BREAKTHROUGH AGENDA

THE BREAKTHROUGH AGENDA REPORT 2025

Accelerating Sector Transitions Through Stronger International Collaboration

iea

In collaboration with the Climate High-Level Champions

Marrakech Partnership

Global Climate Action

International Energy Agency (IEA)

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The Climate High-Level Champions – mandated at COP 21 and appointed annually by COP Presidencies – drive ambitious climate action by connecting governments with voluntary solutions led by cities, regions, businesses, investors, Indigenous peoples and civil society. They oversee delivery of the Marrakech Partnership five-year plan, flagship campaigns such as Race to Zero and Race to Resilience, and now the Action Agenda - a unified roadmap aligning non-state actors around delivery of the Global Stocktake outcomes. Ms Nigar Arpadarai and Mr Dan Ioschpe serve as the current Climate High-Level Champions for COP 29 and COP 30.

Disclaimer

About this report

Since its launch at COP 26, the Breakthrough Agenda has become established as an annual collaborative process centred around the Conference of the Parties (COP) meetings of the United Nations Framework Convention on Climate Change (UNFCCC). It is currently supported by over 60 countries representing over 80% of global GDP, and by over 150 initiatives working to enhance collaboration within major emitting sectors. Countries can endorse Breakthrough goals to make clean technologies and sustainable practices more affordable, accessible and attractive than their alternatives by 2030 in the power, road transport, hydrogen, steel, cement and buildings sectors.

The Breakthrough Agenda establishes an annual cycle to track developments towards these goals, identify where further co-ordinated international action is urgently needed to accelerate progress and then galvanise public and private international action behind these specific priorities in order to make these transitions quicker, cheaper, and easier for all.

To initiate this cycle, world leaders tasked the IEA and the Climate High-Level Champions to develop an annual Breakthrough Agenda report to provide an independent evidence base and expert recommendations for where stronger international collaboration is needed. From 2022-2024, the reports contained a detailed assessment on the state of international collaboration across these sectors in areas such as definitions, standards and certification, demand creation and management, research and innovation, finance and investment, infrastructure, and trade conditions, among others.

The Breakthrough Agenda Report 2025 – the fourth in the annual series – takes a different approach to previous reports, in that it does not contain the same detailed sector-by-sector assessment. Instead, this year's report focuses on enhancing the methodology behind the detailed progress assessments, provides practical examples of collaboration through deep dives, and introduces a new focus chapter on fertilisers.

FOREWORD

The global deployment of low-emissions energy technologies is progressing rapidly. Electricity generation from low-emissions sources surpassed 40% of the global total for the first time in 2024. Capital flows to renewables, nuclear, grids, storage, low-emissions fuels, and electrification are setting new records and are expected to increase to around USD 2.2 trillion in 2025. The past year has shown that rapid scaling-up is possible when capital flows to low-emissions energy technologies, enabled by a shared vision, policy support and a co-ordinated approach which will continue to dictate the speed of the transition.

Responding to the Global Stocktake requires strong international collaboration across national governments, private sector, banks, international organisations and other non-state actors, as no country or actor can achieve it alone. Shared responsibility, co-developed frameworks, technology co-operation, aligned policies, mobilised finance, knowledge sharing and capacity building accelerate innovation and lower costs. Co-ordinated action also drives collective ambition, strengthens resilience, and creates an inclusive and equitable outcome for all.

The 2025 Breakthrough Agenda Report – the fourth in this annual series – outlines how countries can continue to advance toward the Breakthrough Agenda goals: making clean technologies the most affordable, accessible, and attractive option by 2030 in six major emitting sectors – power, hydrogen, road transport, steel, cement and buildings. This report recognises progress in implementing the Priority International Actions for 2025 announced at COP 29 in Baku, providing evidence of successful co-ordination among governments and non-state actors.

This report adds tangible, implementation-focused “success statements” defining what effective and practical collaboration looks like in each sector by 2030 along with indicators that combine quantitative metrics and qualitative examples to aid progress monitoring. It also introduces a new chapter focused on international collaboration to support the sustainable production and use of fertilisers. Lastly, the report provides practical examples of successful international collaboration through deep dives into supply chains, grids and regional interconnections, road freight corridors, and offtake agreements for near-zero emissions iron.

The Breakthrough Agenda process provides a clear picture of the international collaboration that is taking place in scaling up low emission technologies, and where further efforts are most needed. These annual assessments have consistently found that the opportunities for practical collaboration are far from fully exploited. Leadership in convening countries to jointly address the most pressing challenges of finance, technology and trade will be essential for achieving the Paris Agreement goals.

Progress is evident, but achieving climate ambitions is not guaranteed and it is important to continue leveraging international collaboration. Sustainability must be made profitable and participatory approaches should be prioritised. Investments must be made in adaptive and resilient infrastructure, and we need to mobilise resources to deliver.

International partnerships that span all levels of government, businesses, investors, and civil society are essential to accelerate climate action and we will continue to work together in pursuit of the goals of the Breakthrough Agenda.

Dr Timur Gül	**Ms Nigar Arpadarai**	**Mr. Dan Ioschpe**
Chief Energy Technology Officer International Energy Agency	COP29 Climate High-Level Champion	COP30 Climate High-Level Champion

ACKNOWLEDGEMENTS

The *Breakthrough Agenda Report 2025* was prepared by the International Energy Agency (IEA), in close co-operation with the Climate Champions Team (CCT). The project was designed and directed by Timur Gül (IEA) and Simon Sharpe (CCT). Carl Greenfield (IEA) and Kapil Narula (CCT) contributed to the analysis and report writing and co-ordinated the production of the report.

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The buildings and fertilisers analysis benefited from close collaboration with the UNEP-hosted Global Alliance for Buildings and Construction (GlobalABC) and the International Fertilizer Association (IFA).

Valuable comments and feedback were provided by senior management and other colleagues within the IEA, in particular, Laura Cozzi, Araceli Fernandez Pales, Pablo Hevia-Koch, Peter Levi, Elizabeth Connelly, Eren Cam and Laura Mari Martinez. Lizzie Sayer supported the editing of the manuscript, Charlotte Bracke and Per-Anders Widell provided essential support throughout the process.

Thanks also to IEA Communications and Digital Office, particularly to Jethro Mullen, Lee Bailey, Isabella Batten, Poeli Bojorquez, Curtis Brainard, Astrid Dumond, Merve Erdil, Grace Gordon, Julia Horowitz, Oliver Joy. and CCT's Strategic Communications and Events Team for their support with the production, development and communication of the report.

This project would not have been possible without the financial support provided by the United Kingdom.

The IEA is deeply grateful to the peer reviewers who provided thoughtful and constructive feedback throughout the review process. Their comments and expertise greatly strengthened the quality, clarity and accuracy of the analysis. They include:

Imane Aboulfeth (OCP Group); Laurent Antoni (International Partnership for Hydrogen and Fuel Cells in the Economy); Florian Ausfelder (Dechema); Chris Bataille (Institut du Développement Durable et des Relations Internationales); Nia Bell (Climate Group); Clare Broadbent (World Steel Association); Ysanne Choksey (Agora Industry); Ryan Colker (International Code Council); Joseph Cordonnier (OECD); Peter Dale (Department for Energy Security and Net Zero, United Kingdom); Tim Dallmann (International Council on Clean Transportation); Anne Paula Dekeukelaere (Swiss Federal Institute of Technology in Lausanne); Jennie Dodson (World Business Council for Sustainable Development); Manuel El-Amine (Federal Ministry for Economic Affairs and Energy, Germany); Jinlei Feng (International Renewable Energy Agency); Ankita Gangotra (United Nations Industrial Development Organization); Jorrit Gosens (Australian National University); Annie Heaton

(ResponsibleSteel); Harley Higgins Watson (International Partnership for Hydrogen and Fuel Cells in the Economy); Roland Hunziker (World Business Council for Sustainable Development); Dima Khoury (Global Alliance for Buildings and Construction); Stephanie Kodish (CALSTART), Andreas Kopf (International Transport Forum); Johanna Lehne (E3G); Michael Leibrandt (Federal Ministry for Economic Affairs and Energy, Germany); Yinghao Liu (Baosteel); Elvira Lutter (WIVA P&G); Andrew Minson (Global Cement and Concrete Association); Patrick Molloy (RMI); Alan Monaghan (Mission Innovation's Net Zero Emission Mission); Daniel Morris (Climate Investment Funds); Venu Mothkoor (Niti Aayog); Marc Moutinho (Mission Possible Partnership); Daria Nochevnik (Hydrogen Council); Audrey Nougent (World Green Buildings Council); Olivier Rapf (Buildings Performance Institute Europe); Stephan Raes (OECD); Ommid Saberi (International Finance Corporation); Hugo Salamanca (United Nations Industrial Development Organization); Ashpreet Sethi (International Council on Clean Transportation); Walter Simon (David Mason); Chira Sinziana (Innovation, Science and Economic Development Canada); Urska Skrt (World Business Council for Sustainable Development); Ilina Stefanova (International Renewable Energy Agency); Bernhard Stormyr (Yara International); Kaisa Toroskainen (Global Battery Alliance); Marcus Trommler (Federal Ministry for Economic Affairs and Energy, Germany); Piero Venturi (Directorate of Research and Innovation, European Commission); Giedre Viskantaite (International Renewable Energy Agency); Daniel Weaver (Department for Energy Security and Net Zero, United Kingdom); Edward Webber (Department for Energy Security and Net Zero, United Kingdom); Henry Webber (Department for Environment, Food & Rural Affairs, United Kingdom); Patricia Wild (International Renewable Energy Agency); Matthew Wittenstein (United Nations Economic and Social Commission for Asia and the Pacific), Judy Zakreski (International Code Council) and several colleagues within the Government of Canada that contributed to the review.

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EXECUTIVE SUMMARY

THE VALUE OF INTERNATIONAL COLLABORATION IN THE CURRENT CONTEXT

Well-targeted international collaboration can amplify domestic efforts to reduce emissions and deploy low-emission technologies and solutions. Acting together, countries, companies and global initiatives are in the unique position to harmonise standards, aggregate demand, mobilise finance and move markets in ways that are nearly impossible to achieve in isolation. Geopolitical tensions and economic uncertainty are testing the resilience of international co-operation, but also underscore its importance to avoid fragmentation of global markets and delaying action on emissions reductions. This report therefore identifies many practical opportunities for countries to work together in ways that advance economic development objectives as well as transitions.

The Breakthrough Agenda acts as a framework to identify where collaborative action is most needed. Launched in 2021, the Breakthrough Agenda is supported by 61 countries and over 150 initiatives across 7 major sectors of the economy: power, hydrogen, road transport, steel, cement and concrete, buildings and agriculture. Through a collaborative process, participants are working to make clean technologies and sustainable solutions the most affordable, accessible and attractive option in each sector by 2030.

This year's report takes a step back to define how success should be measured and shows what positive collaboration looks like in practice. A special focus on international collaboration in the fertiliser sector builds on previous efforts under the Agriculture Breakthrough, and is accompanied by chapters that dive deeper into areas where collaboration can be strengthened on iron and steel, trucks, electricity grids and supply chain diversification.

MEASURING PROGRESS ON COLLABORATION AND THE NEED TO DEFINE SUCCESS

The Breakthrough Agenda goals set an ambitious vision for each sector. Countries and non-state actors that participate in the Breakthrough Agenda agree to goals that represent tipping points at which the clean options in each sector become more affordable, accessible and attractive than the fossil fuel option by 2030.

Annual recommendations offer direction to guide collaboration. Every year since their adoption, the Breakthrough Agenda reports have outlined the conditions necessary to achieve the 2030 goals, assessed the state of international collaboration in high GHG-emitting sectors, and provided recommendations on actions to accelerate energy transitions. These annual recommendations help to outline collaborative efforts over the course of the year.

Translating the Breakthrough Agenda goals into action requires a shared and measurable vision of success. While annual recommendations identify the near-term actions needed to reach those goals, this year we are suggesting “success statements” for each sector that provide additional insight on what it means to achieve the ambitious 2030 goals of the Breakthrough Agenda. Each statement is paired with quantitative indicators and qualitative examples, providing a clear picture of measuring progress. The success statements are intended to serve as complementary tools to the annual cycle of recommendations and assessments already embedded in the Breakthrough Agenda process. This two-track approach – recommendations and success statements – may serve to make monitoring more comprehensive and help drive progress across sectors.

PRACTICAL EXAMPLES SHOW THE OPPORTUNITIES OF COLLECTIVE ACTION

Regional experience shows the importance of strong cross-border collaboration to integrate grid infrastructure and build transportation corridors. Both regional grid interconnections and zero-emission freight corridors require deep cross-border collaboration to succeed, as they face similar challenges in aligning technical standards, cost-sharing, financing and governance. For grid infrastructure, international experience in Central America and Southeast Asia shows that durable institutional frameworks, political agreements and harmonised planning are essential to unlock investment and deliver reliable regional interconnections. Experience in Europe and East Africa shows that advancing zero-emission truck corridors depends on multi-country investment packages, co-ordinated grid expansion to support high-capacity charging and regulatory alignment on vehicle and charging standards. In both cases, collaboration provides certainty for investors, ensures clean infrastructure deployment and reduces costs – while also enabling seamless cross-border operations that accelerate the energy transition.

International agreements could reduce risks for investment in near-zero emissions iron and steel production. Offtake agreements, in which a steel producer commits to buy a specified quantity of near-zero emissions iron, could increase the competitiveness of steelmakers in countries with high energy costs, and provide an opportunity for iron exporting countries with abundant low-cost renewable energy resources to move up the value chain. They could play a critical role in enabling investment in new near-zero emissions iron and steel production facilities, by focusing on regions where production can be most competitive. Emerging interest in this approach is visible in projects in Australia, Canada, Germany, Namibia and Sweden. Bilateral agreements on cost-sharing and standards between the governments of the countries concerned are likely to be important to give businesses the confidence to invest.

Supply chain collaboration can deliver tangible progress on security, economic and climate goals, providing an opportunity for emerging markets. Access to clean energy technologies is important for achieving climate goals, but their importance now extends well beyond the realm of climate change — they have become important considerations for industrial and economic policy. The energy transition provides an opportunity for emerging markets and developing economies (EMDEs) to leverage competitive advantages, develop manufacturing capabilities and move up the value chain as global demand for energy technologies and their components grows. While collaboration on clean energy technology supply chains is gaining momentum across several key areas, more efforts are needed on developing resilient and diversified supply chains, including mapping supply chain vulnerabilities, expanding skills transfer and R&D efforts, and developing common standards.

A DEFINING MOMENT TO ADVANCE THE TRANSITION IN FERTILISERS, AT COP 30 AND BEYOND

Energy and agriculture represent key focus areas at this year's climate summit. Brazil has identified energy and agriculture as core thematic pillars of its Action Agenda, recognising their central role in development and efforts to reduce emissions. Fertilisers are an important input to world's agricultural and food systems, making it possible to sustain high crop yields and feed a growing world population. At the same time, fertilisers also consume significant quantities of energy and contribute to around 2.4% of global GHG emissions. Efforts to reduce emissions therefore should not come at the expense of affordable food for the world's poorest, and instead should ensure emissions reduction efforts support equitable and sustainable growth.

Reducing emissions from fertilisers can be made faster and less difficult through international collaboration between producers, governments, farmers and the private sector. Building on the 2024 Breakthrough Agenda Report on Agriculture, this report identifies collaboration priorities in the areas of standards and certification, demand management and creation, international finance and investment, and research and innovation.

Global standards and harmonised frameworks are foundational to progress. Agreed definitions for low- and near-zero emissions fertilisers, lifecycle emissions accounting and certification systems are essential to create a level playing field across markets. Co-ordinated action on soil health indicators and monitoring frameworks can link production innovations to improvements in nutrient use efficiency, crop yields and ecosystem resilience.

Creating demand for low-emissions fertilisers is more effective when major markets act in alignment. Co-ordinated international efforts – including public procurement, blended finance mechanisms and long-term offtake agreements – can send strong market signals that incentivise cleaner production. Joint initiatives between governments and the private sector are needed to ensure that demand-side measures align with climate goals while maintaining food affordability and farmer profitability.

Production-side innovation requires targeted investment and policy support. Scaling up low-emissions ammonia and fertiliser production technologies depends on early-stage finance, technical assistance and cross-border policy alignment. Pilot and demonstration projects, particularly in EMDEs, are critical for testing new technologies and unlocking commercial deployment, while production-focused R&D on energy efficiency, alternative feedstocks and modular facilities can further reduce GHG intensity.

