United Nations Climate Change
Technology Executive Committee

Transformative industry:

Mapping of initiatives that promote low and near zero emission production and products in hard-to-abate sectors

Background Paper
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UNITED NATIONS
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Contents

Contents (continued)

Contents (continued)

List of Figures

List of Tables

Executive Summary

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) goals. Achieving such goals necessitates immediate and widespread international actions to curtail greenhouse gas (GHG) emissions. In this context, the industrial sector stands out as a significant contributor to global GHG emissions, with three primary sectors – cement, chemicals & petrochemicals, and steel industries – collectively referred to as 'Hard to Abate Industries' (HAI) being responsible for nearly 60% of total industrial energy consumption and contributing to around 70% of industrial CO_2 emissions.

This report aims to map existing initiatives in the above-mentioned HAI sectors and to identify areas where the Technology Executive Committee (TEC) can add value to support the objectives of the PA related to the industrial sector decarbonization. This is aligned with the overarching aim of the Technology Framework, as outlined in the Katowice Rule Book. This mapping exercise furnishes valuable insights and information necessary to facilitate the effective implementation of transformative technologies 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.

This document provides an overview of sectoral emissions and indicators for the three HAI sectors; cement, steel, and chemicals & petrochemicals. It provides an assessment and mapping of the global and sectoral studies, roadmaps and initiatives relevant to HAI sectors. Some of the reviewed global roadmaps include, "Mission Possible Roadmap: Reaching net-zero carbon emissions from harder-to-abate sectors" developed by the Energy Transitions Commission; "Net Zero by 2050 – A Roadmap for the Global Energy Sector" and "Achieving Net Zero Heavy Industry Sectors in G7 Members" by the IEA; and "State of Climate Action 2022" by the World Resources Institute. Section 2 in the report provides deeper analysis of each of the global and sectoral roadmaps and initiatives. This document also provides an identification of innovative low-emission and net zero technologies and enabling policies towards implementation of such technologies. These technologies are provided by sector and divided according to the intervention type and in alignment with the mitigation measures provided by IPCC AR6. The studied technologies are categorized as follows:

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

For each of the technologies, several factors are taken into account to further explain the technology and understand the applicability of utilizing it in the countries that have not yet done so. Section 3 in the report provides more details specific to each sector. The studied details for each sectoral technology include:

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

Moreover, 10 countries are selected for an in-depth assessment together with the global-level analysis in nationally determined contributions (NDCs), biennial reports (BRs), biennial update reports (BURs), technology needs assessments (TNAs), and long-term low-emissions development strategies (LT-LEDS). 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 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 and the final list of selected countries is presented in Table 1 below. For each of the countries, Section 4 in the report presents the HAI-relevant national documents, production and emissions from each HAI sector, identified mitigation goals, reported technology gaps and needs, and whether the country's targets are aligned with the IEA roadmaps.

Table 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 favour 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

In general, it was observed that the reported data by the selected countries identified some of the technologies mentioned in the roadmaps, either as implemented or as a technological need. While some of the technologies were not mentioned by such countries, most of the technologies were reported as in the pilot stage or not mature enough for implementation on a large scale yet. However, a notable finding is that the HAI sectors are not sufficiently represented in NDCs and LT-LEDS. This underscores the need for enhanced NDCs to bridge this gap. Additionally, it was observed that the least data was obtained for the chemicals & petrochemicals sector, which may be due to the fact that the sector is divided into numerous products with different production processes and therefore unifying the reporting and collaboration for this sector is expected to be hard.

Based on the country-level assessment, various kinds of enabling policies and trends can be observed in the field of decarbonizing the HAI sectors. As shown in Table 2, many of those enabling policies and trends are cross-sectoral and, accordingly, Table 3 reflects many of those cross-cutting challenges that need to be tackled when designing policies to achieve a multiplier and synergistic effect. Section 5 in the report presents more details about the various challenges and the various trends and policies observed in the field of HAI decarbonization.

Table 2: Observed trends and enabling policies in the decarbonization market of the HAI sectors (countries applying such a trend/policy are included in brackets in the table)

Trends & Enabling Policies	**Cement**	**Steel**	**Chemicals**
National funding for decarbonization implementation support	✔ (France)	✔ (France, Canada)	✔ (France)
National funding for research and innovation support	✔ (France, USA)	✔ (France, USA, Japan)	✔ (USA)
Bilateral countries' collaboration on accelerating decarbonization commercialization		✔ (Japan-Australia partnership on decarbonization through technology)	✔ (Japan-Australia partnership on decarbonization 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 mechanisms	✔ (India)	✔ (India)	✔ (India)
Joint innovation and research programmes between different sectoral players	✔ (Germany)	✔ (China)	
Recycling law for construction waste	✔ (Japan)		
Developing standards for eco-friendly products	✔ (Japan)		
Commercial products using an alternative material/energy source	✔ (Japan)[1]		
Joint collaboration between production companies and low-carbon technology providers	✔ (Germany)		

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[1] http://www.claisse.info/2013%20papers/data/e583.pdf

Table 2: Observed trends and enabling policies in the decarbonization market of the HAI sectors (countries applying such a trend/policy are included in brackets in the table) (continued)

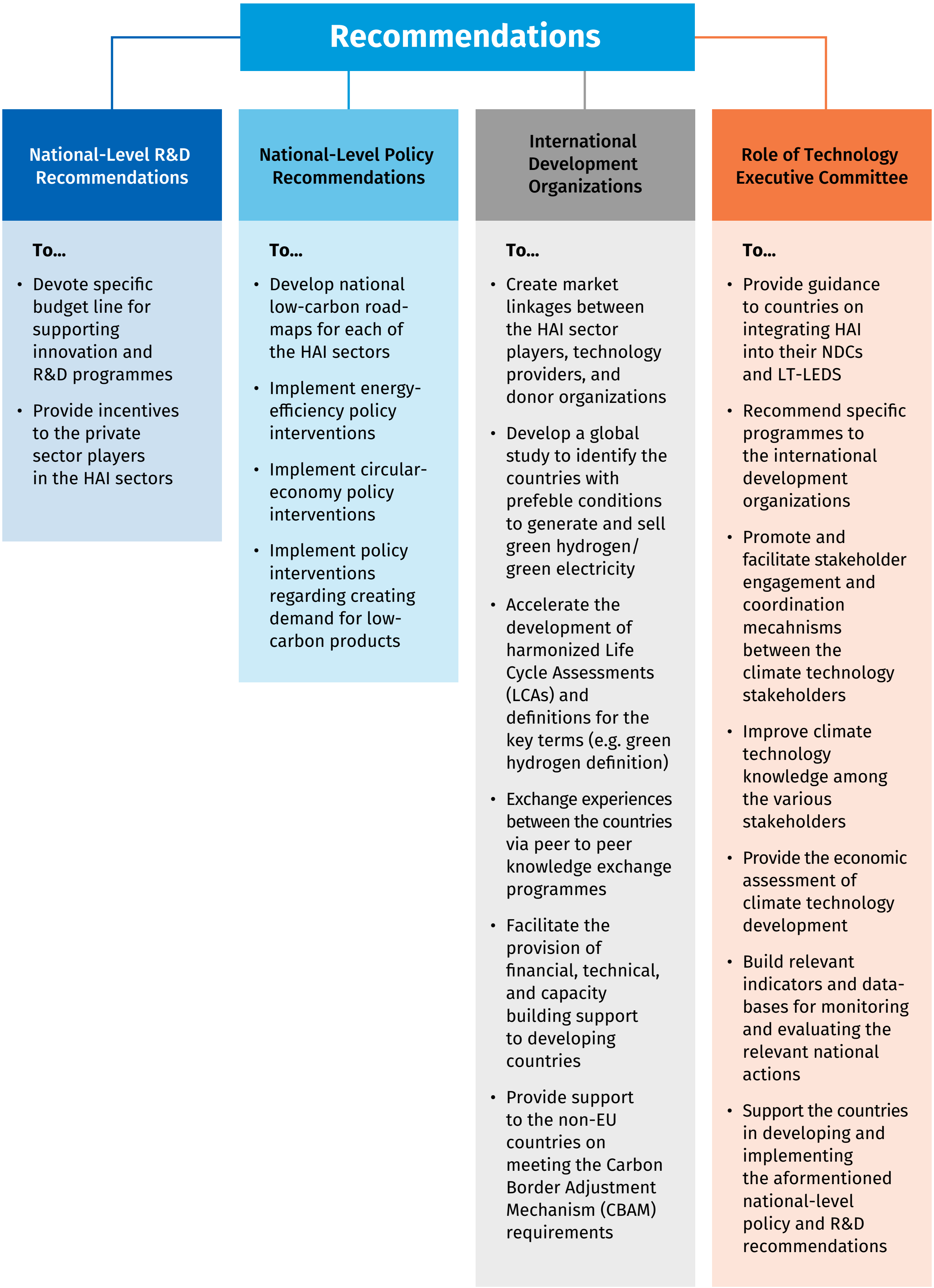
Trends & Enabling Policies	Cement	Steel	Chemicals
Commercial hydrogen injection	✔ (CEMEX: Europe & Mexico)		
Off-shore CCS	✔ (Heidelberg: Bulgaria)		
Carbon pricing	✔ (ETS: Europe)	✔ (ETS: Europe)	✔ (ETS: Europe)

Table 3: 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 alternative 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	✔	✔	✔
Renewable energy infrastructure (e.g. electricity, green hydrogen)	✔	✔	✔

Finally, based on the findings of all the previous work, several recommendations are developed and presented in Figure 1. These recommendations are categorized into national-level R&D recommendations, national-level policy recommendations and international development organization recommended interventions. In addition, this figure presents the proposed role of the TEC to operationalize such recommendations. Section 6 in the report presents more details and directions for each of these recommendations.

Figure 1: Set of recommendations to facilitate the decarbonization of the HAI sectors



Recommendations

National-Level R&D Recommendations

To…

- Devote specific budget line for supporting innovation and R&D programmes
- Provide incentives to the private sector players in the HAI sectors

National-Level Policy Recommendations

To…

- Develop national low-carbon roadmaps for each of the HAI sectors
- Implement energy-efficiency policy interventions
- Implement circular-economy policy interventions
- Implement policy interventions regarding creating demand for low-carbon products

International Development Organizations

To…

- Create market linkages between the HAI sector players, technology providers, and donor organizations
- Develop a global study to identify the countries with prefeble conditions to generate and sell green hydrogen/green electricity
- Accelerate the development of harmonized Life Cycle Assessments (LCAs) and definitions for the key terms (e.g. green hydrogen definition)
- Exchange experiences between the countries via peer to peer knowledge exchange programmes
- Facilitate the provision of financial, technical, and capacity building support to developing countries
- Provide support to the non-EU countries on meeting the Carbon Border Adjustment Mechanism (CBAM) requirements

Role of Technology Executive Committee

To…

- Provide guidance to countries on integrating HAI into their NDCs and LT-LEDS
- Recommend specific programmes to the international development organizations
- Promote and facilitate stakeholder engagement and coordination mecahnisms between the climate technology stakeholders
- Improve climate technology knowledge among the various stakeholders
- Provide the economic assessment of climate technology development
- Build relevant indicators and databases for monitoring and evaluating the relevant national actions
- Support the countries in developing and implementing the aforementioned national-level policy and R&D recommendations

Acronyms and Abbreviations

$	Dollar
°C	Celsius
AAC	Autoclaved Aerated Concrete
AF	Alternative Fuels
AI	Artificial Intelligence
APS	Paris Agreement Scenario
AR5	Fifth Assessment Report
AR6	Sixth Assessment Report
B4IG	Business for Inclusive Growth
BASF	Badische Anilin- und Sodafabrik
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
CBAM	Carbon Border Adjustment Mechanism
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
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
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
GCC	Gulf Cooperation Council
GCCA	Global Cement And Concrete Association
GDM	Gender Diversity Management
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GJ	Gigajoule
GO	Guarantee Of Origin
GoV	Government Of Vietnam
GPIC	Gulf Petrochemicals Industries Co.
Gt	Gigatonne
GW	Gigawatt
H2	Hydrogen
H_2O	Water Vapor
HAI	Hard to Abate Industry
HCl	Hydrogen Chloride
HER	Energy Heat Recovery
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
IPCC	International Panel On Climate Change
ISI	Iron And Steel Industry
ISRI	Institute Of Scrap Recycling Industries

JEF	Young European Federalists
JISF	Japan Iron and Steel Federation
Kg	Kilogram
kWh	Kilowatt Hour
LC3	Limestone Calcined Clay Cement
LCAs	Life Cycle Assessments
LCI	Life Cycle Inventory
LeadIT	Leadership Group For Industry Transition
LLC	Limited Liability Company (US)
LT-LEDS	Long-term Low-Emission Development Strategy
LULUCF	Land Use, Land Use Change and Forestry
MBIs	Market-based Instruments
MENA	Middle East/North Africa
MJ	Megajoule
MOC	Ministry Of Construction (Vietnam)
MRV	Measurement, Reporting And Verification
MSW	Municipal Solid Waste
MT	Megatonne
MTI	Ministry Of Trade and Industry
MTOE	Million Tonnes of Oil Equivalent
MWh	Megawatt 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

OECD	Organization for Economic Co-operation and Development
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
SDGs	Sustainable Development Goals
SDS	Sustainable Development Scenario
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
TAPs	Technology Action Plans
TEC	Technology Executive Committee
TNA	Technology Needs Assessment
TRL	Technology Readiness Level
UAE	United Arab Emirates
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Program
UNIDO	United Nations 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
WEPs	Women’s Empowerment Principles
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°C, with a further aspiration to limit it to below 1.5°C 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[2].

GHG emissions have been rising since the industrial revolution. However, in 2021 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[3]. Global emissions then reported a continuous, though less intense, increase with a rise of 0.9% for 2022 relative to the previous year's levels[4].

The industrial sector stands out as a significant contributor to the global economy, accounting for approximately 21.8% of global Gross Domestic Product (GDP) in 2021. This sector's core constituents are manufacturing (contributing 77.7% of industrial value addition) and the mining and utilities sector (responsible for the remaining 23.3%)[5]. 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 global CO_2eq emissions, thereby positioning it as a major driver of climate change with a total of 34% or 20 $GtCO_2eq$[6].

However, there is a glimmer of hope on the horizon, supported by significant reports such as the IEA's Net Zero by 2050 Roadmap and the UNIDO Industrial Statistics Yearbook 2022. Additionally, the findings from the International Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) emphasize the urgent need to reduce all emissions by 43% by 2030. The adoption of best-available techniques and industrial energy efficiency measures offers the potential to cut CO_2 emissions from heavy industries by two billion tonnes by 2030. This reduction represents a noteworthy 20% decrease in CO_2eq emissions from this sector.[7,8]

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[2] United Nations Framework Convention on Climate Change (UNFCCC), The Paris Agreement: What is the Paris Agreement?

[3] International Energy Agency. Global Energy Review 2022. Available at: https://www.iea.org. 2023

[4] International Energy Agency. CO_2 emissions in 2022. Available at: https://www.iea.org. 2023

[5] United Nations Industrial Development Organization. International Year Book of Industrial Statistics 2022. Available at: https://stat.unido.org. Vienna, 2022

[6] 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

[7] United Nations Industrial Development Organization. International Year Book of Industrial Statistics 2022. Available at: https://stat.unido.org. Vienna, 2022

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

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 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.[9]

Figure 1-1: Emissions from industrial sources (based on IPCC AR6)[10]

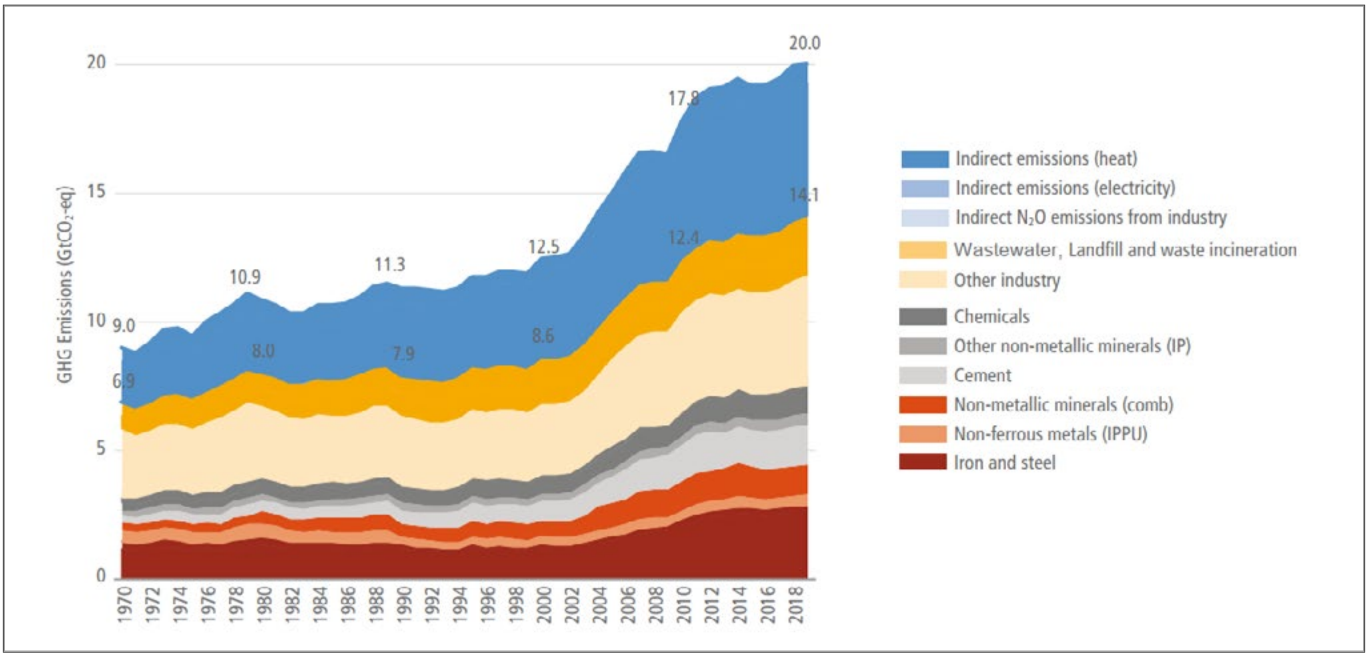

Figure 1-1 shows emissions from industrial sources. Emissions depicted on the left scale, are categorized into two main components: “Comb” represents direct emissions stemming from fuel combustion, while “IPPU” indicates emissions resulting from industrial processes and product use. Additionally, the 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.

In a surprising departure from the increasing trends observed in global emissions in the past, the emissions from industrial processes, in 2022, recorded a 1.7% decrease compared to the previous year. The global reduction was primarily influenced by a significant decrease of 161 million tonnes 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[11].

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[9] 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

[10] https://iea.blob.core.windows.net/assets/bee4ef3a-8876-4566-98cf-7a130c013805/The_Future_of_Petrochemicals.pdf

[11] International Energy Agency. CO_2 emissions in 2022. Available at: https://www.iea.org. 2023

Notably, three primary sectors – cement, chemicals & petrochemicals and steel industries that are 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 CO_2 emissions[12]. Consequently, they are the primary focus of this assessment as these sectors have very high reliance on fossil fuels, long facility lifetimes of 20-50 years and need to fully commercialize, rapidly scale up and deploy near-zero fossil fuel-free carbon alternatives with high capex. Moreover, achieving reductions in these HAI is very challenging.

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 current production levels[13]. 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 assignment is to support the Technology Executive Committee (TEC) in mapping existing initiatives in the above-mentioned hard-to-abate industries (HAI). Additionally, one of the assignment objectives is identifying areas where TEC can add value to support objectives of the Paris Agreement related to the decarbonization of the industry sector. 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 HAIs 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.

In many sectors, emission reductions can be realized by promoting electrification as well as making the power sector low/zero-carbon. However, HAIs are difficult to electrify mainly because their heat demand is huge. Furthermore, only about 40% of CO_2 emissions from the cement sector are energy-related and the remaining 60% are non-energy-related CO_2 emissions from the thermal decomposition of limestone ($CaCO_3$) – the main raw material. Reducing CO_2 emissions from production processes is quite difficult. Besides, iron, cement and petrochemical products are essential basic materials that support our daily life and economic development. These factors are intricately intertwined and make it difficult to reduce emissions in heavy industry sectors.

Additionally, reducing emissions from HAI sectors is not easy and requires overcoming many challenges. These challenges (reflected in detail in chapter 5) include: the maturity level of each technology; high reliance on fossil fuels; 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 the private sector; and CCS-related challenges, including transport infrastructure and liability. Moreover, HAIs face the added complexity of long facility lifetimes, typically spanning 20 to 50 years, which creates transition risks that must be addressed. Addressing these barriers requires the transition to cleaner practices and technologies.

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

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

Moreover, some technologies are facing technical challenges. For example, using alternative raw materials for clinker production in cement has 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 a high content of free lime. In addition, incorporating CO_2 as a one-carbon building block in chemical synthesis is difficult as 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 HAI technology transfer 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 achieve the ambitious targets of the Paris Agreement successfully.

This made mapping HAIs 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 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, and roadmaps and initiatives on HAI. The work also analyses 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 assessments (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 HAIs 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 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 Initiatives in HAI

This section provides an overview of 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 outlook of 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 gigatonnes CO_2 equivalent (Gt CO_2eq) 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_2eq in 2025 and 52.4 (49.1-55.7) Gt CO_2eq in 2030[14].

In light of the IPCCC request per AR6 to reduce emissions from 2023 to 2050 by at least 43%, it is evident that the industrial sector, responsible for 60-70% of global emissions, plays a pivotal role in achieving this reduction target. The success of this endeavor heavily relies on the industrial sector's transition to cleaner practices and technologies. 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[15]. Furthermore, fostering international cooperation is essential to collectively work towards the shared goal of achieving net-zero emissions[16].

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[14] UNFCCC, 2022 NDC Synthesis Report. Available at: https://unfccc.int/ndc-synthesis-report-2022

[15] 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

[16] U. N. Environment, "Emissions Gap Report 2022," UNEP – UN Environment Programme, Oct. 21, 2022. http://www.unep.org/resources/emissions-gap-report-2022

The industrial sector was mentioned as a mitigation option by 47% of the parties[17]. These findings underscore the urgent requirement for comprehensive transformation and the adoption of zero-emission pathways across all sectors, particularly the 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.

2.1.1 Cement Sector

Global cement production was reported to be 4.3 billion tonnes in 2021[18], with total emissions of 1.672 Gt CO_2eq in the same year[19]. This made the cement sector 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%[20]. 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[21].

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 tonnes currently account for 60% of such production. By contrast, cement production in India and Africa is likely to more than triple over the next 35 years as urbanization and infrastructure needs drive huge demand for concrete[22].

Hence, unless there is a major shift to using 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.

