facilitating low-carbon industry.

[111] ibid
[112] ibid

Hydrogen is already well-established in some industries for applications like ammonia and methanol production. However, its broader adoption as a versatile energy carrier and feedstock requires supportive policies, investment in infrastructure, and scaling up renewable hydrogen production. The increasing focus on hydrogen technologies and advancements in its production and utilization methods make it a promising solution for decarbonization [113].

### 3.2.6 Biomass

Biomass is a versatile cross-cutting technology that can contribute significantly to the decarbonization of the industry. Biomass can be used as a source of energy in the steel, cement and chemical sector, in addition to the production of bio-based materials in the chemical sector. It involves utilizing organic materials, such as biomass and biogas, as renewable feedstocks for energy and chemical production. Bioenergy can replace fossil-based fuels in various processes, reducing carbon emissions and promoting sustainability. Biomass can be converted into biofuels, bioplastics, and other bio-based chemicals, offering a cleaner and more sustainable alternative to conventional petrochemicals. The technology's maturity varies depending on the specific application, with some bioenergy processes being well-established while others are still in development. Enabling policies, such as feed-in tariffs and sustainability certification schemes, play a crucial role in promoting the use of bioenergy in the industry. As industry seeks to reduce its reliance on fossil fuels, the adoption of bioenergy can play a significant role in achieving carbon neutrality [114].

[113] ibid
[114] ibid

# 4 COUNTRY LEVEL ANALAYSIS

The countries studied are divided into four different groups starting with the Group of 20 (G20), developing countries (DC), Small Island Developing States (SIDS), and Least Developed Countries (LDCs). The 10 countries were selected based on specific criteria that was agreed upon with UNIDO. Details of the selection process can be found in Annex 2. Data were collected for these countries and an analysis of the gaps based on the technologies identified in the roadmaps and initiatives is conducted. Finally, success stories from different countries are identified and presented.

## 4.1 Countries Selection

The selection process focused on achieving diversity in the selected countries in terms of the geographical location, size of economy, and technological advancement. The countries targeted for selection represents a significant contribution in the sectors defined by the study, which are cement, steel and chemicals and petrochemicals. Accordingly, a set of selection criteria was formulated to serve this purpose. The details of the selection levels, criteria, and assigned weighted scores could be reviewed in Annex 2 and Annex 3, while the final list of selected countries is presented in Table 4-1 below.

Table 4-1: Countries Selected for further study and mapping

| Country Group | Countries Selected | Score (out of 100%) |
|---|---|---|
| **G20 Countries (Total 6)** | China | 90% |
| | Indonesia | 84% |
| | Türkiye* | 75% |
| | Japan** | 72% |
| | Germany*** | 51% |
| | Mexico**** | 49% |
| **Developing Countries (Total 2)** | Vietnam | 69% |
| | Egypt | 47% |
| **Small Island Developing States (Total 1)** | Belize | 40% |
| **Least Developed Countries (Total 1)** | Mauritania | 42% |

* Türkiye is selected to maintain the regional distribution of countries.
** Considering that Japan has implemented several actions in the HAI sectors that could benefit the overall study, it was selected with a score of 72% in favor of South Korea which scored 78%.
*** Germany scored highest of the EU countries, and therefore was selected as a representative of the EU countries.
**** Mexico is selected to maintain the regional distribution of countries as a representative of Latin America.

## 4.2 Country Assessment

For the selected countries, several documents were consulted starting with the latest version of the reports submitted to the UNFCCC such as the NDCs, BRs/BURs, TNAs and LT-LEDS, as well as other national strategies and reports that were issued or prepared by the country regarding the HAI sectors. These documents were reviewed to collect data regarding the emissions from each sector in each country, and therefore, the emission indicators relative to the production capacity ($CO_2$/ton product) and relative to the population data ($CO_2$/capita).

The mitigation goals targeted by different countries are then discussed, followed by a listing of the technology needs that the country declares is needed to reach its mitigation goals. Finally, the gaps in technologies required to reach PA targets based on the sectoral technologies identified in chapter 3 and from the expert judgement about the data reviewed is presented.

The data collected and discussed is included in Table 4-2 for each of the selected countries for each HAI sector separately, starting with cement, followed by steel and chemicals & petrochemicals sector.

It is important to note that although according to the UNFCCC records, the number of countries that have submitted TNAs so far has reached 90 developing countries, with another 26 countries mentioning the TNAs as part of their NDC and 39 other developing countries currently undertaking the task, the review of the selected countries resulted in finding some TNA documents that dated back to 2001 and before, and therefore were judged to be outdated[115].

Additionally, the 2020 TNA synthesis report mentioned that the parties prioritizing the industrial sector as a mitigation measure and therefore reporting a technology needs assessment reached almost 21% for Phase I (2009–2013), and around 12% for Phase II (2014–2017) of the global technology needs assessment project[116].

[115] https://unfccc.int/ttclear/tna
[116] https://unfccc.int/sites/default/files/resource/sbi2020_inf.01.pdf

**Table 4-2: Countries Retrieved Data Analysis for Cement, Steel and Chemicals Sectors**

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| **Cement Sector** | | | | | |
| **China** | NDC (2021)<br>Progress on the implementation of NDC (2022)<br>Second BUR (2018)<br>China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy (2021)<br>TNA (1998)<br>**Other Documents:**<br>China Cement Association, Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022 | **No HAI data was retrieved from UNFCCC submitted documents.**<br>**Production** (2021) 2.365 billion tons<br>**$CO_2$ Emissions**<br>Ourworld data: 0.853 Billion tons $CO_2$ (2021)[117]<br>CCA, Towards Net Zero Roadmap: 1.37 Billion ton $CO_2$ (2020)[118]<br>**Ton $CO_2$/ton cement:**<br>0.36 tons $CO_2$/ton cement (according to Ourworld 2021 data)<br>0.58 ton$CO_2$/ton cement (according to CCA 2020 data:)<br>- 0.6 tons $CO_2$/Capita | **No HAI data was retrieved from UNFCCC submitted documents.**<br>**Reaching Net Zero emissions by the year 2060[119].**<br>Goals breakdown relative to 2020 emissions:<br>2030: ~ 30% reduction<br>2040: ~ 70% reduction<br>2050: 85% reduction | - Currently, Energy efficiency measures to maintain the energy consumption per ton of cement within or below world average are ongoing and need to continue.<br>- Increasing the contribution of alternative fuels (current thermal substitution < 2%), which is dependent on the overall improvement of the alternative fuel supply chain and the removal of policy barriers.<br>- Planned introduction of hydrogen and green electricity as a long-term goal<br>- Raw material substitution from industrial waste, which is dependent on availability, and the utilization of new low-carbon clinker considered as a more future plan.<br>- CCUS is identified as an important player on the road to net zero cement, however the distances between plants and high cost of transportation are the main identified barriers to implementation. | Yes, due to implementing long term polices such as "1+N policy" framework, which includes the formulation of carbon-peaking action plans for key industries, including the building materials industry, in which cement is a major component, and China's 14th Five-Year Plan calls for the pursuit of hydrogen technology as part of the industrial transformation, as well as China's Mid- to Long-Term Hydrogen Industry Development Plan (2021–35)[120]. Also, China has been exploring a variety of innovative mechanisms such as paid allocation, carbon finance, and inclusive carbon. |
| **Indonesia** | NDC (2022)<br>Third BUR (2021)<br>Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (2021)<br>Second TNA on mitigation (2012)<br>**Other Documents**<br>An Energy Sector Roadmap to Net Zero Emissions in Indonesia (2022). | **Production[121]:**<br>- 43.09 Mt (2010)<br>- 76.2 Mt (2019)<br>- Production capacity decreased significantly for about 18.9% in 2020, and reached 71.8 Mt[122]<br>- Estimated to be 70.4 Mt in 2021.[123]<br>- Expected to reach 81.6 Mt in 2030, and 99.6 Mt in 2050.<br>**Emissions[124]:**<br>- 286 Mt $CO_2$ in 2021, with annual $CO_2$ emissions per capita of 0.1 tons.[125] | By 2030, Indonesia targeting to reach[126]:<br>1- 81% clinker to cement ration in BaU.<br>2- 70% clinker to cement ratio in CM1 with GHG emission reduction target of 2.75 Mt $CO_2$.<br>3- 65% clinker to cement ration in CM2, with GHG emission reduction target of 3.25 Mt $CO_2$ | - Application of thermal and electrical efficiency measures through the application of ISO 50001, using energy efficient equipment and energy leakages prevention<br>- Clinker substitution through the encouragement of production, developing regulations to promote use of low carbon cement and R&D of low-clinker content cement.<br>- Increase the use of alternative fuels and raw materials to replace fossil fuels through utilization of waste utilization and strengthening the supply chain.<br>- Integrate CCS and CCUS technologies in cement plants based on investment opportunities and R&D[127]<br>- Establish green standards for cement industry that consider achieving emission targets. | Yes, due to developing near term milestones strategies and implementing supported polices and regulations that led to voluntarily reduce $CO_2$ emissions by 2% from 2011 to 2015 and obligatorily by 3% between 2016 and 2020.<br>Also, publishing a commitment to realize zero emissions by 2060 in the cement industry[128]. |

[117] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[118] China Cement Association, Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022 (can be found at: https://rmi.org/wp-content/uploads/dlm_uploads/2023/02/toward_net_zero_decarbonization_roadmap_for_chinas_cement_industry_executive_summary.pdf)
[119] China Cement Association, Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022 (can be found at: https://rmi.org/wp-content/uploads/dlm_uploads/2023/02/toward_net_zero_decarbonization_roadmap_for_chinas_cement_industry_executive_summary.pdf)
[120] https://rmi.org/insight/net-zero-decarbonization-in-chinas-cement-industry/#download-form
[121] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
[122] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
[123] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
[124] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[125] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[126] https://unfccc.int/sites/default/files/NDC/2022-09/23.09.2022_Enhanced%20NDC%20Indonesia.pdf
[127] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
[128] https://iea.blob.core.windows.net/assets/b496b141-8c3b-47fc-adb2-90740eb0b3b8/AnEnergySectorRoadmaptoNetZeroEmissionsinIndonesia.pdf

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| **Türkiye** | NDC (2022)<br>BR (2023)<br>**Other Documents**<br>Waste heat recovery in Turkish cement industry: review of existing installations and assessment of remaining potential<br>Turkish Cement Focus (Globalcement.com)<br>Abstract on the potential GHG emissions reduction in Türkiye through the cement industry (Cementis) | **Production**<br>- Production amounts not available<br>**Emissions**[129]<br>- Total IPPU sector emissions 66.8 Mt $CO_2$eq (2020)[130]<br>- Cement sector emissions 45.6 Mt $CO_2$eq (2020) representing 8.7% of the National GHG emissions<br>- 44.4, Mt CO2eq in 2021, with an annual $CO_2$ emission per capita of 0.52 tons.[131] | - Türkiye to shift all CEM I to LC3 to reduce $CO_2$ emissions from fuel[132]. It is expected to cut $CO_2$ emissions by 12.4 Mt of $CO_2$ eq.[133]<br>- Türkiye has implemented a pilot phase for measuring, reporting and verification (MRV) of emission reductions in cement, refinery, and electricity sectors, which covers approximately 55% of Türkiye's total emissions.[134] | - Enhance the application of $CO_2$ emissions technologies in cement production, as well as material use, fuel resources and energy saving measurements and perform cost effectiveness of alternative scenarios<br>- Clinker substitution through the encouragement of production, developing regulations to promote use of low carbon cement and R&D of low-clinker content cement.<br>- Increase the use of alternative fuels and raw materials to replace fossil fuels through utilization of waste utilization and strengthening the supply chain.<br>- Türkiye aims to increase the usage of Carbon capture and disposal | Mostly yes, as the Turkish cement industry has been an early adopter of finance mechanisms and supporting R&D studies. This is reflected in developing the "Green Growth Technology Roadmap" and receiving international funding for the first phase to achieve legislative enforcement, including a pilot phase for measuring, reporting and verification (MRV) of emission reductions in cement, refinery, and electricity sectors[135]. |
| **Japan** | NDC (2021)<br>BR (2019)<br>Long-Term Strategy under the Paris Agreement (2021)<br>**Other Documents:**<br>Our World in Data (website)<br>Technology Roadmap for "Transition Finance" in Cement Sector (Ministry of Economy, Trade and Industry) | **Production:**<br>58 M ton (2019)<br>**Emissions:**<br>- 23.8 Mt $CO_2$ with an annual $CO_2$ emission per capita of 0.19 tons.[136] | - Reaching carbon neutrality by 2050, as indicated in the roadmap "Carbon Recycling Technologies"[137] | - Support the research and development of innovative technologies to include carbon neutral related studies<br>- Support low-carbon and decarbonization technologies to become commercial in the cement sector by linking it with other sectors<br>- Consider overcoming the drastically changed energy-intensive sector, which will result in making carbon neutrality hard to be applied in Japan<br>- Support the technologies financially to overcome uncertainties in their implementation<br>- Japan needs to work on transition including energy conservation and energy transition aiming at decarbonization, and advance efforts on energy saving/efficient technologies[138] | Yes, due to boosting innovative technologies, such as the use raw materials during clinker production, cement with low clinker ratio, and cement with high blended material ratio[139]. Also, developing supporting laws and standards such as mandating to classify and recycle waste generated during construction and demolition works. Japan has also developed standards for recycled concrete aggregate (RCA) and recycled-aggregate concrete (RAC)[140].<br>Japan is also advocate for international cooperation as it has partnered with Australia on the de-carbonization through technology project.[141] |
| **Germany** | NDC (2020)<br>BR (2019) | **Production**<br>- No production data stated<br>**Emissions** | - A study conducted by the German association for cement (VDZ), 27% reduction in $CO_2$ is expected to be reached by | - Provide the necessary infrastructure, for example the infrastructure needed for carbon-free power consumption and the transportation of $CO_2$ and hydrogen | Yes, due to adopting innovative technologies. Alongside reduction in the clinker content in cement, and the increased use of alternative fuels |