Use-side strategies must complement production changes to maximise impact. Improving nutrient use efficiency, adopting biological and organic inputs, and implementing context-specific soil management practices are critical to reducing GHG emissions from fertiliser application. International collaboration on long-term soil monitoring, data-sharing, and farmer-centred interventions can enable evidence-based approaches that optimise nutrient efficiency, boost yields and restore degraded lands, while avoiding unintended environmental consequences.

Chapter 1. Introduction

State of the transition

Global investment in clean energy technologies – including those covered under the Breakthrough Agenda sectors – has increased by more than 30% since the first Breakthrough Agenda Report was launched in 2022, compared to an increase of 1% for investment in fossil fuels. Clean energy investment is on course to reach a record USD 2.2 trillion this year, attracting nearly twice as much capital as fossil fuels. This reflects efforts to reduce emissions, as well as the growing influence of energy security considerations and industrial competitiveness as the "Age of Electricity" draws closer.

Ten years ago, global investments in fossil fuel supply were 30% higher than in electricity generation, grids and storage. This year, electricity investments are set to be around 50% higher than investments in coal, oil and natural gas combined, driven by the rapid rise in electricity demand for industry, cooling, electric mobility, data centres and artificial intelligence.

Solar PV continues to be the single largest item in the global energy investment inventory (USD 450 billion) but spending on nuclear power (USD 70 billion) and battery storage (USD 65 billion) is also rising in 2025. Electric vehicle (EV) sales continue to increase despite uncertainties around policy evolution; EV sales globally are on track to exceed 20 million in 2025 – reaching more than one-quarter of all cars sold worldwide. Global sales of heat pumps, which reached their highest levels so far in 2022, are showing signs of a rebound.

Investment in grids – the backbone of the electricity system – meanwhile, is struggling to keep pace with rising power demand and renewables deployment. While this can be partially explained by lengthy permitting procedures, tight supply chains for transformers and cables, and economic pressures in emerging markets and developing economies (EMDEs) are also contributing factors. The latter two are key areas of focus for international collaboration, and the subject of two deep dives of this year's Breakthrough Agenda Report. In addition, rapid deployment of energy storage – particularly battery storage – shows promise, as record capacity additions can help support grid functions.

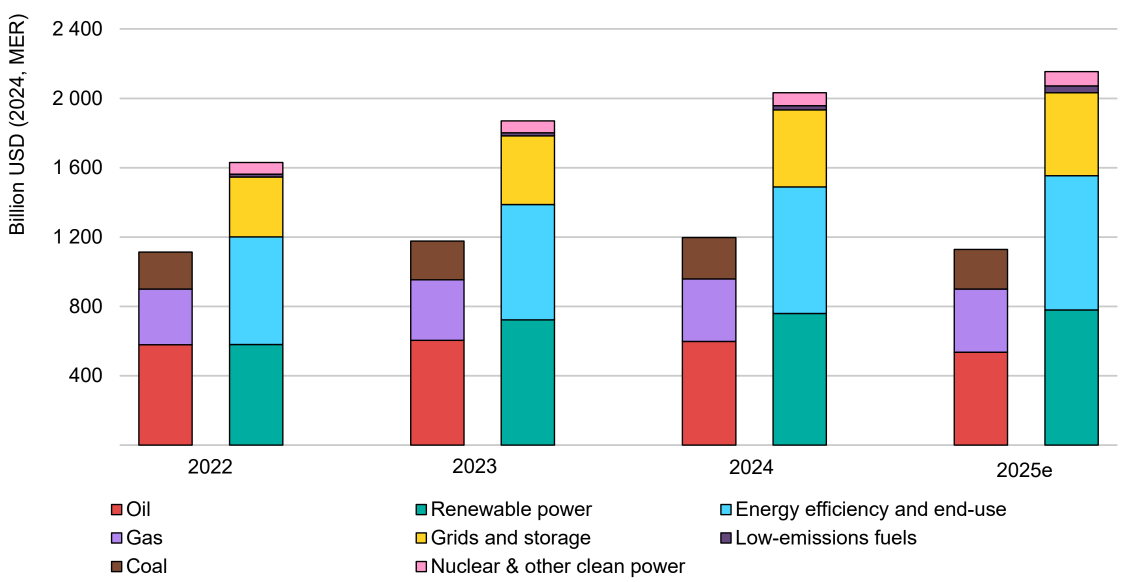
Progress is slower in those parts of the energy system where the clean technology options available are less mature or more expensive than fossil incumbents. In the hydrogen sector, for example, it remains much cheaper to produce hydrogen from fossil fuels, and this gap has widened recently due to lower prices for natural gas and higher prices for electrolysers. The use of low-emissions hydrogen and its derivatives can offer an emissions reduction pathway for several sectors, such as shipping and steel production, and is an important focus of the Hydrogen Breakthrough; so far, however, use of hydrogen remains concentrated in the refining and chemicals sector and dominated by hydrogen produced from unabated fossil fuels.

Targeted innovation can help bring clean energy technologies to market, and recent years have seen a steady increase in innovation activity. Energy R&D spending has grown at an average annual rate of 6%. Sectors with urgent innovation needs, such as the steel and cement sectors, need co-ordinated action to ensure projects can successfully be commercialised across multiple regions and contexts.

It will take time for the deeper impacts of investment and innovation in clean technologies on global emissions to be fully revealed. Last year, global energy demand increased strongly by 2.2%, pushing up CO_2 emissions to around 37.8 billion tonnes. With 80% of the total, growth in energy demand was led by EMDEs, where per-capita energy demand is still low; the remainder was in advanced economies, which saw demand grow for the first time after several years of decline. Despite this surge in energy demand, and despite the global economy expanding by more than 3% last year, growth in global energy-related CO_2 emissions slowed to 0.8% in 2024, compared to 1.1% in 2023. Increased natural gas consumption in China, the United States, the Middle East and India was the largest contributor to global CO_2 emissions growth in 2024.

There continue to be large disparities in clean technology investment and deployment. Although clean energy investments have reached record levels, EMDEs (excluding China) have captured less than 10% of the growth over the past decade. A growing financing gap in developing economies points to a larger need for international collaboration. International public funding can be a catalyst for private finance and currently accounts for around 7% of clean energy investment in EMDEs (excluding China), or about USD 32 billion annually, but this is well below developing country needs and expectations. Reaching climate and sustainable development goals in EMDEs will require investments from multiple types of investors and support from multiple sources of finance. All types of funding will need to be scaled up: public and private funding, domestic and international, concessional and non-concessional – but two elements stand out. Firstly, there is a need for greater involvement of the private sector, incentivised by public sector support to de-risk investments, and secondly, for well-co-ordinated, enhanced international financial and technical support. Concessional finance can be a key enabler of clean energy investments in EMDEs and its importance was highlighted for the power, hydrogen, road transport and buildings sectors in the Breakthrough Agenda Report 2024.

Figure 1.1 Global investment in clean energy and fossil fuels, 2022-2025e



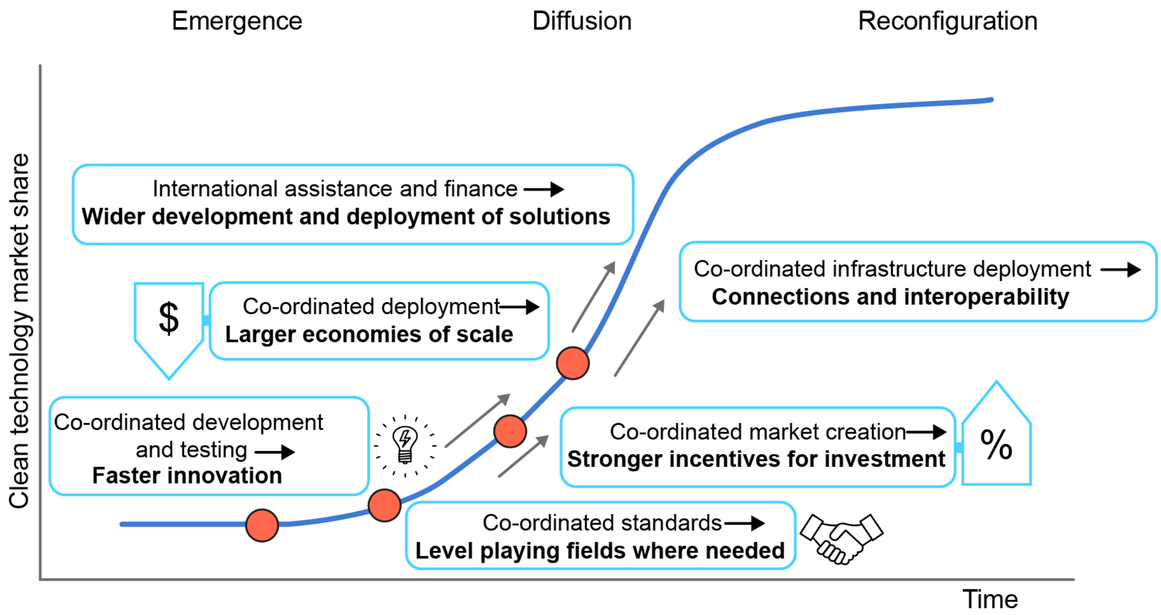
Source: IEA (2025), World Energy Investment.

International collaboration and the Breakthrough Agenda

Accelerating progress in clean energy transitions will demand stronger and more targeted international collaboration. While individual country actions can support progress, co-ordinated international action can amplify investment signals, share risk, and drive forward innovation, deployment and market creation across key sectors.

Collaboration does not look the same for all sectors. Sectors where the transition is still nascent, such as energy-intensive industries, may require a focus on demonstrating new technologies and overcoming structural barriers to their early deployment. For sectors that are more advanced in the transition, collaboration may more usefully target infrastructure co-ordination and interoperability, or the removal of financial barriers that inhibit the wider deployment of the new technologies globally. Collaboration can also take place along value chains, where governments, industry and investors work together to enhance supply chain diversification.

Figure 1.2 How international collaboration can accelerate progress



Source: Adapted from Victor, Geels & Sharpe (2019), Accelerating the Low Carbon Transition.

This collaborative approach must be led by governments, but can benefit from more diverse participation. Partnerships with the private sector, financial institutions and subnational actors are vital to ensure that clean energy solutions become more accessible, affordable, and rapidly deployed across regions and major emitting sectors – the goal of the Breakthrough Agenda since its launch at COP 26.

While this report focuses mainly on collaborative actions and initiatives at the governmental level, the private sector plays an important role in setting long-term strategies and delivering the scale of investment needed for energy transitions. To this end, over the past 2 years, the World Business Council for Sustainable Development has led an effort through the

Breakthrough Agenda to track the sentiment of leading global businesses on the pace of the transition, the actions being taken and the next steps needed to scale investments. The Breakthrough Business Barometer, the latest of which was published in June, surveys over 300 businesses across more than 50 countries. Recent findings show that 85% of business leaders surveyed in 2025 think international co-ordination on finance, trade, standards and infrastructure is important, but only 28% reported meaningful progress over the past year. Businesses are calling for stronger international collaboration to reduce fragmentation and scale transition markets faster.

The Breakthrough Agenda process is designed to understand and outline the collaborative efforts under way in each sector, and to identify where existing efforts should be strengthened or reprioritised – and where new action should be initiated. To help facilitate these efforts, organisations (or responsible persons) in each sector have been selected to facilitate co-ordination across initiatives, countries and non-state actors, mapping their activities across each section and area of collaboration through updated landscape maps.

Breakthrough sector	Sector facilitator
Power	International Renewable Energy Agency
Hydrogen	International Partnership for Hydrogen and Fuel Cells in the Economy
Road Transport	International Council on Clean Transportation
Steel	United Nations Industrial Development Organization
Cement and Concrete	Global Cement and Concrete Association
Buildings	Global Alliance for Buildings and Construction
Agriculture	N/A

Every year since the COP 26 launch, the Breakthrough Agenda Reports have made recommendations on how countries and the private sector can better target, co-ordinate and enhance collaboration across key emitting sectors: power, hydrogen, road transport, steel, cement, buildings and agriculture. From 2022-2024, our reports contained a detailed assessment on the state of international collaboration across these sectors in areas such as definitions, standards and certification, demand creation and management, research and innovation, finance and investment, infrastructure, and trade conditions, among others. Across these years, we have found that progress is not a straightforward process: gains in one year or one area of collaboration do not necessarily lead to progress in the next. However, one reoccurring finding throughout the past three Breakthrough Agenda Reports has been that support to EMDEs is a crucial element of international collaboration that urgently requires more focus.

The Breakthrough Agenda Report 2025 takes a different approach to previous reports, in that it does not contain the same detailed sector-by-sector assessment. As such, the recommendations outlined in the Breakthrough Agenda Report 2024 will remain the same, with signatory countries having the opportunity at COP 30 in Brazil this year to refresh their Priority Actions set in 2024. The Breakthrough Agenda Report 2026 will return to a detailed assessment of each of the sectors covered by the Breakthrough Agenda over a longer time horizon, to allow sufficient time for recommendations to be implemented and progress to be demonstrated.

Instead, this year's report focuses on three core areas:

- **Establishment of success statements in each sector**: Tangible, implementation-focused success criteria in each sector can support work to achieve the ambitious goals of the Breakthrough Agenda. This year's report identifies 3-4 statements that define what successful and practical collaboration looks like in each sector by 2030. These statements are more detailed than the 2030 Breakthrough Agenda goals and take a longer view than the yearly progress assessments; they will complement future recommendations for further collaboration. To measure if the statement is on track to being met, the report proposes indicators that combine quantitative metrics and qualitative examples.
- **A focus on international collaboration on fertilisers**: The 2024 Breakthrough Agenda Report on Agriculture narrowed its focus to two of the highest-emitting sub-sectors in agriculture: livestock and fertilisers. This year's report dives deeper into the fertilisers sector, in terms of production and use, and offers insights into areas where collaboration can be strengthened. One such area is agreement on a common taxonomy for cleaner technology pathways relevant to fertilisers. The Hydrogen Breakthrough uses "low-carbon and renewable hydrogen", which has a clear and direct connection to fertilisers. Others, like the Steel and Cement Breakthroughs use "near-zero emissions", the Road Transport Breakthrough uses "zero emission" and the Buildings Breakthrough uses "near-zero emissions and resilient". All of these taxonomies reflect the political consensus among countries under each Breakthrough and technical discussions. Whatever the sector, the taxonomy used should be based on analytically robust definitions – a key reason why collaboration on standards and definitions is so important across many sectors. In the absence of a common taxonomy for fertilisers, this chapter refers to the cleaner alternatives as low-emissions fertilisers.
- **Deep dives to highlight collaboration opportunities**: Collaboration can take many forms across different sectors. To highlight how countries have successfully worked together, or how they *could* work together in the future, this report offers four deep dives on international collaboration: in clean energy supply chains, grids and regional interconnections, road freight corridors, and offtake agreements for near-zero emissions iron.

CHAPTER 2. CRITERIA FOR SUCCESS AND FURTHER PROGRESS

THE NEED TO DEFINE SUCCESS IN 2030

The Breakthrough Agenda is designed to accelerate international collaboration on clean technologies and solutions, targeting key sectors across the global economy that are major GHG-emitters. It was established by the UK COP 26 Presidency. Countries and non-state actors that participate in the Breakthrough Agenda agree to goals that focus on tipping points at which the clean option becomes more affordable, accessible and attractive than the fossil fuel option in each sector. The agreed goals are as follows:

Breakthrough sector	Breakthrough sector goal
Power	Clean power is the most affordable and reliable option for all countries to meet their power needs efficiently by 2030
Hydrogen	Affordable renewable and low-carbon hydrogen is globally available by 2030
Road Transport	Zero-emission vehicles are the new normal and are accessible, affordable and sustainable in all regions by 2030
Steel	Near-zero emissions steel is the preferred choice in global markets, with efficient use and production established and growing in every region by 2030
Cement and Concrete	Near-zero emissions cement is the preferred choice in global markets, with efficient use and near-zero emission cement production established and growing in every region of the world by 2030
Buildings	Near-zero emissions and resilient buildings are the new normal in all regions by 2030
Agriculture	Climate-resilient, sustainable agriculture is the most attractive and widely adopted option for farmers everywhere by 2030

Every year since the 2030 goals were adopted, the Breakthrough Agenda reports have outlined the conditions necessary to achieve those goals, assessed the state of international collaboration in each of the Breakthrough sectors, and provided recommendations on priority actions that countries and other actors should take together to reduce the cost and difficulty of transitions over the course of this decade. These annual recommendations inform governments and other stakeholders involved in climate change diplomacy and practical collaboration, and help to orient efforts over the course of the year ahead.