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[17] ibid

[18] https://www.iea.org/data-and-statistics/charts/global-cement-production-in-the-net-zero-scenario-2010-2030-5260

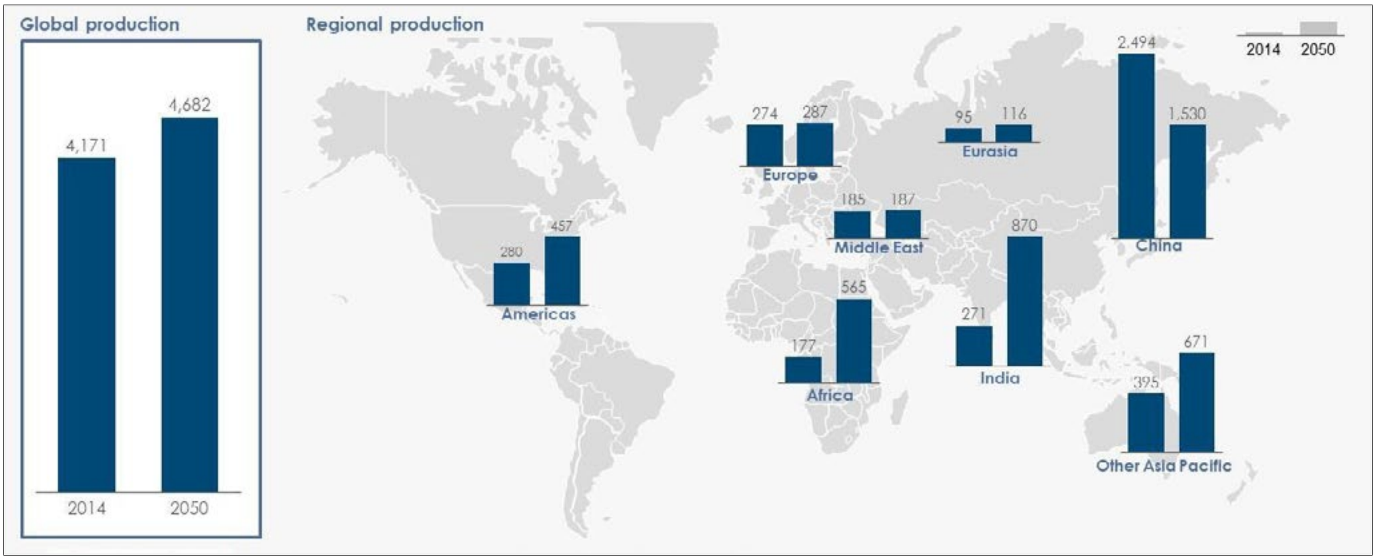
[19] https://ourworldindata.org/grapher/annual-co2-cement?tab=table&facet=none

[20] https://www.researchgate.net/figure/Cement-productions-share-of-global-CO-2-emissions-adapted-from-Czigler-et-al-2020_fig1_354873215

[21] https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry

[22] https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Cement_final.pdf

Figure 2-1: Global cement production by 2050 according to IEA's Reference Technology Scenario[23]



Note: Global and China bar graphs are not on the same scale as other regions/countries

Source: IEA (2017), Energy Technology Perspectives; IEA-CSI (2018), Technology Roadmap – Low-carbon transition in the cement industry

2.1.2 Steel Sector

Demand for steel was estimated to have declined by 5% in 2020 relative to 2019. However, global demand for steel is likely to grow by more than a third by 2050. The iron and steel sub-sector is considered the second-largest share of energy consumption and the largest source of emissions (about 2.6 Gt CO_2 annual direct emissions and about 1.1 Gt CO_2 of indirect emissions) of the industrial sector, which represents about one quarter of the industrial CO_2 emissions among heavy industries (including process emissions)[24]. As per the IPCC document, "Climate Change 2022: Mitigation of Climate Change", increments of GHG emissions from iron and steel (direct emissions only) from 2000 to 2019 were recorded to be 1.35 Gt CO_2eq[25].

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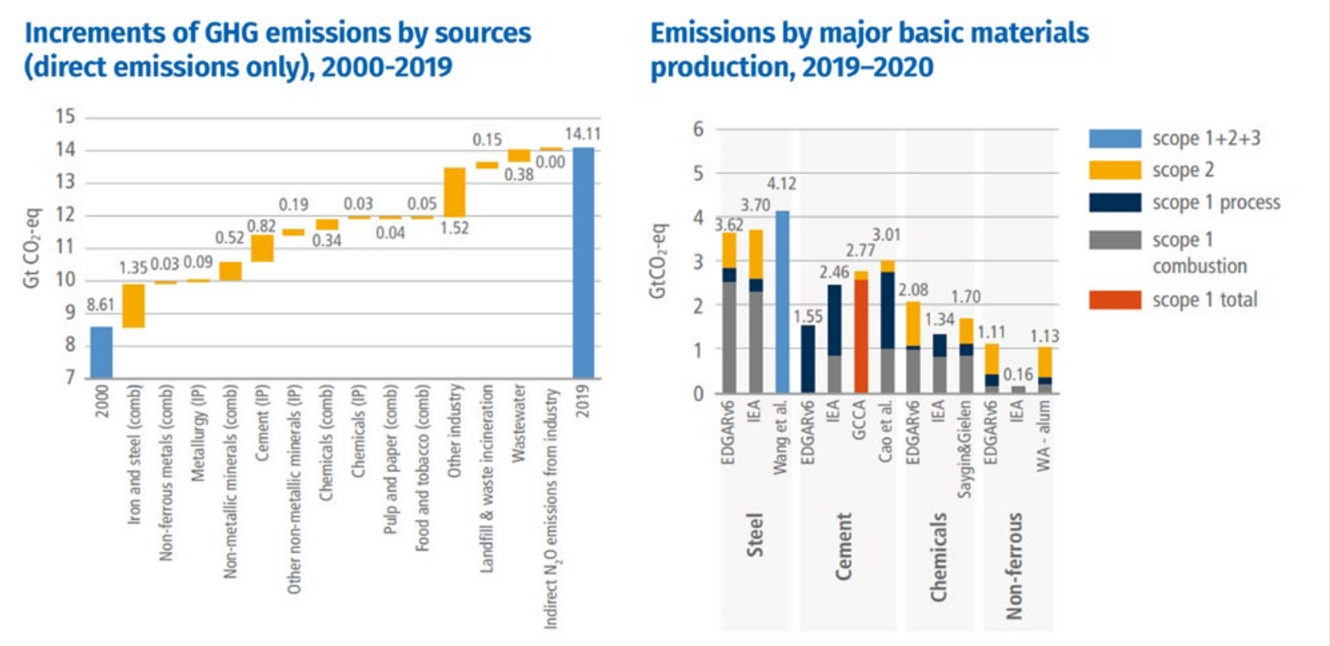
[23] https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Cement_final.pdf

[24] https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

[25] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf

Figure 2-2: Industrial sector direct global greenhouse gas (GHG) emissions[26]



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

Table 2-1: Dynamics And Structure Of The Iron And Steel Industry Greenhouse Gas (GHG) Emissions[27]

Source	Average annual growth rate from 2011-2019	Share in total industrial sector emissions in 2019	2019 emissions $MtCO_2eq$
Direct CO_2 emissions from fuel combustion	2.28%	12.4%	2481
Industrial processes CO_2 – Metallurgy	3.10%	2.0%	391

The steel sector is currently responsible for about 8% of global final energy demand and 7% of energy sector CO_2 emissions.[28]

As shown in Figure 2-3, from the Stated Policies Scenario (STEPS) prepared by the IEA compiling country policies and actions, it is projected that GHG emissions will slightly increase by 2050 compared to 2019 despite the expected large rise in production. This is attributed to increasing the reliance on using scrap and the increased uptake of the Direct Reduced Iron in the Electric Arc Furnace (DRI-EAF) route.

However, as per the IEA Iron and Steel Technology Roadmap report, 40% of the cumulative emissions reductions will be from the material efficiency strategies in the

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[26] 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) https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter11.pdf

[27] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf

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

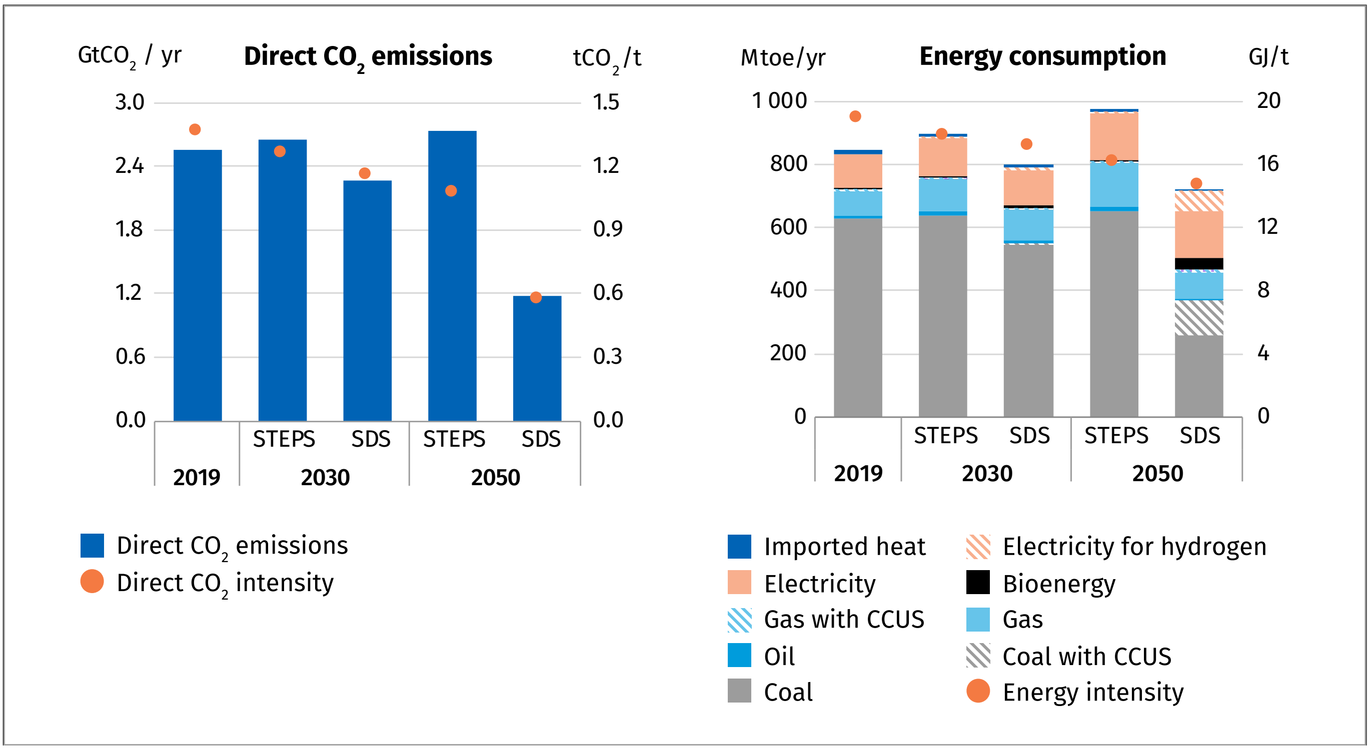
Sustainable Development Scenario. Additionally, improvements in technology performance together with the material efficiency strategies could reach up to 90% of the emission reductions under the Sustainable Development Scenario in 2030.[29]

Moreover, 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[30]. As shown in Figure 2-3, employing more ambitious low-carbon solutions following the Sustainable Development Scenario (SDS) can result in an 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.

It is worth mentioning that the paths of these two scenarios, SDS and STEPS, in emissions reduction are also approximately the same as those examined in the IEA flagship modelling publication, the World Energy Outlook (WEO).

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[31].

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)[32]



Source: IEA 2020. All rights reserved

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[29] https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

[30] https://www.iea.org/articles/driving-energy-efficiency-in-heavy-industries

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

[32] https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

2.1.3 Chemicals and Petrochemicals Sector

The chemicals 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[33,34].

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 with CO_2 emissions representing around 3.6% of the total industrial sector emissions in 2019[35].

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[36]. These emissions result from the combustion of fuels. A significant portion of the chemical sector's energy input 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[37].

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[38].

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[33] IEA (2020), Energy Technology Perspectives 2020, IEA, Paris. https://www.iea.org/reports/energy-technology-perspectives-2020, License: CC BY 4.0

[34] "World Greenhouse Gas Emissions: 2019," World Resources Institute. https://www.wri.org/data/world-greenhouse-gas-emissions-2019

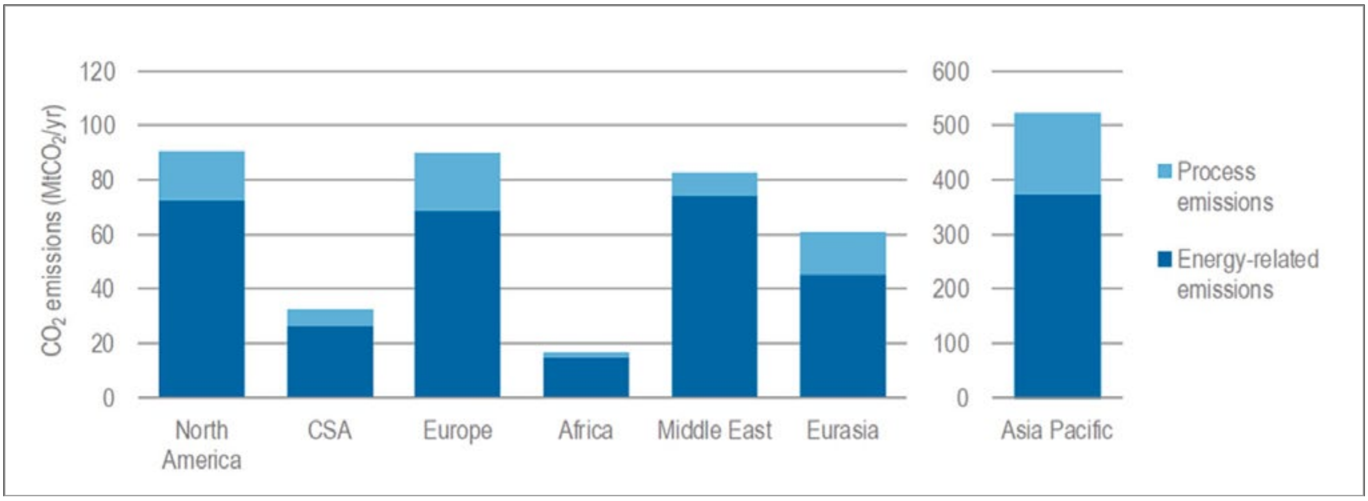
[35] Bashmakov, I.A., L.J. Nilsson, A. Acquaye, C. Bataille, J.M. Cullen, S. de la Rue du Can, M. Fischedick, Y. Geng, K. Tanaka, 2022: Industry. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental 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

[36] ibid

[37] ibid

[38] 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 https://iea.blob.core.windows.net/assets/bee4ef3a-8876-4566-98cf-7a130c013805/The_Future_of_Petrochemicals.pdf

Figure 2-4: Direct CO_2 emission of primary chemicals by region in 2017[39]



Note: CSA = Central and South America; Asia Pacific region includes 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 constitute 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 chemicals 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[40].

According to the IEA's Reference Technology scenario mentioned in "The Future of Petrochemicals" report[41], the global demand for chemicals is projected to increase alongside economic growth, particularly in emerging economies, so 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 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 production of chemicals until 2050[42].

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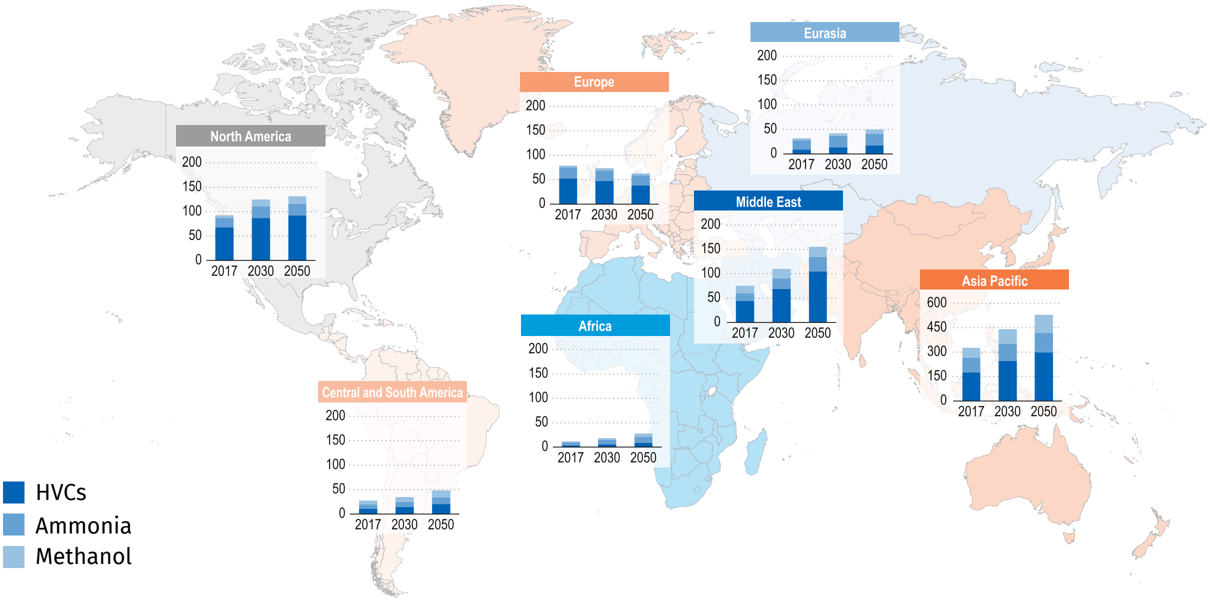
[39] ibid

[40] IEA (2020), Energy Technology Perspectives 2020, IEA, Paris. https://www.iea.org/reports/energy-technology-perspectives-2020, License: CC BY 4.0

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

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

Figure 2-5: Regional production of primary chemicals in the Reference Technology Scenario[43]



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

In the Reference Technology Scenario as referenced in the IEA's "The Future of Petrochemicals", CO_2 emissions from the chemicals 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 gigatonnes 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[44].

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[45].

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

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

[44] ibid

[45] IEA (2020), Energy Technology Perspectives 2020, IEA, Paris. https://www.iea.org/reports/energy-technology-perspectives-2020, License: CC BY 4.0

2.2 Roadmaps and Initiatives

2.2.1 Global Industrial Roadmaps and Initiatives

Roadmaps and initiatives play a key role in organizing 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[46], which has played an important role in the development of countless technologies in recent decades. Increased R&D funding for 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 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
IPCC	2022	Climate Change 2022: Mitigation of Climate Change Working Group III Contribution to the Sixth Assessment Report

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

Table 2-2: Global Industrial Roadmaps And Initiatives (continued)

Issuing Entity	Year of Issuing	Name of Publication
	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 Industry Transition (LeadIT)	2019	Leadership Group for Industry Transition (LeadIT)

2.2.1.1 Global Roadmaps

2.2.1.1.1 Mission Possible Roadmap: Reaching net-zero carbon emissions from harder-to-abate sectors[47]

"Mission Possible" is a roadmap that 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 that 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): reducing demand for carbon-intensive products and services; improving energy efficiency and deploying decarbonization technologies across all sectors.

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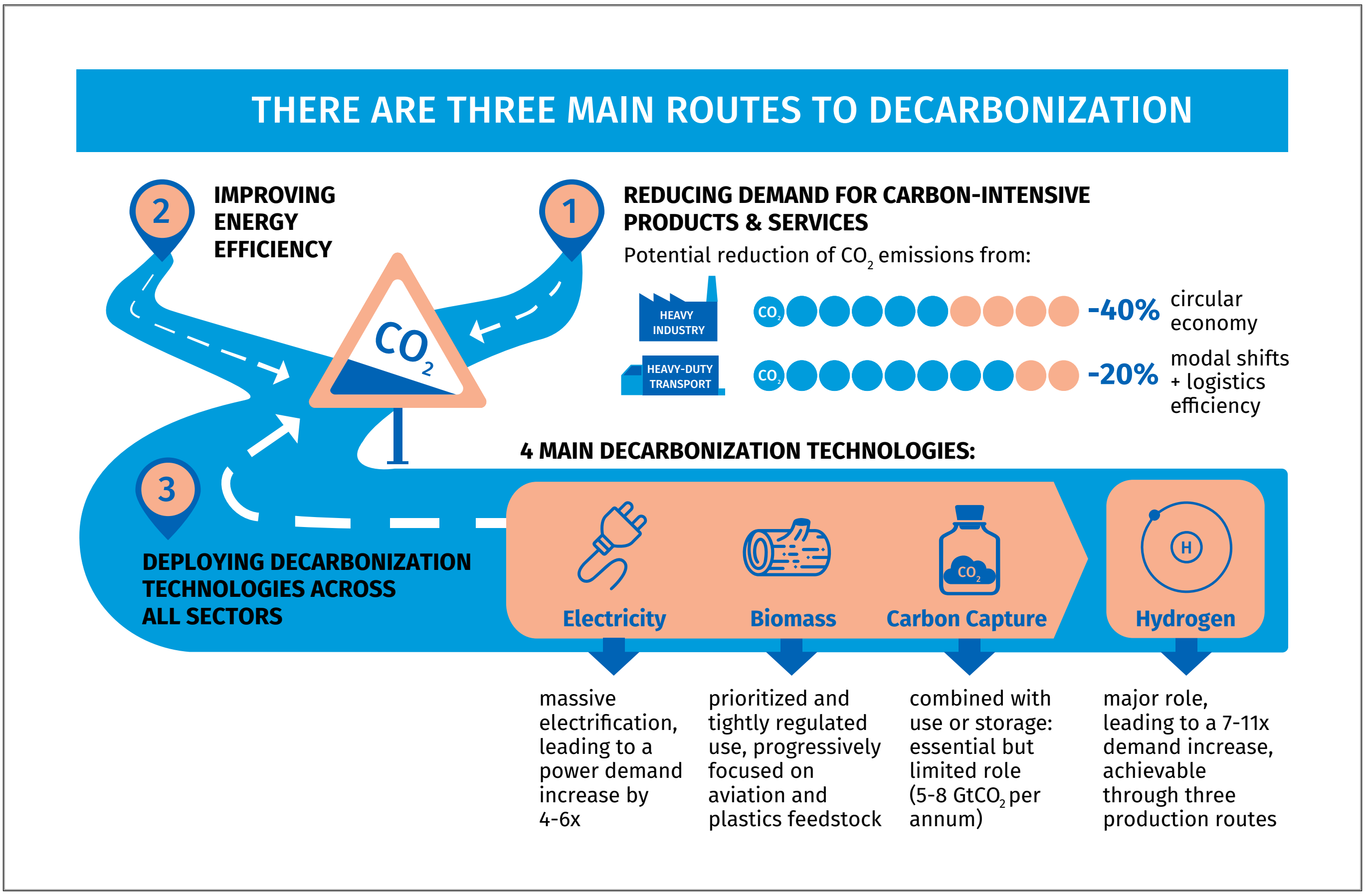
[47] https://www.energy-transitions.org/publications/mission-possible/#download-form,%20https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Cement_final.pdf

Figure 2-6: Routes to decarbonization according to Mission Possible roadmap[48]



Key policy levers to accelerate the decarbonization of hard-to-abate sectors according to the “Mission Possible” roadmap include:

- Focusing on carbon-intensity mandates for industrial processes, heavy-duty transport and the carbon content of consumer products;
- Introducing adequate carbon pricing by pursuing a comprehensive pricing system;
- 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[49]

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 for the four largest materials in terms of emissions (steel, plastics, aluminium, and cement). The key conclusion from this roadmap is that a circular economy can make deep cuts to emissions from heavy

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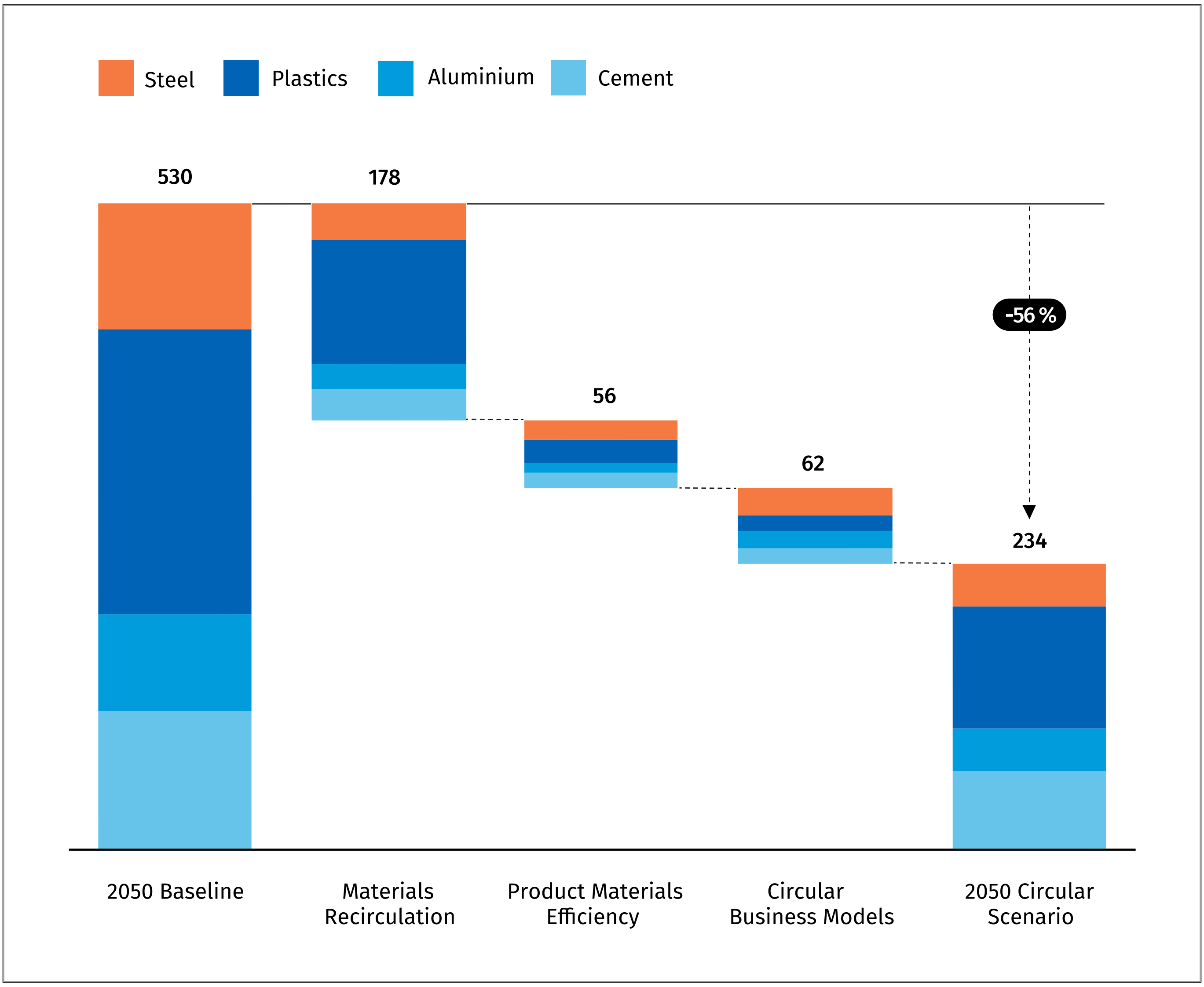
[48] https://www.energy-transitions.org/publications/mission-possible/#download-form,%20https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Cement_final.pdf

[49] https://www.sitra.fi/app/uploads/2018/06/the-circular-economy-a-powerful-force-for-climate-mitigation.pdf

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. These are materials recirculation, more material-efficient products and new circular business models that promote how buildings and transportation vehicles could be utilized more efficiently.