[129] https://unfccc.int/sites/default/files/resource/8NC-5BR%20T%C3%BCrkiye.pdf
[130] https://unfccc.int/sites/default/files/resource/8NC-5BR%20T%C3%BCrkiye.pdf
[131] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[132] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
[133] https://www.cementis.com/wp-content/uploads/2018/08/Turkey-GHG-from-Cement.pdf
[134] https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf,
[135] https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf
[136] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[137] https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_cement_eng.pdf
[138] https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_cement_eng.pdf
[139] https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_cement_eng.pdf
[140] https://link.springer.com/article/10.1007/s10163-022-01412-x
[141] https://gaspathways.com/cemex-invests-in-hiirocs-clean-hydrogen-technology-596

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| | Update to the long-term strategy for climate action of the Federal Republic of Germany (2022)<br>**Other Documents**<br>Decarbonizing Cement and Concrete: A $CO_2$ Roadmap for the German cement industry<br>Our World in Data (website) | - The general EU GHG reduction target is 55% by 2030 compared to 1990 levels (including Germany)[142]<br>- The sectors covered included Industrial processes and product use<br>- 13.2 Mt $CO_2$ in 2021, with annual rate per capita from cement industry of 0.16 ton/capita.[143] | 2030 as part of the neutrality scenario, and 36% reduction by 2050 under the ambitious reference scenario.[144] | - Increase the usage of carbon capture technologies.<br>- Create a collaboration among the whole value chain, starting including suppliers, manufacturers, and designers.<br>- Apply an effective policy to allow the competitive production of low-carbon technologies and create markets.<br>- Provide policy framework for competitiveness and innovative markets for low-and carbon neutral cement. | containing biomass as a substitute for the majority of fossil energy sources. German cement manufacturers have been working intensively for years under the auspices of VDZ and the European Cement Research Academy (ECRA) to further develop new technologies[145]. |
| **Mexico** | Third BUR (2022) – in Spanish<br>Mexico's Climate Change Mid-Century Strategy (2016)<br>NDC (2022) - Spanish<br>**Other Documents**<br>The Mexico-FICEM 2030 Roadmap<br>Our World in Data (website) | **Production**<br>No data available<br>**Emission**<br>- Total industrial sector emission was 30.9 Mt $CO_2$eq in 2019. The cement sector was reported as 19.4 $CO_2$eq[146]<br>- Total emissions of 22,339,198 tons of $CO_2$eq in 2021.[147]<br>- Carbon emissions per capita were 0.18 tons per capita in 2021.<br>- In 2013, emissions from the industry sector were 114.9 Mt of $CO_2$eq, with cement being the main contributor with 9.7 Mt (26.3%) due to the consumption of fossil fuels, and 20.5 Mt of $CO_2$eq due to industrial processes.[148] | - A roadmap of the cement industry was launched in 2023, that was based on the roadmap of the Cement Sustainability Initiative of the year 2018.<br>- Mexico aims to reduce the carbon intensity of the cement industry to be 520 kg $CO_2$/ton cement, instead of 629 kg $CO_2$/ton cement. This would achieve 17% reduction in carbon emissions.[149]<br>- Increasing co-processing rate up to 32%<br>- Reducing clinker content in the cement to 66%. | - Based on the study conducted by Global Efficiency Intelligence, and Lawrence Berkeley National Laboratory, five key pillars can help in reduction of $CO_2$ emissions in Mexico. These pillars are: energy-efficiency, fuel switching, clinker substitution, carbon capture, utilization and storage. The use of modern technologies that support each pillar is required in Mexico.[150]<br>- Cooperation between different sectors such as academia, industry, government, etc., providing green financing and enhance the regulatory framework are all requirements to achieve the goals in Mexico's roadmap.<br>- The foregoing is required to promote the deployment of emission reduction mechanisms, such as: a) the co-processing of waste through joint work with authorities at all levels, and b) the promotion of low-carbon cement and concrete through the work at the regulatory level, and c) consumption of less energy per unit of product through optimization of clinker kilns.[151] | Yes, due to developing the supporting R&D & studies. Mexico has its roadmap of the cement industry, and has developed some other supporting studies such as the LLC study to analyze decarburization potential for the Mexican cement industry, and Nationally appropriate mitigation actions (NAMA) study for the cement sector related to Substitution of primary fuels by alternative fuel[152]. |
| **Vietnam** | NDC (2022)<br>BUR3 (2021)<br>NIR (2021)<br>**Other Documents** | **Production**<br>There is no production data.<br>**Emissions**<br>- Total emissions in 2016 316 Mt $CO_2$eq of which the IPPU | - In 2014-2015, MOC has developed a completed MRV tool for cement sector under the support of Nordic Development Fund which is | - Support access to in-depth knowledge and experience in high technology, will allow good energy management practice as it is identified as the major technology barrier | Partially yes, as Vietnam is working under the finance mechanisms support as it has gained funding from the Nordic Development Fund (NDF) with the project "Pilot Program for Supporting Up- |

[142] https://unfccc.int/sites/default/files/NDC/2022-06/EU_NDC_Submission_December%202020.pdf
[143] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[144] https://hakangurdal.com/wp-content/uploads/2021/10/Executive_Summary_VDZ_Study_Decarbonising_Cement_and_Concrete_2020.pdf
[145] https://hakangurdal.com/wp-content/uploads/2021/10/Executive_Summary_VDZ_Study_Decarbonising_Cement_and_Concrete_2020.pdf
[146] https://unfccc.int/sites/default/files/resource/Mexico_3er_BUR.pdf
[147] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf
[148] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf
[149] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf
[150] https://gccassociation.org/2050-net-zero-roadmap-one-year-on/action-progress-case-studies-canacem/
[151] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf
[152] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| | Final Readiness Plan for the Cement Sector in Vietnam (2016)<br>USAID Vietnam Low Emission Energy Problem (V-LEEP)<br>Our World in Data (website) | was 14.6% (46 Mt $CO_2$eq). Cement accounted for 79.8% of IPPU (36.8 Mt $CO_2$eq)[153]<br>- 54.1 Mt of $CO_2$ emissions in 2021, with 0.56 tons annual $CO_2$ emissions from cement industry per capita[154] | based on the CSI Cement $CO_2$ and Energy Protocol. These solutions to reduce GHG emissions, have resulted in reducing 4.06 Mt$CO_2$eq in the sub-sectors of mining industry, construction materials and chemical industry.[155] | - Improve the current technical level, skills, and knowledge for these technologies can help to overcome many difficulties in technology implementation<br>- The economic size of scale, and the lack of capital resources are still barriers against Vietnam's efforts in cement industry.<br>- A national target program should be developed to support energy audit fees for cement plants.<br>- Increase the tariff of the electricity price as it is considered low in Vietnam and there has been no clear roadmap for in the near future that will certainly do not motivate the industry to implement these technologies | scaled Climate Change Mitigation Action in Vietnam's Cement Sector". Vietnam also starts to implement the Readiness Plan actively, with some actions, such as conducting further studies to revise the Master Plan according to suggestions from the project, and seek international financial support for capacity building. Vietnam has developed a completed MRV tool for cement sector under the support of the same fund.[156]<br>However, having MRV system only does not mean that they are aligned with IEA 2050 roadmap since there are no clear plan to implement specific technologies. |
| **Egypt** | NDC (2023)<br>BUR1 (2019)<br>TNA (2001)<br>**Other Documents**<br>Low Carbon Roadmap for the Egyptian Cement Industry ()2016<br>Our World in Data (website) | **Production**<br>No production data available<br>**Emissions**<br>- Total IPPU sector emissions 12.5% of total GHG emissions (about 40.6 Mt $CO_2$eq) for 2015. Cement alone was reported as 51% of IPPU emissions (20 Mt $CO_2$)[157]<br>- 16.2 Mt $CO_2$ in 2021, with an annual $CO_2$ emission of 0.15 tons per capita.[158]<br>- Carbon emissions from the cement industry are expected to increase about 820 kg $CO_2$ per ton cement as a result of the environmental law amendments in April 2015.[159] | - For Egypt, no official plans are written in the UNFCCC documents. However, the roadmap of EBRD included 15% reduction in $CO_2$ emissions to be achieved by 2030.[160] | - Egypt still needs to assess the technologies available in the cement industry objectively, as well as their energy saving and $CO_2$ mitigation potential.<br>- Provide the financial and economic conditions, this is to allow the cement companies to effectively implement the mitigation technologies.<br>- The government efforts for cement industry also included implementing alternative fuels partial substitution, lowering the clinker content in cement up to 80% conditional on meeting relevant national standards, and energy efficiency improvements [161]<br>- Provide the adequate policy, legislative and regulatory actions, appropriate financial resources and the preservation of the industry's competitiveness<br>- Lack of stakeholder engagement, and it is recommended to institutionalize regular consultations with the stakeholders involved in the implementation of such policy measures, as it | Partially yes, due to developing the supporting R&D & studies. As Egypt has developed the "Low-Carbon Roadmap for the Egyptian Cement Industry".<br>This Roadmap was developed under the EBRD-funded project "Egypt: Technology and Policy Scoping for a Low-Carbon Egyptian Cement Industry"[162]. Also, the supporting policy measurements such as the ministerial Decree 49/2021 for mandatory partial replacement of alternative fuels in cement sector that was issued in March 2021 by the Ministry of Environment[163].<br>However, there is still a need for having clear plans in the UNFCCC document, as plans in other supporting documents are not enough. |

[153] https://unfccc.int/sites/default/files/resource/Viet%20Nam_NIR2016.pdf
[154] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[155] https://unfccc.int/sites/default/files/NDC/2022-11/Viet%20Nam%20NDC%202022%20Update.pdf
[156] https://pdf.usaid.gov/pdf_docs/PA00ZGKC.pdf
[157] https://unfccc.int/sites/default/files/resource/BUR%20Egypt%20EN.pdf
[158] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[159] https://www.thegreenwerk.net/download/Low_Carbon_Roadmap_for_the_Egyptian_Cement_Industry.pdf
[160] https://www.thegreenwerk.net/download/Low_Carbon_Roadmap_for_the_Egyptian_Cement_Industry.pdf
[161] https://unfccc.int/sites/default/files/NDC/2023-06/Egypts%20Updated%20First%20Nationally%20Determined%20Contribution%202030%20%28Second%20Update%29.pdf
[162] https://www.thegreenwerk.net/download/Low_Carbon_Roadmap_for_the_Egyptian_Cement_Industry.pdf
[163] https://unfccc.int/sites/default/files/NDC/2023-06/Egypts%20Updated%20First%20Nationally%20Determined%20Contribution%202030%20%28Second%20Update%29.pdf