The 2030 goals are ambitious and broad in nature. To complement them, this year the report proposes 3 or 4 "success statements" for each sector. The aim is to make the ambitions of the 2030 Breakthrough Agenda Goals actionable by offering a concrete vision of success for each sector by 2030. These success statements are intended to add value by defining measurable achievements that can be tracked in future Breakthrough Agenda reports, alongside recommendations for collaboration.

Each success statement is supported by at least one quantitative indicator to measure progress over time and qualitative examples to show progress against the statement. The aim is not to measure every detail or to offer rigid benchmarks, but rather to guide collective efforts and focus international collaboration where it can have the greatest impact.

While annual recommendations help guide near-term priorities and align international co-operation, success statements add further clarity by providing a shared understanding of the outcomes these recommendations are ultimately meant to achieve. This two-track approach will allow for a more comprehensive monitoring and for driving progress across sectors.

LOOKING BEYOND TO 2035

The Breakthrough Agenda's 2030 goals mark important objectives, but they are not an end point for international collaboration. As the energy and policy landscape continues to evolve, it is important that countries begin to look beyond 2030 and initiate discussions on what collective ambition should look like by 2035. This is not about shifting focus away from near-term progress; rather, it is about recognising that sustained momentum requires longer-term direction.

Setting a vision for the mid-2030s can help ensure today's efforts lay the groundwork for deeper transitions ahead and provide greater long-term certainty to support investment planning. The Business Breakthrough Barometer 2025 found that while more than 90% of global businesses have maintained or increased their net zero transition investments in the past year, half of them have less confidence in governments' support for the net zero transition than they did last year. A clear long-term vision, supported by governments and other actors, can provide the confidence needed to sustain investment momentum.

The world of today is already different to the world in which the 2030 goals were first conceived – technologies have matured, market dynamics have shifted, and geopolitical challenges have intensified. The 2030s will bring new opportunities, challenges and expectations that will require updated strategies and collaborative targets. By beginning the conversation now, countries and other actors can better anticipate future needs in a way that keeps pace with both climate goals and economic realities.

Forward-planning also ensures that the actions taken towards 2030 goals are aligned with a longer-term trajectory. Early dialogue on post-2030 goals will give countries the chance to collectively shape the next phase of collaboration, ensuring the Breakthrough Agenda remains responsive, resilient and ambitious in a rapidly changing world

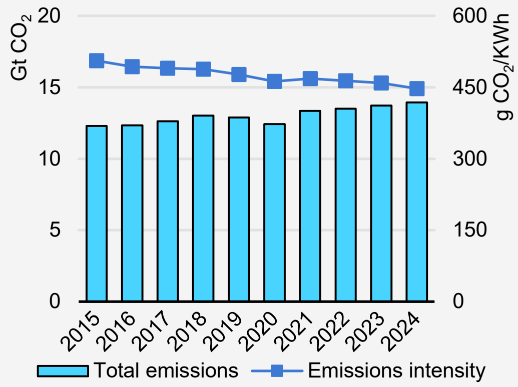
.

Power

State of the transition

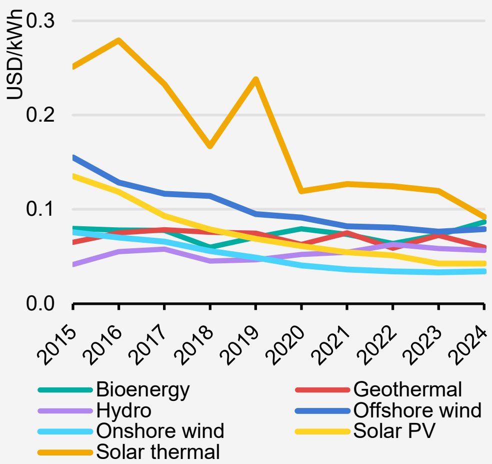
The power sector has seen significant year-on-year progress in renewables deployment, constraining increases in fossil-fired generation as growth in emissions shows signs of slowing down. Business leaders are optimistic about the pace of the transition, but more efforts will be needed to meet the COP 28 goal of tripling renewable energy capacity by 2030.

Emissions



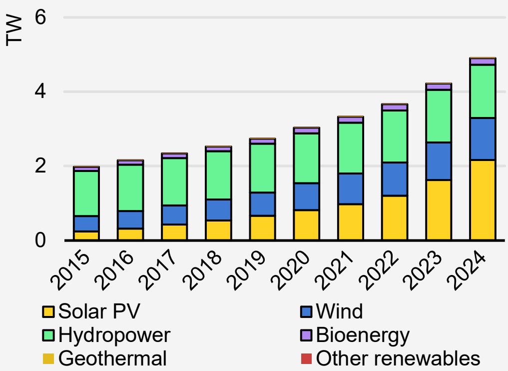
- Global emissions from electricity generation rose by 1.2% in 2024 to around 13.9 Gt of CO_2, following an increase of 1.6% in 2023.
- The global emissions intensity of electricity generation is on a contracting trend, with a record 3% reduction in 2024 compared to 1% in 2023. This improvement reflects the rapid growth in renewable energy and nuclear electricity production relative to rising demand.

Cost[1]



- On an levelised cost of electricity (LCOE) basis, renewables remained the most cost-competitive option for new electricity generation in 2024.
- Onshore wind remained the most affordable source of new generation globally in 2024, with a weighted average LCOE of USD 0.034/kWh, followed by solar PV (USD 0.043/kWh) and hydropower (USD 0.057/kWh).

Deployment



- Rising generation from renewables and nuclear power made up over 80% of global growth in electricity generation in 2024 – a step up from 2023, when they accounted for two-thirds of total growth.
- Global renewable power capacity is expected to reach 2.6 times its 2022 level by 2030, falling short of the COP 28 pledge of tripling renewable energy capacity.

[1] Levelised cost of electricity (LCOE); source: IRENA Renewable Power Generation Costs in 2024.

SUCCESS STATEMENTS: POWER

THE RAPID DEPLOYMENT OF CLEAN POWER GENERATION CONTINUES AND EXPANDS CONSIDERABLY IN ALL REGIONS OF THE WORLD.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Electricity generation continues to have the highest emissions in the energy sector, with around 13.9 Gt CO_2 emitted in 2024.
- Renewables, nuclear and other low-emissions electricity technologies are readily available to cut emissions. Faster deployment globally hinges on progress in all regions of the world, not just where deployment is taking place today.
- Recent progress and record growth years for renewables deployment, in particular, have been promising, but tapping into untouched potential in more regions and supporting the deployment of nuclear power can unlock greater emissions reductions.

QUANTITATIVE INDICATOR FOR SUCCESS

- Installed regional capacity and generation share of low-emissions power generation.

QUALITATIVE EXAMPLES OF COLLABORATION

- In 2025, the Energy Transition Council expanded its support to Latin America to help countries in the region deliver ambitious Nationally Determined Contributions (NDCs), in addition to continued support for the COP 28 Global Renewables and Energy Efficiency Pledge.
- At the G20 Summit in Brazil in 2024, more than a dozen countries launched the Global Clean Power Alliance (GCPA) to speed up the deployment of low-emissions power generation. The GCPA Finance Mission was launched to close the financing gap in emerging markets and, in the lead-up to COP 30, the GCPA aims to define how high-quality investment planning can facilitate greater private sector investment.
- At COP 28, 200 countries made a landmark pledge to triple renewable energy capacity globally by 2030, and over 20 countries pledged to triple nuclear energy capacity by 2050.

COUNTRIES SCALE UP INVESTMENT IN GRID INFRASTRUCTURE AND ENERGY STORAGE, WITH TARGETED SUPPORT FOR EMERGING MARKETS AND DEVELOPING ECONOMIES TO SUPPORT GROWING ELECTRIFICATION AND ENERGY SECURITY NEEDS.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- The timely expansion of grids is essential to supporting electrification, energy security and the decarbonisation of electricity supply.
- As more parts of the economy electrify (such as through the adoption of heat pumps or electric vehicles) and demand greater amounts of electricity (such as for air conditioning), additional strain will be placed on the grid. Higher dependency on electricity means that access to a reliable, secure supply is even more important.
- In particular, the acceleration of renewable energy deployment calls for a modernisation of distribution grids and establishment of new transmission corridors to connect renewable resources and build out grid-scale storage.
- Emerging markets and developing economies (EMDEs) excluding China have seen grid investment decline by 7% per year on average in recent years, despite robust electricity demand growth, gaps in energy access and the need to continue improving reliability in many regions.

QUANTITATIVE INDICATOR FOR SUCCESS

- Global investment in grids and storage, with a focus on international public financing to EMDEs.

QUALITATIVE EXAMPLES OF COLLABORATION

- At COP 29, nearly 60 countries committed to the Global Energy Storage and Grids Pledge, which sets a goal of deploying 1 500 GW of energy storage, doubling global grid investments, and developing 25 million kilometres of grid infrastructure by 2030. The number of countries has now increased to 65, with over 100 non-state actors as signatories.
- In August 2025, the Green Grids Initiative finalised the Climate Finance Principles to Unlock Grids Financing, a landmark framework designed to unlock investment in electricity transmission, distribution and storage infrastructure. The Climate Finance Principles provide a forward-looking, methodology-neutral framework to assess the climate eligibility of grid investments.

COUNTRIES TAKE FORWARD EFFORTS TO ENHANCE CROSS-BORDER ELECTRICITY TRADING, SUPPORTED BY THE DEVELOPMENT OF REGIONAL POWER INTERCONNECTIONS.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Interconnected grids can improve overall grid stability and flexibility, increase the diversity of resources for serving demand and provide a smoothing effect on variable renewables. Better interconnections allow countries and regions with excess clean energy to transfer it to areas with higher demand or less available capacity.

- Enabled by interconnections, cross-border electricity trade can lead to overall cost savings and revenue generation across the interconnected region, helping finance in-country deployments and reducing the cost of achieving energy and climate goals.
- While agreements on principles and best practice guidelines are an important foundation, an increased focus on deal-making is needed to bring progress in this area in line with the Power Breakthrough goal.
- Efforts need to go beyond resolving technical issues around interconnectors and move towards agreeing on plans for implementation and the harmonisation of regulatory and trading frameworks.

Quantitative indicator for success

- Volume of electricity generation traded across borders.

Qualitative examples of collaboration

- In August 2025, ministers of the Association of Southeast Asian Nations (ASEAN) countries welcomed a proposal by the World Bank and Asian Development Bank to develop the ASEAN Power Grid Financing Initiative, which will mobilise financing and provide technical support. The banks have so far pledged more than USD 12 billion to support this effort.
- In the context of the Renewable Energy Transition Accelerator, three knowledge products have been published by IEA, the World Bank and the International Renewable Energy Agency (IRENA), covering different aspects of regional interconnections: Institutional architecture; transmission pricing; and harmonisation of grid codes. These aim to provide regulators with examples and tools to ensure interconnectors increase flexibility in grids and support higher uptake of renewables.

Just transition plans are incorporated into financial development assistance to address the socio-economic impacts of energy transitions, particularly in fossil fuel-dependent countries and regions.

Why is it important to achieve the success statement to reach the sectoral breakthrough goal?

- To ensure a just transition in the power sector, it will be crucial to accelerate learning from successful projects and to use this knowledge to better target resources towards a greater number of fossil fuel-dependent regions. In particular, there is enormous potential to expand activity into coal-intensive regions.
- Just transition plans designed to mitigate job losses and livelihood disruption in coal regions are essential to ensure that local communities both benefit from and support the transition. These strategies and financial plans should include training and reskilling programmes as well as protections, informed by dialogue and stakeholder participation.
- Dedicated funding should be allocated to environmental restoration plans. All these aspects are essential for building legitimacy and social acceptance, while reducing the risks of opposition, conflicts and delays.
- While there are a growing number of activities addressing the socio-economic impacts of the energy transition, these efforts are still in their early stages.

QUANTITATIVE INDICATOR FOR SUCCESS

- Percentage of coal workers covered by coal-specific just transition policies, announced and fully funded.

QUALITATIVE EXAMPLES OF COLLABORATION

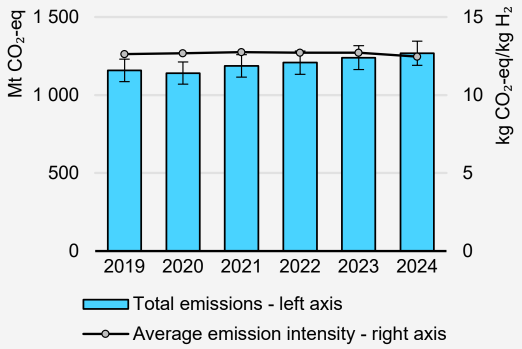
- The IEA's Global Commission on People-Centred Clean Energy Transitions, comprised of energy, climate and labour leaders from governments and organisations around the world, released the Blueprint for Action on Just and Inclusive Energy Transitions, a major new guide for governments worldwide on translating the G20 Principles for Just and Inclusive Energy Transitions into real-world policy and practice.
- At COP 29, Uganda, and the bank Standard Chartered, joined the Powering Past Coal Alliance, a coalition working to advance the transition from unabated coal power generation to clean energy. While no coal-fired generation exists in Uganda, this signals that the country commits to not build any new coal in the future.

HYDROGEN

STATE OF THE TRANSITION

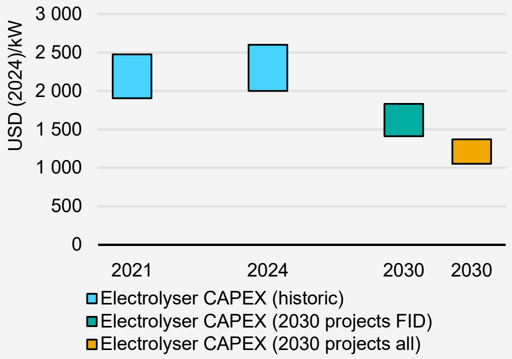
The deployment of renewable and low-carbon hydrogen[1] and reduction in the production and use of hydrogen from unabated fossil fuels is significantly behind where it needs to be to get on track with the IEA Net Zero Emissions by 2050 Scenario (NZE Scenario), despite significant progress achieved in the last few years in this nascent sector. This outlook is reflected in the business community, where leaders report a deceleration in the pace of transition.

Emissions[2]



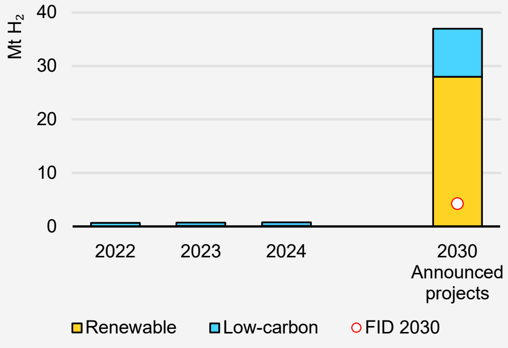
- Hydrogen production today is associated with emissions of almost 1 300 Mt CO_2 equivalent (CO_2-eq) and there has been no progress in reducing them – in contrast, emissions have edged up in recent years.
- However, the increase in global production (which neared 100 Mt in 2024) has kept the global average emissions intensity of hydrogen production almost constant over the past 5 years.

Costs[3]



- Renewable and low-carbon hydrogen remains more expensive than hydrogen from unabated fossil fuels.
- The cost gap has increased recently due to slower-than-expected deployment, inflation and the fall in fossil fuel prices.
- Electrolyser capital cost is expected to decrease through scale-up, innovation and improved manufacturing, but cost declines will depend on the pace of deployment.

Deployment



- Renewable and low-carbon hydrogen reached 0.8 Mt in 2024, making up less than 1% of global production.
- Based on projects with a final investment decision (FID), renewable and low-carbon hydrogen production can reach over 4 Mt by 2030, but they represent only 9% of all announced projects (up from 6% last year).

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[1] This report does not define a specific carbon intensity limit for renewable and low-carbon hydrogen. All the production routes covered by this term will need to achieve verifiable low-carbon intensities that trend towards near zero by 2030. This implies that fossil-based hydrogen production must operate with high carbon capture rates applied to all streams containing CO_2, and that the captured carbon must be permanently stored underground to prevent its release into the atmosphere. Methane leakage must be reduced to near zero, if not completely avoided. Rigorous measurement, reporting and verification of emissions will be needed.

[2] Includes upstream emissions of fossil fuel supply. Error bars reflect the variability of emissions depending on the allocation method for the production of hydrogen as a by-product in the petrochemical industry.