Figure 2-7: EU emissions reductions potential from the "Circular Economy Roadmap" in 2050 (Mt of Carbon Dioxide Per Year)[50]



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[50] https://www.sitra.fi/app/uploads/2018/06/the-circular-economy-a-powerful-force-for-climate-mitigation.pdf

2.2.1.1.3 Roadmap to 2050: A Manual for Nations to Decarbonize by Mid-Century[51]

This 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.

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 centres, 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 and electrification of technologies in addition to deployment and use of green synthetic fuels.

The roadmap also provides several recommendations for the decarbonization of industrial sectors with a focus on the cement, iron and steel and petrochemicals (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.

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[51] 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

- 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, sustainable 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 to 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 Net Zero by 2050 – A Roadmap for the Global Energy Sector[52]

The “Net Zero by 2050” roadmap was prepared by the IEA in 2021 and was updated in September 2023. It highlights that despite the current gap between rhetoric and reality on emissions, there are still pathways to achieving net zero emissions by 2050. The pathway set out in this roadmap is designed to ensure technical feasibility and 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: the newest clean technologies have been demonstrated at a scale and there is 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.

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[52] 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

The roadmap also highlights the following:

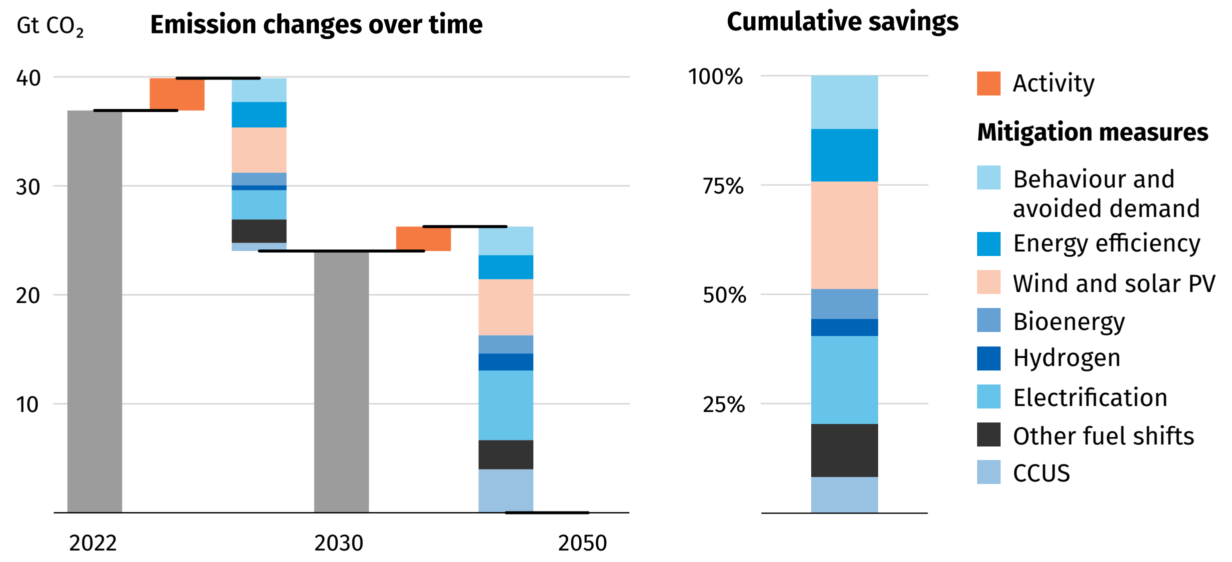
- The criticality of increasing R&D spending on the key decarbonization technologies. Around USD 90 billion needs to be mobilized to complete the required portfolio of demonstration decarbonization projects.
- The need for long-term policy frameworks with clear step-by-step plans to facilitate an orderly 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.
- Recommend increasing investments in clean energy and energy efficiency as they are projected to surpass fossil energy investments by a significant margin, with a 10-to-1 ratio in favour of clean energy by 2030, thus fostering a sustainable energy future.

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 industrial sector is expected to accelerate during the 2030s as the roll-out of low-emission fuels and other emission-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 the application 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, skilful policy design and implementation, technology deployment, infrastructure building, international cooperation, and efforts across many other areas.

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).

Figure 2-8: IEA emissions reductions by mitigation measure in the NZE, 2020-2050[53]



Expansion of solar PV, wind and other renewables, energy intensity improvements and direct electrification of end-uses combined contribute 80% of emission reductions by 2030

Notes: Activity = energy services demand changes from economic and population growth. CCUS includes BECCS and DACS

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[53] IEA (2023), Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach, IEA, Paris https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach, License: CC BY 4.0

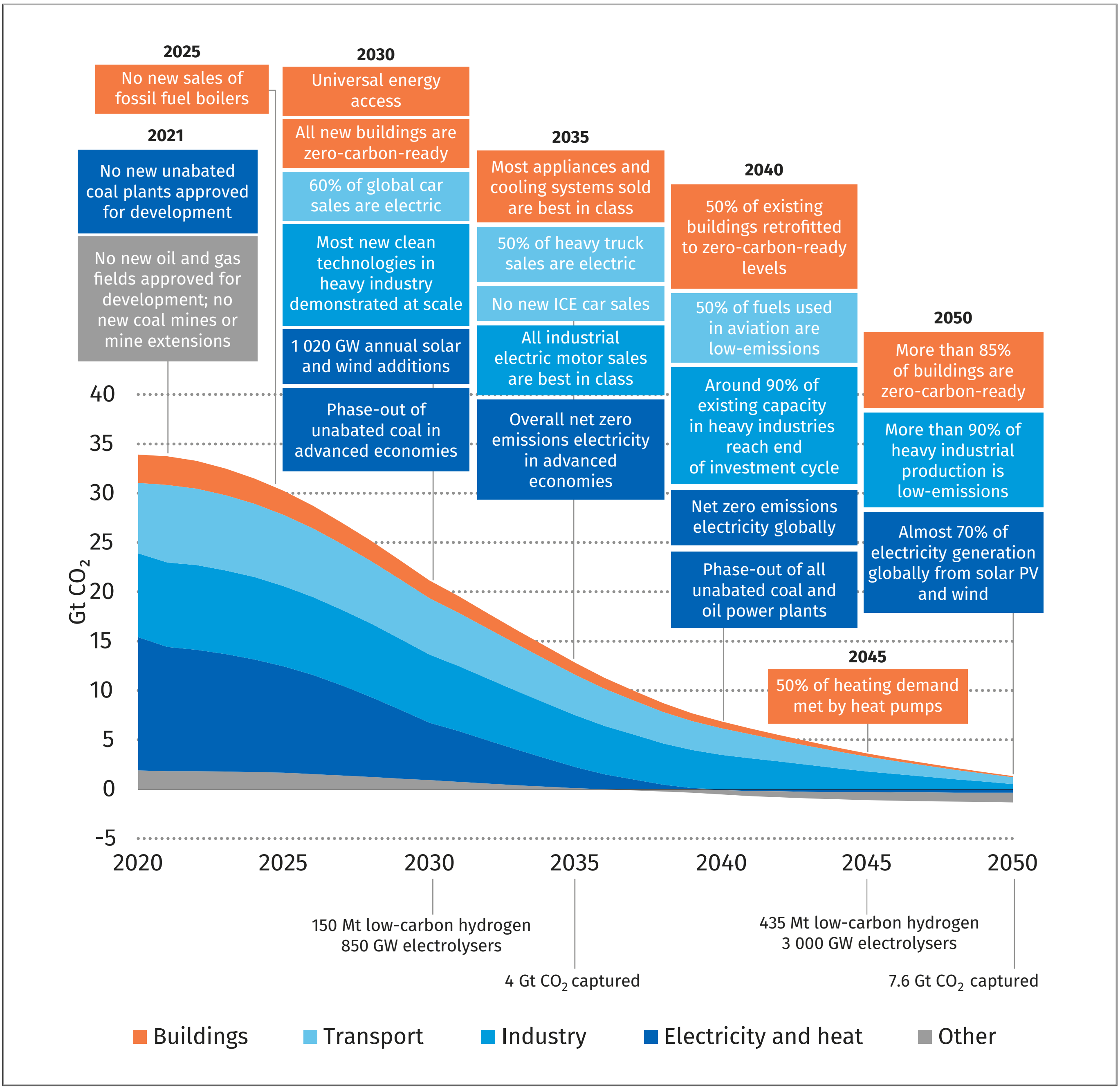
It is worth noting that the IEA has published a new roadmap for members of the G7 for achieving Net Zero in the heavy industry sectors, discussed in the subsequent section as a means to transit quickly to zero-emission industries and stop investing in technologies reliant on fossil fuels.

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, including:

- 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.

The 2023 update of the Net Zero Energy (NZE) Scenario reveals several notable differences from the 2021 version. While both scenarios aim for net zero energy sector CO_2 emissions by 2050, the 2023 edition reflects higher emissions until 2030 due to a strong post-Covid-19 economic rebound and slower action in prior years. Energy demand in 2030 is slightly higher, driven by the post-pandemic economic recovery and delays in implementing energy efficiency policies. Notably, the 2023 NZE Scenario features increased use of coal, partly to support emerging economies and address natural gas security concerns related to geopolitical events. Solar PV plays a more prominent role, although reduced wind capacity projections maintain a combined wind and solar PV share of around 40% in total generation. Electric vehicles (EVs) take centre stage, benefitting from increased sales and supply chain scaling, leading to greater electrification in road transport and heat pump deployment. However, some technologies like wind, hydrogen and carbon capture, utilization and storage experience slower deployment in the 2023 scenario due to supply chain constraints and market framework development challenges. While the path to net zero emissions by 2050 in the 2023 NZE Scenario is steeper, the latest IPCC reports underscore the growing urgency of achieving this goal, emphasizing that the journey remains open but necessitates further action beyond 2030.

Figure 2-9: IEA Key milestones in the pathway to net zero[54]



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 in addition to 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 are compiled from the previously discussed roadmaps. Although there are no new milestones or targets developed in the report, it acts as a guide to decision-makers in government, companies, investing firms, and funding institutions dedicated to accelerating climate action.[55]

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[54] ibid

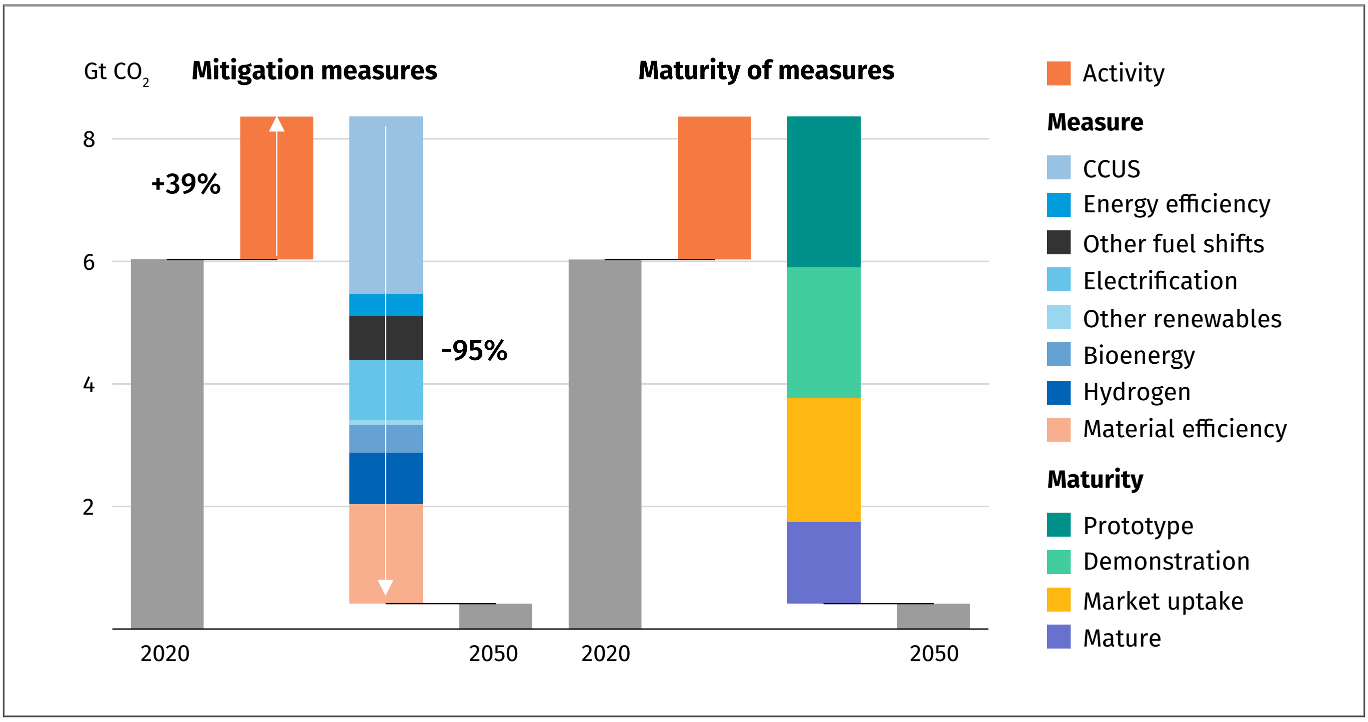
[55] S. Boehm et al., “State of Climate Action 2022,” Oct. 2022 [Online]. Available: https://www.wri.org/research/state-climate-action-2022

2.2.1.1.6 Achieving Net Zero Heavy Industry Sectors in G7 Members[56]

This is a new roadmap by the 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 industrial 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 CO_2 emission reductions in heavy industries by mitigation measure in the 2050 net zero scenario from the "Achieving Net Zero" roadmap. According to this roadmap, the G7 moves even faster than the global average under the scenario, achieving emissions reductions of 27% by 2030 (compared to 18% for the rest of the world), 70% by 2040 (compared to 58% for the rest of the world) and 95% by 2050 (compared to 92% for the rest of the world). 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[57]



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[56] IEA, https://iea.blob.core.windows.net/assets/c4d96342-f626-4aea-8dac-df1d1e567135/AchievingNetZeroHeavyIndustrySectorsinG7Members.pdf

[57] IEA, https://iea.blob.core.windows.net/assets/c4d96342-f626-4aea-8dac-df1d1e567135/AchievingNetZeroHeavyIndustrySectorsinG7Members.pdf

The “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 the deployment of near-zero-emission industrial technologies and associated infrastructure;
- Create differentiated markets for near-zero-emission material production;
- Explore a non-binding inter-governmental 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.

2.2.1.1.7 Climate Change 2022: Mitigation of Climate Change Working Group III Contribution to the Sixth Assessment Report[58]

This is the third part of the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) and was prepared by its Working Group III. It provides an updated global assessment of current and projected emissions from all sources and sectors, mitigation options that reduce emissions or remove greenhouse gases from the atmosphere and progress towards meeting climate ambitions. The industry chapter in the report emphasizes the energy- and emissions-intensive basic materials industries and key strategies for reaching net zero emissions. It also mentions that an industrial transition to net zero emissions is possible via the following considerations:

- Costs can be significant but not usually low as a share of final products;
- Electrification as key mitigation option and demand for electricity will increase;
- Hydrogen importance for steel, chemicals and feedstock;
- Circular economy important to reduce demand for primary resources and lower emissions;
- Material efficiency to reduce emissions along the lifecycle transition away from carbon-intense infrastructures;
- Strategic sequencing of options needed based on maturity to avoid lock-in with transparency on progress critical.

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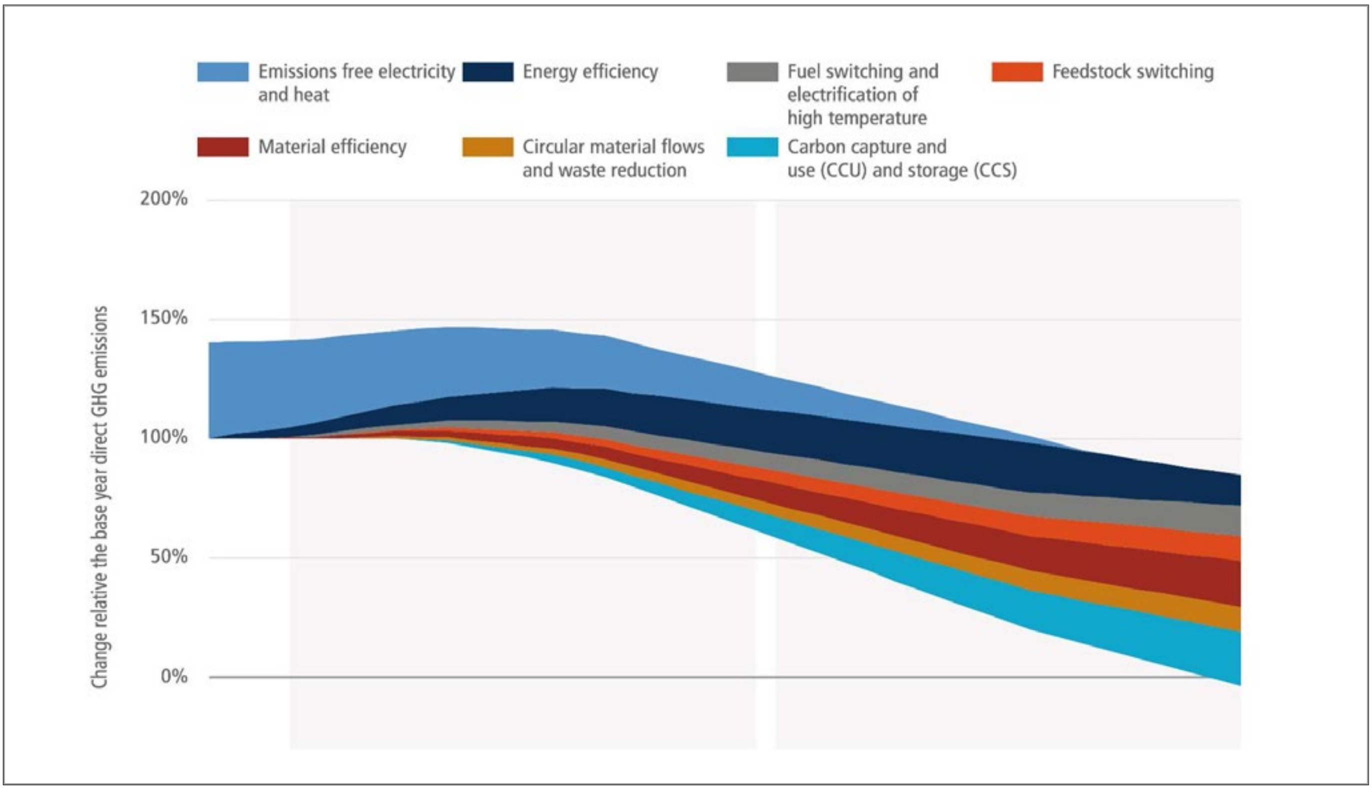
[58] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf

Figure 2-11: Decarbonization pathways towards zero emissions across industries according to the IPCC AR6 report[59]



2.2.1.2 Global Initiatives

2.2.1.2.1 The Industrial Deep Decarbonization Initiative (IDDI)[60]

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

The initiative brings together a strong coalition of related initiatives and organizations, including the Mission Possible Platform, the Climate Group, the Leadership Group for Industry Transition (LeadIT), the World Economic Forum, Responsible Steel and First Movers' Coalition as well as industry associations, particularly the World Steel Association (WSA) and the Global Cement and Concrete Association (GCCA), to tackle carbon-intensive construction materials such as steel and cement.

In 2022, the IDDI launched an update to its Green Public Procurement (GPP) pledge. At its most ambitious level, the Pledge commits governments to start requiring that steel, cement and concrete used in all public construction projects are low-emission and that 'signature projects' use near-zero-emission materials. Three governments (Canada,

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[59] https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/tn_meetings/222d07b060cc40a4b78300a68e59c826/46225fbb019d40e09a5a70fd57019cab.pdf

[60] https://www.cleanenergyministerial.org/initiatives-campaigns/industrial-deep-decarbonisation-initiative/#:~:text=Overview,for%20low%2Dcarbon%20industrial%20materials.%20https://www.unido.org/IDDI

Germany and the United Kingdom) are currently conducting national consultations on the level of the Pledge they are able to commit to. By 2025, 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[61]

The “Net-Zero Industries Mission Initiative” is a global initiative launched by the 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.

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[62,63]

This initiative is a result of a 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 strong enough to ensure that 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, concrete, steel, aluminium, 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[64]:

- Cement with embodied carbon below 184 $kgCO_2eq$/tonne
- Concrete that meets the embodied carbon limits set out in Table 2-3

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[61] https://explore.mission-innovation.net/mission/net-zero-industries/
[62] https://www.weforum.org/first-movers-coalition/partners
[63] https://www.weforum.org/first-movers-coalition
[64] https://www3.weforum.org/docs/WEF_FMC_Cement_Concrete_Commitment.pdf

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

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

They also commit to purchasing near-zero-emissions steel satisfying the following criteria[65]:

- Crude steel from near-zero CO_2 technology production facilities
- 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, the World Resources Institute (WRI), and the World Wide Fund for Nature (WWF)[66]. The SBTi was established in 2015 to help companies set emissions reduction targets in line with climate science and Paris Agreement goals[67]. The initiative defines and promotes best practice in emissions reduction 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 the independent assessment and validation of targets[68]. Over 1,000 organizations worldwide are leading the zero-carbon transformation by setting emissions reduction targets grounded in climate science through the SBTi[69].