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| | | | | could be a regular roundtable or a steering committee. | |
| **Belize** | NDC (2021)<br>BUR (2021)<br>Low Emissions Development Strategy and Action Plan (2023) | No Production or emission data retrieved for sector | | | NO |
| **Mauritania** | NDC (2022)<br>Second BUR (2021)<br>TNA (2017) - French | No Production or emission data retrieved for sector | | | NO |
| | | | **Steel Sector** | | |
| **China** | NDC (2021)<br>Progress on the implementation of NDC (2022)<br>Second BUR (2018)<br>China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy (2021)<br>TNA (1998)<br>**Other Documents**<br>Comparison of carbon dioxide emissions intensity of steel production in China, Germany, Mexico, and the United States (2016)<br>Climate Transparency Report: Comparing G20 Climate Action (2022)<br>Iron and Steel Technology Roadmap<br>Net-Zero Roadmap for China's Steel Industry | **Production**<br>- 50% of world steel production was from China in 2014, based on Worldsteel.org statistics.<br>**Emissions**<br>- 272.7 Mt of $CO_2$ emissions from metal production.[164]<br>- Carbon intensity reached 1562.2 $kgCO_2$/tonne product in 2019.[165] | - Under the Net-Zero scenario, total $CO_2$ emissions will decrease to about 78 $MtCO_2$ per year in 2050.[166]<br>- China will accelerate green and low-carbon transformation in the industrial sector. Efforts will be made to accelerate the industries to peak carbon dioxide emission as soon as possible, which include steel industry. Continuously, reduce carbon dioxide emission from industrial processes. Accelerate the construction of green and zero-carbon industrial parks and supply chain pilots.[167] | - Adoption of electric furnace steelmaking-hot rolling short-process production process<br>- Promotion of non-ferrous metal smelting short-process production Process technology; improve the production process of calcium carbide and lime, and reduce carbon dioxide in the production process<br>- Circular economy policies should be developed in a manner that fits the industry's environment in China to allow the use of scrap steel. | Yes, as the Chinese government is promoting actively new technologies to reduce emissions from steel industry. Additionally, it is raising the public's awareness of green and low-carbon consumption by allowing nationwide participation and improving the living environment. Moreover, there is continuous improvement in legal and regulations to reflect the current status of carbon peaking and carbon neutrality and setting specific laws and regulations for promoting carbon neutrality, as well as developing a sound policy system. |
| **Indonesia** | NDC (2022)<br>Third BUR (2021)<br>Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (2021)<br>Second TNA on mitigation (2012)<br>**Other Documents**<br>Climate Transparency Report: Comparing G20 Climate Action and Responses to the Covid-19 Crisis. | **Production**<br>- 15 Mt per year, which increased with 12.6% per year from 2010 to 2016, and is estimated to stay relatively stagnant until 2030.[168]<br>- Production is expected to grow 5.59% per year from 5.76 Mton in 2030 to 17.1 Mton in 2050.[169]<br>**Emissions**<br>- 6,927 Gg of $CO_2$eq in 2019.[170]<br>- Carbon intensity of steel production was 1656 $kgCO_2$tonne product in 2016.[171] | - Indonesia has energy efficiency and energy management policies focused on industry, with targets for 15.4% reduction in GHG emissions for iron and steel industry.[172]<br>- Reduction target of 0.6 Mton $CO_2$eq by 2030 for CM1<br>- Reduction target of 0.9 Mton $CO_2$eq by 2030 for CM2 | - Enhancing utilizing scrap as an alternative material (iron ore) in DRI and Basic oxygen furnace (BOF).[173] | Yes, as improvements have been implemented in the steel industry including change in technologies (e.g., from DRI/direct reduced iron to blast furnace and BOF/basic oxygen furnace) besides the implementation of the energy efficiency and energy management policies. |

164 https://www.sciencedirect.com/science/article/abs/pii/S0921344916301458
165 https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-China-Web.pdf
166 https://www.globalefficiencyintel.com/netzero-roadmap-for-china-steel-industry
167 https://unfccc.int/sites/default/files/resource/China%E2%80%99s%20Mid-Century%20Long-Term%20Low%20Greenhouse%20Gas%20Emission%20Development%20Strategy.pdf
168 https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
169 https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
170 https://www.climate-transparency.org/wp-content/uploads/2020/11/Indonesia-CT-2020-WEB.pdf
171 https://www.climate-transparency.org/wp-content/uploads/2020/11/Indonesia-CT-2020-WEB.pdf
172 https://www.climate-transparency.org/wp-content/uploads/2020/11/Indonesia-CT-2020-WEB.pdf
173 https://unfccc.int/sites/default/files/resource/IndonesiaBUR%203_FINAL%20REPORT_2.pdf

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| **Türkiye** | NDC (2022)<br>BR (2023)<br>**Other Documents**<br>Climate Transparency Report: Comparing G20 Climate Action<br>Energy efficiency and $CO_2$ mitigation potential of the Turkish iron and steel industry using the LEAP (long-range energy alternatives planning) system, 2015 | **Production**<br>No data available<br>**Emissions**<br>- GHG emissions from iron and steel was 11.52 Mt $CO_2$eq (2020)[174].<br>- Carbon intensity of steel production was 775.3 kg$CO_2$/tonne product in 2019.[175] | - Ambition to reduce carbon emissions increased from 21% to 41% by 2030 compared to Türkiye's first NDC BAU scenario.[176] | - Türkiye continues to rely on fossil fuel, despite the ongoing reduction in renewable technology costs, which could provide reliable power cost-effectively. | Mostly yes, as Türkiye has drafted a zero carbon roadmap for the steel industry. Additionally, the Turkish steel industry has supporting R&D studies. This is reflected in developing the "Green Growth Technology Roadmap" achieving legislative enforcement, including measuring, reporting and verification (MRV) of emission reductions in steel industry, and electricity sectors[177]. However, the IEA roadmaps include fuel switching either full or partial substitution of fossil energy inputs with less carbon-intensive alternatives, e.g., natural gas and bioenergy. On the other hand, Türkiye continues to rely on fossil fuel. |
| **Japan** | NDC (2021)<br>BR (2019)<br>Long-Term Strategy under the Paris Agreement (2021)<br>**Other Documents**<br>Green Public Procurement of Steel in Japan (2023)<br>Japan-Australia Partnership on Decarbonization Through Technology (2022)<br>Iron and Steel Technology Roadmap (2020) | **Production**<br>- 99 million tons of steel were produced in 2019.<br>**Emissions**<br>- Trends in $CO_2$ emissions and removals in iron and steel industry in 2015 was 160299 thousand tons $CO_2$.[178] | - Japan recently released roadmaps for de-carbonizing the iron and steel sector, setting out specific targets and laying out concrete steps for their steel sectors, with the French plan calling for emission reductions of 31% by 2030[179] | - Japan is aiming to develop technologies to substantially reduce emissions from the blast furnace.[180]<br>- Using CCUS technology to reuse off-gases from blast furnaces to reduce energy input requirements.[181]<br>- Using technologies that enable the usage of hydrogen and fuel ammonia 26 since many iron and steel factories are located in ports and coastal areas.[182]<br>- Creation of enabling policies to - Focus more R&D on the technologies that will accelerate reaching net zero emissions. | Yes, as Japan has released its roadmap for de-carbonizing the iron and steel sector, allowing new technologies to reduce emissions, reusing off-gases and enabling the usage of clean energy. Additionally, supporting the R&D studies to accelerate reaching net zero emissions. |
| **Germany** | NDC (2020)<br>BR (2019)<br>Update to the long-term strategy for climate action of the Federal Republic of Germany (2022)<br>**Other Documents**<br>Achieving Net Zero Heavy Industry Sectors in G7 Members | **Production**<br>No data available<br>**Emissions**<br>- Around 48 million tons of $CO_2$eq in 2020.[183]<br>- Carbon intensity of steel production was 1,174 kg$CO_2$/ton product in 2019.[184] | - Germany has committed to becoming greenhouse gas neutral by 2045. After 2050, the greenhouse gas balance is to be negative. | CCUS Technology:<br>- By 2025, Converting off-gases to chemicals: Carbon2Chem pilot plant in Germany initiated by ThyssenKrupp in 2018 has produced ammonia and methanol from steel off-gases; aiming for industrial scale plant by 2025 (ThyssenKrupp, 2020a and 2020b). | Yes, due to adopting innovative technologies. |

[174] https://unfccc.int/sites/default/files/resource/8NC-5BR%20T%C3%BCrkiye.pdf
[175] https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Turkey-Web.pdf
[176] https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf
[177] https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf
[178] https://unfccc.int/sites/default/files/resource/Japan-BR3-3-BR3-JPN-E.pdf
[179] https://www.iea.org/reports/iron-and-steel
[180] https://www.iea.org/policies/14739-japan-australia-partnership-on-decarbonisation-through-technology
[181] https://www.iea.org/policies/14739-japan-australia-partnership-on-decarbonisation-through-technology
[182] https://unfccc.int/sites/default/files/resource/Japan_LTS2021.pdf
[183] https://www.statista.com/statistics/1395878/greenhouse-gas-emissions-steel-industry-germany/
[184] https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Germany-Web.pdf

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| | Climate Transparency Report: Comparing G20 Climate Action<br>Greenhouse gas emissions in the steel industry in Germany from 1995 to 2020 (Statista) | | | - By 2030, using CCUS in Blast furnace: off-gas hydrogen enrichment and/or CO2 removal for use or storage: ROGESA pilot testing H2-rich coke oven gas in a blast furnace in Germany, with implementation in two blast furnaces expected as early as 2020 (Saarstahl, 2019).<br>Hydrogen Technology:<br>- By 2030, DRI, Natural gas-based with high levels of electrolytic H2 blending<br>- Salzgitter steelworks is undertaking MW-scale electrolyser demonstration in Germany and conducting a feasibility study for integrating a hydrogen DRI plant into the existing site, as part of the SALCOS project (SALCOS, 2019).<br>- ThyssenKrupp is planning to build commercial DRI plants incorporating hydrogen by the mid-2020s (ThyssenKrupp, 2020a). | |
| **Mexico** | Third BUR (2022) – in Spanish<br>Mexico's Climate Change Mid-Century Strategy (2016)<br>NDC (2022) - Spanish<br>**Other Documents**<br>Climate Transparency Report: Comparing G20 Climate Action | - Total $CO_2$ emissions from metal industry were 17,305.67 $GgCO_2eq$ in 2019, and the share of the iron and steel production was 16,887.72 $GgCO_2eq$.[185]<br>- Carbon intensity of steel production was 915 $kgCO_2$/ton product in 2019.[186] | - Mexico has set a mitigation action with regards to the energy efficiency and sustainable consumption in the transformation processes (M2.10) to promote highly efficient technologies, fuel substitution, industrial process redesign, and $CO_2$ capture technologies in energy-intensive industries such as steel industry [187] | 1- Hydrogen Technology:<br>- DRI: Natural gas-based with high levels of electrolytic H2 blending: In the 1990s Tenova tested 90% hydrogen use in Mexico (scale of 9 kt/yr DRI production) (Tenova, 2018).<br>2- CCUS Technology:<br>- DRI: Natural gas-based with $CO_2$ capture: Currently, two plants operated in Mexico by Ternium since 2008 capturing 5% of emissions (0.15-0.20 Mt/yr combined) for use in the beverage industry, with planning underway to scale up capture capacity (Ternium, 2018). | Partially yes, as Mexico is promoting highly efficient technologies, fuel substitution such as utilizing hydrogen and biofuel as source of energy, industrial process redesign, and $CO_2$ capture technologies. |
| **Vietnam** | NDC (2022)<br>BUR3 (2021)<br>NIR (2021)<br>**Other Documents**<br>Final Readiness Plan for the Cement Sector in Vietnam (2016)<br>USAID Vietnam Low Emission Energy Problem (V-LEEP) | **Production**<br>- Total designed capacity of the sector is 19 million tons of crude steek per year.<br>- Actual production was 15,471 thousand tons in 2018.<br>**Emissions**<br>- GHG emissions in 2018 were 30.12 million tons $CO_2$ using BOF technology, and 5.67 million tons using EAF technology.<br>- Carbon intensity of steel production in 2018 was 2.51 tons $CO_2$ per tonne crude steel | By implementing the mitigation measures announced by Vietnam:[188]<br>- A reduction up to 5.3 million tons of $CO_2eq$ can be reached by 2025.<br>- A reduction up to 10.8 million tons of $CO_2eq$ can be reached by 2030. | - Vietnam should focus on R&D to accelerate the implementation of appropriate technologies that aim to achieve "net zero"<br>- The potential exists in principle to reduce net emissions of ironmaking essentially to 'zero', by means of breakthrough technologies as below (will not be commercially available before 2030):<br>1- Reduction of iron oxide by hydrogen (H2O emissions instead of $CO_2$), if the hydrogen is made from water using renewable electricity<br>2- Metal (Fe) production by electrolysis, if the electricity for electrolysis is renewable<br>3- Carbon capture and storage (stop the release of $CO_2$ to atmosphere). Technology may be feasible only in | Partially yes, as Vietnam has identified the breakthrough technologies essential to reach net zero such as using hydrogen and/or renewable energy source to reduce iron ores to iron.<br><br>Additionally, an energy benchmarking has been initiated and developed for the steel industry, but not released. |

[185] https://unfccc.int/sites/default/files/resource/Mexico_3er_BUR.pdf
[186] https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Mexico-Web.pdf
[187] https://unfccc.int/files/focus/long-term_strategies/application/pdf/mexico_mcs_final_cop22nov16_red.pdf
[188] FINAL TASK 2 REPORT Development of a pilot crediting program applicable for the steel sector in Vietnam, December 2020