[3] Electrolyser capital costs. The 2030 values refer to the projected cost with a deployment equivalent to the electrolysis capacity that has at least reached final investment decision and to all announced projects.

Success Statements: Hydrogen

Governments implement clear rules that set thresholds for acceptable levels of emissions for hydrogen producers and users to be eligible for support schemes, based on International Organization for Standardization (ISO) standards, or at least consistent with ISO standards.

Why is it important to achieve the success statement to reach the sectoral breakthrough goal?

- Uncertainty around regulations relating to emission levels considered acceptable by countries when determining eligibility for support schemes has been delaying investment decisions on both supply and demand, as private sector investors may be at risk of non-compliance.
- Consistency with ISO standards can facilitate mutual recognition of certificates, which is critical to minimise market fragmentation and ensure that trade is not limited to bilateral agreements.
- Referring to the emissions intensity of hydrogen in regulations can support a technology-neutral approach.

Quantitative indicators for success

- Number of countries with rules on emissions thresholds for hydrogen production using methodologies consistent with ISO standards.
- Share of global hydrogen production located in countries with rules on emissions thresholds for hydrogen production using methodologies consistent with ISO standards.

Qualitative examples of collaboration

- The IEA Hydrogen Technology Collaboration Programme (TCP) "Task" for the Certification of Hydrogen and Derivatives is developing a technical mutual recognition framework for certification schemes.
- The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) and the IEA Hydrogen TCP co-ordinated the development of a Hydrogen Certification 101 paper, which benefited from contributions of the International Renewable Energy Agency (IRENA), the Hydrogen Council and the International Power-to-X Hub. The paper aims to create a common language on certification, which could help to enable mutual recognition of certificates.

Governments implement policy measures and regulations for the use of renewable and low-carbon hydrogen in sectors where hydrogen is already used and in high-value end uses.

Why is it important to achieve the success statement to reach the sectoral breakthrough goal?

- Policy support is fundamental to stimulate demand for renewable and low-carbon hydrogen, which could, in turn, unlock investment on the supply side and ultimately result in infrastructure development.
- Stimulating demand can enable scale-up of renewable and low-carbon hydrogen production, which can lead to production cost reductions through economies of scale and learning-by-doing.
- Demand-pull policies can stimulate technology innovation and advance demonstration projects, particularly in new high-value end-use applications such as steel, shipping and aviation.

Quantitative indicators for success

- Number of countries with implemented demand-pull policies (including carbon contracts for difference, fuel standards, grants for demand creation, loan and loan guarantees on the demand side, mandates and quotas, public procurement instruments and tax incentives for the demand side) in existing hydrogen applications (refining, ammonia production and methanol production).
- Share of global hydrogen demand covered by the above-mentioned implemented policies for the adoption of renewable and low-carbon hydrogen.

Qualitative examples of collaboration

- The outcome of talks on the proposed International Maritime Organization (IMO)'s Net-Zero Framework, if approved by IMO member states in October 2026 following an adjournment of discussions in 2025, could provide maritime operators with greater future visibility on the need to adopt low-emissions fuels (including renewable and low-carbon hydrogen and derivatives). This can stimulate long-term offtake agreements for fuels that are normally purchased on the spot market.

Private sector commitments for the use of renewable and low-carbon hydrogen translate into firm offtake and purchase agreements.

Why is it important to achieve the success statement to reach the sectoral breakthrough goal?

- Project developers are struggling to secure creditworthy offtake agreements that can help to de-risk projects.
- A significant number of offtake agreements have been announced in the past 5 years, but the majority remain preliminary, without any binding conditions for suppliers and offtakers, and without long-term commitment.

- Securing firm, long-term offtake agreements is the principal method of de-risking investment on the supply side.

QUANTITATIVE INDICATORS FOR SUCCESS

- Cumulative firm offtake agreements for renewable and low-carbon hydrogen.

QUALITATIVE EXAMPLES OF COLLABORATION

- Several buyers' platforms for derivatives produced using hydrogen (including e-fuels) are helping to pool demand for renewable and low-carbon hydrogen and providing an opportunity to negotiate advanced offtake agreements. Examples include the Sustainable Aviation Buyers Alliance, the Zero Emissions Maritime Buyers Alliance and the Sustainable Steel Buyers Platform.

GOVERNMENTS, MULTILATERAL DEVELOPMENT BANKS AND DEVELOPMENT FINANCE INSTITUTIONS SCALE UP CONCESSIONAL FINANCE TO EMERGING MARKETS AND DEVELOPING ECONOMIES TO HELP LARGE-SCALE PROJECTS FOR THE PRODUCTION OF RENEWABLE AND LOW-CARBON HYDROGEN TO REACH FINAL INVESTMENT DECISIONS.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Progress on the production and use of renewable and low-carbon hydrogen in emerging markets and developing economies (EMDEs) has been limited, despite their strong potential for cost-competitive production, and opportunities to benefit from economic development and reduced dependency on imported fossil fuels.
- Projects under development in EMDEs face significant financial barriers, particularly due to the comparatively high cost of capital, which is preventing investment decisions.
- Scale-up of concessional finance must be accompanied by continued support for technical assistance to address other barriers, such as unclear or incomplete regulatory frameworks and lack of infrastructure readiness, and to address over-reliance on export markets rather than domestic opportunities to create in-country wealth.

QUANTITATIVE INDICATOR FOR SUCCESS

- Kilotonnes per year of renewable and low-carbon hydrogen production capacity facilitated by concessional finance reaching final investment decision (FID) in EMDEs.

QUALITATIVE EXAMPLES OF COLLABORATION

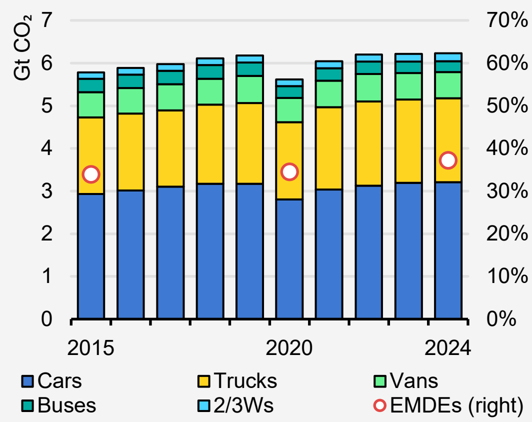
- At COP 29, development finance institutions pledged to support the World Bank's 10 GW Lighthouse Initiative, with the objective of helping developing country projects of 100 MW – 1 GW to reach FIDs by 2030. There are now 15 participating development finance institutions.
- The United Nations Industrial Development Organization (UNIDO)'s Accelerate-to-Demonstrate (A2D) Facility supported Namibia's first project for fertiliser production using renewable hydrogen to begin construction.
- The World Bank's Climate Investment Fund and Green Climate Fund have provided concessional finance for projects in Brazil and Paraguay.

Road transport

State of the transition

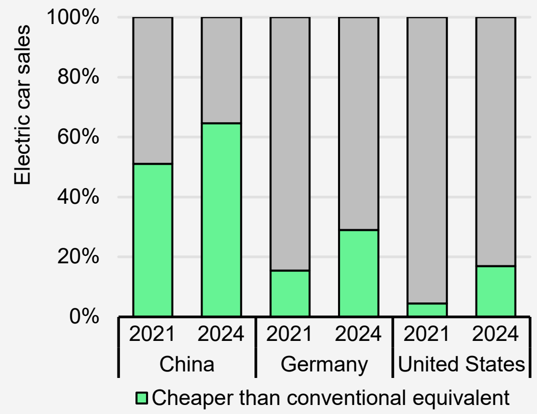
Across the global fleet, CO_2 emissions per km driven have slightly fallen since 2020, thanks to increasingly stringent fuel economy standards and record-breaking electric vehicle (EV) sales. Zero-emission vehicles (ZEVs) displaced about 1.3 million barrels of oil in 2024, nearly equivalent to the total road oil consumption of Brazil. Despite this, overall CO_2 emissions have stagnated as vehicle ownership has grown, and ZEV uptake remains highly uneven across regions. Business sentiment was mixed in 2024, reflecting these trends. Stronger international collaboration on technology deployment, policy alignment, and investment, particularly to support emerging economies, will be essential to accelerate cost reductions and ensure a globally co-ordinated transition.

Emissions



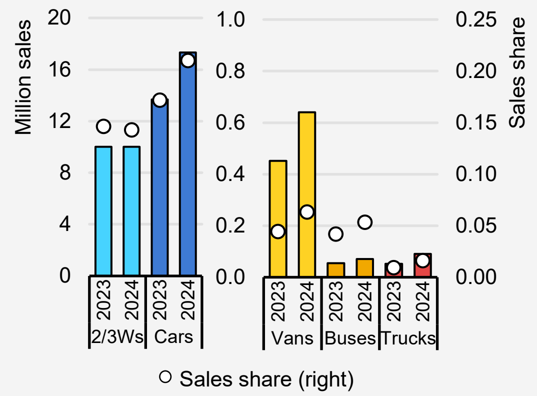
- Road sector emissions were just over 6 Gt CO_2 in 2024, 8% higher than in 2015. Growth averaged only 0.2% annually from 2019 to 2024, down from 1.7% per year between 2015 and 2019.
- Over 60% of road emissions are from passenger cars or vans, followed by trucks (about one-third), and buses and 2/3 wheelers just 7%.
- Since 2015, emissions in emerging economies (excluding China) have risen sharply, at over 18%, compared to 2.5% in the rest of the world.

Cost



- Closing the purchase price gap between electric and conventional cars is essential for mass adoption. Declining battery costs and growing market competition are driving improvements in affordability.
- Electric car affordability improved across all major markets between 2021 and 2024. In China, around two-thirds of electric cars were cheaper than their conventional counterparts in 2024.

Deployment



- Electric car sales surpassed 17 million in 2024, growing nearly 30% year-on-year. They accounted for 22% of total car sales, meaning cars overtook 2/3-wheelers as the most electrified road transport segment. Electrification of 2/3-wheelers stagnated at about 15% in 2024.
- The electric bus and truck market continued to expand, growing by 30% and 75%, respectively. Sales of electric vehicles are highest in China, where around 1 in 10 cars is now electric.

SUCCESS STATEMENTS: ROAD TRANSPORT

ZERO-EMISSION LIGHT-DUTY VEHICLE PLEDGES ARE TRANSLATED INTO POLICIES, AND MORE KEY MARKETS JOIN HEAVY-DUTY VEHICLE PLEDGES.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- While significant recent growth in electric vehicle (EV) sales is encouraging, it remains uneven across geographies and segments. Governments play an important role in accelerating zero-emission vehicle (ZEV) adoption by setting high-level targets and adopting related regulations for fuel economy or CO_2 standards. By working together, countries can amplify the signal for greater ZEV adoption.
- More effort is needed in translating voluntary targets into deployment policies for the light-duty vehicle (LDV) segment. Around 20% of the global LDV market is now covered by binding policies to achieve 100% ZEV sales on a timeline aligned with the 2015 Paris Agreement. A further 10% of the market has voluntary commitments in place.
- Heavier segments are at an earlier stage of the transition, with a ZEV sales share of less than 2% for medium- and heavy-duty vehicles (MHDVs) compared to over 20% for the LDV segment. This highlights the need for stronger policy focus on heavier segments, and more collaboration between countries on relevant ZEV targets. Only 20% of the heavy-duty vehicle (HDV) market is covered by ZEV targets, and a far smaller share by policies to implement those targets.

QUANTITATIVE INDICATOR FOR SUCCESS

- Share of new LDV sales covered by ZEV enabling policies aligned with the 2015 Paris Agreement.
- Share of global MHDV markets that have joined ZEV MHDV pledges.

QUALITATIVE EXAMPLES OF COLLABORATION

- Two new trucking sector members joined the First Movers Coalition, where truck owners and operators commit to making at least 30% of their purchases of new heavy-duty trucks zero-emission by 2030, as well as 100% of new medium-duty truck purchases.
- At COP 29, Costa Rica signed the ZEV Declaration, which targets 100% ZEV sales of new cars and vans by 2035.
- In April 2025, a green corridor aimed at supporting zero-emissions MHDVs was announced as a part of the Global Green Road Corridor Initiative. In phase 1, the Mediterranean Corridor will run 1 000 km from Algeciras in Spain to Avignon in France.
- In April 2025, Montenegro and Peru became signatories of the Global Memorandum of Understanding on zero-emission MHDVs, which now has 40 signatories, representing around 21% of the global MHDV market.

INTERNATIONAL PUBLIC AND PRIVATE FINANCE IS SCALED UP IN EMERGING MARKETS AND DEVELOPING ECONOMIES TO SUPPORT ROAD TRANSPORT DECARBONISATION INITIATIVES.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- At 4%, the share of EVs in new car sales remains lower in emerging markets and developing economies (EMDEs) other than China compared to in advanced economies (13%). Imports of relatively affordable EVs from Chinese car makers are supporting an increase in the sales share in EMDEs, but decarbonisation of road transport remains capital intensive, especially as the cost of capital in EMDEs is higher than in advanced economies.
- Public finance can also support international collaboration on the growing trade in used EVs, by funding systems to track imports and exports, enforcing standards for vehicle condition, and building local service networks (see next Success Statement). Such investments increase transparency and ensure that used EV flows strengthen, rather than undermine, road transport decarbonisation.
- Alongside access to finance, EMDEs can benefit from other international support such as assistance to build capacity for policy design and implementation and de-risking facilities to leverage private sector investments.

QUANTITATIVE INDICATORS FOR SUCCESS

- International public financing for road transport electrification or charging infrastructure in EMDEs excluding China.

QUALITATIVE EXAMPLES OF COLLABORATION

- The Global Facility to Decarbonise Transport (GFDT) is a multi-donor trust fund established at COP 26 to provide financial and technical assistance to EMDEs for transport decarbonisation. In 2025, the GFDT selected over 20 projects to receive a total of nearly USD 4.4 million.
- At COP 27, governments, corporates and financial institutions created the Collective for Clean Transport Finance (CCTF). In 2024, CCTF started designing a potential pilot project with Brazil on demand aggregation for electric buses, which could provide a framework to be replicated in other countries. In 2025, CCTF is working to secure funding to operationalise its flagship projects.
- At COP 29, companies under the Zero Emission Vehicles Emerging Markets Initiative (ZEV-EM-I) signalled demand for approximately 9 000 electric vehicles in Mexico by 2027; and more than 17 000 electric vehicles by 2030, including freight and passenger vehicles.

Global interoperability enables electric vehicles to charge seamlessly anywhere in the world

Why is it important to achieve the success statement to reach the sectoral breakthrough goal?

- At present, not all EVs can charge at all public or semi-public stations, due to incompatible connector types, which can vary regionally and by car model, as well as due to proprietary networks. These limitations reduce convenience, create uncertainty for drivers, and can slow adoption.
- There are seven major connector types for electric cars; J1772 and IEC Type 2 are typically used for slow charging, while the other five are used for fast charging: NACS, CCS, CCS (2), CHAdeMO and GB/T. For charging above 350 kW, two connector types are common: Megawatt Charging System (MCS) and ChaoJi. With new models and charging technologies continuing to emerge, international co-operation is essential to harmonise charging standards in order to prevent waste and ensure usability of cars across different geographic regions.
- In addition, transparent and simple payment systems are crucial for public charging. Ensuring drivers know the price in advance builds trust in the charging network and encourages wider use.
- Data sharing and transparency are needed to make chargers easily findable in order to improve accessibility and driver confidence, whether through in-vehicle operating systems, mobile applications or roadside signage.

Quantitative indicator for success

- Number of connector types

Qualitative examples of collaboration

- The European Union and the United States issued a joint statement recognising the MCS as adopted by international standardisation bodies.

Battery end-of-life management discussions are translated into national policies and capacity-building initiatives, particularly in emerging markets and developing economies.

Why is it important to achieve the success statement to reach the sectoral breakthrough goal?

- Growing demand for EVs is increasing demand for the critical minerals used in batteries. Battery end-of-life management can provide a significant secondary source of supply of critical minerals that is more sustainable and less geographically concentrated than primary supply. These benefits are greatest when recycling facilities are located domestically.
- This means that there is a need to develop battery end-of-life strategies, which could call for either new recycling capacity in EMDEs (where imports of used EVs are expected to rise in the coming decade); or plans to send end-of-life vehicles back to recycling centres, such as to the battery or vehicle manufacturer.