2.2.2 Sectoral Roadmaps and Initiatives

R&D efforts support the expansion of decarbonization options in all industry sectors. For industries to encourage the implementation of emerging technologies, several sector specific HAI roadmaps and initiatives have been 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 the cement sector. Table 2-4 includes a summary of cement sector roadmaps showing the mitigation targets and 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.

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

[66] Science Based Targets initiative – Wikipedia. https://en.wikipedia.org/wiki/Science_Based_Targets_initiative

[67] Ambitious corporate climate action – Science Based Targets. https://sciencebasedtargets.org/

[68] ibid

[69] 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 and construction (22%) • Efficiency in concrete production (11%) • Savings in cement and binders (9%) • Savings in clinker production (11%) • Carbon capture and utilization/storage (CCUS) (36%) • Decarbonization of electricity (5%) • CO_2 sink: recarbonation (6%)	**CO_2 reductions will be accelerated through the following actions:** • Promote investments in low-carbon cement manufacturing. • Stimulate demand for low-carbon concrete products. • Create the infrastructure needed for a circular and net zero manufacturing environment. • Increase clinker substitution – including fly ash, calcined clays, ground granulated blast-furnace slag (GGBS), and ground limestone. • Reduce use of fossil fuels and increase use of alternative fuels. • Improve efficiency in concrete production. • Improve efficiency in the design of concrete projects and use of concrete during construction, including recycling. • Invest in technology and innovation. • Develop CCUS technology and infrastructure. • Collaborate in establishing a policy framework to achieve net zero concrete.
The equivalent of almost 90% of today's direct global industrial CO_2 emissions by 2050	The Technology Roadmap: Low-Carbon Transition in the Cement Industry	• Thermal energy efficiency (3%) • Fuel switching (12%) • Reduction of clinker-to-cement ratio (37%) • Innovative technologies (incl. carbon capture) (48%)	**The following policies are highlighted to be applied by governments:** • Eliminate energy price subsidies, which can act as a barrier to the use of energy efficient technologies. • Develop and reinforce waste management regulations, encompassing waste avoidance, collection, sorting, and treatment. • Promote the use of blended cements in sourcing and public procurement policies. • Reward clean energy investments. • Provide flexibility to local energy grids – for example, fiscal incentives for Energy Heat Recovery (EHR). • Develop plant- or sector-level energy efficiency improvement target-setting programmes. • Co-ordinate the 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.

Table 2-4: Cement Sector Roadmaps Summary (continued)

Roadmap	Mitigation target and timeframe	Technology focus for target achievement	Enabling Policies
The Role of Cement in the 2050 Low Carbon Economy Roadmap	80% reduction in emissions by 2050	Multiple paths to emissions reduction: • Kiln efficiency and fuel mix (136 Mt CO_2) • Clinker substitution and novel cements (125 Mt CO_2) • Transport efficiency (123 Mt CO_2) • Non-CO_2 GHG (123 Mt CO_2eq) • Decarbonization of power (113 Mt CO_2) • Breakthrough technologies (34 Mt CO_2)	• Provide access to R&D funds to stimulate breakthrough technologies – for example, making grinding more efficient. • 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. • Ensure industries have access to electricity at fair and affordable price levels (including taxes and fees), which means a liberalized electricity market is crucial. • Support and fund R&D of all aspects related to CCS to accelerate greenhouse gas reduction in cement manufacture. • Finance for new research to develop alternative ways to use the captured carbon emissions. • Identify and develop storage sites with transport solutions, such as a dedicated pipeline network.
Cementing the European Green Deal: reaching climate neutrality along the cement and concrete value chain by 2050	By 2050, net zero	• 783 kgCO_2/t reduction of emissions of cement: • 280 CCS/CCU • 160 clinker (decarbonated raw material 27, biomass fuels 71, low-carbon clinker 17, H2 and electrification 19) • 117 cement (clinker substitution 72, electrical efficiency and re-electricity 35, carbon neutral transport 10) • 116 emissions • 59 concrete (concrete mix 52, carbon neutral transport 7) • 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. • 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. • Develop sufficient infrastructure for energy-intensive industries, including cementinfrastructure to transport, re-use and store the CO_2 it captures. • Develop 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. • Provide access to public funding for innovation, CO_2 pipeline infrastructure and renewable electricity as well as a high CO_2 price and the ability to pass onCO_2 costs. • Provide access to funding for research, take-up of low carbon products and the efficient revision of standards.

Table 2-4: Cement Sector Roadmaps Summary (continued)

Roadmap	Mitigation target and timeframe	Technology focus for target achievement	Enabling Policies
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 and optimize designs for the lowest lifecycle emissions • **Mid-term:** Increase the use of alternative fuels and use renewable energy • **Long-term:** Carbon capture and introduce new cement blends	• Accelerate research, funding and investment in manufacturing, material innovation and CCUS technologies and associated infrastructure. • Streamline regulation, siting and permitting practices for facility and infrastructure modernization. • Recognize and credit industry reduction levers. • Support community acceptance of CCRs, alternative fuels, CCUS, and other manufacturing technologies. • Consider a market-based carbon price – preferably a cap-and-trade mechanism. • Support market acceptance of low-carbon alternative cements and concrete. • Adopt performance-based standards for building materials. • Consider the full product, material and building lifecycle in procurement standards and policy.
The Net-Zero Roadmap for Autoclaved Aerated Concrete	By 2050, net zero	• Low-carbon cement and lime (69%) • Optimizing factories and switching fuel sources (13%) • Optimizing assembly and end-of-life disposal (7%) • Low-emissions transport (3%) • 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 lifecycle emissions for buildings and construction products to: • Allow for recarbonation to be accounted for in CO_2 abatement; • Take into account the benefits of properties such as thermal mass in avoiding emissions for heating and cooling buildings; • Support the development of industry-wide approaches to circularity; • 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 with the largest contribution to CO_2 emissions coming from the use phase; • Switch to low-carbon cement and lime binders that are used as raw materials in the manufacture of Autoclaved Aerated Concrete (AAC); • Switch to renewable energy sources together with efficiency improvements within factories that manufacture AAC; and • Switch to cement-based products such as AAC that absorb CO_2 during their lifespan.

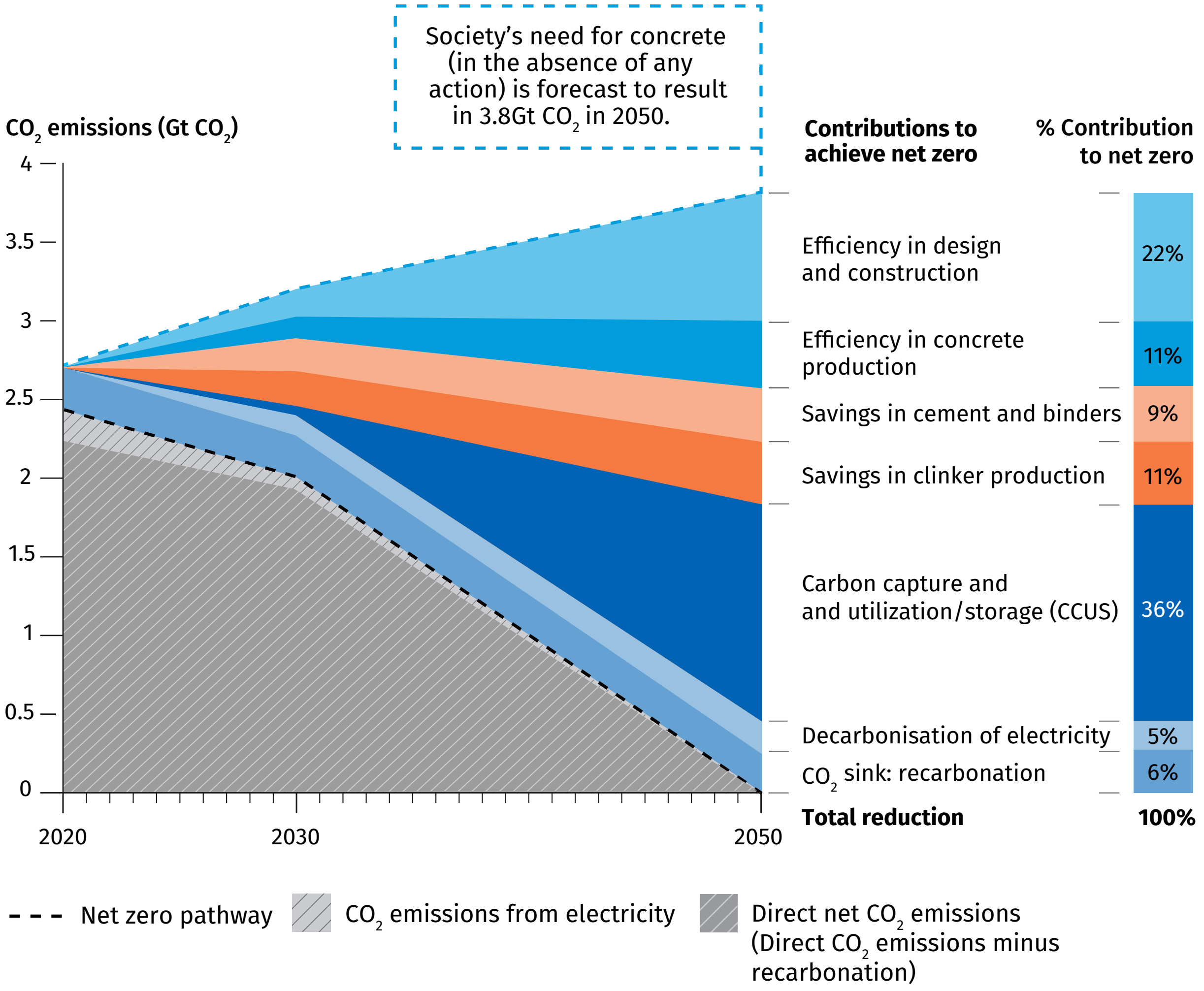
Note: MPP will publish a concrete and cement sector transition strategy in 2023

2.2.2.1.1 The GCCA 2050 Cement and Concrete Industry Roadmap

In 2020, member companies of the GCCA came together as leaders in the sector to commit to producing carbon neutral concrete by 2050 in line with global climate targets.[70] 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 mid-century. As shown in Figure 2-12 below, the proposed roadmap actions between 2020 and 2030 will prevent almost 5 billion tonnes of CO_2 emissions in total from entering the atmosphere compared to a business-as-usual scenario.

Figure 2-12: The net zero pathway according to the GCCA 2050 Cement and Concrete Industry Roadmap[71]



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[70] https://gccassociation.org/concretefuture/wp-content/uploads/2022/10/GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf

[71] https://gccassociation.org/concretefuture/wp-content/uploads/2022/10/GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf

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

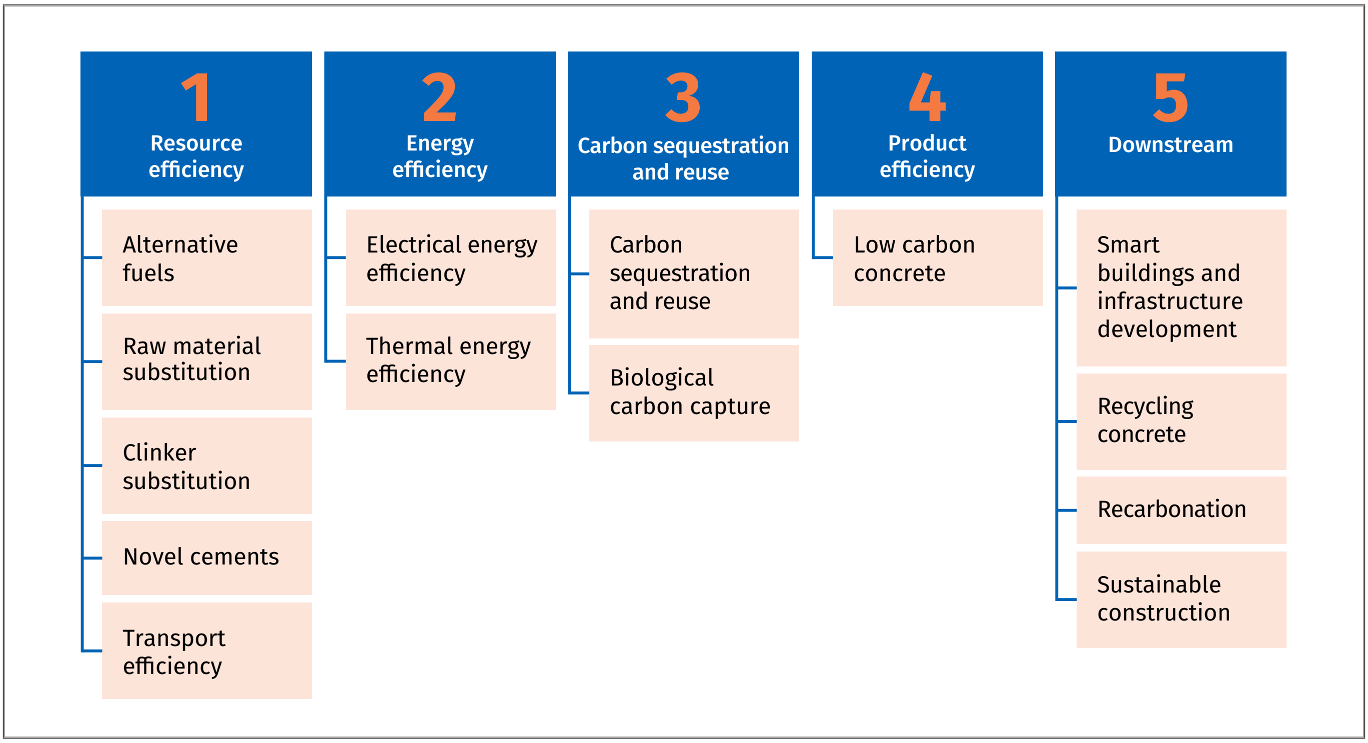
This Technology Roadmap builds on the long-standing collaboration of the IEA with the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD)[72]. Developed in 2018, the roadmap outlines a detailed action plan for specific stakeholders till 2050 as a reference and a source of inspiration for international and national policy makers to support evidence-based decisions and regulations.

It sets out 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.

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 focuses on what can be done to reduce CO_2 in cement production using today's technology and speculates on what could be achieved by 2050[73]. It highlights innovative applications and concrete products that could contribute to the industry transition 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. It is focused on five routes to achieving these objectives, three of which are considered to be "under the sector's control" (as shown in Figure 2-13 below).

Figure 2-13: The five routes to achieving carbon neutrality according to the Role of Cement in the 2050 Low Carbon Economy Roadmap[74]



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[72] https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry

[73] https://lowcarboneconomy.cembureau.eu/wp-content/uploads/2018/09/cembureau-full-report.pdf

[74] https://lowcarboneconomy.cembureau.eu/wp-content/uploads/2018/09/cembureau-full-report.pdf

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)[75]. It outlines the path towards carbon neutrality along the entire value chain. It looks at how carbon emissions reduction can be achieved 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. The first is to produce a 40% gross reduction compared to the 1990 CO_2 emissions by 2030 (equal to 472 kg CO_2/t of cement). The 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 to guide the industry on the most ambitious journey to carbon neutrality[76]. It focuses on the entire value chain, beginning at the cement plant and ending with the buildings and roads. Its 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.

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[77]. 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 lifecycle 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 initiative, launched in 2022, is a partnership with WBCSD and World GBC. It includes corporate partnerships with 22 companies committed to using low- and net zero emission concrete and, effectively, cement as its key ingredient[78]. 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 the GGCA, the Innovandi Global Cement and Concrete Research Network is an association of 40 global institutions representing academia and 34 cement and concrete manufacturers as well as technology suppliers representing industry. This association

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[75] https://cembureau.eu/media/cpvoin5t/cembureau_2050roadmap_lowcarboneconomy_2013-09-01.pdf

[76] https://www.cement.org/docs/default-source/membership-2020/pca_roadmap-to-carbon-neutrality_jan-2022.pdf?sfvrsn=9b26febf_2

[77] https://eaaca.org/wp-content/uploads/2022/08/EAACA_Net-Zero-Roadmap-for-AAC_2022-08-12.pdf

[78] https://www.theclimategroup.org/concretezero

aim to gather efforts on research, in areas such as energy efficiency, clinker production, CCUS/ technologies, new materials, and low-carbon and recycling technologies[79].

2.2.2.2.3 The Innovandi Open Challenge

The Open Challenge, launched in 2021, is a global programme for start-ups with GCCA members. It aims to support cement decarbonizing technologies[80]. 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 to develop new technologies and/or define new business cases[81] as well as to extend 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 GHG emissions from the sector. Although a number of country-level and company-level roadmaps were identified for the steel sector – for example, in the European Union and other countries – the global roadmaps were scarcer and are represented by the IEA Iron and Steel technology roadmap. A summary of the identified roadmaps 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.

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[79] https://gccassociation.org/innovandi/gccrn/

[80] https://gccassociation.org/concretefuture/wp-content/uploads/2022/10/GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf

[81] https://gccassociation.org/innovandi/openchallenge/oc2023/

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. Continue towards net zero afterwards.	• Efficient use of steel together with material efficiency measures (40% of CO_2 emissions savings), including:
		  • Reducing material demands following the Sustainable Development Scenario (SDS) of operation
		  • Material replacement to lower GHG emitters
		• Enhancing energy efficiency in existing facilities (20% of CO_2 emissions savings), including early closure or under-utilization of existing facilities
		• Developing advanced steel manufacturing processes (40% of CO_2 emissions savings):
		  • Use of alternative energy sources such as hydrogen
		  • Utilizing CCUS
		  • Bioenergy and direct electrification
			The polices could be summarized as follows:[82]
			• Set a long-term CO_2 emission reduction target.
			• Manage the assets currently available and near-term investment.
			• Enhance and encourage international cooperation.
			• Support R&D and technologies related to net zero emission.
			The following provides some initiatives by specific countries/organizations:[83]
			• Some countries have implemented carbon pricing mechanism.
			• 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, the steel industry sustained free allowances for emissions equivalent to production at a benchmark emission intensity.
			• The European Union is currently working on proposals related to the mechanism of adjusting the carbon border, which aims to provide an additional method for addressing the potential impact of the emissions trading system (ETS) on industrial competitiveness.
			• The People's Republic of China ("China") has undefined plans with unspecified dates regarding steel industry.
			• The 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.
			• The German government has commenced a competence centre related to climate mitigation measures in energy-intensive industries (KEI) to support emission reductions (IN4climate.NRW, 2020; KEI, 2020).
			• Some steel manufacturers and industry associations have set targets aimed at reducing emissions and developing sustainable roadmaps.
			• The World Steel Association "step up" programme is to collect and report standardized data related to CO_2 emissions.
			• The European Union is developing a system to classify environmental objectives, including climate change mitigation.

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[82] https://www.mdpi.com/2071-1050/13/22/12548

[83] https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

Table 2-5: Steel Sector Roadmaps Summary (continued)

Roadmap	Mitigation target and timeframe	Technology focus	Enabling Policies
Clean Steel Partnership Roadmap	**For the EU:** Achieve 50% reduction by 2030. Reach 80-95% reduction by 2050. Ultimately reach carbon neutrality.	• Enhancing circular economy and resource efficiency practices • Smart use of carbon through process integration • Carbon capture and use and storage • Fuel substitution to avoid carbon intensive fuels via utilizing renewable energy (e.g., replacing fossil fuels with hydrogen and electricity-based metallurgy)	• Encourage cooperation on clean steel in EU programmes. • Enable the utilization of resources outside EU programmes, through an optimum combination of funding and financing schemes from Member States and regions. • Enable a regulatory framework for the potential impacts of the partnership to be delivered. • Support R&D and technologies related to net zero emissions. • Ensure the provision of an appropriate and sustainable financing programme[84].

Mission Possible Partnership Roadmap	Reach net zero emissions by 2050	• Reduction in CO_2 emissions via circularity (estimated reduction of 37% by 2050 and about 52% by 2100):
		  • Increasing recycling in steel production
		  • Shifting to a more circular economy and reducing the total steel demand
		• Energy efficiency improvements (estimated improvements to be 15-20% of present energy consumption on average globally)
		• Decarbonization of ore-based steel production via:
		  • Technology readiness
		  • Cost trade-off
			• Encourage R&D support.
			• Each government must set up its policy framework to encourage private sector actions.
			• Develop and set up codes which require efficiency in steel utilization and any other materials.
			• Carbon pricing and regulations on steel production seeking international agreement between all countries.
			• Set up regional steel specifications.

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

2.2.2.3.1 The Iron and Steel Technology Roadmap[85]

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

The roadmap proposed by the IEA and revised by the 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 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 emission reductions of about 40%.

According to the 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 at today's level to 0.6 t CO_2/tcs by 2050.[86]

2.2.2.3.2 Clean Steel Partnership Roadmap[87]

The Clean Steel Partnership Roadmap was developed by the European Union in 2020 to realize the EU goal of carbon neutrality. The roadmap sets the goal of reducing 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 EU Member States in order to successfully implement the highlighted operational objectives in developing countries as well as developed countries.

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

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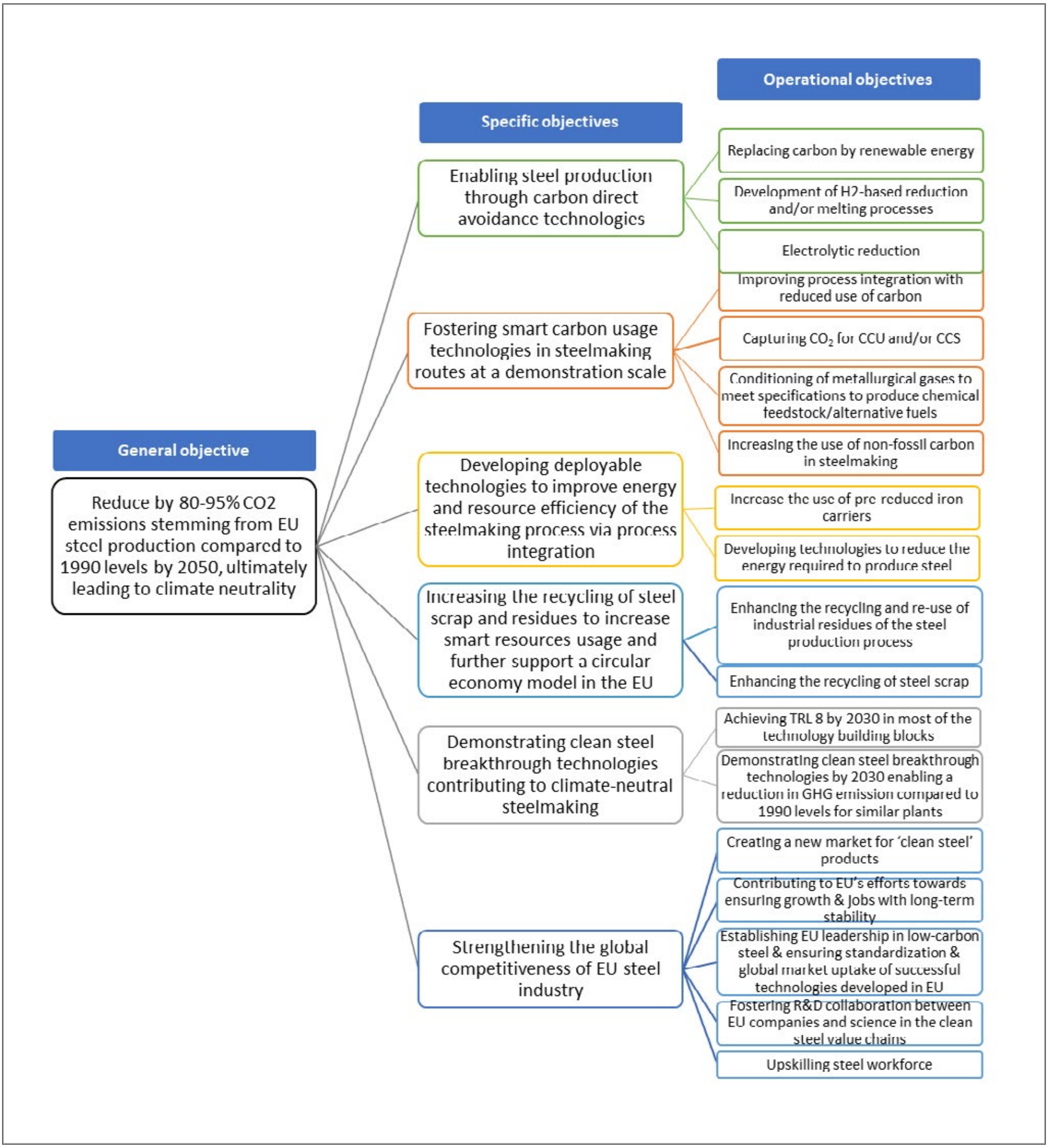
[85] IEA, Iron and Steel Technology Roadmap, 2020. Available at: https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

[86] https://www.mdpi.com/2071-1050/13/22/12548

[87] ESTEP AISBL, Clean Steel Partnership Roadmap, 2020. Available at: https://www.estep.eu/assets/Uploads/200715-CSP-Roadmap.pdf

Figure 2-14: The objectives tree as set by the Clean Steel Partnership Roadmap[88]



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[88] ibid

2.2.2.3.3 Mission Possible Partnership Roadmap[89]

“Mission Possible” is a roadmap that was developed in 2018 by the Energy Transitions Commission with contributions from over 200 industry experts and outlines the possible routes to fully decarbonize the steel industry.