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| | | from BF-BOF technology, and 0.8 tons $CO_2$ per tonne crude steel from EAF technology. | | very specific locations with suitable geological structures, and might not be scalable | |
| **Egypt** | NDC (2023)<br>BUR1 (2019)<br>TNA (2001)<br>**Other Documents**<br>Arab Iron & Steel Union (Website)<br>State Information Service (Website)<br>Assessment of Carbon Dioxide Emission and Its Impact on High-Rise Mixed-Use Buildings in Egypt (2021)<br>Industrial Energy Efficiency Project – Benchmarking Report for Iron and Steel Sector (2014) | **Production**<br>- 10.3 million tons of steel were produced in 2021[189], making it the largest steel producer in MENA Region.[190]<br>**Emissions**<br>- GHG emissions from iron and steel production were 3,136 Gg of $CO_2$eq, while the carbon emission factor was 2081 kg $CO_2$/ ton steel[191 192]. | - Using the EAF technology instead of BOF as can be seen from the production numbers for each technology from 2003 till 2012. EAF are more sustainable to the sources of energy available in Egypt. | - Due to Egypt's economic challenges, breakthrough technologies and renewable energy technologies are not commonly available in the market, resulting in huge pressure on companies to use old, less-efficient technologies and sources of energy.<br>- It has prompted the Central Bank of Egypt in March 2022 to depreciate the exchange rate overnight by around 16% to stem the widening net exports deficit. These soaring inflationary pressures necessitates that the Government further intensifies its poverty reduction efforts. Consequently, all these factors limit Egypt's ambition on allocating future climate investments | No. |
| **Belize** | NDC (2021)<br>BUR (2021)<br>Low Emissions Development Strategy and Action Plan (2023) | | | | |
| **Mauritania** | NDC (2022)<br>Second BUR (2021)<br>TNA (2017) – French<br>**Other Documents**<br>Unlocking the Potential of Steel Production in Mauritania with Green Energy: A Path to Economic Growth and Sustainability | | | | |
| **Chemical Sector** | | | | | |
| **China** | NDC (2021)<br>Progress on the implementation of NDC (2022)<br>Second BUR (2018)<br>China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy (2021)<br>TNA (1998)<br>**Other Documents**<br>An Energy Roadmap to Carbon Neutrality in China (2021). | **Production**<br>- The production is expected to increase nearly 30% by 2030, and 40% by 2060.<br>**Emissions**<br>- Direct $CO_2$ emissions from chemicals production were 530 Mt in 2020. | - Under the APS (Announced Pledges Scenario), direct $CO_2$ emissions are expected to decrease by 90% from 530 Mt to 60 Mt in 2060. This would make the $CO_2$ intensity fall from 2.5-ton $CO_2$ per ton of primary chemicals to 0.2 ton $CO_2$ per ton of primary chemicals by 2060.[193] | - The technology needs to reach the Paris Agreement targets for the chemical industry sector include innovative technologies such as CCUS (carbon capture, utilization, and storage) and electrolytic hydrogen. These technologies are projected to cover 85% of primary chemicals production by 2060 and contribute to 40% of the cumulative emissions reductions by that year.<br>- More than one-third of the cumulative emissions reductions in the sector are associated with technologies that are not commercially available today. These technologies rely on the large-scale development of supply infrastructure, particularly | Yes, China is promoting carbon market policies and trading platforms in addition to pushing towards the implementation of CCUS and green hydrogen. |

[189] https://aisusteel.org/en/5794/
[190] https://www.sis.gov.eg/Story/178692/Fitch-Ratings-Egypt-2nd-largest-steel-producer-in-MENA-region?lang=en-us
[191] https://unfccc.int/sites/default/files/resource/BUR%20Egypt%20EN.pdf
[192] https://fount.aucegypt.edu/cgi/viewcontent.cgi?article=2678&context=etds
[193] IEA (2021), An energy sector roadmap to carbon neutrality in China, IEA, Paris https://www.iea.org/reports/an-energy-sector-roadmap-to-carbon-neutrality-in-china, License: CC BY 4.0

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| | | | | for CCUS, electricity generation, hydrogen production from electrolysers, and storage. | |
| **Indonesia** | NDC (2022)<br>Third BUR (2021)<br>Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (2021)<br>Second TNA on mitigation (2012)<br>**Other Documents**<br>An Energy Sector Roadmap to Net Zero Emissions in Indonesia (2022) | **Production**<br>No data available<br>**Emissions**<br>- In 2019, the chemical industry resulted in 13.6 Mt $CO_2$eq which is about 0.7% of the total emissions, and about 10.5 Mt $CO_2$eq (0.5%) indirectly through the energy use.[194] | - In the Announced Pledges Scenario (APS), $CO_2$ emissions from the other industries category, which includes the chemical industry, are projected to fall by more than 60% by 2060.[195] | - The targeted reduction is achieved through electrification and other fuel switching, which are the main measures for decarbonization in the chemical sector.<br>- Indonesia does provide information on the reduction targets and actions for specific industries within the chemical sector, such as the ammonia plant and the nitric acids industry. The information about the needs to achieve the Paris Agreement targets were not clearly stated although the technological know-how in the implementation is implied.[196]<br>- Low-carbon technologies that provide heat in other industry branches are available. However, their uptake is slowed by technology costs, financing hurdles, and insufficient incentives for adoption.[197] | Yes, Indonesia is targeting 60% by 2060 for all industries by means of electrification, fuel switching material and energy efficiency, CCUS and avoided demand. |
| **Türkiye** | NDC (2022)<br>BR (2023) | - According to the fourth BUR, the chemical industry sector contributed 3% of the total national greenhouse gas (GHG) emissions about 0.75 Mt $CO_2$ in 2017.[198] | - Türkiye aims to conduct Green Growth Technology Roadmap studies for sectors such as chemicals.[199]<br>- Türkiye's main mitigation policies in the industry sector for 2030 include increasing the use of biofuels, refuse-derived fuel (RDF), alternative fuels, and raw materials in industrial facilities.[200]<br>- The above-mentioned measures are aimed at reducing the carbon footprint of industrial products and increasing the use of renewable energy and resource and energy efficiency in the industry sector. | - Some potential technology needs for the chemical industry sector could include:<br>1- Process optimization: Implementing advanced process control systems and optimization techniques to improve energy efficiency and reduce emissions in chemical manufacturing processes.<br>2- Carbon capture and utilization (CCU): Developing and deploying technologies that capture and utilize carbon dioxide emissions from chemical production processes, such as carbon capture and storage (CCS) or carbon utilization technologies.<br>3- Renewable feedstocks: Exploring and adopting renewable feedstocks and bio-based materials as alternatives to fossil fuel-based feedstocks in chemical production processes.<br>4- Advanced catalysts: Developing and utilizing advanced catalysts that enable more efficient and sustainable chemical reactions, reducing energy consumption and emissions.<br>A clear roadmap to identify the potentiality of different technologies to support the "Green Transition in the Industry" include: | Partially, Türkiye has the intention of developing a plan for the decarbonization and has identified key mitigation policies and actions aligning with the IEA's roadmap such as fuel and raw material switching. |

[194] "Indonesia. Biennial update report (BUR). BUR3. | UNFCCC." https://unfccc.int/documents/403577
[195] IEA (2022), An Energy Sector Roadmap to Net Zero Emissions in Indonesia, IEA, Paris https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia, License: CC BY 4.0
[196] "Enhanced NDC - Republic of Indonesia | UNFCCC." https://unfccc.int/documents/615082
[197] IEA (2022), An Energy Sector Roadmap to Net Zero Emissions in Indonesia, IEA, Paris https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia, License: CC BY 4.0
[198] FOURTH BIENNIAL REPORT OF TURKEY.pdf (unfccc.int)
[199] Republic of Türkiye (unfccc.int)
[200] Republic of Türkiye (unfccc.int)

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| | | | | - Create enabling policies to technologies that have proven feasibility in reducing greenhouse gas emissions in Türkiye and provide financial incentives for companies to shift to these technologies.<br>- Implementing circular economy principles in the chemical industry, such as recycling and reusing waste materials, promoting resource efficiency, and minimizing waste generation. | |
| **Japan** | NDC (2021)<br>BR (2019)<br>Long-Term Strategy under the Paris Agreement (2021)<br>**Other Documents**<br>Direction for the Chemical Industry Based on 2050CN | **Production**<br>No data available.<br>**Emissions**<br>- The emissions from the chemical industry reached around 15% of the energy-related emission (57.6 million tons $CO_2$) and about 5.7% (4.3 million tons $CO_2$) of the emissions other than energy-related.[201] | - The targets and estimates are for the fiscal year 2030 and are not broken down specifically for the chemical industry.<br>- The focus is on Japan's overall goal of reducing greenhouse gas emissions by 46% in fiscal year 2030 from its fiscal year 2013 levels. | - There is a stress on the importance of competitive utilities, such as electricity, LNG, biomass, ammonia, and hydrogen, for the chemical industry. Ensuring a reliable and affordable supply of these utilities while transitioning to low-carbon alternatives may pose challenges for the sector.[202]<br>- There is a need for restructuring the supply chain at industrial complexes. This may involve changes in logistics, infrastructure, and collaboration among different stakeholders. Implementing such changes may pose challenges in terms of coordination, investment, and adapting to new business models.[203]<br>- There is a future challenge of producing plastics from sources other than naphtha. This suggests that the industry may face challenges in developing and implementing technologies that enable the production of plastics from alternative feedstocks. This transition may require significant investments in research and development, as well as changes in manufacturing processes.<br>- There is a need for mechanisms to gain consumer understanding, such as CFP (Carbon Footprint), mass balance rules, and carbon pricing. The chemical industry may face challenges in effectively communicating the environmental impact of its products to consumers and gaining their support for sustainable alternatives. | Partially, Although there are no announced reduction target specifically for the chemical sector, Japan has plans for fuel and feedstock switching, circular economy practices, and behavioral changes. |
| **Germany** | NDC (2020)<br>BR (2019)<br>Update to the long-term strategy for climate action of the Federal Republic of Germany (2022)<br>**Other Documents**<br>Decarbonizing the Chemical Industry (2023) | - As of 2021, the industrial sector in Germany contributed 181 Mt $CO_2$ emissions out of the country's total emissions of 762 Mt $CO_2$.<br>- Within the industrial sector, the chemicals industry was responsible for 40 Mt $CO_2$. | - The current decarbonization goals are set to achieve an overall reduction of approximately 45 percent in $CO_2$ emissions by 2030, with a specific target of reducing industrial emissions by 35 | - To achieve the Paris Agreement targets, it is important to consider potential synergies and trade-offs within the chemical sector. This involves exploring how the industry can transition from being an energy-intensive and | Partially, Although there are no announced reduction target specifically for the chemical sector, Germany has plans for energy efficiency, researching and developing new technologies, and circular economy practices. |

[201] "Japan's Long-Term Strategy under the Paris Agreement | UNFCCC." https://unfccc.int/documents/307817
[202] https://ja.eu-japan.eu/sites/default/files/imce/2023.2.27%20METI.pdf
[203] https://ja.eu-japan.eu/sites/default/files/imce/2023.2.27%20METI.pdf

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| | | | percent or 63 Mt $CO_2$ emissions.[204] | high-emitting sector to becoming a solution-provider for other sectors.[205]<br>- Achieving the Paris Agreement targets require the adoption and development of new technologies in the chemical industry. The existing and developing technologies for various chemical product groups have been identified. However, implementing these technologies and transitioning to cleaner production processes can be challenging.[206]<br>- The chemical industry is energy-intensive, and it currently accounts for 8% of the final energy demand in Germany. Reducing energy consumption and transitioning to cleaner energy sources poses significant challenges for industry.<br>- The chemical industry is a major emitter of greenhouse gas (GHG) emissions in Germany, contributing 19% of the total direct industrial emissions. While the industry has made progress in reducing emissions over the past three decades, further transformation is required to meet Germany's carbon goals.<br>- The circular economy measures are needed to transform the chemical industry. Implementing circular economy practices, such as recycling and reusing materials, requires collaboration and coordination among different stakeholders in the industry. | |
| **Mexico** | Third BUR (2022) – in Spanish<br>Mexico's Climate Change Mid-Century Strategy (2016)<br>NDC (2022) - Spanish | - Chemical industry emits $N_2O$, $CO_2$ and $CH_4$, and reached 4.6 Mt $CO_2$eq in 2019 (6.26% of the industrial sector emissions). | - Emissions from the chemical industry decreased from 1990 to 2019 by approximately 37.62%.<br>- The overall country goal is to reduce GHG emissions by or before 2026, as stated in Mexico's NDC.[207]<br>- The NDC more ambition trajectory estimates a reduction of 36% in GHG emissions from the baseline and aims to reach 311 Mt $CO_2$e by 2050.[208] | - Mexico does not provide specific information about the technology needs to reach the Paris Agreement targets for the chemical industry sector. However, it does mention the need to promote highly efficient technologies, fuel substitution, and industrial process redesign in energy-intensive industries such as the chemical industry.[209] | Partially, Although there are no announced reduction target specifically for the chemical sector, Mexico is committed to promote high efficiency technologies, fuel substitution, circular economy practices and CCUS. |