- Collaboration is needed between countries that export EVs and countries where EVs reach end-of-life, as is collaboration on regulatory frameworks and standards for managing the recycling and reuse of EV batteries. Exploratory workshops remain at an early stage (see below) and will need to scale up to translate into sizeable impact.

Quantitative indicators for success

- Global battery recycling capacity and share in EMDEs.
- Share of battery demand covered by recycled material.

Qualitative examples of collaboration

- Progress is underway toward a second release of the Battery Passport indicator framework, data exchange and assurance rulebook, as well as supporting materials, to allow early adoption in support of regulatory requirements, and pave the way for large-scale uptake of Battery Passport certification.
- According to the United Nations Environment Programme, more than 30 country projects have now included an end-of-life component in their national electric mobility programmes

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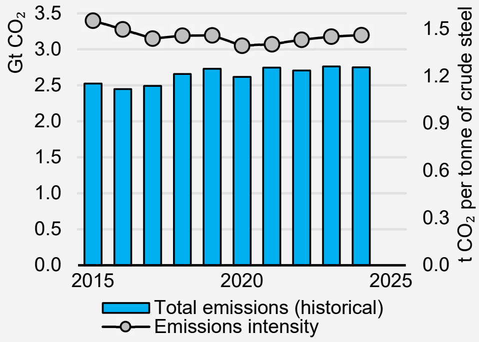
STEEL

STATE OF THE TRANSITION

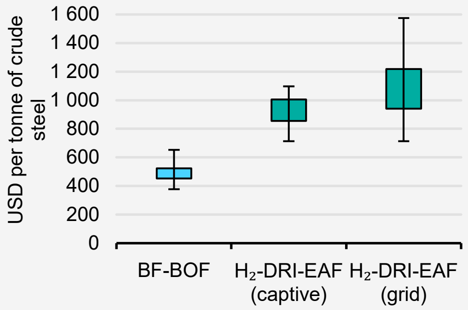
The steel sector is not on track to meet net zero by 2050. Despite the first near-zero emissions[1] plants being due to come online in 2026, progress has stalled, with projects struggling to reach final investment decisions and over 10 Mt of capacity being delayed this year. In the business community, fewer leaders are confident (7%) the sector will reach the 2030 Breakthrough Agenda goal than in 2024 (20%). Most projects are only near-zero emissions *capable*,[2] and lack firm technology details and timelines. Greater collaboration is required to strengthen enabling conditions, policy support, and demand signals to overcome deployment barriers.

Emissions



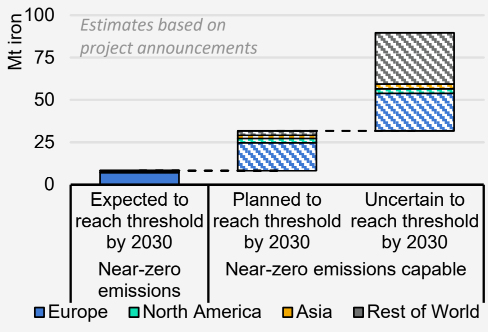
- Total CO_2 emissions remain largely unchanged from recent years, while direct CO_2 emissions intensity has seen an uptick since 2021.
- Both must fall in the coming years to get on track with the IEA's Net Zero Emissions by 2050 Scenario (NZE Scenario).

Cost[3]



- Blast furnace-basic oxygen furnace (BF-BOF) routes make up about 70% of global steel production today.
- Hydrogen direct reduced iron electric arc furnace (H_2 DRI-EAF) routes are emerging as a preferred low-emissions option in certain regions. Early commercial plants using 100% hydrogen blends are estimated to cost 50-140% more than BF-BOF plants today, varying based on region, which is slowing deployment.

Deployment[4]



- Capacity for near-zero emissions iron by 2030 remains unchanged from 2024, at about 10 Mt. Near-zero emissions capable capacity is largely the same as in 2024, at just over 80 Mt. Of this, 25 Mt has plans to operate as near-zero emissions by 2030 but comes from early-stage projects. The rest plan to operate using natural gas initially, with unclear timelines for transitioning to full near-zero emissions.
- Getting on track with the NZE Scenario will require accelerating these near-zero emissions capable projects to run as fully near-zero emissions by 2030.

[1] "Near-zero emissions" refers to projects that will operate at an emissions intensity consistent with near-zero emissions from the start, as defined in the IEA report Achieving Net Zero Heavy Industry Sectors in G7 Members

[2] "Near-zero emissions capable" is capacity that operates with the same core process equipment as near-zero emissions capacity and will attain a substantial reduction in emissions intensity (compared to current conventional technologies) from the start, but initially falls short of the emissions intensity for near-zero emissions, with clear plans to reduce emissions further to a level consistent with near-zero emissions at a later date and with technical capabilities such that it can reach near-zero emissions without substantial additional capital investment in core process equipment.

[3] Levelised cost of production (LCOP). Estimated LCOPs are based on regional averages, accounting for variation in energy inputs and costs by region, and do not include explicit policy supports, e.g. carbon pricing or subsidies. Regional variation in capital and non-energy operating expenses is not considered. Energy prices, intensities, and fuel mixes from 2024 are used for calculation of LCOPs. The box shows the range of expected typical LCOPs; whiskers show the average LCOP in higher- and lower-cost regions.

[4] Near-zero emissions projects are those that have achieved a final investment decision (FID) or provided strong certainty that FID will be achieved, and meet the criteria in footnote 1. Near-zero emissions capable projects that have given clear indications they will operate as near-zero emissions by 2030 but are at an earlier stage are considered "planned to reach threshold by 2030". Near-zero emissions capable projects that initially operate using gas and lack clear timelines for achieving near-zero emissions are considered "uncertain to reach threshold by 2030.

SUCCESS STATEMENTS: STEEL

GLOBAL INTEROPERABILITY BETWEEN LEADING EXISTING DEFINITIONS AND STANDARDS FOR NEAR-ZERO AND LOW-EMISSIONS STEEL IS ESTABLISHED, AND EXISTING EMISSIONS MEASUREMENT METHODOLOGIES ARE MADE MORE TRANSPARENT, INTEROPERABLE AND NET ZERO COMPATIBLE, WITH COHERENT CHAIN OF CUSTODY RULES.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Definitions and standards that establish emissions intensity thresholds for near-zero and low-emissions steel production can underpin enabling mechanisms and policies. These can feed into product-level thresholds, which can support further emissions reductions as well as material efficiency measures.
- Interoperability and/or comparability of different definitions, standards and certifications for near-zero and low-emissions steel – either through a method for determining equivalency established for use by governments and buyers, or mutual recognition among standards owners – provides greater transparency and clarity to actors across international markets, which can unblock action.
- Emissions measurement methodologies underpin definitions and standards, as well as other uses, by providing a framework for measuring and accounting emissions.
- Interoperable and net zero compatible[1] methodologies can improve comparability and reduce reporting burden. Existing schemes offer a robust basis, but some require revisions to make them fit for purpose, and a way to translate between methodologies is needed.
- Chain of custody schemes help track materials and attributes through supply chains, and alternative schemes are emerging as mechanisms to provide flexibility and encourage action on decarbonisation. In all cases, robust reporting and verification are important to avoid double-counting emissions reductions and ensure additionality, as are rules for consistent emissions accounting and appropriate, transparent marketing of materials.
- Greater clarity on the process and responsibilities for revising existing methodologies could accelerate and guide convergence towards greater alignment, especially in policy applications.

QUANTITATIVE INDICATOR FOR SUCCESS

- Number of leading definitions[2] and standards that have established equivalency or mutual recognition.
- Share of production potentially covered by voluntary labels for near-zero and low-emissions steel.

[1] Interoperability means that different methodologies are coherent and work alongside each other (e.g. it becomes possible to compare their results on an equivalent basis), enabling clear and consistent communication and interpretation, even though methodologies may not be exactly the same due to different purposes and/or scopes. Net zero compatibility means that measurement methodologies can be applied to the full range of technologies that are needed for the net zero transition, and are designed in a way that incentivises choices in favour of the net zero transition.
[2] i.e. those that are in use and/or under consideration by a substantive number of steel producers across multiple countries.

QUALITATIVE EXAMPLES OF COLLABORATION

- The Steel Standards Principles (SSP) group is working towards interoperability of emissions measurement methodologies for steel, including building on the IEA's Net Zero Measurement Principles. This is supported by input and guidance from its 60+ endorsing organisations, which include intergovernmental organisations that can ensure co-ordination with discussions among governments.
- Multilateral fora (e.g. the IEA Working Party on Industrial Decarbonisation, Climate Club, OECD Inclusive Forum on Carbon Mitigation Approaches and Industrial Deep Decarbonisation Initiative [IDDI]) are facilitating co-operation between governments on definitions and measurement methodologies. The Climate Club Members Statement at COP 29 affirmed emerging common understandings on definitions and convergence among scientific, public and private initiatives on thresholds.
- The International Organization for Standardization (ISO) and Greenhouse Gas (GHG) Protocol recently announced a partnership to harmonise their existing GHG standards and co-develop new standards for emissions measurement and reporting, serving as a potential positive step towards greater interoperability for emissions measurement that could be taken forward in the steel sector.

NEAR-ZERO AND LOW-EMISSIONS STEEL DEMAND COMMITMENTS ARE CONSIDERABLY EXPANDED AND INCLUDE NEW MARKETS AND END-USE SECTORS, AND COMMITMENTS ARE CONVERTED TO FIRM OFFTAKE AND ADVANCE PURCHASE AGREEMENTS.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Demand commitments for near-zero emissions steel are a major pull factor for the establishment of lead markets, helping to de-risk early deployments of emerging technologies and encourage scale-up. In parallel, demand for low-emissions steel can facilitate progress on decarbonisation and growth of markets for lower-emissions materials.
- Despite efforts from first movers, demand for near-zero and low-emissions steel has not been sufficient to encourage production growth at the pace and scale needed for the industry transition, and regional and sectoral gaps remain.
- Demand commitments, especially when aggregated, can amplify market signals and accelerate the process of securing offtakes. Public procurement commitments can be a key lever. Commitments across different regions and sectors build momentum for broad market scale-up.
- Firm offtakes and advance purchase agreements provide certainty for suppliers, facilitating final investment decisions (FIDs) and supporting the establishment of supply chains.

QUANTITATIVE INDICATORS FOR SUCCESS

- Cumulative number of public and private offtakes or purchase agreements for near-zero emissions steel.
- Number of countries in which public and/or private organisations have made demand commitments for near-zero emissions steel or in which government policies to incentivise private purchases have been implemented.

QUALITATIVE EXAMPLES OF COLLABORATION

- Existing public and private sector initiatives (First Movers Coalition, SteelZero, IDDI) for near-zero and low-emissions steel demand aggregation are enabling market formation through focused efforts to support their members in translating demand commitments into offtakes. Today, over 70 organisations have made commitments under these initiatives. Further momentum was built at COP 29 with a joint call to action for governments to take up the IDDI Green Public Procurement Pledge.
- Buyer-supplier matching programmes are getting off the ground (Sustainable Steel Buyers Platform, First Suppliers Hub, Near-Zero Steel 2030 Challenge), signalling a total of 3.3 Mt of demand in 2024 to help facilitate new offtakes.

SCALED-UP DELIVERY PROGRAMMES FOR INTERNATIONAL FINANCIAL AND TECHNICAL ASSISTANCE HAVE ENABLED LARGE-SCALE PROJECTS ACROSS ALL REGIONS, BUILDING ON PILOT ASSISTANCE PROGRAMMES AND DRAWING ON LEARNINGS FROM RD&D AND EARLY COMMERCIAL NEAR-ZERO EMISSIONS STEEL PROJECTS.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Emerging markets and developing economies (EMDEs) are not well represented in the project pipeline for near-zero emissions steel, partly because conditions for first-of-a-kind investments are typically less favourable than in advanced economies. Financial and technical assistance could help enable deployment.
- Many existing assistance programmes are still at an early stage and require successful piloting before being scaled up. Stronger and broader engagement in matchmaking platforms can improve the delivery of assistance to help fast-track large-scale projects in EMDEs.
- Learnings from the first wave of large-scale near-zero emissions steel projects – mainly in advanced economies – could de-risk and facilitate subsequent deployments in EMDEs. Likewise, collaboration on RD&D, including with EMDEs, could support development of emerging solutions.
- Deepened engagement in initiatives that aim to improve the quality and efficacy of knowledge exchange can enable faster innovation and drive down deployment costs.
- Expansion of targeted assistance programmes and bilateral strategic partnerships can offer more tailored support and, in the case of the latter, can foster stronger relations and co-operation that can create reciprocal benefits.

QUANTITATIVE INDICATOR FOR SUCCESS

- Number of large-scale projects for near-zero emissions steel reaching FIDs in EMDEs that are engaged in assistance programmes and/or relevant bilateral partnerships.
- Amount of venture capital funding invested in the steel sector globally and by region.

QUALITATIVE EXAMPLES OF COLLABORATION

- The COP 29 Global pledge for scaling international assistance for industry decarbonisation committed USD 1.3 billion in support from several governments and initiatives.
- The Global Matchmaking Platform (GMP) was launched at COP 29 by the United Nations Industrial Development Organization (UNIDO) and the Climate Club, with the aim of making

support for industrial decarbonisation more accessible for EMDEs. To date, over 20 countries have been engaged through the GMP.

- Climate Investment Funds selected 7 countries for support through their USD 1 billion Industry Decarbonization Investment Program, with an offer of technical assistance to another 19 countries.
- ITA announced new partnerships with Bahrain, Egypt, and the United Arab Emirates to advance industry decarbonisation and help fast-track projects to reach FID.
- Bilateral partnerships have taken steps forward, such as Brazil-United Kingdom's expanded partnership on industrial decarbonisation and India-Sweden's recently announced funding for project development.

BILATERAL, PLURILATERAL AND/OR MULTILATERAL TRADE PARTNERSHIPS FOR NEAR-ZERO AND LOW-EMISSIONS IRON AND STEEL HAVE EMERGED IN GLOBAL MARKETS.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Strategic trade partnerships for near-zero and low-emissions iron and steel can create economic opportunities, including opportunities for EMDEs to export higher-value materials in the supply chain, and for partner countries to source cost-efficient materials, boosting competitiveness.
- Current global trade dynamics make it difficult for near-zero and low-emissions iron and steel to compete in global markets, and trade partnerships could therefore help unlock investment that may otherwise be held back.
- Co-operation between smaller groups on trade partnerships could help establish supply chains for export of near-zero and low-emissions iron and steel, serving as seeds of progress. This could include co-ordination on a shared understanding of definitions – and the underlying emissions measurement methodologies – for near-zero and low-emissions steel (see success statement 1).
- Lessons learned from early trade partnerships could inform discussions within international fora to better guide dialogue, assess benefits and impacts in existing supply chains, identify and address priority trade barriers, raise policy ambition, and foster further partnerships, to the benefit of the broadest possible number of governments.
- Concrete actions and collective outcomes of this kind are a key step towards enabling competitive markets for near-zero and low-emissions steel and iron.

QUANTITATIVE INDICATOR FOR SUCCESS

- Number of countries in which public and/or private organisations are involved in trade partnerships for near-zero emissions iron or steel.

QUALITATIVE EXAMPLES OF COLLABORATION

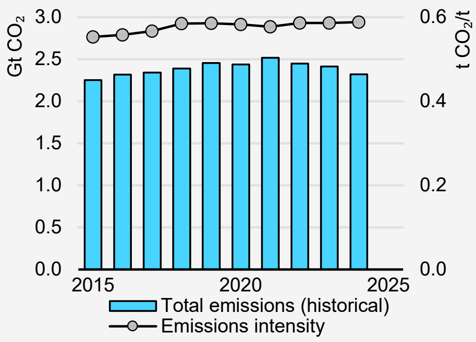
- International trade partnerships are emerging for near-zero and low-emissions iron and steel (HyIron-Benteler near-zero emissions iron, Thyssenkrupp-Progressive Green Solutions near-zero emissions iron, HBIS-Italy low-emissions steel). Other collaborations are developing supply chains for scaling-up trade partnerships in the future (Fortescue-Baowu Steel).
- International fora continue to deepen dialogue around factors that could impact trade of near-zero emissions iron and steel, such as on globally interoperable definitions and standards (Climate Club), carbon leakage and spillovers (Climate Club) and on emissions and trade (OECD Steel Committee Global Forum on Steel Excess Capacity, World Trade Organization).