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

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

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

Figure 2-15: The three significant routes to reaching net zero CO_2 emissions as identified by MPP roadmap[90]

Demand management	**Maximum CO_2 emissions reduction potential**
• Greater and better scrap recycling • Redesigning products for materials efficiency and circularity • More intensive use of steel-based products (e.g. sharing)	**-38%**
Energy efficiency	
• Use high-pressure gas leaving the furnace to power other equipment • Coke dry quenching	**-15/20%**
Decarbonization technologies	
• Scrap-based EAF	**-100%**
• Gas-based DRI (transition fuel)	**-50%**
• Charcoal in BF/BOF (localized)	**-100%**
• Carbon capture	**-90%**
• Hydrogen-based DRI	**-100%**
• Electrolysis of iron	**-100%**

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

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

2.2.2.4 Steel Sector Initiatives[91,92]

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

Table 2-6: Steel sector initiatives overview

Initiative	Overview of general direction
Mission Innovation Initiative	Aims to accelerate actions and investments in R&D making clean energy attractive, affordable and accessible for all to reach the PA goals towards net zero. • Identify goals and providing a regulatory framework. • Ensure sufficient access to materials needed in the manufacturing process. • Reform of the electricity market design.
First Movers' Coalition (FMC) Initiative	Aims 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.
Industrial Deep Decarbonization Initiative (IDDI)	The IDDI aims to motivate the call for low-carbon materials through green public procurement (GPP) by: • Globally standardizing the definition of low-carbon steel and how to calculate the embodied carbon. • Developing and publicly disclosing a global framework with accessible data that is easy to navigate. • Setting up a worldwide standard goal for the public procurement of green steel.
Science Based Targets initiative (SBTi)	Aims at achieving the PA 1.5°C goal by motivating companies to set science-based targets and enhance their competitive advantage in the transformation to a net zero economy. • Integrate new pathways in SBTi's target-setting tool. • Identify and assess the 1.5°C goal modeling scenarios. • Integrate the adjusted Sectoral Decarbonization Approach (SDA) calculation method for the steel industry. • Road-test new target-setting resources. • Develop guidance for science-based target-setting in the steel sector.
WSA Climate Action: Policy and initiatives	Aims to achieve PA goals by reducing CO_2 emissions. • Reduce emissions from the manufacturing process. • Encourage reuse, remanufacturing and recycling processes. • Develop advanced steel products to reach net zero carbon dioxide emissions.

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[91] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en

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

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

A 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[93]. 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.

2.2.2.4.3 Industrial Deep Decarbonization Initiative (IDDI)[94,95]

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

- Globally standardizing the definition of low-carbon steel and how to calculate the embodied carbon.
- Developing and publicly disclosing 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 centres. 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, the United Arab Emirates (UAE) the United States, and Brazil are members of the IDDI, with more countries 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 reductions.

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

[94] https://www.industrialenergyaccelerator.org/areas-of-work/the-industrial-deep-decarbonization-initiative/

[95] https://www.cleanenergyministerial.org/initiatives-campaigns/industrial-deep-decarbonisation-initiative/

2.2.2.4.4 Science Based Targets initiative (SBTi)[96]

The SBTi aims to develop a set of science-based target-setting procedures, tools and guidance that will assist steel companies and other stakeholders to understand the target-setting ambition, short-term and long-term, essential for meeting the 1.5°C goal of the Paris Agreement.

The SBTi Steel Project procedures, tools and guidance include:

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

The SBTi Steel Project was mobilized at the end of November 2021 and the official launch and socialization of resources was expected by September 2023 by 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.

2.2.2.4.5 WSA Climate Action: Policy and Initiatives

World Steel Association members have set the "Climate Action: Policy and Initiatives"[97] aim to reduce CO_2 emissions from the 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 by reducing their own impact.
- Achieving efficiency and the circular economy by encouraging reuse, remanufacturing and recycling – all key elements of the circular economy.
- Enabling 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 in 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 is a summary of the roadmap's findings.

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[96] https://sciencebasedtargets.org/resources/files/SBTi-Steel-Guidance.pdf

[97] 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)	2025-2050
	Limit long-term global average temperature rise to 2°C by achieving necessary emissions reductions by 2050.
		• Catalytic and related process improvements offer a 20% to 40% reduction in energy intensity for chemical products by 2050, considering various scenarios.
		DECHEMA Model:
		• Energy savings potential approaching 13.2 Exajoules (EJ) by 2050 and 1 gigatonnes (Gt) of carbon dioxide equivalent (CO_2eq) per year by 2050 versus a “business-as usual” scenario.
		IEA Model:
		• Energy efficiency improvements, closely linked to the catalysis roadmap, contribute to over 60% of projected emissions reductions in the IEA 2DS scenario.
		• Other significant reductions come from carbon capture and storage (CCS) at 25% and energy recovery at 8%.
		• Fuel switching, specifically from coal to gas, accounts for only 4% or less of emissions reductions.
		• 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.
		• Low-Demand Case:
		  • Energy use in the chemicals sector is projected to increase from 42 EJ in 2010 to 85 EJ in 2050.
		  • 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.
		  • This scenario also assumes a higher level of biomass and waste use, accounting for 4% of total chemical energy use by 2050.
		• High-Demand Case:
		  • Energy use in the chemicals sector could increase to 96 EJ in 2050, reflecting higher demand.
		  • The emissions reduction potential is still significant, considering energy efficiency improvements and other measures outlined in the IEA 2DS scenario.
		• The roadmap does not give a specific percentage for each technology but these technology categories were discussed regarding the technology needs and mentioned the ROI of each one.
		• Feedstock production efficiency: olefins
		• Alternative means of fuel production: fuels
		• Biomass as feedstock: ethanol/ethylene and aromatics
		• Hydrogen production.
			• Stakeholder collaboration and public-private partnerships are crucial for success.
			• Governments should create a favorable environment for energy efficiency gains and emission reductions.
			• Industry must prioritize top opportunities, accelerate investments and R&D, and collaborate with academia.
			• Policy support for R&D is essential.
			• All stakeholders should contribute to innovation from training to industrial-scale R&D.

Table 2-7: Chemicals Sector Roadmaps Summary (continued)

Roadmap	Mitigation target and timeframe	Technology focus	Enabling Policies

The Future of Petrochemicals – Towards more sustainable plastics and fertilizers	2030-2050	• Emissions reduced by 45% by 2050.
		• Plastic recycling:
		  • Secondary plastic production volumes from recycled resins increase by 65% by 2030 and double by 2050.
		• Feedstock changed:
		  • Oil feedstock demand for primary chemical production in the CTS is 5% lower in 2030 and 13% lower in 2050, relative to the RTS.
		• CCUS:
		  • 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 gigatonnes of carbon dioxide ($GtCO_2$) is captured cumulatively by 2050, 10% of which is captured before 2030.
		• Coal to natural gas shifts.
		• For methanol and ammonia, an almost entire shift away from coal to natural gas and coke oven gas takes place in the CTS.
		• Energy Efficiency:
		  • 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.
		• Innovative low-CO_2 processes.
		• 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.
			• Implementation of effective regulatory actions to reduce CO_2 emissions and air pollution and meet stringent air quality standards.
			• Implementation of plant-level benchmarking schemes and incentivizing their adoption through fiscal incentives.

Table 2-7: Chemicals Sector Roadmaps Summary (continued)

Roadmap	Mitigation target and timeframe	Technology focus	Enabling Policies
Ammonia Technology Roadmap	Net Zero 2050 Stated Policies Scenario (baseline analysis) and Sustainable Development Scenario (net zero CO_2 emissions by 2070).	• CCS: 11% • Electrolysis: 75% • Utilizing efficiency improvements. • Developing supporting infrastructure. • 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. • Policies to improve energy and use efficiency, reducing energy consumption in the ammonia production process. • Support for the development of infrastructure such as storage and transportation facilities to facilitate the deployment and integration of innovative technologies. • 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[98]

Developed in 2013, this 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 chemicals 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 reductions, 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 favourable environment that encourages additional gains in energy efficiency and lowers energy-related emissions. Industry is expected to 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 a 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 chemicals 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[99]

Developed in late 2021, this 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.

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-

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[98] 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

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

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 have 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[100]

Developed in 2018, this report analyzes the chemicals sector and its development in relation to the UN SDGs. The report is focused on mapping the transition towards sustainability and, therefore, is considered as a roadmap. It identifies two priority areas for a sustainable transition in the chemicals 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 chemicals 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.

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

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 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 chemicals 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 Chemicals sector initiatives

The following section details the initiatives observed for the chemical sector, with an overview of each.

Table 2-8: Chemicals Sector Initiative Overview

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

2.2.2.6.1 The Low-Carbon Emitting Technologies initiative[101]

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 chemicals sector on a path to reach net zero by 2050. The initiative aims at enhancing the chemical industry's enabling role for achieving 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 emissions reduction. It involves capturing CO_2 streams from industrial processes and utilizing the captured carbon as a raw material in valuable products or as an energy/hydrogen carrier. While this initiative primarily focuses 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.

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[101] "Low-Carbon Emitting Technologies." https://initiatives.weforum.org/low-carbon-emitting-technologies-initiative/home

3. Low Emissions and Net Zero Technologies and Enabling Policies

This section includes identification of innovative low-emission and net zero technologies and enabling policies towards the implementation of such technologies for each of the HAIs: 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 chemicals 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)

This was done in alignment with the mitigation measures provided by the IPCC. According to the AR6 report, mitigation options which relate to the industrial sector are organized in six equally important strategies: (i) demand for materials; (ii) materials efficiency; (iii) circular economy and industrial waste; (iv) energy efficiency; (v) electrification and fuel switching; and (vi) CCUS, feedstock and biogenic carbon[102].

For each of the technologies obtained, several factors are taken into account to further explain the technology and understand 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[103]
5. Whether the technology is considered cross-sectoral or not

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[102] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf

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

Table 3-1: Low Emissions And Net Zero Technologies For The Cement Sector

Technologies	Circular economy practices for energy consumption reduction			Energy efficiency and direct use of renewable heat and biomass			Carbon capture and storage (CCS) and carbon capture, utilization and storage (CCUS)	
Cement Sector								
Type	Efficiency in design and construction (it includes buildings' design optimization, construction site efficiencies and concrete recycling).	Technologies related to enhancing concrete's efficiency of production (it includes technologies reducing the cement proportion in concrete mix (e.g. using admixtures), in addition to the 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 and demolition waste to air for CO_2 uptake).
Maturity and 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 tonne binder per year (expert judgment).	Investments of about USD 6.25 per m^3 per year of hydrogen (expert judgment). 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.	–

Table 3-1: Low Emissions And Net Zero Technologies For The Cement Sector (continued)

Technologies	Circular economy practices for energy consumption reduction			Energy efficiency and direct use of renewable heat and biomass			Carbon capture and storage (CCS) and carbon capture, utilization and storage (CCUS)	
Implementation timeframe	According to the GCCA roadmap, GHG emissions reductions from implementation will be 7% and 22% in 2030 and 2050 respectively compared to the business-as-usual (BAU scenario).	According to the GCCA roadmap, optimizing concrete production regarding binder utilization can result in the reduction of binder demand emissions of 5% and 14% in 2030 and 2050 respectively compared to the BAU scenario.	According to the 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 a 0.5% reduction in overall CO_2 emissions.	According to the 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 is expected to increase from 6% at present to 22% by 2030 and 43% by 2050.	According to the 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 the GCCA roadmap, global recarbonation is expected to be 318 and 242 Mt CO_2 in 2030 and 2050 respectively and there will be a reduction of CO_2 emissions from cement by 6% in 2050.

Table 3-1: Low Emissions And Net Zero Technologies For The Cement Sector (continued)

Technologies	**Circular economy practices for energy consumption reduction**			**Energy efficiency and direct use of renewable heat and biomass**			**Carbon capture and storage (CCS) and carbon capture, utilization and storage (CCUS)**	
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 needed to incentivize investments in concrete recycling.	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 the production of concrete in project sites.	This will involve changes in codes and standards to allow for an increased percentage of Portland cement alternatives; scaling up best-practice dissemination and support to make use of novel products viable.	Support for adopting hydrogen strategies and technologies that support demand for the industrial sector is required, as the majority of policies in place are focused on demand creation in transportation, even though it accounts for most of the current demand. Also, policies incentivizing relevant R&D activities are required.	Allowing for fast and efficient permitting of captive power plants based on waste heat recovery, appropriate tax policies and incentives for energy efficient plants as well as the revision of energy subsidy programmes are required.	Policies regulating waste management and distribution are required, at both the local and international level. In addition, policies are required to incentivize investments in the full biomass value chain.	Policies are needed to help develop, de-risk and deploy the technology and infrastructure over time to help transform the industry worldwide. This includes financial 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 relevant R&D activities are required.	An innovative set of policies regarding treating crushed concrete as well as building waste is required. This would enable recarbonation to reach its full potential. Also, policies incentivizing 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 The 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 renewable heat and biomass	Carbon capture asd Storage (CCS) and carbon capture, utilization and storage (CCUS)	
Steel Sector								
Type	Steel industry co-products (slag)[104]	Scrap use in the steel industry[105]	Industrial process GHG reduction measures (e.g. energy management systems and recovery of energy throughout the steelmaking process)[106]	Electrolysis in ironmaking (iron ore)[107]	Hydrogen (H_2)-based ironmaking by replacing NG with H_2[108]	Biomass in steelmaking[109] – there are constraints on expanding the supply of bioenergy and possible trade-offs with sustainable development goals, including avoiding conflicts at local level with other uses of land, notably for food production and biodiversity protection[110].	Carbon capture and storage (CCS)[111]	Carbon capture, utilization and storage (CCUS)[112]

[104] https://worldsteel.org/wp-content/uploads/Fact-sheet-Steel-industry-co-products.pdf

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

[106] https://worldsteel.org/wp-content/uploads/Fact-sheet-energy-in-the-steel-industry-2021-1.pdf

[107] https://worldsteel.org/wp-content/uploads/Fact-sheet-Electrolysis-in-ironmaking.pdf

[108] https://worldsteel.org/wp-content/uploads/Fact-sheet-Hydrogen-H2-based-ironmaking.pdf

[109] https://worldsteel.org/wp-content/uploads/Biomass-in-steelmaking.pdf

[110] https://www.iea.org/articles/what-does-net-zero-emissions-by-2050-mean-for-bioenergy-and-land-use

[111] https://worldsteel.org/wp-content/uploads/Carbon-Capture-Storage_2023.pdf

[112] https://worldsteel.org/wp-content/uploads/Carbon-capture-use-and-storage-2023.pdf

Table 3-2: Low Emissions And Net Zero Technologies For The Steel Sector (continued)

Technologies	Circular economy practices for energy consumption reduction		Process Optimization and Efficiency Improvements	Direct use of clean electricity from renewable sources		Direct use of renewable heat and biomass	Carbon capture asd Storage (CCS) and carbon capture, utilization and storage (CCUS)	
Maturity and barriers	Mature About 97.5% worldwide of the material effiency rate was from the contribution of the recovery and use of steel industry co-products.	Mature However, there is a delay in production time and availability for recycling.	Mature Since 1960, energy efficiency has improved savings of about 60% in energy consumed to produce one tonne of crude steel.	Not mature	Mature Since 1960, energy efficiency has improved savings of about 60% in energy consumed to produce one tonne of crude steel.	Mature (albeit at a small replacement ratio)	Not mature 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 in the Netherlands through Tata Steel).	Mature There is a CCUS pilot from the Emirates Steel plant where CO_2 is captured and injected into the Abu Dhabi National Oil Company's oil reservoirs. There is a pilot in the chemicals industry in New Zealand to convert waste gases from a steel plant to ethanol has been replicated on a commercial scale in China (2018). Heidelberg-Cement is also involved in a large-scale carbon capture project at its Lengfurt plant in Germany in partnership with Linde.

Table 3-2: Low Emissions And Net Zero Technologies For The Steel Sector (continued)

Technologies	Circular economy practices for energy consumption reduction		Process Optimization and Efficiency Improvements	Direct use of clean electricity from renewable sources		Direct use of renewable heat and biomass	Carbon capture asd Storage (CCS) and carbon capture, utilization and storage (CCUS)	
Maturity and barriers (continued)								In Brevik, Norway, Heidelberg-Cement’s most advanced CCS project is being developed. This project, known as Brevik CCS, is part of the larger Northern Lights project, which aims to capture CO_2 from various industrial sources and store it permanently underground. The Brevik CCS project is expected to capture 400,000 tonnes of CO_2 annually.

Table 3-2: Low Emissions And Net Zero Technologies For The Steel Sector (continued)

Technologies	Circular economy practices for energy consumption reduction		Process Optimization and Efficiency Improvements	Direct use of clean electricity from renewable sources		Direct use of renewable heat and biomass	Carbon capture asd Storage (CCS) and carbon capture, utilization and storage (CCUS)	
Costs estimation	The slag cost ranges from a few cents to about USD 120/tonne or more.[113]		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 control technology, and material efficiency.	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) The IEA analysis found that the cost of producing hydrogen from renewable electricity by 2030 could fall 30% as a result of cost reductions in renewables and the scaling up of hydrogen production.	Quintupling the supply of biofuels by 2030 will require USD 124 billion annually.	The IEA found that innovative processes (including CCS on the blast furnace, smelt reduction and gas-based DRI) are expected to cost 10-50% more than conventional technology within a given regional context, taking into account that this cost increase significantly exceeds profit margins from steel production today.	Not all CCUS applications have the same cost. The source of CO_2 has direct impact on the cost as follows[114]: • CO_2 from ISR cost range is from about USD 380/tCO_2 to USD 500/tCO_2 • CO_2 from Gas DRI cost range is from about USD 440/tCO_2 to USD 640/tCO_2.

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[113] https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-iron-steel-slag.pdf

[114] https://www.iea.org/commentaries/is-carbon-capture-too-expensive

Table 3-2: Low Emissions And Net Zero Technologies For The Steel Sector (continued)

Technologies	Circular economy practices for energy consumption reduction		Process Optimization and Efficiency Improvements	Direct use of clean electricity from renewable sources		Direct use of renewable heat and biomass	Carbon capture asd Storage (CCS) and carbon capture, utilization and storage (CCUS)	
Costs estimation (continued)							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.	
Implementation timeframe	Already implemented over the past 20 years and the average recovery rate for slag varies from 80% for steel manfacturing to 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. 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 have 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%.[115]	IEA modelling suggests 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 the 'Sustainable Development Scenario' (SDS) as part of the IEA 2020 technology roadmap. Additionally, its use is expected to reach 12 Mt annually by 2050.	For conventional biofuels, the implementation is dependent on the supply chain's ability to meet the demand. For a bio-coal pilot in Brazil, it was found that not all biomass can be used due to its physical and chemical properties.	Under the IEA's core 'Sustainable Development Scenario' (SDS), by 2070 about 75% of all the CO_2 emissions produced globally in iron and steel will be captured.	It is expected by 2030, 2050 and 2070 that CCUS contributions to CO_2 emission reductions will reach 4%, 25% and 31% respectively, with a cumulative reduction of 25%.[116]

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[115] https://www.diva-portal.org/smash/get/diva2:711353/FULLTEXT02.pdf

[116] https://www.iea.org/reports/ccus-in-clean-energy-transitions/ccus-in-the-transition-to-net-zero-emissions

Table 3-2: Low Emissions And Net Zero Technologies For The Steel Sector (continued)

Technologies	Circular economy practices for energy consumption reduction		Process Optimization and Efficiency Improvements	Direct use of clean electricity from renewable sources		Direct use of renewable heat and biomass	Carbon capture asd Storage (CCS) and carbon capture, utilization and storage (CCUS)	
Implementation timeframe (continued)					The IEA's modelling suggests that, by 2050, below 8% of total steel production will utilize electrolytic hydrogen as the primary reducing agent (or 14% of primary production).	Therefore, only improved biomass can be utilized, through torrefaction (bio-coal) or pyrolysis (charcoal). A large-scale demonstration is expected to reach zero emissions by 2025[117].		

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

Table 3-2: Low Emissions And Net Zero Technologies For The Steel Sector (continued)

Technologies	Circular economy practices for energy consumption reduction		Process Optimization and Efficiency Improvements	Direct use of clean electricity from renewable sources		Direct use of renewable heat and biomass	Carbon capture asd Storage (CCS) and carbon capture, utilization and storage (CCUS)	
Potential enabling policies reported	Develop policies to extend the use of co-product in other industries (e.g. cement, glass, fertilizer, etc.) to save natural resources and reduce the environmental impact by raising awareness such as modifying public and political perception needs.	In order to make best use of the expected growth in scrap availability and use, it is recommended that the stakeholders could agree on a global classification given the international nature of scrap trade. A scrap global classification aims to agree on making best use of the expected high growth in scrap availability and use.[118]	Allow for fast and efficient permitting of captive power plants based on waste heat recovery, appropriate tax policies and incentives for energy efficient plants, and the revision of energy subsidy programmes.	Policies are needed for iron electrolysis to become economically 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).	Adopt hydrogen strategies and technologies that support demand for the industrial sector, as the majority of policies in place are focused on demand creation in transportation, even though it accounts for most current demand. Also policies incentivizing relevant R&D activities are required.	Regulations and legislative frameworks should be developed to ensure the good management of forests for the sustainable supply of wood. In addition, policies are required to incentivize investments in the full biomass value chain.	Enabling policies for CCS/CCUS should include financial 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 relevant R&D activities are required.	Enabling policies for CCS/CCUS should include financial 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).

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

Table 3-2: Low Emissions And Net Zero Technologies For The Steel Sector (continued)

Technologies	Circular economy practices for energy consumption reduction		Process Optimization and Efficiency Improvements	Direct use of clean electricity from renewable sources		Direct use of renewable heat and biomass	Carbon capture asd Storage (CCS) and carbon capture, utilization and storage (CCUS)	
Potential enabling policies reported (continued)							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.”	Also policies incentivizing 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.”
Cross-sectoral technology (Y/N)	N	N	Y	N	Y	Y	Y	Y

Table 3-3: Low Emissions And Net Zero Technologies For The 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
Chemicals Sector								
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 and barriers	Fairly mature, but still in progress	Not mature 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.	Not mature	Mature	Not mature	The technology is mature, but not widely implemented in the chemicals sector yet.	Not mature The use of bioenergy in the chemicals sector is still in the early stages of development.	Not mature, but relatively advanced compared to other sectors. 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.