204 "Decarbonizing the German chemical industry | McKinsey." https://www.mckinsey.com/industries/chemicals/our-insights/decarbonizing-the-chemical-industry
205 https://elib.dlr.de/147841/1/1.%20IPG%20Final%20Report_original.pdf
206 https://elib.dlr.de/147841/1/1.%20IPG%20Final%20Report_original.pdf
207 "Mexico: Updated NDC 2022 | UNFCCC." https://unfccc.int/documents/624282
208 "Mexico: Updated NDC 2022 | UNFCCC." https://unfccc.int/documents/624282
209 "Mexico's Climate Change Mid-Term Strategy | UNFCCC."

| Country | Identified HAI Documents: | Production and Emissions | Identified mitigation goals | Reported Technology Needs and Gaps | Alignment with IEA roadmaps (Yes/No) |
|---|---|---|---|---|---|
| **Vietnam** | NDC (2022)<br>BUR3 (2021)<br>NIR (2021) | - In the latest BUR, the chemical industry sector accounted for about 2.8% of the industrial emissions (1.3 $MtCO_2eq$).[210]<br>- Emissions from Ammonia productions were about 1.27 $MtCO_2eq$ while the rest were from the production of Nitric Acid. | - Vietnam aims at increasing the application of the best technologies to reduce $N_2O$ emissions according its NDC. | - Vietnam does not provide specific details about the technology needs to reach the Paris Agreement targets for the chemical industry sector. It mentions that solutions to reduce greenhouse gas (GHG) emissions have been applied in the chemical industry, including the application of advanced technology. However, it does not elaborate on the specific technologies or measures required to achieve the targets set by the Paris Agreement for the chemical industry sector. | No. |
| **Egypt** | NDC (2023)<br>BUR1 (2019)<br>TNA (2001) | - Egypt's IPPU sector is responsible for approximately 12.5% of the country's total greenhouse gas emissions, totaling around 40.7 Mt $CO_2eq$.[211]<br>- The chemical industry accounts for a significant portion, contribution 18% of the total emissions of the IPPU sector.[212]<br>- Total emissions of the chemical industry in 2015 were 2.8 Mt of $CO_2$, 0.083 Mt of $CH_4$, and 4.5 Mt of $N_2O$.[213] | - Egypt's NDC does not explicitly address the decarbonization of the chemical industry.[214]<br>- The NDC stated a range of strategies that can indirectly support the decarbonization efforts.[215] | - Egypt's strategies to support decarbonization are dependent upon using energy efficient technologies, and more use of natural gas.[216]<br>- Financial and technical support are required to support Egypt's decarbonization process. | No. |
| **Belize** | NDC (2021)<br>BUR (2021)<br>Low Emissions Development Strategy and Action Plan (2023) | | | | No. |
| **Mauritania** | NDC (2022)<br>Second BUR (2021)<br>TNA | | | Although the current NDC and BUR documents do not report emissions from the chemicals sector, the countries TNAs included a future plan to[217]:<br>- Develop the industry.<br>- Use of minerals that have strategic value.<br>- Sustainably developing the energy sector.<br>The country could use support in the development of new industrial activities to follow the best available low-carbon technologies that can support the industrial development with a lower footprint from the beginning. | No. |

210 "Vietnam. Biennial update report (BUR). BUR 3. | UNFCCC." https://unfccc.int/documents/273504
211 "Egypt. Biennial update report (BUR). BUR 1. | UNFCCC." https://unfccc.int/documents/204823
212 "Egypt. Biennial update report (BUR). BUR 1. | UNFCCC." https://unfccc.int/documents/204823
213 "Egypt. Biennial update report (BUR). BUR 1. | UNFCCC." https://unfccc.int/documents/204823
214 "Egypt's Updated First Nationally Determined Contribution 2030 (Second Update) | UNFCCC." https://unfccc.int/documents/630376
215 "Egypt's Updated First Nationally Determined Contribution 2030 (Second Update) | UNFCCC." https://unfccc.int/documents/630376
216 "Egypt's Updated First Nationally Determined Contribution 2030 (Second Update) | UNFCCC." https://unfccc.int/documents/630376
217 https://unfccc.int/sites/default/files/resource/sbi2020_inf.01.pdf

## 4.3 Technologies Gap Assessment

This part includes an analysis of the of the gap analysis between the technologies identified in the global roadmaps and initiatives versus the technologies mentioned in the climate change related documents for different countries, mainly the NDCs, BRs/BURs and LT-LEDS, which are presented in Table 4-3 to Table 4-5.

In general, it was observed that the data from the countries selected identified some of the technologies mentioned by the roadmaps, either as implemented or as a technological need. While some of the technologies were not mentioned, mostly the technologies that were identified as in the pilot stage or not mature enough for implementation on large scale yet.

Additionally, it was observed that the least data was obtained for the chemicals & petrochemicals sector maybe due to the fact that the sector is divided into numerous product with different production processes and therefore unifying the reporting and collaboration for this sector is expected to be the hardest.

Table 4-3: Technologies gap assessment between roadmaps/initiatives vs countries documents for cement sector

| Countries | Policy/ Technology | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Policies related to Efficiency in design and construction** | **Technologies and policies related to enhancing Concrete's efficiency of production** | **Technologies related to savings in cement and binders** | **The use of green hydrogen as a fuel** | **Enhancing the energy efficiency of clinker production** | **The use of waste-derived fuels, biomass and other alternative fuels in clinker production** | **Carbon Capture Utilization and Storage (CCUS)** | **(Re)carbonation/$CO_2$ sink** |
| **China** | Not mentioned | Y/Available | Identified as a need | Identified as a need | Y/Available | Y/Available | Identified as a need | Not mentioned |
| **Indonesia** | Y/Available | Identified as a need | Y/Available | Not mentioned | Identified as a need | Identified as a need | Identified as a need | Not mentioned |
| **Türkiye** | Not mentioned | Identified as a need | Not mentioned | Not mentioned | Identified as a need | Y/Available | Not mentioned | Not mentioned |
| **Japan** | Y/Available | Identified as a need | Identified as a need | Not mentioned | Identified as a need | Identified as a need | Identified as a need | Not mentioned |
| **Germany** | Identified as a need | Y/Available | Y/Available | Identified as a need | Identified as a need | Y/Available | Identified as a need | Identified as a need |
| **Mexico** | Not mentioned | Not mentioned | Identified as a need | Not mentioned | Identified as a need | Identified as a need | Identified as a need | Not mentioned |
| **Vietnam** | Not mentioned | Not mentioned | Identified as a need | Not mentioned | Identified as a need | Identified as a need | Not mentioned | Not mentioned |
| **Egypt** | Identified as a need | Identified as a need | Y/Available | Not mentioned | Identified as a need | Identified as a need | Not mentioned | Not mentioned |
| **Belize** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |
| **Mauritania** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |

**Table 4-4: Technologies gap assessment between roadmaps/initiatives vs countries documents for steel sector**

| Countries | Technologies | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Steel industry co-products (slag) | Scrap use in the steel industry | Industrial Process GHGs reduction measures | Electrolysis in ironmaking (iron ore) | Hydrogen (H2)-based ironmaking by replacing NG with H2 | Biomass in steelmaking | Carbon capture and storage (CCS) | Carbon capture and use and storage (CCUS) |
| **China** | Not mentioned | Y/Available | Y/Available | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |
| **Indonesia** | Not mentioned | Y/Available | Not mentioned | Y/Available | Not mentioned | Not mentioned | Not mentioned | Not mentioned |
| **Türkiye** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |
| **Japan** | Not mentioned | Not mentioned | Identified as a need | Not mentioned | Identified as a need | Not mentioned | Y/Available | Identified as a need |
| **Germany** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Identified as a need | Not mentioned | Y/Available | Y/Available |
| **Mexico** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Identified as a need | Not mentioned | Not mentioned | Y/Available |
| **Vietnam** | Identified as a need | Identified as a need | Not mentioned | Identified as a need | Identified as a need | Identified as a need | Identified as a need | Not mentioned |
| **Egypt** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |
| **Belize** | No metal production is occurring | | | | | | | |
| **Mauritania** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |

Table 4-5: Technologies gap assessment between roadmaps/initiatives vs countries documents for chemicals sector

| Countries | Technologies | | | | | | |
|---|---|---|---|---|---|---|---|
| | CCUS | Green Hydrogen | Electrification | Alternative energy sources | alternative feedstock | Advanced Catalysts | Circular economy |
| **China** | Y/Available | Y/Available | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |
| **Indonesia** | Not mentioned | Not mentioned | Y/Available | Not mentioned | Not mentioned | Not mentioned | Not mentioned |
| **Türkiye** | Y/Available | Not mentioned | Not mentioned | Y/Available | Y/Available | Y/Available | Y/Available |
| **Japan** | Not mentioned | Y/Available | Not mentioned | Y/Available | Y/Available | Not mentioned | Not mentioned |
| **Germany** | Not mentioned | Not mentioned | Not mentioned | Y/Available | Not mentioned | Not mentioned | Y/Available |
| **Mexico** | Not mentioned | Not mentioned | Not mentioned | Yes | Not mentioned | Not mentioned | Not mentioned |
| **Vietnam** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |
| **Egypt** | Not mentioned | Not mentioned | Not mentioned | Y/Available | Not mentioned | Not mentioned | Not mentioned |
| **Belize** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |
| **Mauritania** | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned | Not mentioned |

## 4.4 Success Stories

In order to benefit and potentially replicate the success stories that was recorded in different countries and regions in the world, the following part includes a number of success stories that was recorded in each HAI sector.

### 4.4.1 Cement Sector

Countries and regions making notable progress in decarbonizing cement through the development of process related interventions, progressing CCS projects and enabling policies as follows.

In France, the government will invest EUR 5.6 billion by 2030 to reduce the $CO_2$ emissions of heavy industries, including cement, steel and aluminum. With EUR 610 million for innovation and clean technology deployment, and EUR 5 billion for direct support of decarbonization solutions for industrial sites, focusing on hydrogen or carbon capture.[218]

The US set out a budget of 5.8 USD billion in 2022 for industrial decarbonization to support the reduction of around 17% of the total estimated emissions of 2030 which is equal to 200 Mt of $CO_2$[219]. This was done along with investments in CCS demonstrations and infrastructure to reduce emissions from the cement sector.

ENERGY STAR Certification is available to seven industrial sectors in Canada (including cement and steel), as a part of their support to improve energy performance. This aim to share best practices and highlight the industrial achievements, and includes two programs ENERGY STAR Certification and ENERGY STAR Challenge [220].

In China, the Ministries of Industry and Information Technology, launched the Carbon Peak Implementation Plan for Building Materials Industry in 2022 in collaboration with National Development and Reform Commission, of Ecology and Environment, and of Housing and Urban-Rural Development[221]. This is Focusing on the cement and lime industries, through the development of low-carbon materials and technology, reduction in energy consumption, and the transition to clean and green energy.

The Netherlands, Sweden, Germany, France, the UK and the US were identified in a policy analysis by the World Economic Forum and the Global Cement and Concrete Association (GCGA) which aim to analyze the adoption of regulation on low carbon concrete and construction, and implementation of supporting schemes[222].

The most notable experiences correspond to projects in developed countries; however, three technical assistances from the CTCN to Vietnam, Congo and South Africa stand out as successful stories of technical transfer to developing countries in the cement sector. See Table 4-6.

[218] https://www.iea.org/policies/15029-france-2030-investment-plan-heavy-industry-decarbonisation-investment
[219] https://www.iea.org/energy-system/industry/cement
[220] https://www.iea.org/policies/7952-energy-star-for-industry-certification-and-challenge
[221] https://www.iea.org/energy-system/industry/cement
[222] https://www.iea.org/energy-system/industry/cement

Table 4-6: CTCN success stories technology transfer in cement sector

| Title | CTCN support |
|---|---|
| Study on the identification and evaluation of technologies and industrial processes used in cement producing industries in Congo<br><br>https://www.ctc-n.org/technical-assistance/projects/study-identification-and-evaluation-technologies-and-industrial | • General audit of technologies, processes and materials of the cement plants;<br>• Detailed energy audit of selected cement plants;<br>• Identification of activity data (AD) and emission factors (EF);<br>• Development of audit and management protocols and monitoring;<br>• Identification of technologies and processes for a more efficient and sustainable cement industry. |
| Pilot demonstration of Energy Service Company (ESCO) model for greenhouse gases emission reduction in the cement sector. Vietnam<br><br>https://www.ctc-n.org/technical-assistance/projects/pilot-demonstration-energy-service-company-esco-model-greenhouse | • Review and selection of pilot site for ESCO model<br>• Development of feasibility study and investment report<br>• Technical assistance for technology transfer<br>• Demonstration of MRV for GHG emissions and energy efficiency<br>• Evaluation and introduction of the model among the whole sector |
| Substantial GHG emissions reduction in the cement industry by using waste heat recovery combined with mineral carbon capture and utilization. South Africa<br><br>https://www.ctc-n.org/technical-assistance/projects/substantial-ghg-emissions-reduction-cement-industry-using-waste-heat | • Analysis of chemical components of exhaust gas from an existing cement kiln and concrete wastes such as concrete sludge to make a recommendation of appropriate reaction conditions and to estimate its operational cost.<br>• Financial assessment of domestic market demand and value for the bi-products from cement production and use of this information to calculate the GHG marginal abatement costs of the mineral carbon capture and utilization technology.<br>• Development of a business plan and strategic recommendations for commercial application of the analysed technologies. |

### 4.4.2 Steel Sector

For the steel sector, a number of projects were identified in line with the efforts to reduce the GHG emissions from the sector through energy substitution measures or enabling policy support as mentioned.