Cement and concrete

State of the transition

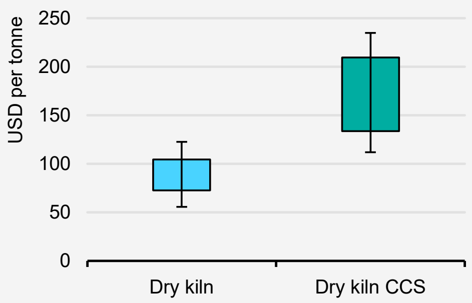
The cement sector is not on track for net zero by 2050. A key milestone was achieved this year when the first commercial cement facility with carbon capture and storage (CCS) came online, thanks to collaborative efforts. Business leaders noted a slight increase in the pace of the transition, although confidence in the sector's ability to meet the Breakthrough Agenda goal has declined. The project pipeline for near-zero emissions cement still falls short of the scale needed, with regional gaps. Greater collaboration can help strengthen enabling conditions, demand signals and finance, in order to bridge this deployment gap.

Emissions



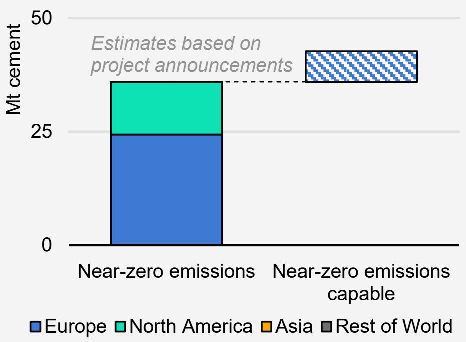
- Total CO_2 emissions are higher today than in 2015. Reductions in recent years have come from declines in global production, while direct CO_2 emissions intensity remains unchanged.
- Both need to fall in the coming years to get on track for net zero by 2050, with contributions from improved material efficiency, greater use of alternative fuels and supplementary cementitious materials (SCMs), and CCS.

Cost[1]



- Production costs for early commercial plants for near-zero emissions cement using CCS are estimated to be 75-150% higher than today's conventional plants, varying by region.
- This cost premium will need to be addressed to meet the pace of the IEA Net Zero Emissions by 2050 Scenario (NZE Scenario). Complementary measures such as material efficiency and increased use of SCMs – when paired with CCS – could potentially lower the cost of the transition.

Deployment[2]



- Since last year, capacity for near-zero emissions[3] cement by 2030 has grown by 30% to about 35 Mt, driven by new projects and greater clarity on how 3 Mt of announced near-zero emissions capable[4] capacity would operate, leading to its re-allocation.
- Capacity for the remaining near-zero emissions capable projects remained unchanged at 7 Mt.
- Despite this progress, the project pipeline falls short of the pace of the NZE Scenario by 2030. Closing the gap will require collaborative efforts.

[1] Levelised cost of production (LCOP). Estimated LCOPs are based on regional averages, accounting for variation in energy inputs and costs by region, and do not include explicit policy supports, e.g. carbon pricing or subsidies. Regional variation in capital and non-energy operating expenses is not considered. Energy prices, intensities, and fuel mixes from 2024 are used for calculation of LCOPs. The box shows the range of expected typical LCOP values; whiskers show the average LCOP in higher- and lower-cost regions.
[2] Near-zero emissions projects are those that have reached a sufficiently advanced development stage, and meet the criteria in footnote 3. Concept-stage projects are considered only near-zero emissions capable due to greater uncertainty of its completion.
[3] "Near-zero emissions" refers to projects that will operate at an emissions intensity consistent with near-zero emissions from the start, as defined in the IEA report Achieving Net Zero Heavy Industry Sectors in G7 Members.
[4] "Near-zero emissions capable" is capacity that operates with the same core process equipment as near-zero emissions capacity and will attain a substantial reduction in emissions intensity (compared to current conventional technologies) from the start – but initially fall short of the emissions intensity for near-zero emissions – with clear plans to reduce emissions further to a level consistent with near-zero emissions at a later date and with technical capabilities such that it can reach near-zero emissions without substantial additional capital investment in core process equipment.

SUCCESS STATEMENTS: CEMENT AND CONCRETE

EXISTING DEFINITIONS FOR NEAR-ZERO AND LOW-EMISSIONS CEMENT AND CONCRETE ARE ADOPTED ACROSS ALL REGIONS AND ANY ADAPTATIONS ARE GLOBALLY INTEROPERABLE, AND EXISTING EMISSIONS MEASUREMENT METHODOLOGIES ARE MADE MORE TRANSPARENT, INTEROPERABLE AND NET ZERO COMPATIBLE, WITH COHERENT CHAIN OF CUSTODY RULES.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Definitions and standards that establish emissions intensity thresholds for near-zero and low-emissions cement and concrete production can underpin many enabling mechanisms. These can feed-in to product-level thresholds, which can support further emissions reductions as well as material efficiency measures.
- Coalescence around existing definitions – and promotion of their use – could avoid the creation of more proposals and associated challenges to clarity.
- Emissions measurement methodologies provide a framework for measuring and accounting emissions to support the development of definitions and standards, among other uses
- Interoperable and net zero compatible[1] methodologies can improve clarity and reduce reporting burden. Existing schemes offer a robust basis, but some require revisions to make them fit for purpose, and a method to translate among methodologies is needed.
- Chain of custody schemes help track materials and attributes through supply chains, and alternative schemes are emerging as mechanisms to provide flexibility and encourage action on decarbonisation. In all cases, robust reporting and verification are important to avoid double-counting emissions reductions and ensure additionality, as are rules for consistent emissions accounting and appropriate, transparent marketing of materials.
- Greater clarity on the process and responsibilities for revising existing methodologies can accelerate and guide convergence towards greater alignment, especially in policy applications.

QUANTITATIVE INDICATOR FOR SUCCESS

- Number of countries using interoperable definitions or standards for near-zero and low-emissions cement or concrete in the development and implementation of policy measures.
- Share of production potentially covered by voluntary labels for near-zero and low-emissions cement or concrete.

QUALITATIVE EXAMPLES OF COLLABORATION

- At COP 29, the Global Cement and Concrete Association (GCCA) launched their Global Ratings for Cement and Concrete, designed for interoperability with existing definitions like the Industrial Deep Decarbonisation Initiative (IDDI)'s definitions for near-zero and low-emissions

[1] Interoperability means that different methodologies are coherent and can work alongside one another (e.g. it becomes possible to compare the results of two methodologies on an equivalent basis), enabling clear and consistent communication and interpretation, even though methodologies may not be exactly the same due to different purposes and/or scopes. Net zero compatibility means that measurement methodologies can be applied to the full range of technologies that are needed for the net zero transition and are designed in a way that incentivises choices in favour of the net zero transition.

cement. In parallel, the German Cement Works Association (VDZ) developed the Cement Carbon Class in alignment with these definitions. In addition, Cement Concrete and Aggregates Australia are launching an adaptation of the definition in Australia.

- ConcreteZero established the equivalency of its Low Embodied Carbon Concrete Threshold across multiple global rating systems, providing a template towards improved interoperability of definitions.
- Efforts are underway to develop chain of custody guidelines and robust book-and-claim systems, including by the GCCA, and by RMI and the Center for Green Market Activation. In the case of the latter, a draft framework for a book-and-claim system was published in August 2025.
- Multilateral fora (e.g. the IEA Working Party on Industrial Decarbonisation, Climate Club, OECD Inclusive Forum on Carbon Mitigation Approaches, IDDI) are facilitating co-operation between governments on definitions and measurement methodologies. The Climate Club Members Statement at COP 29 affirmed the emerging common understandings on definitions and convergence among scientific, public and private initiatives on thresholds.
- The International Organization for Standardization (ISO) and Greenhouse Gas (GHG) Protocol recently announced a partnership to harmonise their existing GHG standards and co-develop new standards for emissions measurement and reporting, serving as a potential positive step towards greater interoperability for emissions measurement that could be taken forward in the cement and concrete sectors.

NEAR-ZERO AND LOW-EMISSIONS CEMENT AND CONCRETE DEMAND COMMITMENTS ARE CONSIDERABLY EXPANDED AND INCLUDE NEW MARKETS AND END-USE SECTORS, AND COMMITMENTS ARE CONVERTED TO FIRM OFFTAKE AND ADVANCE PURCHASE AGREEMENTS.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Signalled demand for near-zero emissions cement and concrete is a major pull factor to establish lead markets, helping de-risk early deployments and encouraging scale-up. The impact could be even greater when complemented with parallel demand for low-emissions materials and material efficiency measures, which can encourage progress on near-term emissions reductions and growth of markets for lower-emissions materials.
- Demand for near-zero and low-emissions cement and concrete is limited to small offtakes and falls short of the pace and scale needed for the industry transition.
- Demand commitments, especially when aggregated, can amplify market signals and accelerate the process of securing offtakes. Public procurement commitments can be a key lever.
- Broad coverage of commitments can build momentum for market scale-up across all contexts. Uptake could be accelerated by revision of construction and building codes to allow greater use of cements using alternative raw materials while meeting performance and safety requirements.
- Firm offtakes and advance purchase agreements provide greater certainty for suppliers, facilitating final investment decisions (FIDs) and the establishment of supply chains.

Quantitative indicators for success

- Cumulative number of public and private offtakes or purchase agreements for near-zero emissions cement and/or concrete.
- Number of countries in which public and/or private organisations have made demand commitments for near-zero emissions cement and/or concrete, or in which government policies to incentivise private purchases have been implemented.

Qualitative examples of collaboration

- Existing public and private sector initiatives (First Movers Coalition, ConcreteZero, IDDI) for near-zero and low-emissions cement and concrete demand aggregation are enabling market formation through focused efforts to support their members in translating demand commitments into offtakes. Today, over 40 organisations have made commitments under these initiatives. Further momentum was built at COP 29 with a joint call to action for governments to take the IDDI Green Public Procurement Pledge.
- FMC First Suppliers Hub is facilitating new offtakes through its buyer-supplier matching platform, which now has over 40 offerings for lower-emissions cement and concrete. More recently, RMI and the Center for Green Market Activation launched the Sustainable Concrete Buyers Alliance to aggregate demand.

Scaled-up delivery programmes for international financial and technical assistance have enabled large-scale projects across all regions, building on pilot assistance programmes and learnings from RD&D and early commercial near-zero emissions cement projects.

Why is it important to achieve the success statement to reach the sectoral breakthrough goal?

- Emerging markets and developing economies (EMDEs) are not well represented in the project pipeline for near-zero emissions cement and concrete, due in part to conditions for first-of-a-kind investments that are typically less favourable than in advanced economies. Financial and technical assistance could help enable deployment.
- Many existing assistance programmes are still at an early stage and require successful piloting before being scaled up. Stronger engagement in matchmaking platforms improves delivery of assistance to help fast-track large-scale projects in EMDEs.
- Learnings from the first wave of large-scale near-zero emissions cement projects – mainly in advanced economies – could de-risk and facilitate subsequent deployments in EMDEs. Likewise, collaboration on RD&D, including with EMDEs, could support development of emerging solutions.
- Deepened engagement in knowledge exchange initiatives with the aim to improve the quality and efficacy of information exchange can enable faster innovation and drive down deployment costs.
- Expansion of targeted assistance programmes and bilateral strategic partnerships can offer more tailored support and, in the case of the latter, can foster stronger bilateral relations and co-operation that can create reciprocal benefits.

Quantitative indicator for success

- Number of large-scale projects for near-zero emission cement reaching FIDs in EMDEs that are engaged in assistance programmes and/or relevant bilateral partnerships.
- Amount of venture capital funding invested in the cement and concrete sector globally and by region.

Qualitative examples of collaboration

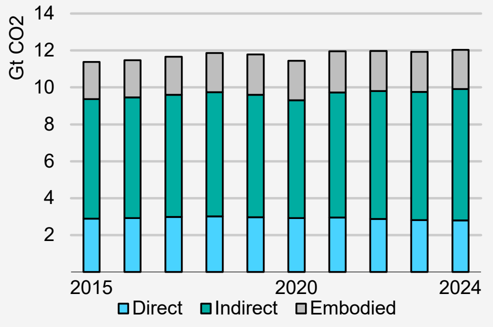
- The COP 29 Global pledge for scaling international assistance for industry decarbonisation committed USD 1.3 billion in support from several governments and initiatives.
- The Global Matchmaking Platform (GMP) was launched at COP 29, to make support for industrial decarbonisation more accessible for EMDEs. To date, over 20 countries have been engaged through the GMP.
- Through a partnership between ITA and Brazil, three cement decarbonisation projects were selected for support in Brazil, with the goal to advance them to reach FID.
- Thanks to GCCA's 2050 Net Zero Roadmap Accelerator Program, nearly 50% of production outside of China is now covered by decarbonisation roadmaps, with current efforts focused on EMDEs.

BUILDINGS

STATE OF THE TRANSITION

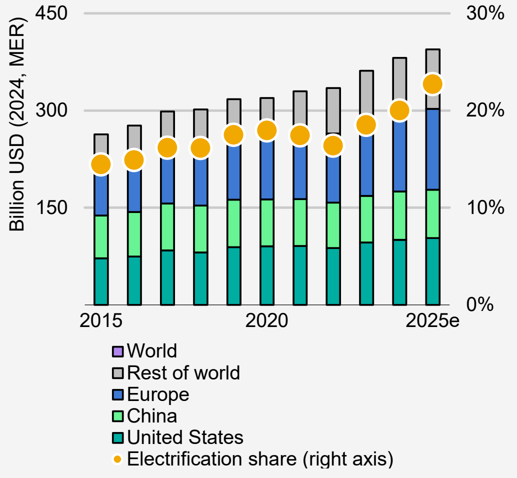
Buildings generate more than one-third of global energy use and emissions, making them central to net zero and resilience objectives. Yet the sector is lagging behind: floor space is growing faster than efficiency, cooling demand is rising in hot regions, and most buildings in areas with cold climates – many heated by fossil fuels today – will still be standing in 2050. Encouragingly, business leaders report seeing a small increase in the pace of transition.

Emissions[1]



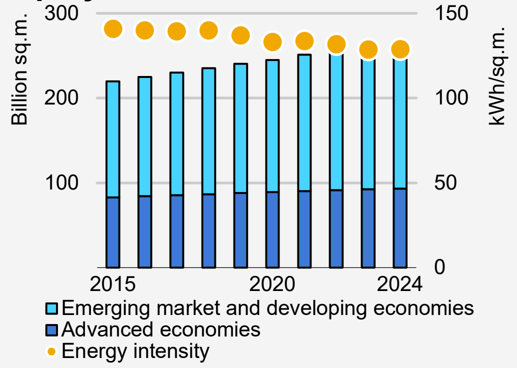
- Sectorial CO_2 emissions trends have been fairly stable since 2018.
- Efficiency gains in buildings are improving energy use, but rising ownership of appliances and extreme weather increasingly offset these benefits.
- Emissions intensity of steel and cement is largely the same as 2020, while global construction activity has slowed in recent years.

Cost[2]



- Investment in building energy efficiency has risen over the past decade, but growth is now stalling, while spending on electrification grows steadily.
- High-efficiency building envelopes often entail higher upfront costs, constraining uptake in markets without dedicated financial support mechanisms.
- Strengthening the business case requires better recognition of high efficiency buildings' broader societal value, including enhanced resilience, health benefits, and long-term affordability.

Deployment[3]



- Energy intensity has decreased about 8% since 2015, driven by policy development globally.
- However, total floor area is set to continue increasing, especially in developing economies, where 80% of growth to 2050 is expected. Many of these economies lack robust building and energy codes.

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[1] Global energy combustion and process emissions from the buildings sector in the IEA Net Zero Emissions by 2050 Scenario, 2010-2030. Embodied emissions refer to emissions in cement, steel and aluminium. In this scenario, all material-using sectors are competing for near-zero emission materials. Bricks and glass would represent a further 3% of global emissions.

[2] Cost of energy efficiency (incremental spending to acquire equipment that consumes less energy than would otherwise have been used to provide the service), renewables and electrification (of non-full electric end-uses). 2025e = estimated values. Source: Adapted from IEA (2025), World Energy Investment 2025. The electrification share excludes renewables.

[3] Built floor area at the global scale and average buildings final energy consumption intensity.