Table 3-3: Low Emissions And Net Zero Technologies For The Chemicals Sector (continued)

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
Maturity and barriers (continued)		Additionally, increased recycling of plastics can also help reduce the demand for primary feedstocks in chemical production.						
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). 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.	CCUS is generally considered to be a costly technology, requiring significant investment in infrastructure and operation.

Table 3-3: Low Emissions And Net Zero Technologies For The Chemicals Sector (continued)

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
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. “Net Zero by 2050 – A Roadmap for the Global Energy Sector” targets 54% reuse in plastics collection and 35% reuse in secondary production.	Not determined in the roadmaps.	Not determined in the roadmaps.	The implementation timeframe for Process Optimization and 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 H2 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 product types.	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. “Net Zero by 2050 – A Roadmap for the Global Energy Sector” targets 540 Mt CO_2 reduction by 2050.

Table 3-3: Low Emissions And Net Zero Technologies For The Chemicals Sector (continued)

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
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[119]. Also policies incentivizing relevant R&D activities are required.	Enabling policies for sustainable feedstock and raw material substitution include sustainability certification schemes for raw materials. Also policies incentivizing 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, fast and efficient permitting of captive power plants based on waste heat recovery, appropriate tax policies and incentives for energy efficient plants, and the revision of energy subsidy programmes are required.	There is a need to adopt hydrogen strategies and technologies that support demand for the industrial sector, as the majority of policies in place are focused on demand creation in transportation, even though it accounts for most current demand. Also policies incentivizing 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. Regulatory systems for the supply chain, as well as forestry preservation policies for coal substitution with bio-coal are required. In addition, policies are required to incentivize investments in the full biomass value chain	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 relevant R&D activities are required.
Cross-sectoral technology (Y/N)	Y	N	N	Y	Y	Y	Y	Y

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[119] "Chemicals," IEA. https://www.iea.org/energy-system/industry/chemicals

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, which is primarily used in cement production 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, improve the ocean environment. However, the decarbonization of steel will reduce the amount of the slag produced.

3.2.2 Carbon Capture and Storage (CCS) and Carbon Capture, Utilization and Storage (CCUS)

CCUS applications include oxygenated compounds (polycarbonate, urethane, etc.), biomass-derived chemicals, commodity chemicals (olefin, BTX, etc.), and minerals (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 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[120].

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[121].

3.2.5 Hydrogen Production and Utilization

Hydrogen production and utilization is another cross-cutting technology with immense potential for 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. 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[122].

[120] ibid
[121] ibid
[122] ibid

3.2.6 Biomass

Biomass is a versatile cross-cutting technology that can contribute significantly to the decarbonization of industry. Biomass can be used as a source of energy in the steel, cement and chemicals sectors in addition to the production of bio-based materials in the chemicals sector. While traditional biomass use is phased out in the Net Zero Energy (NZE) Scenario, modern bioenergy experiences remarkable growth, more than doubling by 2050. This expansion is driven by its capacity to serve as a direct drop-in substitute for fossil fuels and is supported by investments in advanced conversion technologies. Modern solid bioenergy is anticipated to increase from 11 exajoules in 2022 to 22 exajoules by 2050, contributing significantly to the industry's efforts to reduce cumulative emissions by approximately 7%.[123]

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 industry.
As industry seeks to reduce its reliance on fossil fuels, the adoption of bioenergy can play a significant role in achieving carbon neutrality[124].

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[123] Ibid
[124] ibid

4. Country Level Analysis

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 were 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 geographical location, size of economy and technological advancement. The countries targeted for selection represent a significant contribution in the sectors defined by the study, which are cement, steel and chemicals & petrochemicals. Accordingly, a set of selection criteria was formulated to serve this purpose. The details of the selection levels, criteria and assigned weighted scores can 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 favour 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 emissions indicators relative to the production capacity (CO_2/tonne 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 are required 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.

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[125].

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[126].

[125] https://unfccc.int/ttclear/tna

[126] https://unfccc.int/sites/default/files/resource/sbi2020_inf.01.pdf

Table 4-2: Countries Retrieved Data Analysis For The 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) • Progress on the implementation of NDC (2022) • Second BUR (2018) • China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy (2021) • TNA (1998) **Other Documents:** • China Cement Association, Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022	**No HAI data was retrieved from UNFCCC submitted documents.** **Production** (2021): • 2.365 billion tonnes **CO_2 emissions:** • Our World in Data: 0.853 billion tonnes CO_2 (2021).[127] • CCA, Towards Net Zero Roadmap: 1.37 billion tonnes CO_2 (2020).[128] **Tonnes CO_2/tonne cement:** • 0.36 tonnes CO_2/tonne cement (according to Our World in Data 2021). • 0.58 tonnes CO_2/tonne cement (according to CCA 2020 data:) • 0.6 tonnes CO_2/capita.	**No HAI data was retrieved from UNFCCC submitted documents.** **Reaching Net Zero emissions by the year 2060.**[129] Goals breakdown relative to 2020 emissions: 2030: ~ 30% reduction 2040: ~ 70% reduction 2050: 85% reduction	• Currently, energy efficiency measures to maintain the energy consumption per tonne of cement within or below the world average are ongoing and need to continue. • 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. • Planned introduction of hydrogen and green electricity as a long-term goal. • Raw material substitution from industrial waste, which is dependent on availability, and the utilization of new low-carbon clinker is considered as more of a future plan.	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. Also, China's 14th Five-Year Plan calls for the pursuit of hydrogen technology as part of industrial transformation, as well as China's Mid- to Long-Term Hydrogen Industry Development Plan (2021–35)[130]. Also, China has been exploring a variety of innovative mechanisms such as paid allocation, carbon finance and inclusive carbon.

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[127] https://ourworldindata.org/grapher/annual-co2-cement?tab=table

[128] China Cement Association, Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022. Available at: https://rmi.org/wp-content/uploads/dlm_uploads/2023/02/toward_net_zero_decarbonization_roadmap_for_chinas_cement_industry_executive_summary.pdf)

[129] China Cement Association, Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022. Available at: https://rmi.org/wp-content/uploads/dlm_uploads/2023/02/toward_net_zero_decarbonization_roadmap_for_chinas_cement_industry_executive_summary.pdf)

[130] https://rmi.org/insight/net-zero-decarbonization-in-chinas-cement-industry/#download-form

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
China (continued)				• CCUS is identified as an important player on the road to net zero cement. However, the distances between plants and the high cost of transportation are the main identified barriers to implementation.	
Indonesia	• NDC (2022) • Third BUR (2021) • Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (2021) • Second TNA on mitigation (2012) **Other Documents:** • An Energy Sector Roadmap to Net Zero Emissions in Indonesia (2022)	**Production[131]:** • 43.09 Mt (2010). • 76.2 Mt (2019). • Production capacity decreased significantly to about 18.9% in 2020 and reached 71.8 Mt.[132] • Estimated to be 70.4 Mt in 2021.[133] • Expected to reach 81.6 Mt in 2030 and 99.6 Mt in 2050. **Emissions[134]:** • 286 Mt CO_2 in 2021, with annual CO_2 emissions per capita of 0.1 tonnes[135]	By 2030, Indonesia aims to reach[136]: • 81% clinker-to-cement ratio in BaU. • 70% clinker-to-cement ratio in CM1 with a GHG emissions reduction target of 2.75 Mt CO_2. • 65% clinker-to-cement ratio in CM2, with a GHG emissions reduction target of 3.25 Mt CO_2.	• Use of thermal and electrical efficiency measures through the application of ISO 50001, using energy efficient equipment and energy leakages prevention. • Clinker substitution through the encouragement of production, developing regulations to promote the use of low carbon cement and R&D of low-clinker content cement. • Increase the use of alternative fuels and raw materials to replace fossil fuels through waste utilization and strengthening the supply chain.	Yes, due to developing near-term milestone strategies and implementing supporting polices and regulations that led to voluntarily reductions in CO_2 emissions of 2% from 2011 to 2015 and obligatorily of 3% between 2016 and 2020. Also, publishing a commitment to realize zero emissions by 2060 in the cement industry[137].

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[131] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
[132] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
[133] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
[134] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[135] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[136] https://unfccc.int/sites/default/files/NDC/2022-09/23.09.2022_Enhanced%20NDC%20Indonesia.pdf
[137] https://iea.blob.core.windows.net/assets/b496b141-8c3b-47fc-adb2-90740eb0b3b8/AnEnergySectorRoadmaptoNetZeroEmissionsinIndonesia.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Indonesia (continued)				• Integrate CCS and CCUS technologies in cement plants based on investment opportunities and R&D[138]. • Establish green standards for the cement industry that consider achieving emissions targets.	

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[138] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

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 (2023) **Other Documents:** • Waste heat recovery in Turkish cement industry: review of existing installations and assessment of remaining potential • Turkish Cement Focus (Globalcement.com) • Abstract on the potential GHG emissions reduction in Türkiye through the cement industry (Cementis)	**Production:** • Production amounts not available. • **Emissions[139]:** • Total IPPU sector emissions of 66.8 Mt CO$_2$eq 2020).[140] • Cement sector emissions of 45.6 Mt CO$_2$eq (2020), representing 8.7% of national GHG emissions. • 44.4 Mt CO$_2$eq in 2021, with annual CO$_2$ emissions per capita of 0.52 tons.[141]	• Türkiye to shift all CEM I to LC3 to reduce CO$_2$ emissions from fuel[142]. This is expected to cut CO$_2$ emissions by 12.4 Mt of CO$_2$eq.[143] • Türkiye has implemented a pilot phase for measuring, reporting and verification (MRV) of emission reductions in the cement, refinery and electricity sectors, which covers approximately 55% of Türkiye's total emissions.[144]	• Enhance the application of CO$_2$ emissions technologies in cement production, as well as material use, fuel resources and energy saving measurements and assess the cost-effectiveness of alternative scenaris. • Clinker substitution through the encouragement of production, developing regulations to promote use of low-carbon cement and R&D into low-clinker content cement. • Increase the use of alternative fuels and raw materials to replace fossil fuels through waste utilization and strengthening the supply chain. • 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 the cement, refinery and electricity sectors[145].

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[139] https://unfccc.int/sites/default/files/resource/8NC-5BR%20T%C3%BCrkiye.pdf

[140] https://unfccc.int/sites/default/files/resource/8NC-5BR%20T%C3%BCrkiye.pdf

[141] https://ourworldindata.org/grapher/annual-co2-cement?tab=table

[142] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf

[143] https://www.cementis.com/wp-content/uploads/2018/08/Turkey-GHG-from-Cement.pdf

[144] https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf,

[145] https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Japan	- NDC (2021) - BR (2019) - Long-Term Strategy under the Paris Agreement (2021) **Other Documents:** - Our World in Data (website) - Technology Roadmap for "Transition Finance" in Cement Sector (Ministry of Economy, Trade and Industry)	**Production:** - 58 M tonnes (2019). **Emissions:** - 23.8 Mt CO_2 with annual CO_2 emissions per capita of 0.19 tonnes.[146]	- Reaching carbon neutrality by 2050, as indicated in the roadmap "Carbon Recycling Technologies".[147]	- Support the research and development of innovative technologies to include carbon neutral related studies. - Support low-carbon and decarbonization technologies to become commercial in the cement sector by linking it with other sectors. - Consider overcoming the drastically changed energy-intensive sector, which will result in making carbon neutrality hard to be applied in Japan. - Support the technologies financially to overcome uncertainties in their implementation. - Work on transition, including energy conservation and energy transition aiming at decarbonization, and advance efforts on energy saving/ efficient technologies.[148].	Yes, due to boosting innovative technologies, such as the use of raw materials during clinker production, cement with a low clinker ratio and cement with high blended material ratio[149]. Also, developing supporting laws and standards such as mandating to classify and recycle waste generated during construction and demolition works. Japan has developed standards for recycled concrete aggregate (RCA) and recycled-aggregate concrete (RAC)[150]. Japan is also an advocate for international cooperation as it has partnered with Australia on a de-carbonization through technology project.[151]

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[146] https://ourworldindata.org/grapher/annual-co2-cement?tab=table
[147] https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_cement_eng.pdf
[148] https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_cement_eng.pdf
[149] https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_cement_eng.pdf
[150] https://link.springer.com/article/10.1007/s10163-022-01412-x
[151] https://gaspathways.com/cemex-invests-in-hiirocs-clean-hydrogen-technology-596

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Germany	• NDC (2020) • BR (2019) • Update to the long-term strategy for climate action of the Federal Republic of Germany (2022) **Other Documents:** • Decarbonizing Cement and Concrete: A CO_2 Roadmap for the German cement industry • Our World in Data (website)	**Production:** • No production data stated **Emissions:** • The general EU GHG reduction target is 55% by 2030 compared to 1990 levels (including Germany).[152] • The sectors covered included industrial processes and product use. • 13.2 Mt CO_2 in 2021, with an annual rate per capita from the cement industry of 0.16 tonne/capita.[153]	• A study conducted by the German association for cement (VDZ) shows a 27% reduction in CO_2 is expected to be reached by 2030 as part of the neutrality scenario and a 36% reduction by 2050 under the ambitious reference scenario.[154]	• Provide the necessary infrastructure – for example, the infrastructure needed for carbon-free power consumption and the transportation of CO_2 and hydrogen. • Increase the usage of carbon capture technologies. • Create a collaboration among the whole value chain and start including suppliers, manufacturers and designers. • Apply an effective policy to allow the competitive production of low-carbon technologies and create markets. • Provide a policy framework for competitiveness and innovative markets for low-and carbon neutral cement.	Yes, due to adopting innovative technologies. Alongside reduction in the clinker content in cement and the increased use of alternative fuels 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[155].

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[152] https://unfccc.int/sites/default/files/NDC/2022-06/EU_NDC_Submission_December%202020.pdf

[153] https://ourworldindata.org/grapher/annual-co2-cement?tab=table

[154] https://hakangurdal.com/wp-content/uploads/2021/10/Executive_Summary_VDZ_Study_Decarbonising_Cement_and_Concrete_2020.pdf

[155] https://hakangurdal.com/wp-content/uploads/2021/10/Executive_Summary_VDZ_Study_Decarbonising_Cement_and_Concrete_2020.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Mexico	• Third BUR (2022) – in Spanish • Mexico's Climate Change Mid-Century Strategy (2016) • NDC (2022) – in Spanish **Other Documents:** • The Mexico-FICEM 2030 Roadmap • Our World in Data (website)	**Production:** No data available **Emissions:** • Total industrial sector emission was 30.9 Mt CO_2eq in 2019. • The cement sector was reported as 19.4 CO_2eq[156]. • Total emissions of 22,339,198 tonnes of CO_2eq in 2021.[157] • Carbon emissions per capita were 0.18 tonnes per capita in 2021. • In 2013, emissions from the industry sector were 114.9 Mt of CO_2eq, 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_2eq due to industrial processes.[158]	• A roadmap of the cement industry was launched in 2023, which was based on the roadmap of the Cement Sustainability Initiative of the year 2018. • Mexico aims to reduce the carbon intensity of the cement industry to be 520 kg CO_2/tonne cement, instead of 629 kg CO_2/ tonne cement. This would achieve a 17% reduction in carbon emissions.[159] • Increasing the co-processing rate up to 32%. • Reducing clinker content in the cement to 66%.	• Based on the study conducted by Global Efficiency Intelligence and the Lawrence Berkeley National Laboratory, five key pillars can help in the reduction of CO_2 emissions in Mexico. These pillars are: energy-efficiency; fuel switching; clinker substitution; and carbon capture, utilization and storage. The use of modern technologies that support each pillar is required in Mexico.[160] • Cooperation between different sectors such as academia, industry, government, etc., providing green financing and enhancing the regulatory framework are all requirements to achieve the goals in Mexico's roadmap.	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 decarbonization 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[161].

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[156] https://unfccc.int/sites/default/files/resource/Mexico_3er_BUR.pdf
[157] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf
[158] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf
[159] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf
[160] https://gccassociation.org/2050-net-zero-roadmap-one-year-on/action-progress-case-studies-canacem/
[161] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Mexico (continued)				- Promote the deployment of emissions reduction mechanisms such as: a) the co-processing of waste through joint work with authorities at all levels; b) low-carbon cement and concrete through the work at the regulatory level; and c) consumption of less energy per unit of product through the optimization of clinker kilns.[162]	
Vietnam	- NDC (2022) - BUR3 (2021) - NIR (2021) **Other Documents:** - Final Readiness Plan for the Cement Sector in Vietnam (2016) - USAID Vietnam Low Emission Energy Problem (V-LEEP) - Our World in Data (website)	**Production:** There is no production data. **Emissions:** - Total emissions in 2016 were 316 Mt CO_2eq of which the IPPU was 14.6% (46 Mt CO_2eq). - Cement accounted for 79.8% of the IPPU (36.8 Mt CO_2eq).[163] - 54.1 Mt of CO_2 emissions in 2021, with 0.56 tonnes annual CO_2 emissions from cement industry per capita.[164]	- In 2014-2015, MOC has developed a completed MRV tool for the cement sector under the support of the Nordic Development Fund which is based on the CSI Cement CO_2 and Energy Protocol. These solutions to reduce GHG emissions have resulted in reducing 4.06 MtCO_2eq in the sub-sectors of mining, construction materials and chemicals.[165]	- Support for 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. - Improve the current technical level, skills and knowledge in these technologies, which can help to overcome many difficulties in technology implementation. - The economic scale and the lack of capital resources are still barriers against Vietnam's efforts in the cement industry.	Partially yes, as Vietnam is working under finance mechanisms support as it has gained funding from the Nordic Development Fund (NDF) with the project "Pilot Program for Supporting Up-scaled Climate Change Mitigation Action in Vietnam's Cement Sector". Vietnam is also starting 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 is seeking international financial support for capacity building.

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[162] https://canacem.org.mx/site/wp-content/uploads/2023/03/Hoja-de-Ruta-Mexico-FICEM.pdf

[163] https://unfccc.int/sites/default/files/resource/Viet%20Nam_NIR2016.pdf

[164] https://ourworldindata.org/grapher/annual-co2-cement?tab=table

[165] https://unfccc.int/sites/default/files/NDC/2022-11/Viet%20Nam%20NDC%202022%20Update.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Vietnam (continued)				• A national target programme should be developed to support energy audit fees for cement plants. • Increase the tariff in the electricity price as it is considered low in Vietnam and there has been no clear roadmap for the near future to motivate the industry to implement these technologies.	Vietnam has developed a completed MRV tool for the cement sector with the support of the same fund.[166] However, having only an MRV system does not mean that the country is aligned with the IEA 2050 roadmap since there is no clear plan to implement specific technologies.
Egypt	• NDC (2023) • BUR1 (2019) • TNA (2001) **Other Documents:** • Low Carbon Roadmap for the Egyptian Cement Industry 2016)(• Our World in Data (website)	**Production:** No production data available **Emissions:** • The total IPPU sector emissions were 12.5% of total GHG emissions (about 40.6 Mt CO_2eq) for 2015. Cement alone was reported as 51% of IPPU emissions (20 Mt CO_2).[167] • 16.2 Mt CO_2 in 2021, with an annual CO_2 emission of 0.15 tonnes per capita.[168]	• For Egypt, no official plans are written in the UNFCCC documents. However, the roadmap of EBRD included a 15% reduction in CO_2 emissions to be achieved by 2030.[169]	• Assess the technologies available in the cement industry objectively as well as their energy saving and CO_2 mitigation potential. • Provide the financial and economic conditions to allow cement companies to effectively implement mitigation technologies. • Government efforts for the cement industry also include implementing alternative fuels partial substitution, lowering the clinker content in cement up to 80% conditional on meeting relevant national standards and energy efficiency improvements.[170]	Partially yes, due to developing supporting R&D and studies. Egypt has developed the “Low-Carbon Roadmap for the Egyptian Cement Industry”. This Roadmap was developed under the EBRD-funded project, “Egypt: Technology and Policy Scoping for a Low-Carbon Egyptian Cement Industry”[171]. Also, the supporting policy measurements such as the ministerial Decree 49/2021 for mandatory partial replacement of alternative fuels in the cement sector that was issued in March 2021 by the Ministry of Environment[172].

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[166] https://pdf.usaid.gov/pdf_docs/PA00ZGKC.pdf

[167] https://unfccc.int/sites/default/files/resource/BUR%20Egypt%20EN.pdf

[168] https://ourworldindata.org/grapher/annual-co2-cement?tab=table

[169] https://www.thegreenwerk.net/download/Low_Carbon_Roadmap_for_the_Egyptian_Cement_Industry.pdf

[170] https://unfccc.int/sites/default/files/NDC/2023-06/Egypts%20Updated%20First%20Nationally%20Determined%20Contribution%202030%20%28Second%20Update%29.pdf

[171] https://www.thegreenwerk.net/download/Low_Carbon_Roadmap_for_the_Egyptian_Cement_Industry.pdf

[172] https://unfccc.int/sites/default/files/NDC/2023-06/Egypts%20Updated%20First%20Nationally%20Determined%20Contribution%202030%20%28Second%20Update%29.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Egypt (continued)		• Carbon emissions from the cement industry are expected to increase about 820 kg CO_2 per tonne cement as a result of environmental law amendments in April 2015.[173]		• Provide the adequate policy, legislative and regulatory actions, appropriate financial resources and preservation of the industry's competitiveness. • Institutionalize regular consultations with stakeholders involved in the implementation of such policy measures – for example, a regular roundtable or a steering committee.	However, there is still a need for clear plans in the UNFCCC document as plans in other supporting documents are not enough.
Belize	• NDC (2021) • BUR (2021) • Low Emissions Development Strategy and Action Plan (2023)	No production or emissions data retrieved for the sector.			No
Mauritania	• NDC (2022) • Second BUR (2021) • TNA (2017) – in French	No production or emissions data retrieved for the sector.			No

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[173] https://www.thegreenwerk.net/download/Low_Carbon_Roadmap_for_the_Egyptian_Cement_Industry.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Steel Sector					
China	• NDC (2021) • Progress on the implementation of NDC (2022) • Second BUR (2018) • China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy (2021) • TNA (1998) **Other Documents:** • Comparison of carbon dioxide emissions intensity of steel production in China, Germany, Mexico, and the United States (2016) • Climate Transparency Report: Comparing G20 Climate Action (2022) • Iron and Steel Technology Roadmap • Net-Zero Roadmap for China's Steel Industry	**Production:** • 50% of world steel production was from China in 2014, based on Worldsteel.org statistics. **Emissions:** • 272.7 Mt of CO_2 emissions from metal production.[174] • Carbon intensity reached 1562.2 $kgCO_2$/tonne product in 2019.[175]	• Under the Net Zero scenario, total CO_2 emissions will decrease to about 78 Mt CO_2 per year in 2050.[176] • 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 the steel industry. • Continuously reduce carbon dioxide emissions from industrial processes. • Accelerate the construction of green and zero-carbon industrial parks and supply chain pilots.[177]	• Adoption of electric furnace steelmaking – the hot-rolling, short-process production process. • 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. • 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 actively promoting new technologies to reduce emissions from the 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 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.

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[174] https://www.sciencedirect.com/science/article/abs/pii/S0921344916301458

[175] https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-China-Web.pdf

[176] https://www.globalefficiencyintel.com/netzero-roadmap-for-china-steel-industry

[177] https://unfccc.int/sites/default/files/resource/China%E2%80%99s%20Mid-Century%20Long-Term%20Low%20Greenhouse%20Gas%20Emission%20Development%20Strategy.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Indonesia	• NDC (2022) • Third BUR (2021) • Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (2021) • Second TNA on mitigation (2012) **Other Documents:** • Climate Transparency Report: Comparing G20 Climate Action and Responses to the Covid-19 Crisis	**Production:** • 15 Mt per year, which increased by 12.6% per year from 2010 to 2016 and is estimated to stay relatively stagnant until 2030.[178] • Production is expected to grow 5.59% per year from 5.76 Mt in 2030 to 17.1 Mt in 2050.[179] **Emissions:** • 6,927 Gg of CO_2eq in 2019.[180] • Carbon intensity of steel production was 1656 kgCO_2 tonne product in 2016.[181]	• Indonesia has energy efficiency and energy management policies focused on industry, with targets for a 15.4% reduction in GHG emissions for the iron and steel industry.[182] • Reduction target of 0.6 Mt CO_2eq by 2030 for CM1. • Reduction target of 0.9 Mt CO_2eq by 2030 for CM2.	• Enhance utilizing scrap as an alternative material (iron ore) in direct reduced iron (DRI) and basic oxygen furnace (BOF).[183]	Yes, as improvements have been implemented in the steel industry, including change in technologies (e.g. from DRI to blast furnace and BOF) besides the implementation of energy efficiency and energy management policies.