In Brazil, The UNDP/GEF Project “Production of sustainable, renewable biomass-based charcoal for the iron and steel industry in Brazil” had the objective of reducing greenhouse gas (GHG) emissions from the iron and steel (I&S) sector in the Brazilian state of Minas Gerais by developing and demonstrating enhanced, clean conversion technologies for renewable, biomass-based charcoal production and implementing an effective, supportive policy framework. The project was addressing the identified barriers that impede the clean and efficient conversion of biomass resources to charcoal for the iron and steel sector in Brazil. The project promoted the availability of sustainable, renewable biomass-based charcoal, produced efficiently and at a competitive cost level compared to mineral coke. The major project outcomes include:[223]

- A policy framework implementation to promote the use of renewable biomass-based charcoal by the iron and steel sector. This policy framework was supported by an internationally recognized system for monitoring achieved GHG emission reductions;
- The technology and human capacity base for clean charcoal conversion in Brazil was strengthened by technical assistance and targeted training; and

[223] UNDP, 2019. Brazil: Basic Report Information. Available at: https://erc.undp.org/evaluation/documents/download/15317

- Commercial charcoal production facilities were built under a competitive bidding mechanism to deliver objectively verifiable renewable biomass-based charcoal and GHG emission reductions.[224]

The project is expected to reduce greenhouse gas emissions from the iron and steel sector in Minas Gerais by up to 2 million tons of $CO_2$ equivalent per year, for which a large demonstration project was expected to be operational by 2020, and to reach net zero by 2025. The project is also expected to create jobs in the charcoal production and iron and steel sectors.[225] [226].

#### 4.4.2.1 Vietnam[227]

On another note, The Vietnam Green Growth Strategy (VGGS) identified several goals for the steel industry sector, including improving the energy efficiency and reducing energy consumed in production activities, transportation, and trade.

At the sectoral level, the Vietnam Partnership for Market Readiness Project (the project) supported the design of a crediting program in the steel industry on a pilot scale, including (a) assessment of crediting program readiness, (b) development of crediting program on a pilot scale, and (c) identification of feasible CPIs.

As stated in the Grant Agreement (Grant No. TF0A2914), one of the Project Development Objectives (PDOs) is to strengthen the Government of Vietnam's (GoV) capacity reduce greenhouse gas (GHG) emissions by developing market-based instruments (MBIs).

The project carried out four researches that directly contributed in achieving the intermediate results indicators. About 2,000 stakeholders from different entities such as research institutions and universities, government counterparts, state-owned enterprises, private enterprises, and development partners contributed in developing these outputs. All were brought together through the Project Management Unit (PMU), stakeholders consultations including consultation workshops.

**Table 4-7: Achievement of Intermediate Results Indicators**

| Intermediate Results Indicator | Achieved |
|---|---|
| **Component 1: Strengthening capacity for developing carbon pricing approaches including through priority building blocks for MBIs** | |
| Option study for carbon pricing approaches completed (Yes/No) | Yes |
| National principles and criteria for credited NAMAs developed (Yes/No) | Yes |
| **Component 2: Readiness to pilot selected market-based instruments** | |
| Guidelines on GHG emissions data collection and management system, relevant reporting forms, and MRV protocol for the steel sector developed (Yes/No) | Yes |
| Option study and action plan developed for mid-to long-term market-based carbon pricing approaches applicable to steel industry in Vietnam after 2020 (Yes/No) | Yes |
| **Component 3: Program management and stakeholder engagement facilitation** | |
| Number of consultations evidencing that stakeholder engagement and communications strategy on promoting carbon pricing approaches in key GHG emitting sectors is implemented (Target: 3) | 25 |

[224] UNDP, 2022. Final Report Terminal Evaluation of the UNDP-supported GEF-financed project "Production of sustainable, renewable biomass-based charcoal for the iron and steel industry in Brazil" PIMS 4675 - GEF ID 4718. Available at: https://erc.undp.org/evaluation/documents/download/19939

[225] GEF, 2023. Production of Sustainable, Renewable Biomass-based Charcoal for the Iron and steel Industry in Brazil. Available at: https://www.thegef.org/projects-operations/projects/4718

[226] https://www.iea.org/reports/iron-and-steel-technology-roadmap

[227] https://documents1.worldbank.org/curated/en/343091624562711541/pdf/Implementation-Completion-and-Results-Report-ICR-Document-Vietnam-Partnership-for-Market-Readiness-P152797.pdf

Indonesia’s TNA that was submitted in 2012 included an action implemented in the country’s steel sector, which is the utilization of the Regenerative Burner Combustion System (RBCS) technology which is a waste heat recovery technology which uses waste heat from the furnace exhaust for heating combustion air at the furnace, thus reducing the $CO_2$ and NOx emissions.

At the time of reporting, the technology has been implemented and reported results is that the technology could save up to 35% of energy, increase production by 15%, as well as improve product quality, reduce defects and lower the maintenance cost.

Based on the fact that Indonesian steel plant operators already had experience in the installation and operation of such technology, it was estimated that replication should be easy, and that a Return on Investment (ROI) of 13 months approximately could be achieved. While the main obstacle identified was the production time that will be lost during the installation process itself and until the reheating of the furnace is complete [228].

### 4.4.3 Chemical Sector

Several countries have made significant progress in the decarbonization of the chemical industrial sector, from both developed and developing countries and they are as presented below.

The European Union (EU), which has demonstrated a strong commitment to energy transition and decarbonization (Chen et al.)[229]. The EU has implemented climate policies and regulations that incentivize the adoption of low-carbon technologies and promote the reduction of greenhouse gas emissions[230]. This has led to the development and deployment of innovative technologies and processes in the chemical industry, such as the utilization of renewable feedstocks and the electrification of industrial processes[231]. The EU's focus on material and emission efficiency strategies has also contributed to the reduction of carbon emissions in the steel industry[232].

Another success story is Brazil, which has leveraged its abundant biomass resources, such as sugarcane, to produce bio-based chemicals like bio-ethylene[233]. By utilizing ethanol and sugarcane bagasse as feedstocks, Brazil has been able to reduce carbon emissions and make its chemical industry more competitive[234].

Additionally, countries like Poland have made significant strides in the development of photovoltaic installations and the promotion of renewable energy sources, contributing to the decarbonization of the power generation sector[235].

[228] Indonesia’s second Technology Needs Assessment (mitigation), 2012, (available at: https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TNR_CRE/e9067c6e3b97459989b2196f12155ad5/621d32b1f9704764be63a9e8004d176e.pdf)
[229] L. Chen, G. Msigwa, M. Yang, A. Osman, S. Fawzy, D. Rooneyet al., "Strategies To Achieve a Carbon Neutral Society: A Review", Environ Chem Lett, vol. 20, no. 4, p. 2277-2310, 2022. https://doi.org/10.1007/s10311-022-01435-8
[230] M. Åhman, L. Nilsson, B. Johansson, "Global Climate Policy and Deep Decarbonization Of Energy-intensive Industries", Climate Policy, vol. 17, no. 5, p. 634-649, 2016. https://doi.org/10.1080/14693062.2016.1167009
[231] M. Boon, "A Climate Of Change? the Oil Industry And Decarbonization In Historical Perspective", Bus. Hist. Rev., vol. 93, no. 1, p. 101-125, 2019. https://doi.org/10.1017/s0007680519000321
[232] M. Axelson, S. Oberthür, L. Nilsson, "Emission Reduction Strategies In the Eu Steel Industry: Implications For Business Model Innovation", Journal of Industrial Ecology, vol. 25, no. 2, p. 390-402, 2021. https://doi.org/10.1111/jiec.13124
[233] C. Oliveira, P. Rochedo, R. Bhardwaj, E. Worrell, A. Szklo, "Bio-ethylene From Sugarcane As a Competitiveness Strategy For The Brazilian Chemical Industry", Biofuels, Bioprod. Bioref., vol. 14, no. 2, p. 286-300, 2019. https://doi.org/10.1002/bbb.2069
[234] ibid
[235] G. Lew, B. Sadowska, K. Chudy-Laskowska, G. Zimon, M. Wójcik-Jurkiewicz, "Influence Of Photovoltaic Development On Decarbonization Of Power Generation—example Of Poland", Energies, vol. 14, no. 22, p. 7819, 2021. https://doi.org/10.3390/en14227819

These success stories highlight the importance of supportive policies, technological innovation, and the utilization of renewable resources in driving the decarbonization of the chemical industry sector. By learning from these examples, other countries can implement similar strategies and accelerate their own decarbonization efforts.

# 5 CHALLENGES, TRENDS AND POLICIES

## 5.1 Analysis of Challenges

There are various challenges facing the decarbonization of the HAI sectors. As shown in Table 5-1, many of those challenging are cross-cutting across the three sectors. Hence, designing policies which tackles such cross-cutting challenges can have a multiplier and synergistic effect.

As shown in section 3, several decarbonization technologies have not yet reached the commercial application stage. Hence, while the demand for the various products keep increasing, some long-lived traditional capacity additions can enter into service in the upcoming years; thus reducing the overall mitigation potential. In addition, the technologies that are applied in specific countries may not be feasible to be applied in others due to the differences in the energy prices. In addition, business owners in such very competitive sectors will not prioritize investing in decarbonization technologies without ensuring suitable de-risking mechanisms; thereby ensuring that the generated product will not lose its market competitiveness[236]. On the other hand, some of the response measures aiming at creating a market for the decarbonized products (e.g. the EU Carbon Border Adjustment Mechanism “CBAM” which is applied to Cement, Steel and Ammonia) is causing severe challenges to the developing countries whose relevant exports from these products has significant contribution to their gross domestic product (GDP).

On the technical side, the heavy utilization of biomass is one of the key decarbonization options in the 3 sectors; however, it faces both technical and logistical challenges; the latter mainly attributed to the limited supply of sustainably sourced bioenergy[237]. The latter can be even exacerbated by the competition between the various sectors. Similarly, CCS is one of the key cross-cutting decarbonization technologies; however, it faces various challenges regarding the disparity between the plant location and the storage location, in addition to the liability of having potential negative consequences including ground water contamination and seismicity (the technology faces acceptance challenges in some countries like Austria). Some other plants can also face challenges in having captive renewable energy power plants to ensure having zero-carbon electricity feed into the industrial process. This will most probably be attributed to financial feasibility; either because of the low grid electricity price, or the limited availability of the renewable energy source in the plant location (e.g. solar, wind, biomass, etc.). Generating green hydrogen inside the plants can also face technical feasibility challenges in water stressed areas as every ton of hydrogen needs at least 9 tons of water. In addition, it may not be feasible for each industrial plant to generate its own green hydrogen; however, at the same time having centralized green hydrogen generation plants may not be feasible due to the extremely low density of hydrogen requiring expensive transport infrastructure. Similarly, having a dedicated green electricity grid may not be practical due to the incurred high cost. The following sub-sections present a brief analysis about some of the sector-specific challenges.

[236] K. Holmes, Z. E, M. Kerxhalli-Kleinfield, R. deBoer, "Scaling Deep Decarbonization Technologies", Earth's Future, vol. 9, no. 11, 2021. https://doi.org/10.1029/2021ef002399

[237] Taking steel production as an example, biomass is used in Brazil in blast furnaces after being subjected to pyrolysis/torrefaction. However, it is technically challenging to fully rely on it due to its less favorable mechanical properties compared to coke.