SUCCESS STATEMENTS: BUILDINGS

COUNTRIES HAVE ADOPTED AND IMPLEMENTED BUILDING CODES, STANDARDS AND OTHER POLICIES THAT ARE ALIGNED WITH INTERNATIONALLY ENDORSED DEFINITIONS AND PRINCIPLES OF NEAR-ZERO EMISSIONS AND RESILIENT BUILDINGS.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Building codes, standards and certifications shape how buildings are designed, constructed, operated and renovated, providing an opportunity to embed energy and material efficiency, circularity, low-emissions and climate resilience practices across the building life cycle for decades. They can serve to improve design, construction and management quality across the sector, if they are supported by compliance and enforcement mechanisms.
- As such, codes, standards and other types of regulations support the deployment of compliant equipment and materials at scale.
- Building codes aligned with the definitions and principles for near-zero emissions and resilient buildings (NZERBs) improve international comparability, helping guide investment, drive demand and facilitate global knowledge-sharing.
- As global built floor area is expected to grow by about 45% by 2050 – particularly in emerging markets and developing economies (EMDEs) with increasing demand for cooling – codes, standards and certifications for NZERBs will be increasingly important for ensuring efficient and resilient constructions and technologies.

QUANTITATIVE INDICATORS FOR SUCCESS

- Number of countries supporting internationally endorsed definitions and principles of NZERBs.
- Number of countries with building codes and other policies aligned with the definition and principles of NZERBs.
- Percentage share of projected new floor space to 2050 covered by building codes and standards aligned with the definition and principles of NZERBs.

QUALITATIVE EXAMPLES OF COLLABORATION

- The Intergovernmental Council for Buildings and Climate, with over 60 member and observer countries as of July 2025, offers a high-level platform to guide global action in the sector.
- Common definitions and principles are emerging. Led by the World Green Building Council (WorldGBC), together with multiple other organisations, a public consultation on draft definitions and principles of NZERBs closed in June 2025 and the outcome is due for publication at COP 30.
- The World Bank and Global Facility for Disaster Reduction and Recovery jointly launched a Global Assessment of Building Codes to track development. The Global Indicators Group developed a global dataset on building code effectiveness and compliance.
- The International Code Council (ICC) runs the Building Capacity for Sustainable and Resilient Buildings campaign to support development of a robust building regulatory ecosystem, with a focus on the establishment and compliance of building codes.

- The OECD Decarbonising Buildings in Cities and Regions programme supports governments at all levels to accelerate decarbonisation and resilient measures in the building sector, across themes including efficiency, whole-life-carbon emissions, digitalisation and finance.
- The WorldGBC developed a Nationally Determined Contributions (NDCs) Scorecard for Sustainable Buildings, a digital tool co-created with national Green Building Councils (GBCs), governments, and more than 800 stakeholders to help policy makers assess and strengthen national policies and codes in support of NDCs.
- IEA Technology Collaboration Programmes (TCPs) are deepening work on research priorities for building design and technologies. In particular, the IEA Energy in Buildings and Communities (EBC) TCP's Working Group on Building Energy Codes brings together 12 countries as well as The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the ICC to foster stronger collaboration in addressing critical issues in the development and application of Codes.
- The Living Art of Building initiative is collaborating with the United Nations University Institute for Integrated Management of Material Fluxes and of Resources to expand R&D on building materials. R&D can inform updates to building codes by providing scientific evidence and technical standards, including data on the performance, safety and application of new construction materials, techniques and enabling technologies.

GOVERNMENTS AT ALL LEVELS, ACTING BOTH AS INVESTORS AND OCCUPANTS, ARE PROCURING AND OPERATING PUBLICLY OWNED BUILDINGS, INCLUDING MATERIALS AND TECHNOLOGIES, IN ALIGNMENT WITH THE DEFINITION AND PRINCIPLES OF NEAR-ZERO EMISSIONS AND RESILIENT BUILDINGS, AND ARE ACTIVELY SHARING THEIR EXPERIENCES AND LEARNINGS WITH OTHER GOVERNMENTS.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Public procurement represents a significant share of the construction market; this buying power can be directed to support the deployment of new technologies and practices, reducing risks, and building capacity in the industry for the wider market. It can also provide a long-term signal to private investors by creating a testbed for near-zero and low-emissions products.
- Aggregated demand can create economies of scale that drive down upfront cost premiums for NZERBs (both new-builds and retrofits) and the construction practices, materials, appliances and equipment they require.
- Growth in demand can support wider public acceptance and the normalisation of higher standards across the value chain. More broadly, public spending can support local employment and reskilling and upskilling, and create incentives for local manufacturing and construction companies.

QUANTITATIVE INDICATOR FOR SUCCESS

- Number of countries implementing performance-based public procurement for buildings aligned with the definition and principles of NZERBs.

QUALITATIVE EXAMPLES OF COLLABORATION

- The One Planet Network launched its Global Framework for Action on Sustainable and Circular Public Procurement at COP 29, to drive demand for “Near-Zero and Resilient Buildings”.
- The over 140 signatories of the WorldGBC’s Net Zero Carbon Buildings Commitment are supporting procurement-based supply chain levers. C40 leads the commitment at the subnational level, with Net Zero Carbon Building and Clean Construction Accelerators.
- The Solar Impulse Foundation has developed a Catalogue of Solutions for deployment to be published at COP 30, which can serve as a reference for public procurement. This was developed through a multi-stakeholder process, following a blueprint launched at COP 29.
- The Market Transformation Action Agenda, led by the World Business Council for Sustainable Development identifies collective actions on decarbonisation along the built environment value chain, building on GlobalABC's Market Transformation Levers.
- The Industrial Deep Decarbonisation Initiative developed Green Public Procurement guidelines, which cover key implementation steps, with a focus on steel and cement.
- Built by Nature supports cross-border collaboration on timber and market transformation via demand-side coalitions. It launched the Principles for Responsible Timber Construction, in partnership with Bauhaus Earth, and the Climate Advisers with the Forests and Climate Leaders Partnership Greening Construction with Sustainable Wood Initiative.
- SteelZero and ConcreteZero are international collaborative initiatives that leverage procurement commitments from major buyers to drive demand for low-emissions steel and cement.

GLOBAL ANNUAL INVESTMENT IN NEAR-ZERO EMISSION AND RESILIENT BUILDINGS GROWS SIGNIFICANTLY, RELATIVE TO TODAY.

WHY IS IT IMPORTANT TO ACHIEVE THE SUCCESS STATEMENT TO REACH THE SECTORAL BREAKTHROUGH GOAL?

- Upgrading buildings to be NZERBs will require significant investments globally, including for the renovation of existing buildings. Governments alone cannot fund the shift; an increase in private capital is also needed.
- As the need for housing increases globally, public funding or regulation to direct private investment is important to ensure that affordable housing meets NZERBs principles, especially for the most vulnerable populations.
- Public funding and blended finance can help de-risk and crowd in private capital, and make the cost of risk mitigation more transparent.
- Improved access to a diversified pool of private capital instruments (private equity, venture capital, green debt) could further support companies working on developing NZERBs. For investors, this could present a balanced risk-return profile and the potential for long-term economic value in emerging markets and technologies.
- As investments in NZERBs rise, cost premiums associated with specific characteristics of NZERBs can also be brought down through economies of scale and learning-by-doing.

Quantitative indicator for success

- Annual investment in energy efficiency, electrification and renewables in the buildings sector (USD 380 billion in 2024).

Qualitative examples of collaboration

- The Partnership for Energy Efficiency in Buildings launched support for carbon-market projects in in the buildings sector under Article 6 of the Paris Agreement. It is providing countries with training and support to develop proposals, starting with Morocco.
- The Market Accelerator for Green Construction, an assistance programme, was launched by the United Kingdom in partnership with the International Finance Corporation.
- The Green Climate Fund (GCF) provides financing to developing countries for adaptation and resilience, including resilient building design and retrofits.
- The Cities Climate Finance Leadership Alliance launched the Net Zero Carbon Buildings Instrument Database, which includes financial tools.
- The Climate Bonds Initiative (CBI) taxonomy was developed through multi-stakeholder engagement that supports comparability in the sustainable finance market. This is a global guidebook specifying what qualifies as a green investment, including in buildings. A Buildings Criteria 2.1 was released to expand the framework to include both new and existing buildings and incorporate whole-life carbon metrics.
- The Green Home Finance Principles were published by the Green Finance Institute, focusing on green mortgages and retrofit funding.
- The Finance Hub of the GlobalABC provides a discussion platform and presents solutions for mitigation and climate adaptation for the sector, as well as mapping existing efforts.
- In 2025, GREEN – a network of institutional investors in real estate – partnered with Leaders of the Urban Future to launch works to streamline environmental, social and governance data practices, improve access to reliable energy and carbon performance metrics, and address systemic barriers preventing the real estate sector from accurately pricing climate risk and accelerating decarbonisation.

Countries take forward efforts to increase annual retrofit rates, especially in advanced economies.

Why is it important to achieve the success statement to reach the sectoral breakthrough goal?

- It is estimated that in advanced economies, 80% of the 2050 building stock has already been built. This creates a big opportunity for retrofitting rather than building new floor area.
- Retrofitting can also improve comfort, health and living conditions, beyond expanding potential to integrate adaptation and resilience into the existing stock.
- Retrofitting can support the local economy by driving demand for skilled labour across construction, engineering and design sectors.
- The oldest building stock is mostly located in cold climates that require space heating. This currently represents half of building energy use, two-thirds of which is currently supplied by fossil fuels. Retrofits are critical to support clean heating.

Quantitative indicator for success

- Annual retrofit rates in advanced economies and share of deep retrofits.

Qualitative examples of collaboration

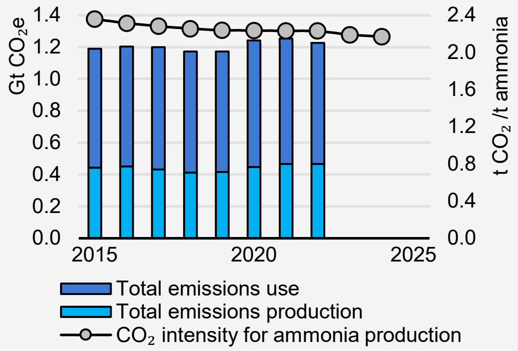
- Within the Energy Efficiency Hub activities, the Energy Efficiency in Buildings task force published an article on Energy Efficiency Financing for Buildings, informed by several workshops organised over 2024, with a focus on financing instruments for retrofits.
- The UN Development Programme, with GCF support, is running a “De-risking and Scaling-up Investment in Energy Efficient Building Retrofits” project in Armenia, combining international donor financing with national implementation (2017–2026).
- GBCs in the European Union have supported member states to develop stakeholder-led Long Term National Renovation Strategies. Under the revised Energy Performance of Buildings Directive, these strategies will now need to be updated into National Building Renovation Plans that have a clear pathway to achieve a fully decarbonised building stock by 2050.

FERTILISERS

STATE OF THE TRANSITION

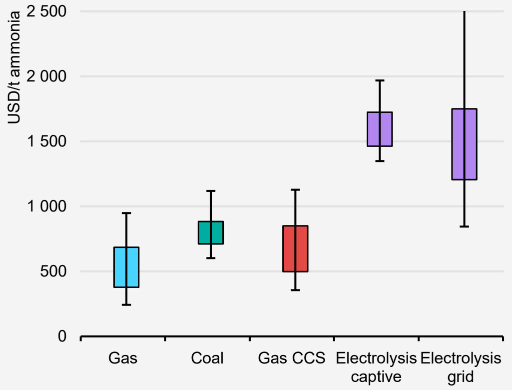
The fertiliser sector's global emissions have held steady over the past decade. With demand set to increase, a significant shift in fertiliser production, composition and use will be needed to align with net zero emissions by 2050. In 2024, low-emissions ammonia (ammonia being the form of nitrogen used in synthetic fertilisers) represented less than 2% of global production.

Emissions[1]



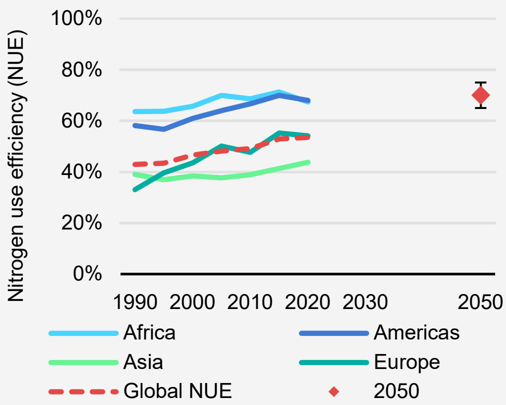
- Around 60-70% of fertiliser-related GHG emissions occur during fertiliser use; the rest occur during production. In total, fertilisers emit around 1.23 Gt CO_2 equivalent per year globally.
- The emissions intensity of ammonia has fallen by 1.1% annually over the last 10 years, driven primarily by improvements in energy efficiency.

Cost[2]



- Excluding policies such as CO_2 pricing, ammonia production today is estimated to cost on average 30% more using carbon capture and storage (CCS) and three times more using electrolysis when compared to conventional routes. Scale and narrowing price differentials with fossil fuels can help to reduce this gap.
- Globally, low-emissions ammonia production projects for fertilisers account for 19 Mt (less than 10% of total production), including operational projects and those that have reached final investment decision (FID) or completed feasibility studies.

Use[3]



- Emissions from fertiliser use need to be cut by around 70% to reach net zero by 2050 according to the International Fertilizer Association, through improved nitrogen use efficiency (NUE), use of inhibitors to reduce losses, crop rotation and land sparing, with residual emissions sequestered in the soil.
- NUE varies across regions, but the global average needs to increase from 55% to 70% by 2050 in the above scenario, more than doubling the recent annual growth rate.

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[1] Based on data from the United Nations Food and Agriculture Organization, including GHG emissions of synthetic fertiliser manufacturing and use, and manure applied to cropland.

[2] Levelised cost of production (LCOP). Estimated LCOPs are based on regional averages, accounting for variation in energy inputs and costs by region, and do not include explicit policy supports, e.g. carbon pricing. Regional variation in capital and non-energy operating expenses is not considered. Energy prices, intensities, and fuel mixes from 2024 are used for calculation of LCOPs. The box shows the range of expected typical LCOPs; whiskers show the average LCOP in higher- and lower-cost regions. Production costs observed in some projects can be outside the range presented, which relates to a global average: in the green ammonia auction under the Solar Energy Corporation of India, a historic low price of USD 641/t was achieved.

[3] Source: Based on data from International Fertilizer Association (2022), Reducing Emissions from Fertilizer Use.

CHAPTER 3. FERTILISERS

SIGNIFICANCE OF THE SECTOR

Fertilisers are a source of nutrients used by plants to grow, constituting a key input to the world's agricultural and food systems. While plants obtain carbon, hydrogen and oxygen directly from water and the atmosphere, they also require essential nutrients such as nitrogen, phosphorus and potassium, which are often limited in natural soils. Fertilisers supplement these nutrients, making it possible to sustain high crop yields and feed a growing world population.

Fertilisers are, however, an important source of GHG emissions. They are estimated to have contributed to around 1.23[1] Gt of CO_2-equivalent (CO_2-eq) in 2022, or 2.4%[2] of global GHG emissions. Beyond emissions, the improper and excessive use of fertilisers can lead to substantial environmental impacts, including water pollution from nutrient run-off, air pollution from ammonia volatilisation, and soil degradation.

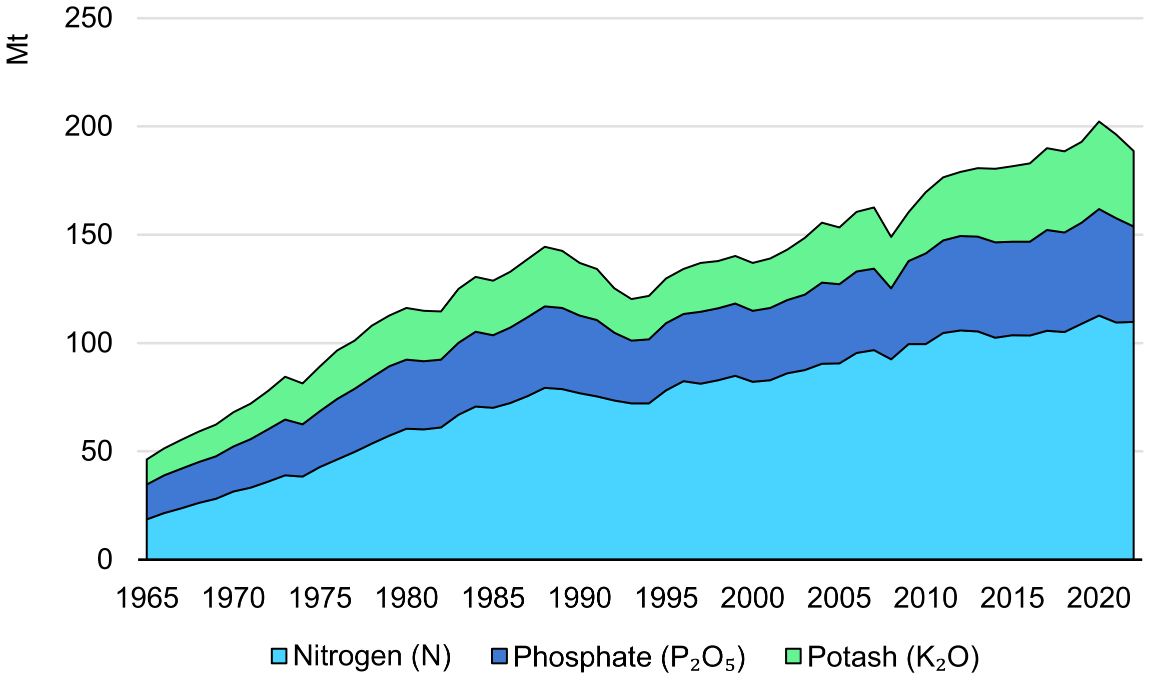
Production of fertilisers, which can be categorised into mineral and organic types, accounts for around 30-40% of the total GHG emissions from the fertiliser value chain. Supporting the achievement of global climate goals will require a significant shift in technology and investment in the industry, particularly given the long operational lifetimes of fertiliser production facilities, which often exceed 30 years.