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[178] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf

[179] https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf

[180] https://www.climate-transparency.org/wp-content/uploads/2020/11/Indonesia-CT-2020-WEB.pdf

[181] https://www.climate-transparency.org/wp-content/uploads/2020/11/Indonesia-CT-2020-WEB.pdf

[182] https://www.climate-transparency.org/wp-content/uploads/2020/11/Indonesia-CT-2020-WEB.pdf

[183] https://unfccc.int/sites/default/files/resource/IndonesiaBUR%203_FINAL%20REPORT_2.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

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 (2023) **Other Documents:** • Climate Transparency Report: Comparing G20 Climate Action • 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:** • No data available **Emissions:** • GHG emissions from iron and steel were 11.52 Mt CO_2eq (2020).[184] • Carbon intensity of steel production was 775.3 $kgCO_2$/tonne product in 2019.[185]	• Ambition to reduce carbon emissions increased from 21% to 41% by 2030 compared to Türkiye's first NDC BAU scenario.[186]	• Türkiye continues to rely on fossil fuels, 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" and achieving legislative enforcement, including measuring, reporting and verification (MRV) of emissions reductions in the steel industry, and electricity sectors[187]. However, the IEA roadmaps include fuel switching to 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.

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[184] https://unfccc.int/sites/default/files/resource/8NC-5BR%20T%C3%BCrkiye.pdf

[185] https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Turkey-Web.pdf

[186] https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf

[187] https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Japan	• NDC (2021) • BR (2019) • Long-Term Strategy under the Paris Agreement (2021) **Other Documents:** • Green Public Procurement of Steel in Japan (2023) • Japan-Australia Partnership on Decarbonization Through Technology (2022) • Iron and Steel Technology Roadmap (2020)	**Production:** • 99 million tonnes of steel were produced in 2019. **Emissions:** • CO_2 emissions and removal in the iron and steel industry in 2015 was 160,299 thousand tonnes CO_2.[188]	• Japan recently released roadmaps for de-carbonizing the iron and steel sector, setting out specific targets and laying out concrete steps for its steel sector, with the French plan calling for emission reductions of 31% by 2030.[189]	• Japan is aiming to develop technologies to substantially reduce emissions from the blast furnace.[190] • Use CCUS technology to reuse off-gases from blast furnaces to reduce energy input requirements.[191] • Use technologies that enable the usage of hydrogen and fuel ammonia 26 since many iron and steel factories are located in ports and coastal areas.[192] • Create 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 decarbonizing the iron and steel sector, allowing new technologies to reduce emissions, reusing off-gases and enabling the usage of clean energy. Additionally, supporting R&D studies to accelerate reaching net zero emissions.

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[188] https://unfccc.int/sites/default/files/resource/Japan-BR3-3-BR3-JPN-E.pdf

[189] https://www.iea.org/reports/iron-and-steel

[190] https://www.iea.org/policies/14739-japan-australia-partnership-on-decarbonisation-through-technology

[191] https://www.iea.org/policies/14739-japan-australia-partnership-on-decarbonisation-through-technology

[192] https://unfccc.int/sites/default/files/resource/Japan_LTS2021.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Germany	• NDC (2020) • BR (2019) • Update to the long-term strategy for climate action of the Federal Republic of Germany (2022) **Other Documents:** • Achieving Net Zero Heavy Industry Sectors in G7 Members • Climate Transparency Report: Comparing G20 Climate Action • Greenhouse gas emissions in the steel industry in Germany from 1995 to 2020 (Statista)	**Production:** No data available **Emissions:** • Around 48 million tonnes of CO_2eq in 2020.[193] • Carbon intensity of steel production was 1,174 kgCO_2/tonne product in 2019.[194]	• Germany has committed to becoming greenhouse gas-neutral by 2045. After 2050, the greenhouse gas balance is to be negative.	CCUS Technology: • By 2025, Converting off-gases to chemicals: the Carbon2Chem pilot plant in Germany initiated by ThyssenKrupp in 2018 has produced ammonia and methanol from steel off-gases and is aiming for industrial-scale production by 2025 (ThyssenKrupp, 2020a and 2020b). • By 2030, use CCUS in blast furnaces: off-gas hydrogen enrichment and/or CO_2 removal for use or storage, with ROGESA pilot testing an H2-rich coke oven gas in a blast furnace in Germany, with implementation in two blast furnaces expected as early as 2020 (Saarstahl, 2019). Hydrogen technology: • By 2030, natural gas-based DRI • Salzgitter steelworks is undertaking a 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).	Yes, due to adopting innovative technologies.

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[193] https://www.statista.com/statistics/1395878/greenhouse-gas-emissions-steel-industry-germany/

[194] https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Germany-Web.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Germany (continued)				• ThyssenKrupp is planning to build commercial DRI plants incorporating hydrogen by the mid-2020s (ThyssenKrupp, 2020a).	
Mexico	• Third BUR (2022) – in Spanish • Mexico's Climate Change Mid-Century Strategy (2016) • NDC (2022) – Spanish **Other Documents:** • Climate Transparency Report: Comparing G20 Climate Action	• Total CO_2 emissions from the metals industry were 17,305.67 $GgCO_2eq$ in 2019 and the share of the iron and steel production was 16,887.72 $GgCO_2eq$.[195] • The carbon intensity of steel production was 915 $kgCO_2$/tonne product in 2019.[196]	• Mexico has set a mitigation action with regards to 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 the steel industry.[197]	Hydrogen technology: • DRI: Natural gas-based with high levels of electrolytic H2 blending: In the 1990s Tenova tested 90% hydrogen use in Mexico (at a scale of 9 kt/yr DRI production) (Tenova, 2018). CCUS technology: • DRI: Natural gas-based with CO_2 capture: Currently, there are two plants operating 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 a source of energy, industrial process redesign, and CO_2 capture technologies.

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[195] https://unfccc.int/sites/default/files/resource/Mexico_3er_BUR.pdf

[196] https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Mexico-Web.pdf

[197] https://unfccc.int/files/focus/long-term_strategies/application/pdf/mexico_mcs_final_cop22nov16_red.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Vietnam	• NDC (2022) • BUR3 (2021) • NIR (2021) **Other Documents:** • Final Readiness Plan for the Cement Sector in Vietnam (2016) • USAID Vietnam Low Emission Energy Problem (V-LEEP)	**Production:** • The total designed capacity of the sector is 19 million tonnes of crude steek per year. • Actual production was 15,471 thousand tonnes in 2018. **Emissions:** • GHG emissions in 2018 were 30.12 million tonnes CO_2 using BOF technology and 5.67 million tonnes using EAF technology. • The carbon intensity of steel production in 2018 was 2.51 tonnes CO_2 per tonne of crude steel from BF-BOF technology and 0.8 tonnes CO_2 per tonne of crude steel from EAF technology.	• By implementing the mitigation measures announced by Vietnam:[198] • A reduction of up to 5.3 million tonnes of CO_2eq can be reached by 2025. • A reduction of up to 10.8 million tonnes 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”. • The potential exists in principle to reduce the net emissions of ironmaking essentially to zero by means of breakthrough technologies as below (will not be commercially available before 2030): 1. Reduction of iron oxide by hydrogen (H_2O) emissions instead of CO_2 if the hydrogen is made from water using renewable electricity. 2. Metal (Fe) production by electrolysis if the electricity for electrolysis is renewable. 3. Carbon capture and storage (stopping the release of CO_2 into the atmosphere) technology may be feasible only in very specific locations with suitable geological structures and might not be scalable.	Partially yes, as Vietnam has identified the breakthrough technologies essential to reach net zero such as using hydrogen and/or renewable energy sources to reduce iron ores to iron. Additionally, energy benchmarking has been initiated and developed for the steel industry, but not released.

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[198] FINAL TASK 2 REPORT Development of a pilot crediting program applicable for the steel sector in Vietnam, December 2020

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Egypt	- NDC (2023) - BUR1 (2019) - TNA (2001) **Other Documents:** - Arab Iron & Steel Union (website) - State Information Service (website) - Assessment of Carbon Dioxide Emission and Its Impact on High-Rise Mixed-Use Buildings in Egypt (2021) - Industrial Energy Efficiency Project – Benchmarking Report for Iron and Steel Sector (2014)	**Production:** - 10.3 million tonnes of steel were produced in 2021[199], making it the largest steel producer in the MENA region.[200] **Emissions:** - GHG emissions from iron and steel production were 3,136 Gg of CO_2eq, while the carbon emissions factor was 2081 kgCO_2/tonne steel[201,202].	- 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. - It 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 necessitate 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) - BUR (2021) - Low Emissions Development Strategy and Action Plan (2023)				

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[199] https://aisusteel.org/en/5794/

[200] https://www.sis.gov.eg/Story/178692/Fitch-Ratings-Egypt-2nd-largest-steel-producer-in-MENA-region?lang=en-us

[201] https://unfccc.int/sites/default/files/resource/BUR%20Egypt%20EN.pdf

[202] https://fount.aucegypt.edu/cgi/viewcontent.cgi?article=2678&context=etds

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Mauritania	• NDC (2022) • Second BUR (2021) • TNA (2017) – in French **Other Documents:** • Unlocking the Potential of Steel Production in Mauritania with Green Energy: A Path to Economic Growth and Sustainability				

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Chemicals Sector					
China	- NDC (2021) - Progress on the implementation of NDC (2022) - Second BUR (2018) - China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy (2021) - TNA (1998) **Other Documents:** - An Energy Roadmap to Carbon Neutrality in China (2021)	**Production:** - Production is expected to increase nearly 30% by 2030 and 40% by 2060. **Emissions:** - 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 CO_2 intensity fall from 2.5-tonnes CO_2 per tonne of primary chemicals to 0.2 tonnes CO_2 per tonne of primary chemicals by 2060.[203]	- The technology needs to reach the Paris Agreement targets for the chemicals 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. - 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 for CCUS, electricity generation, hydrogen production from electrolysers, and storage.	Yes, China is promoting carbon market policies and trading platforms in addition to pushing towards the implementation of CCUS and green hydrogen.

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[203] 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

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Indonesia	• NDC (2022) • Third BUR (2021) • Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (2021) • Second TNA on mitigation (2012) **Other Documents:** • An Energy Sector Roadmap to Net Zero Emissions in Indonesia (2022)	**Production:** • No data available **Emissions:** • In 2019, the chemicals industry resulted in 13.6 Mt CO_2eq, which is about 0.7% of the total emissions, and about 10.5 Mt CO_2eq (0.5%) indirectly through energy use.[204]	• In the Announced Pledges Scenario (APS), CO_2 emissions from the other industries category, which includes the chemicals industry, are projected to fall by more than 60% by 2060.[205]	• The targeted reduction is achieved through electrification and other fuel switching, which are the main measures for decarbonization in the chemicals sector. • Indonesia does provide information on reduction targets and actions for specific industries within the chemicals sector, such as the ammonia plant and the nitric acids industry. Information about what needs to be done to achieve the Paris Agreement targets were not clearly stated although the technological know-how required for implementation is implied.[206] • 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.[207]	Yes, Indonesia is targeting 60% by 2060 for all industries by means of electrification, fuel switching material and energy efficiency, CCUS and avoided demand.

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[204] "Indonesia. Biennial update report (BUR). BUR3. | UNFCCC." https://unfccc.int/documents/403577

[205] 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

[206] "Enhanced NDC – Republic of Indonesia | UNFCCC." https://unfccc.int/documents/615082

[207] 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

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

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 (2023)	• According to the fourth BUR, the chemicals sector contributed 3% of the total national greenhouse gas (GHG) emissions at about 0.75 Mt CO_2 in 2017.[208]	• Türkiye aims to conduct Green Growth Technology Roadmap studies for sectors such as chemicals.[209] • Türkiye's main mitigation policies in the industrial sector for 2030 include increasing the use of biofuels, refuse-derived fuel (RDF), alternative fuels, and raw materials in industrial facilities.[210] • 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 industrial sector.	• Some potential technology needs for the chemicals sector could include: 1. Process optimization: Implementing advanced process control systems and optimization techniques to improve energy efficiency and reduce emissions in chemical manufacturing processes. 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. 3. Renewable feedstocks: Exploring and adopting renewable feedstocks and bio-based materials as alternatives to fossil fuel-based feedstocks in chemical production processes.	Partially, as Türkiye has the intention to develop a plan for decarbonization and has identified key mitigation policies and actions that align with the IEA's roadmap such as fuel and raw material switching.

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[208] FOURTH BIENNIAL REPORT OF TURKEY.pdf (unfccc.int)

[209] Republic of Türkiye (unfccc.int)

[210] Republic of Türkiye (unfccc.int)

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Türkiye (continued)				4. Advanced catalysts: Developing and utilizing advanced catalysts that enable more efficient and sustainable chemical reactions, reducing energy consumption and emissions. - A clear roadmap to identify the potentiality of different technologies to support the “Green Transition in the Industry” include: 1. Create enabling policies for technologies that have proven feasibility in reducing greenhouse gas emissions in Türkiye and provide financial incentives for companies to shift to these technologies. 2. Implement circular economy principles in the chemicals industry such as recycling and reusing waste materials, promoting resource efficiency and minimizing waste generation.	

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Japan	• NDC (2021) • BR (2019) • Long-Term Strategy under the Paris Agreement (2021) **Other Documents:** • Direction for the Chemical Industry Based on 2050CN	**Production:** No data available **Emissions:** • Emissions from the chemicals industry reached around 15% of energy-related emissions (57.6 million tonnes CO_2) and about 5.7% (4.3 million tonnes CO_2) of emissions other than energy-related.[211]	• The targets and estimates are for the fiscal year 2030 and are not broken down specifically for the chemicals industry. • 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 chemicals industry. Ensuring a reliable and affordable supply of these utilities while transitioning to low-carbon alternatives may pose challenges for the sector.[212] • 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.[213]	Partially. Although there is no announced reduction target specifically for the chemicals sector, Japan has plans for fuel and feedstock switching, circular economy practices and behavioural changes.

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[211] "Japan's Long-Term Strategy under the Paris Agreement | UNFCCC." https://unfccc.int/documents/307817

[212] https://ja.eu-japan.eu/sites/default/files/imce/2023.2.27%20METI.pdf

[213] https://ja.eu-japan.eu/sites/default/files/imce/2023.2.27%20METI.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Japan (continued)				• 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. • There is a need for mechanisms to gain consumer understanding such as CFP (Carbon Footprint), mass balance rules and carbon pricing. The chemicals industry may face challenges in effectively communicating the environmental impact of its products to consumers and gaining their support for sustainable alternatives.	

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Germany	• NDC (2020) • BR (2019) • Update to the long-term strategy for climate action of the Federal Republic of Germany (2022) Other Documents: • 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. • 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 percent or 63 Mt CO_2 emissions.[214]	• To achieve the Paris Agreement targets, it is important to consider potential synergies and trade-offs within the chemicals sector. This involves exploring how the industry can transition from being an energy-intensive and high-emitting sector to becoming a solution-provider for other sectors.[215] • Achieving the Paris Agreement targets requires the adoption and development of new technologies in the chemicals 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.[216] • The chemicals 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.	

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[214] "Decarbonizing the German chemical industry | McKinsey." https://www.mckinsey.com/industries/chemicals/our-insights/decarbonizing-the-chemical-industry

[215] https://elib.dlr.de/147841/1/1.%20IPG%20Final%20Report_original.pdf

[216] https://elib.dlr.de/147841/1/1.%20IPG%20Final%20Report_original.pdf

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Germany (continued)				• 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. • Circular economy measures are needed to transform the chemicals industry. Implementing circular economy practices, such as recycling and reusing materials, requires collaboration and coordination among different stakeholders in the industry.	Partially. Although there is no announced reduction target specifically for the chemicals sector, Germany has plans for energy efficiency, researching and developing new technologies and circular economy practices.
Mexico	• Third BUR (2022) – in Spanish • Mexico's Climate Change Mid-Century Strategy (2016) • NDC (2022) – in Spanish	• The chemicals industry emits N_2O, CO_2 and CH4, and reached 4.6 Mt CO_2eq in 2019 (6.26% of industrial sector emissions).	• Emissions from the chemicals industry decreased from 1990 to 2019 by approximately 37.62%. • The overall country goal is to reduce GHG emissions by or before 2026, as stated in Mexico's NDC.[217]	• Mexico does not provide specific information about the technology needed to reach the Paris Agreement targets for the chemicals 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 chemicals industry.[218]	Partially. Although there is no announced reduction target specifically for the chemicals sector, Mexico is committed to promoting high-efficiency technologies, fuel substitution, circular economy practices, and CCUS.

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[217] "Mexico: Updated NDC 2022 | UNFCCC." https://unfccc.int/documents/624282

[218] "Mexico's Climate Change Mid-Term Strategy | UNFCCC."

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Mexico (continued)			- The NDC's more ambitious trajectory estimates a reduction of 36% in GHG emissions from the baseline and aims to reach 311 Mt CO_2e by 2050.[219]		
Vietnam	- NDC (2022) - BUR3 (2021) - NIR (2021)	- In the latest BUR, the chemicals sector accounted for about 2.8% of industrial emissions (1.3 MtCO_2eq).[220] - Emissions from ammonia production were about 1.27 Mt CO_2eq, while the rest were from the production of nitric acid.	- Vietnam aims to increase the application of the best technologies to reduce N_2O emissions according its NDC.	- Vietnam does not provide specific details about the technology needed to reach the Paris Agreement targets for the chemicals industry sector. It mentions that solutions to reduce greenhouse gas (GHG) emissions have been applied in the chemicals 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 chemicals sector.	No

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[219] "Mexico: Updated NDC 2022 | UNFCCC." https://unfccc.int/documents/624282

[220] "Vietnam. Biennial update report (BUR). BUR 3. | UNFCCC." https://unfccc.int/documents/273504

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Egypt	• NDC (2023) • BUR1 (2019) • 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.[221] • The chemicals industry accounts for a significant portion, contributing 18% to the total emissions of the IPPU sector.[222] • The total emissions of the chemical industry in 2015 were 2.8 Mt of CO_2, 0.083 Mt of CH4 and 4.5 Mt of N_2O.[223]	• Egypt's NDC does not explicitly address the decarbonization of the chemical industry.[224] • The NDC stated a range of strategies that can indirectly support the decarbonization efforts.[225]	• Egypt's strategies to support decarbonization are dependent upon using energy efficient technologies, and more use of natural gas.[226] • Financial and technical support are required to support Egypt's decarbonization process.	No
Belize	• NDC (2021) • BUR (2021) • Low Emissions Development Strategy and Action Plan (2023)				No

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[221] "Egypt. Biennial update report (BUR). BUR 1. | UNFCCC." https://unfccc.int/documents/204823

[222] "Egypt. Biennial update report (BUR). BUR 1. | UNFCCC." https://unfccc.int/documents/204823

[223] "Egypt. Biennial update report (BUR). BUR 1. | UNFCCC." https://unfccc.int/documents/204823

[224] "Egypt's Updated First Nationally Determined Contribution 2030 (Second Update) | UNFCCC." https://unfccc.int/documents/630376

[225] "Egypt's Updated First Nationally Determined Contribution 2030 (Second Update) | UNFCCC." https://unfccc.int/documents/630376

[226] "Egypt's Updated First Nationally Determined Contribution 2030 (Second Update) | UNFCCC." https://unfccc.int/documents/630376

Table 4-2: Countries Retrieved Data Analysis For The Cement, Steel And Chemicals Sectors (continued)

Country	Identified HAI documents:	Production and emissions	Identified mitigation goals	Reported technology needs and gaps	Alignment with IEA roadmaps (Yes/No)
Mauritania	• NDC (2022) • Second BUR (2021) • TNA			Although the current NDC and BUR documents do not report emissions from the chemicals sector, the country's TNAs included a future plan to[227]: • Develop the industry. • Use of minerals that have strategic value. • Sustainably developing the energy sector. The country could use support in the development of new industrial activities to follow the best available low-carbon technologies that can support industrial development with a lower footprint from the beginning.	No

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[227] https://unfccc.int/sites/default/files/resource/sbi2020_inf.01.pdf

4.3 Technologies Gap Assessment

This part includes an analysis 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, most of the technologies were identified as in the pilot stage or not mature enough for implementation on large scale yet. However, a notable finding is that the industrial sector, which accounts for 34% of emissions and requires a transition to Net Zero Emissions (NZE), is not sufficiently represented in NDCs and LT-LEDS. This underscores the need for enhanced NDCs to bridge this gap.

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

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Table 4-3: Technologies Gap Assessment Between Roadmaps/Initiatives And Countries' Documents For The 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 And Countries' Documents For The Steel Sector

Countries	Technologies							
	Steel industry co-products (slag)	**Scrap use in the steel industry**	**Industrial process GHG 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, utilization 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 And Countries' Documents For The 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	Y	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 from and potentially replicate the success stories that were 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 are 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 aluminium. 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.[228]

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[229]. 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 the country's support to improve energy performance. This aims to share best practices and highlight industrial achievements and it includes two programs: ENERGY STAR Certification and ENERGY STAR Challenge[230].

In China, the Ministries of Industry and Information Technology launched the Carbon Peak Implementation Plan for Building Materials Industry in 2022 in collaboration with the National Development and Reform Commission of Ecology and Environment and of Housing and Urban-Rural Development[231]. This is focused 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 aimed to analyze the adoption of regulation on low-carbon concrete and construction and the implementation of supporting schemes[232].

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.

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[228] https://www.iea.org/policies/15029-france-2030-investment-plan-heavy-industry-decarbonisation-investment
[229] https://www.iea.org/energy-system/industry/cement
[230] https://www.iea.org/policies/7952-energy-star-for-industry-certification-and-challenge
[231] https://www.iea.org/energy-system/industry/cement
[232] https://www.iea.org/energy-system/industry/cement

Table 4-6: CTCN Success Stories Of Technology Transfer In The Cement Sector

Title	CTCN support
Study on the identification and evaluation of technologies and industrial processes used in cement producing industries – Congo https://www.ctc-n.org/technical-assistance/projects/study-identification-and-evaluation-technologies-and-industrial	• General audit of the technologies, processes and materials of the cement plants • Detailed energy audit of selected cement plants • Identification of activity data (AD) and emission factors (EF) • Development of audit and management protocols and monitoring • 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 https://www.ctc-n.org/technical-assistance/projects/pilot-demonstration-energy-service-company-esco-model-greenhouse	• Review and selection of a pilot site for the ESCO model • Development of a feasibility study and investment report • Technical assistance for technology transfer • Demonstration of MRV for GHG emissions and energy efficiency • 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 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 • Financial assessment of domestic market demand and value for the biproducts from cement production and use of this information to calculate the GHG marginal abatement costs of the mineral carbon capture and utilization technology • Development of a business plan and strategic recommendations for commercial application of the analyzed 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:[233]

- 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
- Commercial charcoal production facilities were built under a competitive bidding mechanism to deliver objectively verifiable renewable biomass-based charcoal and GHG emission reductions.[234]

The project is expected to reduce greenhouse gas emissions from the iron and steel sector in Minas Gerais by up to 2 million tonnes 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.[235,236]

4.4.2.1 Vietnam[237]

On another note, the Vietnam Green Growth Strategy (VGGS) identified several goals for the steel industry sector, including improving 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 to reduce greenhouse gas (GHG) emissions by developing market-based instruments (MBIs).