Table 5-1: Various challenges facing the decarbonization of the HAI sectors

| Challenge | Cement | Steel | Chemicals |
|---|---|---|---|
| Maturity level of the low-carbon technologies | ✓ | ✓ | ✓ |
| Energy prices | ✓ | ✓ | ✓ |
| Difficulty of replacing existing assets | | | ✓ |
| Supply availability of alternative materials/energy sources | ✓ | ✓ | ✓ |
| Technical challenges using alterative materials /energy sources | ✓ | ✓ | ✓ |
| Potential impact on the product’s use | ✓ | | |
| Public acceptance of changing product composition/ design | ✓ | | |
| Risk of market share loss for private sector | ✓ | ✓ | ✓ |
| Risk of losing export competitiveness | ✓ | ✓ | ✓ |
| CCS-related challenges including transport infrastructure and liability | ✓ | ✓ | ✓ |
| Natural Gas availability | | ✓ | |
| Renewable Energy infrastructure (e.g. electricity, green hydrogen) | ✓ | ✓ | ✓ |

### 5.1.1 Cement Sector

- **Enhancing the availability of supply clinker substitutes**: The global target of clinker ratio is 0.52 by 2050 as per the GCCA roadmap. Such target is challenging, and would require increasing the supply and utilization of traditional and non-traditional clinker substitutes.
- **Lack of financial support:** measures are required to provide financial support and incentives for different technologies such as CCS/CCUS, as well as financing RD&D of technologies to mitigate GHG emissions from cement production in order to accelerate deployment.
- **Technical challenges of alternative raw materials**: Using alternative raw materials for clinker production have some limitations including high concentrations of incompatible elements (e.g., sulphur, magnesium or other), in addition to volatile organic compounds. Hence, it is difficult to employ large substitution rates of such alternatives.
- **Difficulty of application**: Low-carbon cement in concrete may slow down the application process and increase the labor required to get a smooth finish. In addition, high-blended cements may exhibit slow early-stage strength development, which can delay the construction processes.
- **Infrastructure development:** The electrification of the cement industry presents, many challenges, particularly in using electric kilns. Although electric kilns have been prototyped and in the industry recently, their widespread deployment is limited. Electrifying cement kilns has been challenging because of their high temperature needs. As cement industry demands high levels of energy, making it essential to invest heavily in infrastructure to meet the increased power demand in the process of electrification.
- **Public acceptance of changing product composition/design**: Lowering the clinker ratio of cement faces public acceptance problems from both the building owners and citizens as it is seen that this will jeopardize the safety. Similarly, asking for changing the codes to incentivize changing the building’s design (lowering the amount of concrete) faces acceptance and mainstreaming barriers from the various engineering stages (procurement, design and construction).

### 5.1.2 Steel Sector

- **Technical challenges in some technologies**: In order for iron ore electrolysis to become economically feasible, there are technical challenges in the molten oxide electrolysis, and in finding a cheap and carbon-free inert anode resistant to the corrosive conditions. On the other hand, and for the technology of utilizing slag in construction faces the barrier of having high content of free lime.

- **Scrap supply availability**: There is a lag between steel production and its availability for recycling. Accordingly, scrap is unlikely to be sufficient to meet the industry requirements during this century.
- **Natural Gas Availability**: As per IEA Energy Technology Perspectives series, Natural Gas is considered an important transition fuel for steel industry as many facilities currently use blast furnace technology relying on coal as main energy source. Using the DRI technology relying on Natural Gas is fully commercialized including technologies like Midrex and Energiron. This can be later co-fueled by green hydrogen in the future. Hence, investments in such Natural Gas based technologies in the current decade is important. However, this will be feasible mainly for countries with abundant Natural Gas sources.

### 5.1.3 Chemical Sector

- **Difficulty of replacing existing assets**: Taking ammonia as an example, and based on the International Fertilizer Association, the global average age of ammonia plants in 2020 is estimated to be around 24 years. Hence, there are many facilities worldwide which are relatively new. For such facilities, it is difficult to have early retirement and replace the existing very expensive equipment[238].
- **Technical challenges for some technologies**: Biomass-derived carbohydrates are considered superior building blocks for producing value-added compounds compared to those obtained from fossil sources[239]. However, the transition to renewable feedstocks is still in its early stages and faces significant technological and economic challenges[240]. On the other hand, the high thermodynamic stability and kinetic inertness of carbon dioxide ($CO_2$) pose another challenge. Incorporating $CO_2$ as a one-carbon building block in chemical synthesis is difficult due to these properties[241]. However, ongoing research and development are focused on finding ways to utilize $CO_2$ as a feedstock for value-added chemicals[242]. Furthermore, employing 100% green ammonia production means that another $CO_2$ source would be needed for urea, the fact which needs process and technology interventions.

## 5.2 Trends and Enabling Policies

Various kind of enabling policies and trends can be observed in the field of decarbonizing the HAI sectors. As shown in Table 5-2, many of those enabling policies and trends are cross-sectoral, and accordingly sub-section is structured according to the type of trends and enabling policies rather than sectoral.

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[238] K. Holmes, Z. E, M. Kerxhalli-Kleinfield, R. deBoer, "Scaling Deep Decarbonization Technologies", Earth's Future, vol. 9, no. 11, 2021. https://doi.org/10.1029/2021ef002399

[239] N. Maselj, V. Jovanovski, F. Ruiz-Zepeda, M. Finšgar, T. Klemenčič, J. Trputecet al., "Time and Potential-resolved Comparison Of Copper Disc And Copper Nanoparticles For Electrocatalytic Hydrogenation Of Furfural", Energy Tech, vol. 11, no. 6, 2023. https://doi.org/10.1002/ente.202201467

[240] ibid

[241] J. Wang, S. Yu, M. Li, Y. Cheng, C. Wang, "Study Of the Impact Of Industrial Restructuring On The Spatial And Temporal Evolution Of Carbon Emission Intensity In Chinese Provinces—analysis Of Mediating Effects Based On Technological Innovation", IJERPH, vol. 19, no. 20, p. 13401, 2022. https://doi.org/10.3390/ijerph192013401

[242] ibid

Table 5-2: Observed trends and enabling policies in the decarbonization market of the HAI sectors (country(ies) applying such trend/policy is included between brackets inside the table)

| Trends & Enabling Policies | Cement | Steel | Chemicals |
|---|---|---|---|
| National funding for de-carbonization implementation support | ✓ (France) | ✓ (France, Canada) | ✓ (France) |
| National funding for research & innovation support | ✓ (France, USA) | ✓ (France, USA, Japan) | ✓ (USA) |
| Bilateral countries' collaboration on accelerating de-carbonization commercialization | | ✓ (Japan-Australia partnership on de-carbonization through technology) | ✓ (Japan-Australia partnership on de-carbonization through technology) |
| Enhanced support from financial institutions in energy efficiency projects | ✓ (China, India) | ✓ (China, India) | ✓ (China, India) |
| Implementation of energy efficiency measures via market based mechanism | ✓ (India) | ✓ (India) | ✓ (India) |
| Joint innovation and research programs between different sectoral players | ✓ (Germany) | ✓ (China) | |
| Recycling law for construction waste | ✓ (Japan) | | |
| Developing standards for eco-friendly products | ✓ (Japan) | | |
| Commercial Products using alternative material/energy source | ✓ (Japan)[243] | | |
| Joint collaboration between production companies and low-carbon technology providers | ✓ (Germany) | | |
| Commercial hydrogen injection | ✓ (CEMEX: Europe & Mexico) | | |
| Off-shore CCS | ✓ (Heidelberg: Bulgaria) | | |
| Carbon Pricing | ✓ (ETS: Europe) | ✓ (ETS: Europe) | ✓ (ETS: Europe) |

### 5.2.1 National funding for de-carbonization implementation support[244]

This policy was observed in both Canada and France. In France, and according to the "France 2030" Investment Plan- Heavy industry de-carbonization investment", the government will invest EUR 5.6 billion to lower the GHG emissions of domestic heavy industries like the steel, cement, chemicals and aluminum sectors. EUR 5 billion of which will be provided to support the implementation of the industrial de-carbonization strategies, particularly hydrogen or carbon capture. In Canada, the Federal government announced that it will support a company specializing in the manufacturing of a ferroalloy to produce bio-carbon briquettes to replace metallurgical coal. In addition, one other company will be supported by the Strategic Innovation Fund's Net Zero Accelerator initiative to phase out coal-fired steelmaking processes.

### 5.2.2 National funding for research & innovation support[245]

This policy was observed in France, USA and Japan. The aforementioned "France 2030" Investment Plan- Heavy industry de-carbonization investment" provides EUR 610 million to financially support research

243 http://www.claisse.info/2013%20papers/data/e583.pdf
244 https://www.iea.org/policies?year=desc&qs=iron&sector%5B0%5D=Iron%20and%20steel
245 https://www.iea.org/policies?year=desc&qs=iron&sector%5B0%5D=Iron%20and%20steel

initiatives, development of industrial pilots and demonstrations in the HAI sectors. On the other hand, USA announced a USD100 million to setup a research working group with a clear innovation agenda including industrial techniques that capture emissions from the production of steel, concrete, and chemicals. In December 2020, Japan formulated the "Green Growth Strategy Through Achieving Carbon Neutrality" by 2050. One of the key priority fields in that strategy was "$CO_2$ Ultimate Reduction System for Cool Earth 50 (COURSE50)". The latter works on the promotion and development of innovative zero-carbon steel technologies[246].

### 5.2.3 Bilateral countries' collaboration on accelerating de-carbonization commercialization[247]

In 2021, "Japan-Australia partnership on de-carbonization through technology" was launched. Both countries will collaborate and provide investment funding in the development and commercialization of low and zero emissions technologies. These technologies include low-emission steel and iron ore, clean fuel ammonia, and clean hydrogen.

### 5.2.4 Enhanced support from financial institutions in energy efficiency projects[248]

This policy was observed in both China and India. In China, the "Energy Efficiency Credit Guidelines" were issued by the China Banking Regulatory Commission and the National Development and Reform Commission. The guidelines encourage commercial banks to increase their lending for energy efficiency projects in intensive sectors including steel, construction and petrochemicals. In India, the Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE) was setup to help the Financial Institutions (FIs) partly cover the risk of financing energy efficiency projects.

### 5.2.5 Implementation of energy efficiency measures via market based mechanism

This policy was observed in India where the Perform, Achieve, and Trade (PAT) scheme was developed under the National Mission for Enhanced Energy Efficiency (NMEEE). It is a market-based mechanism for enhancing energy efficiency, where specific targets for energy savings are set and companies that achieve their targets are awarded Energy Saving Certificates. The latter can then be traded via an online system. Cement, steel and chemicals sectors are included under this scheme. The steel sector has been able to achieve the total targeted energy savings between 2012-20 which is about 5.5 MTOE and corresponding $CO_2$ reduction of 20 million ton[249].

### 5.2.6 Joint innovation and research programs between different sector players

This policy was observed in China and Germany. In Germany, one of the innovation programs applied is "CI4C" - Cement Innovation for Climate" which is a joint project on the part of the four European cement manufacturers. Based on this, a new patented binder system with excellent technical and ecological qualities called "Celitement" was developed. Celitement is one of the very few products that managed the transition from research to industrial practice. This cement alternative is based on so called hydraulic calcium

[246] https://www.course50.com/en/message/
[247] https://www.iea.org/policies?year=desc&qs=iron&sector%5B0%5D=Iron%20and%20steel
[248] https://www.iea.org/policies?year=desc&qs=iron&sector%5B0%5D=Iron%20and%20steel
[249] Indian Ministry of Steel, 2022. Indian Steel Industry Reduces its Energy Consumption and Carbon Emissions Substantially with Adoption of Best Available Technologies in Modernisation & Expansions Projects. Available at: https://pib.gov.in/PressReleasePage.aspx?PRID=1794782

hydrosilicates (hCHS), which results in about 50 percent reductions in GHG emissions compared to the traditional clinker[250]. In China, a number of Chinese steel companies, such as Baowu Steel, Jiugang Steel, Angang Steel, and Baogang Steel, have jointly developed research institutes and/or joint agreements to work together on the research and development of hydrogen-related innovations.

### 5.2.7 Developing recycling law for construction waste and developing corresponding standards

Early this century, Japan developed a construction material recycling law mandating to classify and recycle waste generated during construction and demolition works. Japan has also developed standards for recycled concrete aggregate (RCA) and recycled-aggregate concrete (RAC). Japan has accordingly almost reached 100% recycling rate for the concrete.

### 5.2.8 Commercial Products using alternative material/energy source

In 2002, the Japanese Industrial Standards (JIS) has officially certified a product called "Ecocement". This product replaces the traditional raw materials of cement "limestone" by municipal waste incinerator ash. One plant in Japan now produces 110,000 tons of Ecocement per year, and this was followed by another one producing about 130,000 tons per year.

### 5.2.9 Joint collaboration between production companies and low-carbon technology providers

CEMEX, one of the leading cement companies, has announced that it has invested in HiiROC, a clean hydrogen production startup in UK, to help achieve its net zero targets. HiiROC has developed technology that uses thermal plasma electrolysis to convert natural gas, flare gas, or biomethane into zero-carbon hydrogen at a lower cost than the other solutions[251].

### 5.2.10 Commercial hydrogen injection

CEMEX has also announced that it has successfully blended hydrogen into its fuel mix in Spain in 2019, and accordingly all the other CEMEX plants in Europe have applied the same technology. CEMEX has recently announced that it will also apply this in its plants in Mexico[252].

### 5.2.11 Off-shore CCS

Heildelberg, one of the leading cement companies, recently announced ANRAV project in Bulgaria which aims to be the first full-chain CCUS project in Eastern Europe. It will link carbon capture facilities at the Bulgarian cement plant through a pipeline system with an offshore permanent storage under the Black Sea[253].

### 5.2.12 Carbon Pricing

Carbon pricing (including ETS) can be an enabling policy for the decarbonization of the industry by sending a price signal to the market, effectively leveling the playing field between fossil- and renewable-based

[250] https://www.schwenk.de/wp-content/uploads/2023/01/SCHWENK-Sustainability-Report-2021_2022.pdf
[251] https://gaspathways.com/cemex-invests-in-hiirocs-clean-hydrogen-technology-596
[252] https://www.cemex.com/w/cemex-to-introduce-hydrogen-technology-to-reduce-co2-emissions-in-four-cement-plants-in-mexico
[253] https://gccassociation.org/2050-net-zero-roadmap-one-year-on/action-progress-case-study-heidelbergcement/

energy solutions[254]. These price signals can be achieved through carbon taxes, emissions-trading systems (ETS – cap and trade), and international offset mechanisms[255]. Carbon pricing is considered the most efficient policy to reduce greenhouse gas emissions[256], and it can support the COVID-19 recovery and the Paris Agreement[257]. Carbon pricing policy changes during the first 20 months of COVID-19 had a negative effect on greenhouse gas emissions, but policy changes with climate-positive effects were broader in scope regarding coverage of emissions and sectors and are, thus, likely to outweigh the climate-negative policy changes[258]. Overall, carbon pricing can reduce emissions by making low- and zero-carbon energy more competitive compared to high-carbon alternatives, and by encouraging reduced use of carbon-containing fuels[259]. However, carbon pricing is usually challenging in developing countries due to its impact on the prices of the main goods; hence, it is usually not one of the priority policy tools adopted by the decision makers.

[254] Towards a sustainable recovery? Carbon pricing policy changes ... - OECD. https://www.oecd.org/coronavirus/policy-responses/towards-a-sustainable-recovery-carbon-pricing-policy-changes-during-covid-19-92464d20/.
[255] ibid
[256] Policy Sequencing Towards Carbon Pricing - Empirical Evidence ... - IMF. https://www.imf.org/en/Publications/WP/Issues/2022/04/01/Policy-Sequencing-Towards-Carbon-Pricing-Empirical-Evidence-From-G20-Economies-and-Other-515609.
[257] Carbon Pricing - Asian Development Bank. https://www.adb.org/sites/default/files/institutional-document/691951/ado2021bn-carbon-pricing-developing-asia.pdf.
[258] ibid
[259] ibid

# 6 RECOMMENDATIONS

Based on the findings of the previous sections, several recommendations are presented here and categorized into national-level R&D recommendations, national-level policy recommendations, and international development organizations recommended interventions.

## 6.1 National-Level R&D Recommendations

**Countries are recommended** to provide specific focus for R&D activities in the field of HAI decarbonization as follows:

- Countries to devote specific budget line for supporting innovation and R&D programmes (see section 5.2.2 for more details about some country experiences). The first step should be to conduct a study to identify the priority technologies that are best suited to the national circumstances. The **country should then develop a detailed action plan** showing the exact activities that the devoted budget will be directed to.
- Countries to **provide incentives to the private sector players in the HAI sectors to encourage them to finance R&D activities related to decarbonization pathways**. Countries can offer more incentives in case various sector players collaborate together in a wider scale R&D programme (see section 5.2.6 for more details about relevant success story).

From the technical perspective, **R&D programmes should address the following aspects** with the aim of generating low-cost proven technologies that are ready for commercial implementation:

**Cement:**

- Zero-carbon hydrogen production technologies, including water electrolysis and thermal plasma electrolysis (section 5.2.10 presents more details about relevant success stories).
- Utilizing hydrogen as a sole fuel in cement kilns.
- Utilizing alternative raw materials in the cement industry to avoid $CO_2$ emissions generated from limestone calcination (section 5.2.8 presents more details about relevant success stories).
- Maximizing the employment of waste-derived fuels as an energy source for clinker production.
- Development of alternative cement and concrete chemistries, including carbon use innovations in the cement and aggregate value chain.
- Development of new construction materials for both buildings and infrastructure, including expanding the range of technical uses of timber.
- Development of industrial-scale re-carbonation technology to maximize $CO_2$ sequestration.
- Identifying the most technically feasible locations worldwide to act as $CO_2$ storage locations.
- Outline a clear process for monitoring and evaluating the progress and success of the recommended interventions.

**Steel:**

- Zero-carbon hydrogen production technologies, including water electrolysis and thermal plasma electrolysis (section 5.2.10 presents more details about relevant success stories). Using hydrogen as a sole fuel in DRI furnaces.
- De-bottlenecking the current technological constraints in the iron oxide electrolysis technology.

- Catalyzing the commercialization of smelting reduction technologies in the steel sector.
- Maximizing the employment of biomass in the steel industry (e.g., by generating briquetted torrefied materials to be used in blast furnaces).
- Identifying the most technically feasible locations worldwide to act as $CO_2$ storage locations.
- Outline a clear process for monitoring and evaluating the progress and success of the recommended interventions.

**Chemicals:**

- Zero-carbon hydrogen production technologies, including water electrolysis and thermal plasma electrolysis (section 5.2.10 presents more details about relevant success stories).
- Identifying the most technically feasible locations worldwide to act as $CO_2$ storage locations.
- Outline a clear process for monitoring and evaluating the progress and success of the recommended interventions.

## 6.2 National-Level Policy Recommendations

**The countries are encouraged to consider the following policies** in the field of HAI decarbonization. Given the different situations of the countries, each country should pick the policies that match its national circumstances.

However, it's essential to acknowledge that the NDCs are not currently comprehensive especially for the HAI sectors in order to meet the PA goals. They only in some cases comprehensively address industry sectors and subsectors, set specific targets, or provide robust Monitoring, Reporting, and Verification (MRV) mechanisms. To align with the goals of the industry and the Paris Agreement, **countries should consider decarbonization elements of HAI sectors while developing NDC documents.**

The key recommendation is that the country develops **national low GHG emission roadmaps for the HAI sectors including the required fiscal, legal and regulatory interventions**. This should accordingly help develop clear and more in-depth policies.

It is also recommended that the countries develop **regular reports on the progress of execution of the roadmap** so as to define the barriers and collaborate with the international development organizations on alleviating them.

The following sub-sections present some recommended general policies.

### 6.2.1 Energy-Efficiency Policy Interventions

Before going into the deep decarbonization technologies (where most of them are not yet mature), it is necessary that the industrial plants work on enhancing their energy efficiency levels. Countries can help in accelerating this via the following policies:

a) **Issuing regulations** mandating ISO 50001 certification by industrial plants, especially HAI (implying that they are having energy management system and employing energy efficient practices).
b) **Simplifying the governmental procedures** required for application for captive waste heat recovery electricity generation licenses.

c) **Developing an accreditation system for national energy consultants**, followed by a system for **mandatory annual energy audit** for the HAI sectors.
d) Defining specific **maximum energy intensity targets** for new facilities.
e) Issuance of national **green bonds and including the de-carbonization technologies** in the HAI sectors in the pool of financed projects.
f) Developing **green loan financial mechanisms with de-risking components** that increase the ambition of the financial institutions in financing energy efficiency and renewable energy measures in the HAI sectors.
g) **Developing a benchmarking system** for selected industrial sectors. A regular report should be shared with all the plants showing the levels of energy intensities across the sector and the applied low-carbon technologies. This should provide incentives for high intensity players to improve their performance. Top performers can then be rewarded e.g., by being nominated to the financial institutions to receive green loans with preferential rates.
h) Outline a clear process for **monitoring and evaluating the progress** and success of the recommended interventions.

### 6.2.2 Circular-Economy Policy Interventions

a) Developing the necessary regulations to enhance the national **solid waste management system** and maximize recycling to ensure having high-quality refuse derived fuels that can be used as alternative fuel in the cement industry.
b) **Developing incentives that can encourage the private sector players** to invest in the waste and concrete recycling facilities.
c) **Issuing national codes** that allow the use of recycled concrete in the construction of the new buildings.
d) **Developing regulations and legislative frameworks** to ensure the good management of forests and ensure sustainable supply of wood. In addition, policies are required to incentivize investments in biomass full value chain.
e) **Supporting the development of recycling trading platforms** where industrial companies can register their waste specifications in a way that is visible to all the other industries (this can result in successful transactions where another company can purchase such waste and use it as a raw material).
f) Outline a clear process for **monitoring and evaluating the progress** and success of the recommended interventions.

### 6.2.3 Policy Interventions Regarding Creating Demand for Low-Carbon Products

a) Modifying the existing building codes to include **low-carbon designs** (i.e. via using less concrete), low-carbon concrete (e.g. by enhancing the share of admixtures in concrete), low-clinker cement, and cement generated from alternative raw materials.
b) **Increasing awareness of the engineering community** and public about the safety of the low-carbon designs and low-clinker cement (e.g., by sharing success stories from other countries)
c) **Public procurement policies** to include low-carbon cement, low-carbon steel, low-carbon concrete and low-carbon chemicals.

d) **Developing incentives that can encourage the private sector players to invest** in low-carbon products (e.g., tax incentives, recognition of best performers in each sector).
e) **Disseminate the best practices** by providing recognition of the pioneer plants and sharing their success stories.
f) **Simplifying the governmental procedures** required for companies applying for renewable energy generation licenses.
g) **Developing green loan or concessional financial mechanisms with de-risking components** that increase the ambition of the financial institutions in financing decarbonization measures in the HAI sectors.
h) Outline a clear process for **monitoring and evaluating the progress** of the recommended interventions.
i) **Implement policy interventions** to stimulate demand for low-carbon products, leveraging demand drivers such as Green Public Procurement (GPP) and Innovative Demand-Driven Innovation (IDDI) strategies.

The following table categorizes the recommended national-level policy interventions according to the technologies discussed in this document. To avoid re-writing the above policies, the table is referring to the numbering of the above sub-sections.

**Table 6-1: Recommended national-level policies for the various technology categories**

| Technology Category | Recommended National-Level Policy (referring to the sub-section numbers) |
|---|---|
| Material efficiency in design and construction | • 6.2.2 b, 6.2.2 c<br>• 6.2.3 a, 6.2.3 b, 6.2.3 c, 6.2.3 d |
| Enhancing concrete efficiency of production | • 6.2.3 a, 6.2.3 d, 6.2.3 e |
| Low-Clinker cement | • 6.2.3 a, 6.2.3 b, 6.2.3 c, 6.2.3 d, 6.2.3 e, 6.2.3 g |
| Employing green hydrogen as a fuel | • 6.2.3 c, 6.2.3 d, 6.2.3 e, 6.2.3 f, 6.2.3 g, 6.2.3 h, 6.2.3 i |
| Employing captive renewable energy power generation plants | • 6.2.3 c, 6.2.3 e, 6.2.3 f, 6.2.3 g, 6.2.3 h, 6.2.3 i |
| Energy efficiency | • 6.2.1 |
| Employing alternative fuels | • 6.2.2 a, 6.2.2 d<br>• 6.2.3 c, 6.2.3 d, 6.2.3 e, 6.2.3 g |
| CCS & CCUS | • 6.2.3 c, 6.2.3 d, 6.2.3 e, 6.2.3 g, 6.2.3 h, 6.2.3 i, 6.2.3 j |
| Material recycling (e.g. steel slag recycling, plastics recycling,…) | • 6.2.2 e<br>• 6.2.3 c, 6.2.3 d, 6.2.3 e, 6.2.3 g, 6.2.3 h, 6.2.3 i |

## 6.3 International Development Organizations Recommended Interventions

- International development organizations (e.g., UNIDO, GIZ, …) to **create market linkages between the HAI sector players, low-carbon technology providers** (including promising start-up companies), **and donor organizations to develop large-scale R&D programmes** with clear agenda. Designing such programmes to have multiple countries with similar technology interests is advisable.

- The feasibility of generating green hydrogen and green electricity differs from one country to another. Hence, countries with net zero targets in the HAI sectors, where it is not feasible to generate green hydrogen or green electricity are encouraged to purchase green hydrogen/green electricity from other countries. It is recommended that purchase agreements include the required energy amounts from several plants and to ensure long-term supply as well. In order that the above recommendation be practical, it is suggested that the **international development organizations (e.g., UNIDO, GIZ, IEA, …) develop a corresponding global study** to identify such two groups of countries, and work on the required matchmaking based on the study outputs.
- International development organizations are recommended to provide support to the non-EU countries on meeting the CBAM requirements.
- **Exchanging experiences between the countries** about the deployment of decarbonization technologies is crucial to speed up the global transformation. Hence, it is recommended that the international development organizations develop peer to peer knowledge exchange programmes between countries with similar technology interests. This can include study tours, technology transfer, and development of collaboration plans.