The project carried out four researches that directly contributed to 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 to developing these outputs. All were brought together through the Project Management Unit (PMU) stakeholder consultations, including consultation workshops.

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

[234] 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

[235] 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

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

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

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 the steel industry in Vietnam after 2020 (Yes/No)	Yes
Component 3: Programme management and stakeholder engagement facilitation	
Number of consultations evidencing that the stakeholder engagement and communications strategy on promoting carbon pricing approaches in key GHG emitting sectors is implemented (Target: 3)	25

4.4.2.2 Indonesia

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 (a waste heat recovery technology that 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 show that the technology could save up to 35% of energy and 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[238].

4.4.3 Chemicals Sector

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

The European Union (EU) has demonstrated a strong commitment to energy transition and decarbonization (Chen et al.)[239]. The EU has implemented climate policies and regulations that incentivize the adoption of low-carbon technologies and promote the reduction of greenhouse gas emissions[240]. This has led to the development and deployment of innovative technologies and processes in the chemicals industry, such as the utilization of renewable feedstocks and the electrification of industrial

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[238] Indonesia's second Technology Needs Assessment (mitigation), 2012. Available at: https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TNR_CRE/e9067c6e3b97459989b2196f12155ad5/621d32b1f9704764be63a9e8004d176e.pdf

[239] 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

[240] 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

processes[241]. The EU's focus on material and emission efficiency strategies has also contributed to the reduction of carbon emissions in the steel industry[242].

Another success story is Brazil, which has leveraged its abundant biomass resources, such as sugarcane, to produce bio-based chemicals like bio-ethylene[243]. By utilizing ethanol and sugarcane bagasse as feedstocks, Brazil has been able to reduce carbon emissions and make its chemical industry more competitive[244].

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[245].

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.

4.5 Gender Diversity And Endorsing Women In The Workforce

4.5.1 Cement Sector

One of Holcim's top priorities is to encourage a diverse and innovative workforce by aiming at increasing the percentage of women in its workforce to reach not less than 25% of its senior management by 2025. In March 2021, Holcim became a signatory of the UN Women's Empowerment principles. Since then, women have represented 36% of the Board, 30% of the Group Executive Committee and 18% of all management levels.

As reported in the Holcim Successful Transformation 2022 Integrated Annual report, the percentage of women has increased over the years from 2020 to 2022 respectively, where the percentage of women at senior management level increased from 17% to 20%, the percentage of women at all management levels increased from 21% to 25%, the percentage of women at non-management level increased from 11% to 13%, and finally the total women workforce percentage increased from 14% to 17%.[246]

In line with the Sustainable Development Goals (SDGs) – mainly SDG 5 ("Achieve Gender Equality and Empower All Women and Girls") – as well as Egypt's Vision 2030, Lafarge Egypt is committed to promoting and encouraging gender equality and women empowerment.

[241] 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

[242] 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

[243] 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

[244] ibid

[245] 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

[246] https://www.holcim.com/sites/holcim/files/2023-02/24022023-finance-holcim-fy-2022-report-full-en-3914999618.pdf

As part of its commitment, Lafarge Egypt on behalf of the German Government, a member of Holcim Group and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) collaborated under the "Employment of Young Women Programme" through functional Gender Diversity Management (GDM) in the Middle East and North Africa (MENA) region.[247]

4.5.2 Steel Sector

Arcelor Mittal focused on improving its gender diversity and supporting equal opportunities by recruiting and promoting women in its workforce. Thus, it is committed to doubling the overall representation of women in its workforce to reach not less than 25% by 2030. Additionally, a number of initiatives have been in place nationally and locally at the sites to endorse the steel industry and encourage women to join the company. These initiatives included interventions in middle and high schools, site visits, relations with the grandes écoles and partnership with the "Elles Bougent" association's "Femmes de steel" operation on the Fos-sur-Mer site.[248]

As per the published "Women in Metals and Mining" article in June 2020, the World Bank reported in its 2020 report that about 60 economies have at least one constraint on women working in the mining field.

In 2019, it was reported as per the disclosed information provided on the workforce gender split from about 66 companies working in the steel or metals and mining sectors that the total women contribution/involvement ranged from 3% to 29%. The average representation of women on the board of directors or supervisory board has been raised from 14% in 2016 to 17% in 2019.

Women's representation on the board of directors at Fortescue Metals Group reached over 50%. Moreover, in 2019, Fortescue Metals Group signed a commitment, called "the ParityPledge", that obliged them to interview at least one qualified woman for every executive position.

In 2016, BHP set a goal for the representation of women across its workforce to reach 50% by 2025. However, by 2020, it managed to raise the overall percentage from 17.6% to 24.5%.

According to India's Tata Steel Latest Integrated and Annual Accounts report for 2021-2022 (115th year), women employees in the workforce increased from 6.1% in 2017 to 7.4% in 2021; however, in 2022 it decreased to reach 6.9%. While women employees in management positions in its workforce had been increasing from 11.1 in 2017 to 12.6 in 2021, in 2022 it decreased to reach 11.7%. It has set a goal of increasing women represented across its workforce to 25% by 2025.

India's Tata Steel is applying focused interventions to achieve greater gender diversity through initiatives like Women@Mines and enabling identified women with leadership potential to have an effective role in community decision-making processes. While about 693 women were enrolled as part of the DISHA project, which is an effort to develop 6,000 women leaders through a structured process of social, political and digital empowerment measures.[249,250]

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[247] https://www.lafarge.com.eg/en/gender-equality-0

[248] https://corporate.arcelormittal.com/media/news-articles/2019-sep-2-arcelormittal-committed-to-gender-equality-in-the-workplace

[249] https://www.spglobal.com/commodityinsights/en/market-insights/special-reports/metals/feature-women-in-metals-and-mining#:~:text=It%20includes%20questions%20on%20workforce,from%203%25%20to%2029%25

[250] https://www.annualreports.com/HostedData/AnnualReports/PDF/OTC_TATLY_2022.pdf

4.5.3 Chemicals & Petrochemicals Sector

Gulf Petrochemicals Industries Co. (GPIC) has been considered as a role model to other companies both in Bahrain and in the Gulf Cooperation Council (GCC) in which it applies women empowerment strategies by recruiting, evolving and retaining more women into various positions including management positions and the highest levels of its corporate structure. Additionally, GPIC has set a zero-discrimination policy, which is supported by its Equal Opportunities Committee.[251]

Badische Anilin- und Sodafabrik (BASF) Group has set a target to increase the percentage of women in its workforce, mainly in leadership positions with disciplinary responsibility, to 30% by 2030. The company has also launched a number of programmes to support women's development, such as a mentorship program and a leadership development programme.[252]

In 2020, BASF renewed its commitment to promoting gender equality by endorsing the United Nations' Women's Empowerment Principles (WEPs). These are seven principles[253] that provide guidance to business on the best practices to promote gender equality and women's empowerment in the workforce and the community.

Additionally, in 2019, BASF joined the global Business for Inclusive Growth (B4IG) initiative and participated with other companies in campaigns beside the G7 and the OECD for wide-ranging growth, more gender equality and the promotion of diversity and inclusion in business. Moreover, BASF was involved in other external initiatives to promote the inclusion of gender diversity and women's contribution/involvement in the workforce, such as the Chefsache initiative and the European Round Table.[254]

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[251] https://www.gpic.com/people/Empowerment/Empowement/

[252] https://www.basf.com/eg/en/who-we-are/sustainability/management-goals-and-dialog/management/our-goals.html

[253] https://asiapacific.unwomen.org/en/countries/china/weps

[254] https://report.basf.com/2020/en/managements-report/responsibility-along-the-value-chain/employees/inclusion-of-diversity.html

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 challenges are cross-cutting across the three sectors. Hence, designing policies which tackle 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 keeps increasing, some long-lived traditional capacity additions may 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 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[255]. On the other hand, some of the response measures aimed at creating and keeping a fair level market for decarbonized products and imports from countries that do not decarbonize at the same speed (e.g. the EU Carbon Border Adjustment Mechanism (CBAM), which is applied to cement, steel and ammonia) are causing severe challenges to the developing countries whose relevant exports from these products makes a significant contribution to their gross domestic product (GDP).

On the technical side, the heavy utilization of biomass is one of the 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[256]. The latter can be further exacerbated by the competition between the various sectors. Similarly, CCS is one of the key cross-cutting decarbonization technologies in most industries. 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 tonne of hydrogen needs at least nine tonnes 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

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[255] 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

[256] 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 favourable mechanical properties compared to coke

dedicated green electricity grid may not be practical due to the incurred high cost. The following sub-sections present a brief analysis of some of the sector-specific challenges.

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 alternative 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 for the clinker ratio is 0.52 by 2050 as per the GCCA roadmap. Such a 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 has some limitations, including high concentrations of incompatible elements (e.g. sulphur, magnesium and 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 labour required to get a smooth finish. In addition, high-blended cements may exhibit slow early-stage strength development, which can delay construction processes.

- **Infrastructure development:** The electrification of the cement industry presents many challenges, particularly in using electric kilns. Although electric kilns have been prototyped in the industry recently, their widespread deployment is limited. Electrifying cement kilns has been challenging because of their high temperature needs. The 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 a 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 to overcome in the molten oxide electrolysis and in finding a cheap and carbon-free inert anode resistant to the corrosive conditions. On the other hand, the technology of utilizing slag in construction faces the barrier of having a 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 industry requirements during this century.
- **Natural gas availability:** As per the IEA Energy Technology Perspectives series, in the SDS natural gas is considered an important transition fuel for the steel industry as many facilities currently use blast furnace technology relying on coal as the main energy source. DRI technology relying on natural gas is fully commercialized, including technologies like Midrex and Energiron. This can be later equipped with CCUS that could help in achieving near-zero emissions or substituted by green (electrolytic) hydrogen in the future. Hence, investments in such natural gas equipped with CCUS-based technologies in the current decade are important. However, this will be feasible mainly for countries with abundant natural gas sources.[257]

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 that are relatively new. For such facilities, it is difficult to have early retirement and replace the existing very expensive equipment[258].
- **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[259]. However, the transition to renewable feedstocks is still in its early stages and faces significant technological and economic challenges[260]. On the other hand, the high thermodynamic stability and kinetic inertness of carbon dioxide (CO_2) poses another challenge. Incorporating

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[257] https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

[258] 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

[259] 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

[260] ibid

CO_2 as a one-carbon building block in chemical synthesis is difficult due to these properties[261]. However, ongoing research and development is focused on finding ways to utilize CO_2 as a feedstock for value-added chemicals[262]. Furthermore, employing 100% green ammonia production means that another CO_2 source would be needed for urea; a fact which needs process and technology interventions.

5.2 Trends And Enabling Policies

Various kinds 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, this sub-section is structured according to the type of trends and enabling policies rather than by sector.

Table 5-2: Observed Trends And Enabling Policies In The Decarbonization Market Of The HAI Sectors (countries applying such trend/policy are included in brackets within the table)

Trends And Enabling Policies	Cement	Steel	Chemicals
National funding for decarbonization implementation support	✓ (France)	✓ (France, Canada)	✓ (France)
National funding for research and innovation support	✓ (France, USA)	✓ (France, USA, Japan)	✓ (USA)
Bilateral countries' collaboration on accelerating decarbonization commercialization		✓ (Japan-Australia partnership on decarbonization through technology)	✓ (Japan-Australia partnership on decarbonization 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 mechanisms	✓ (India)	✓ (India)	✓ (India)
Joint innovation and research programmes between different sectoral players	✓ (Germany)	✓ (China)	
Recycling law for construction waste	✓ (Japan)		
Developing standards for eco-friendly products	✓ (Japan)		
Commercial products using an alternative material/energy source	✓ (Japan)[263]		

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[261] 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

[262] ibid

[263] http://www.claisse.info/2013%20papers/data/e583.pdf

Table 5-2: Observed Trends And Enabling Policies In The Decarbonization Market Of The HAI Sectors (countries applying such trend/policy are included in brackets within the table) (continued)

Trends And Enabling Policies	Cement	Steel	Chemicals
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 Decarbonization Implementation Support[264]

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 aluminium sectors. EUR 5 billion of which will be provided to support the implementation of industrial decarbonization 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 And Innovation Support[265]

This policy was observed in France, the US and Japan. The aforementioned “France 2030 Investment Plan – Heavy industry de-carbonization investment” provides EUR 610 million to financially support research initiatives, the development of industrial pilots and demonstrations in the HAI sectors. On the other hand, the US announced USD 100 million to set up 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” for 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[266].

5.2.3 Bilateral Countries’ Collaboration On Accelerating Decarbonization Commercialization[267]

In 2021, the “Japan-Australia partnership on de-carbonization through technology” was launched. Both countries will collaborate and provide investment funding in the development

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[264] https://www.iea.org/policies?year=desc&qs=iron&sector%5B0%5D=Iron%20and%20steel

[265] https://www.iea.org/policies?year=desc&qs=iron&sector%5B0%5D=Iron%20and%20steel

[266] https://www.course50.com/en/message/

[267] https://www.iea.org/policies?year=desc&qs=iron&sector%5B0%5D=Iron%20and%20steel

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[268]

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 set up to help Financial Institutions (FIs) partly cover the risk of financing energy efficiency projects.

5.2.5 Implementation Of Energy Efficiency Measures Via A 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. The 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 a corresponding CO_2 reduction of 20 million tonne[269].

5.2.6 Joint Innovation And Research Programmes Between Different Sector Players

This policy was observed in China and Germany. In Germany, one of the innovation programmes applied is "CI4C" – Cement Innovation for Climate" – which is a joint project on the part of 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 hydrosilicates (hCHS), which results in about a 50 percent reduction in GHG emissions compared to the traditional clinker[270]. 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 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

Earlier 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 a 100% recycling rate for the concrete.

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[268] https://www.iea.org/policies?year=desc&qs=iron&sector%5B0%5D=Iron%20and%20steel

[269] 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

[270] https://www.schwenk.de/wp-content/uploads/2023/01/SCHWENK-Sustainability-Report-2021_2022.pdf

5.2.8 Commercial Products Using Alternative Material/Energy Source

In 2002, Japanese Industrial Standards (JIS) officially certified a product called “Ecocement”. This product replaces the traditional raw materials of cement “limestone” with municipal waste incinerator ash. One plant in Japan now produces 110,000 tonnes of Ecocement per year and this has been followed by another one producing about 130,000 tonnes 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[271].

5.2.10 Commercial Hydrogen Injection

CEMEX has also announced that it 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[272].

5.2.11 Off-shore CCS

Heidelberg, one of the leading cement companies, recently announced the 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 offshore permanent storage under the Black Sea[273].

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 energy solutions[274]. These price signals can be achieved through carbon taxes, emissions-trading systems (ETS – cap and trade) and international offset mechanisms[275]. Carbon pricing is considered the most efficient policy to reduce greenhouse gas emissions[276] and it can support the COVID-19 recovery and the Paris Agreement[277]. 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[278]. 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[279]. 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 decision-makers.

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[271] https://gaspathways.com/cemex-invests-in-hiirocs-clean-hydrogen-technology-596

[272] https://www.cemex.com/w/cemex-to-introduce-hydrogen-technology-to-reduce-co2-emissions-in-four-cement-plants-in-mexico

[273] https://gccassociation.org/2050-net-zero-roadmap-one-year-on/action-progress-case-study-heidelbergcement/

[274] 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/

[275] ibid

[276] 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

[277] Carbon Pricing – Asian Development Bank. https://www.adb.org/sites/default/files/institutional-document/691951/ado2021bn-carbon-pricing-developing-asia.pdf

[278] ibid

[279] 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 organization recommended interventions. In addition, this section presents the proposed role of the TEC to operationalize such recommendations.

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 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 on a wider scale R&D programme (see section 5.2.6 for more details about a relevant success story).
- Countries to receive guidance from the Technology Mechanism (TEC&CTCN) in the development and prioritization of research and development programmes. By offering expertise and insights on emerging low-carbon technologies, the TEC can help nations identify the most promising avenues for investment and innovation. Furthermore, the TEC can facilitate the exchange of best practices and successful case studies, encouraging collaborative R&D efforts that leverage global expertise and resources. This approach not only accelerates the development of vital technologies, but also ensures that countries' R&D efforts are aligned with the larger goals of the Paris Agreement.

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:

6.1.1 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 recarbonation 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.

6.1.2 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 iron oxide electrolysis technology.
- Catalyzing the commercialization of smelting reduction technologies in the steel sector.
- Using EAF technology instead of BOF.
- 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.

6.1.3 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.
- Replacing fossil fuel heat with renewable heat and replacing the fossil fuel-based feedstocks with bio-based renewable feedstocks.
- 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.

The Technology Mechanism (TEC&CTCN) can assist countries in crafting comprehensive low-carbon roadmaps for key industrial sectors such as cement, steel and chemicals. This includes advising on the integration of fiscal, regulatory and legal frameworks that encourage the adoption of low-carbon technologies and practices. Additionally, the mechanism can advocate for policies that enhance energy efficiency and circular economy principles within these industries. By doing so, the mechanism helps ensure that national policies not only support decarbonization goals, but also contribute to broader sustainable development objectives.

However, it is essential to acknowledge that the NDCs are not currently comprehensive, especially for the HAI sectors, ambitious or qualitative enough to meet the PA goals. They often do not comprehensively address industry sectors and sub-sectors, 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 develop clearer and more comprehensive NDC documents.

The key recommendation is that the country develops national low-carbon roadmaps for each of 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 highly advisable for the countries to develop an internal annual report, incorporating specific reporting and indicators for the deployment of low- and zero-carbon technologies in HAI, to track the progress of roadmap execution. This not only helps in defining barriers, but also facilitates collaboration with international development organizations to effectively alleviate them.

The following sub-sections present some recommended general policies, which were developed in alignment with the sectoral policy instruments provided by the IPCC. According to Table 4.7 in the AR5 report[280], policy instruments related to the industrial sector are economic instruments (such as carbon taxes, subsidies and fiscal incentives), regulatory approaches (including energy efficiency standards and energy management systems), information programmes, and government provision of public goods or services.

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[280] https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf

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 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 in HAIs (implying that they have an energy management system and employ 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 audits for the HAI sectors.
d. Defining specific maximum energy intensity targets for new facilities.
e. Issuance of national green bonds to include the decarbonization technologies in HAI sectors in the pool of financed projects.
f. Developing green loan financial mechanisms with de-risking components that increase the ambition of financial institutions in financing energy efficiency and renewable energy measures in the HAI sectors.
g. Developing a benchmarking system for each industrial sector. An annual report should be shared with all the plants (data of each plant will be kept anonymous) 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 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 a sustainable supply of wood. In addition, policies are required to incentivize investments in the full biomass 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 the 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 private sector players to invest in low-carbon products (e.g. tax incentives or recognition of the 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 market-based mechanisms for energy intensity or GHG emissions (e.g. emission trading systems).

h. Issuance of national green bonds and including the decarbonization technologies in HAI sectors in the pool of financed projects.

i. Developing green loan financial mechanisms with de-risking components that increase the ambition of financial institutions in financing decarbonization measures in the HAI sectors.

j. Developing incentives to transform enhanced oil recovery (EOR) facilities to CCS facilities.

k. 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.

l. Outline a clear process for monitoring and evaluating the progress and success of the recommended interventions.

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 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 • 6.2.3 a, 6.2.3 b, 6.2.3 c, 6.2.3 d
Enhancing the 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 • 6.2.3 c, 6.2.3 d, 6.2.3 e, 6.2.3 g
CCS and 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 or plastics recycling)	• 6.2.2 e • 6.2.3 c, 6.2.3 d, 6.2.3 e, 6.2.3 g, 6.2.3 h, 6.2.3 i

This was done in alignment with the mitigation measures provided by the IPCC. According to the AR6 report, mitigation options that relate to the industrial sector are organized in six equally important strategies: (i) demand for materials; (ii) materials efficiency; (iii) circular economy and industrial waste; (iv) energy efficiency; (v) electrification and fuel switching; and (vi) CCUS, feedstock and biogenic carbon[281]. The following table is a comparison between recommended national-level policy intervention technologies developed in this report and the recommended mitigation strategies by the IPCC AR6 report.

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[281] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf

Table 6-2: Comparison Between Recommended National-Level Policy Intervention Technologies And The Mitigation Strategies Organized by The IPCC AR6 report

Recommended National-Level Policy Intervention Technologies	Recommended Mitigation Strategies by The IPCC AR6 report
Material efficiency in design and construction	Materials Efficiency and Demand for Materials
Enhancing the concrete efficiency of production	
Low-clinker cement	
Employing green hydrogen as a fuel	Electrification and Fuel Switching
Employing captive renewable energy power generation plants	
Employing alternative fuels	
Energy efficiency	Energy Efficiency
CCS & CCUS	CCUS
Material recycling (e.g. steel slag recycling, plastics recycling, etc.)	Circular Economy and Industrial Waste

6.3 International Development Organization Recommended Interventions

- International development organizations (e.g., UNIDO or 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 a clear agenda. Designing such programmes to have multiple countries with similar technology interests is advisable.
- The UNFCCC Technology Mechanism can recommend strategies for establishing linkages between global industry players, technology providers, initiatives, and funding bodies. By doing so, the Mechanism can enhance global cooperation in technology development and deployment, ensuring that international efforts are synergized and effective in driving large-scale industrial decarbonization.
- 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, etc.) develop a corresponding global study to identify such two groups of counties, and work on the required match-making based on the study outputs.
- International development organizations are recommended to provide support to non-EU countries on meeting the CBAM requirements.

- International development organizations are recommended to accelerate the development of harmonized LCAs and some of the debatable definitions in the decarbonization technologies, including that for green hydrogen for example (currently the green hydrogen definition according to both the EU and the Green Hydrogen Organization standards and the European Certification scheme “GH2” is different).
- 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 joint collaboration plans.
- International development organizations are recommended to facilitate the provision of financial, technical, technological, and capacity building support from developed countries to developing countries as per the requirements under the UNFCCC and the Paris Agreement.

6.4 Role Of The Technology Executive Committee

In the context of accelerating technology cooperation to achieve the Paris Agreement’s objectives and delivering mandates regarding enhancing climate technology development and transfer, the TEC may undertake activities in the field of HAI decarbonization as follows:

- Provide guidance to countries on how to integrate hard-to-abate industries and required technologies and decarbonization pathways into their updated NDCs and in their LT-LEDS, including through the use of Technology Needs Assessments (TNAs) and Technology Action Plans (TAPs).
- Support countries to develop and implement national-level R&D programmes as per the specific recommendations mentioned in section 6.1.
- Support countries to alleviate the barriers facing implementing the specific recommendations mentioned in section 6.2.
- Recommend specific programmes to international development organizations in line with the specific recommendations mentioned in section 6.3 and provide support in their design and implementation.

- Promote and facilitate stakeholder engagement and establish coordination mechanisms between climate technology stakeholders.
- Improve climate technology knowledge by initiating new studies for technology development and transfer, publishing success stories and providing technical support on selected highlighted actions.
- Provide the economic assessment of climate technology development and transfer to support informed decision-making for policymakers and manufacturers.
- Build relevant indicators and databases for informing, monitoring and evaluating national and regional climate technology action.
- Reinforce public awareness and engagement and build skills and professional awareness regarding climate technology.

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About the Technology Executive Committee

The Technology Executive Committee is the policy component of the Technology Mechanism, which was established by the Conference of the Parties in 2010 to facilitate the implementation of enhanced action on climate technology development and transfer. The Paris Agreement established a technology framework to provide overarching guidance to the Technology Mechanism and mandated the TEC and CTCN to serve the Paris Agreement. The TEC analyses climate technology issues and develops policies that can accelerate the development and transfer of low-emission and climate resilient technologies.

About the United Nations Industrial Development Organization

The United Nations Industrial Development Organization (UNIDO) is the specialized agency of the United Nations that promotes industrial development for poverty reduction, inclusive globalization and environmental sustainability. UNIDO provides support to its 172 Member States through four mandated functions: technical cooperation; action-oriented research and policy-advisory services; normative standards-related activities; and fostering partnerships for knowledge and technology transfer. For further information, visit: https://www.unido.org/

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