Nitrogen-based fertilisers constitute the majority of mineral fertilisers on the market today, and are the main focus of this chapter. Their production begins with the synthesis of ammonia, which is an energy-intensive process that generates between 1.6-3.2 tonnes of CO_2 per tonne of ammonia,[3] and accounts for 1.1% of global energy-related[4] CO_2 emissions. A significant portion of these emissions results not only from the energy input required but also from inherent chemical reactions, including the need to separate CO_2 from the syngas during production. Further processing steps also contribute emissions, both in the form of additional CO_2 from energy use and other GHGs such as nitrous oxide (N_2O) released during nitric acid production used for ammonium nitrate.

Although smaller in market share and less energy-intensive, phosphorus fertilisers face their own decarbonisation challenges, as their production also generates substantial emissions from chemical reactions. Organic fertilisers are derived from natural sources such as animal manure and compost and often release nutrients slowly as they decompose. Some also contain living micro-organisms that enhance nutrient availability.

[1] Data from United Nations Food and Agriculture Organization (FAO); items included: fertiliser manufacturing, (use of) synthetic fertilisers, (use of) manure applied to soils. Manure left on pasture and manure management are not included.
[2] Global GHG emissions estimated at 52.0 Gt of CO_2-eq in 2022, from EDGAR.
[3] Emissions intensities refer to levels corresponding to Best Available Technologies.
[4] This includes CO_2 emissions from fuel combustion and industrial processes.

Figure 3.1 Global demand for mineral fertilisers by nutrient, 1965-2022



Source: International Fertilizer Association Consumption Database.

Emissions from fertilisers extend well beyond the factory gate. Around 60-70% of total GHG emissions in the fertiliser value chain result from use, as application generates N_2O emissions through soil processes. Depending on the application and the type of fertiliser, the efficiency of fertiliser use can vary significantly – about half of nitrogen-based fertilisers today are used by crops, with fruits and vegetables having the lowest nitrogen use efficiency (NUE), at 14%, compared to soybeans, at 80%. NUE is defined by the International Fertilizer Association (IFA) as "the proportion of nutrients applied from all sources that are taken up by the crop" and is often used to determine the efficiency of fertiliser management, while minimising environmental losses.

There are several opportunities to reduce emissions on the use side, such as by investing in soil health, including increasing the organic matter content, enhancing biological activity, and increasing accessibility of nutrients. Steps to achieve the latter include increasing the nutrient use efficiency, using the appropriate application type (foliar, liquid, solid) and timing depending on conditions, and increasing the use of alternatives including biologicals, soil enhancers and organic fertilisers. There are existing principles guiding appropriate use of fertilisers, such as the "4R" Nutrient Stewardship approach: applying the right source of nutrients, at the right rate, at the right time, and in the right place, which offers a strategic opportunity to enhance NUE. By promoting the use of customised fertilisers, this approach helps optimise nutrient application, reduce environmental and climate impacts, and deliver balanced crop nutrition. It also contributes to reducing the need for land use expansion, while improving soil health, boosting yields, and enhancing farmer livelihoods. There are a number of examples of how investments in soil health, including the efficient use of fertilisers and cover cropping, have helped to restore degraded lands and improve food security, while sequestering carbon in the soil, such as the ALM Green Carbon of Araguaia project in Brazil. Over the past half century there have been substantial shifts in NUE, and while the increased provision of nitrogen inputs to crop production has led to improved crop productivity, it has also contributed to a lower global NUE. Improved nutrient management and healthy soils can help ensure that NUE is optimised in tandem with increasing crop yields.

Targeted international collaboration between countries and the private sector on reducing GHG emissions from the production and use of fertilisers could contribute to bringing down emissions in the agriculture and chemicals sectors. However, emissions-reduction efforts must be carried out in a way that ensures that food production does not shift to practices that could cause more harm, such as clearing new land for food production through deforestation. Similarly, care must be taken when considering actions which increase the costs of crops, which has an impact on food availability and affordability, and is particularly important for emerging markets and developing economies (EMDEs).

THE CASE FOR INTERNATIONAL COLLABORATION

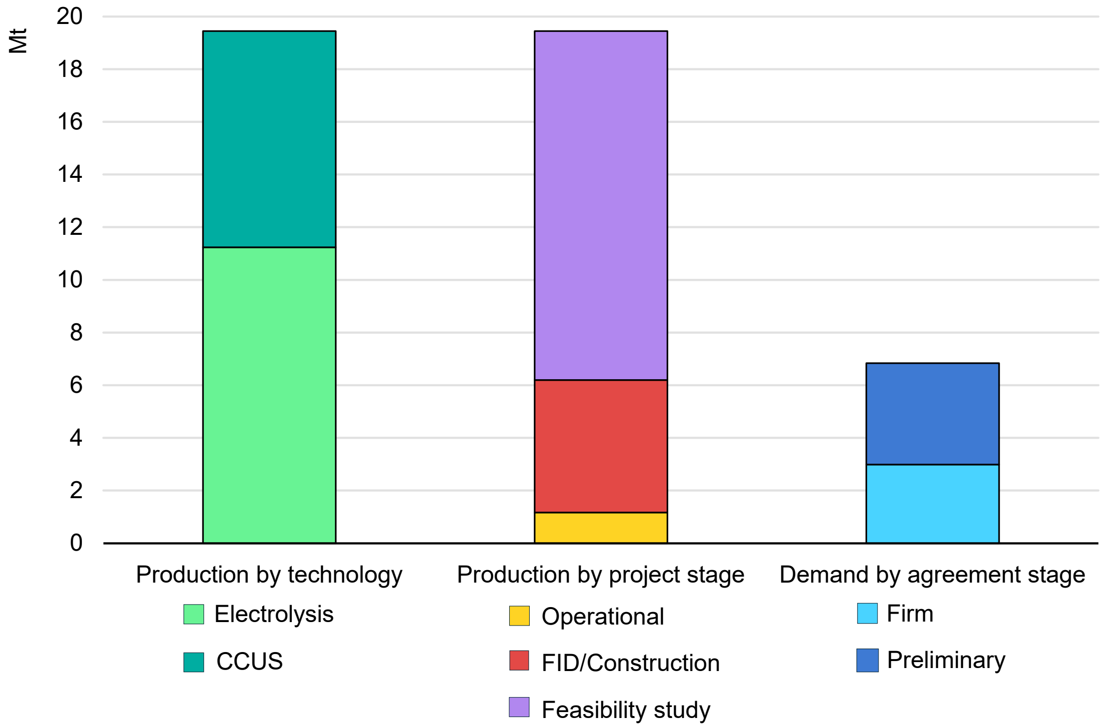
Agriculture overall is responsible for approximately one-third of global GHG emissions. Given the significance of the sector, the Agriculture Breakthrough was launched at COP 26 with the aim of catalysing international collaboration so that “climate-resilient, sustainable agriculture is the most attractive and widely adopted option for farmers everywhere by 2030”. However, the vast scope of the sector made it difficult to focus collective efforts across the hundreds of global and regional initiatives working in different areas. The 2024 Breakthrough Agenda Report on Agriculture therefore focused on two of the highest-emitting sub-sectors: livestock and fertilisers, in order to support development of a more detailed assessment and specific recommendations to accelerate progress. This year’s report builds on those efforts with a specific focus on enhancing international collaboration on fertilisers.

On the supply side, the key feedstock for nitrogen-based fertilisers and the most emission-intensive step of the production process is the production of ammonia, which currently relies on the use of fossil fuels. Approximately 70% of global ammonia production relies on natural gas, while 25% is coal-based, particularly in Asia. Although there are no international agreements on taxonomy yet, there are clean technology options for fertiliser production that could deliver incremental reductions or deeper emissions cuts.

The fertiliser industry has made some progress in reducing emissions intensity over the past few decades through the adoption of energy efficiency improvements, better heat integration and process optimisation. However, these incremental improvements are insufficient to place the sector on a pathway commensurate with reaching net zero emissions by mid-century. Getting on track would require a fundamental transformation of production technologies.

The most promising technology alternatives for deeper emissions cuts are the use of electrolytic hydrogen produced using clean electricity or carbon capture and storage (CCS), or a switch from natural gas to biomethane reforming. However, these technologies currently face cost and infrastructure barriers and are not yet commercially competitive with incumbent processes.

Figure 3.2 Global low-emissions ammonia production projects and demand to 2030



Notes: CCUS = Carbon capture, utilisation and storage; FID = final investment decision. Ammonia for fuel applications excluded from both projects and offtake agreements.
Source: IEA (2025), Hydrogen Production and Infrastructure Projects Database.

Despite these challenges, several companies have begun to invest in low-emissions production technologies. Globally, low-emissions ammonia production projects that are either operational, under construction, or have reached final investment decision (FID) total 6 Mt, with an additional 13 Mt at the feasibility stage. These efforts are encouraging, but demand signals for low-emissions fertilisers remain weak. Firm offtake agreements for low-emissions ammonia currently cover 3 Mt, with around 4 Mt more under preliminary agreements. International collaboration can play a key role in helping to create and increase demand, which is essential for unlocking investment and accelerating market development.

International collaboration on low-emissions hydrogen and ammonia production is already underway in several areas under the Hydrogen Breakthrough, including the development of standards, demand creation mechanisms and joint research initiatives. However, these efforts often stop at the ammonia production stage and do not extend to the full fertiliser value chain, i.e. to downstream production and use. This leaves a critical gap for the main nitrogen-based fertilisers such as urea and ammonium nitrate, and even more so for non-nitrogen fertilisers like phosphates and potash. There is also an urgent need for innovation to increase the efficiency of fertiliser use and to incorporate biological and organic inputs to supplement mineral fertilisers.

Central to reducing GHG emissions associated with fertiliser use and increasing nutrient use efficiency is healthy soil, which is key for food and nutrient security, climate change adaptation and mitigation, biodiversity and ecosystem restoration. Despite its importance, it is estimated that over 40% of the Earth's land is degraded, calling for urgent action to invest in soil restoration to reverse current degradation trends. Degraded soil, for example, does not respond well to mineral fertilisers, further compounding productivity challenges. In addition, it is estimated that 18% of terrestrial land is limited by nitrogen, 43% limited by phosphorus, and the remaining 39% of land could be co-limited by nitrogen and phosphorus. Therefore, understanding biophysical constraints to productivity and other key ecosystem services is critical. There are a number of site- and context-specific approaches and best management practices that can be implemented (including soil cover, crop rotation, no till, integrated soil fertility management, crop diversity, agroforestry, application of compost and farmyard manure, and soil water conservation techniques, among others).

There are also advances to be made – and opportunities for public policies to contribute – from promoting soil health through encouraging a systems approach to agriculture, including exploring opportunities to repurpose some food and agricultural policies to deliver positive environmental and social outcomes, including contributing to climate change mitigation and adaptation. There are currently pilot programmes in East and southern Africa, for example in Malawi, where subsidies have been repurposed to support improving soil health. The World Bank is providing support to countries to promote sustainable agricultural practices that improve soil and land health. While these examples are still in the pilot phase, initial results indicate a positive opportunity to implement and scale sustainable solutions through public incentive programmes, helping farmers overcome challenges to adoption.

As soil health continues to gain momentum on the international agenda, there may be an opportunity to develop overarching global guidance to support countries as they develop national soil health policies and strategies.

As countries and farmers prioritise interventions, more evidence will be needed on what works where, for whom and at what cost. For example, it is estimated that Scope 3 emissions associated with the application of fertilisers on global cropland could be cut by up to 70% in a high potential case and 17% in a low potential case by improving NUE, use of inhibitors, crop rotation, and land sparing, with a further reduction of almost 30% from enhanced soil carbon sequestration measures applied to degraded cropland and grazing lands. However, many of these solutions are not scaling at the pace needed due to economic, policy or knowledge constraints, and greater uptake might require financial incentives for farmers. Reducing emissions from fertiliser use will therefore require global collaboration between governments, researchers, non-governmental organisations, farmers, the fertiliser industry, as well as the food industry and retailers to implement farmer-centred, evidence-based interventions on farm.

PRIORITY AREAS FOR COLLABORATION

Four key areas stand out as immediate priorities for strengthening international collaboration: standards, definitions and certification; demand creation and management; international finance and investment; and research and innovation. Together, action across these areas can unlock faster progress later in this decade.

STANDARDS, DEFINITIONS AND CERTIFICATION

OVERVIEW

Working towards robust, transparent, and ambitious international standards, definitions and certification frameworks for the production of low-emissions fertilisers can support investment decisions. Terms such as “green,” “low-carbon,” or “sustainable” fertilisers are currently being used in an inconsistent manner, with no agreed emissions thresholds or lifecycle boundaries. This lack of clarity makes it difficult for governments to support first-of-a-kind or early deployment projects for low-emissions technologies, as well as for farmers and retailers to distinguish between products, and consequently for cleaner production methods to gain a foothold in the market. It can also undermine the credibility of environmental claims. As a result, producers of low-emissions fertilisers cannot recover the incremental costs of their products, and may struggle to comply with policy instruments such as carbon border adjustment mechanisms (CBAMs), green procurement policies, or voluntary carbon markets across different jurisdictions with differing requirements. Policy measures, such as subsidies, may also be inconsistently aligned with national or international emissions reduction targets. Developing internationally consistent standards and certification schemes, underpinned by transparent, interoperable and net zero-compatible emission measurement methodologies, is therefore crucial to enable market creation, mobilise investment, and support the large-scale deployment of low-emissions fertiliser technologies.

Establishing standards on soil health and soil protection can help increase agricultural productivity and fertiliser efficiency worldwide. Healthy soil is defined by the Intergovernmental Technical Panel on Soils as the “ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems”. Soil properties (chemical, physical and biological) vary as a result of several factors, including land management. This variability results in a variation in yield gaps. However, due to inconsistency in national soil monitoring frameworks, including the lack of consistent indicators, there are gaps in knowledge on the state of soil and land health globally. Poor access to reliable soil data, wide-scale soil testing, and sharing of georeferenced soil data makes it difficult to design appropriate interventions that enhance soil health productivity. Furthermore, the absence of agreed soil health indicators and a systematic monitoring framework hampers assessment and comparison across regions, limiting the ability to address soil health issues. Without these comprehensive and co-designed datasets, regional thresholds and targeting cannot be implemented. Therefore, it is critically important to reach agreement on soil health indicators as part of a consistent and systematic soil health monitoring framework that increases access and use of data to prioritise interventions that reduce GHG emissions. A common indicator framework for measuring and tracking soil health over time would enable countries to identify soil health problems, which can help in designing specific interventions. These also pertain to the development of suitable Monitoring, Reporting and Verification systems that enable the tracking of, for example, soil organic carbon over time, and enable methodologies to quantify and verify GHG reductions from changes in fertiliser use. Global guidance could also address fertiliser subsidies and farming processes that are harmful to soil health and include an accountability framework. International agreement on common soil health indicators and a shared monitoring framework could help identify and bridge knowledge gaps on the state of the world's soil. As a result, findings from unique contexts could be translated into evidence that is comparable across continents, which could eventually contribute to globally acceptable standards and guidelines.

WHAT PROGRESS HAS BEEN MADE

There is currently no definition or certification scheme for fertilisers produced through low-emissions pathways, but progress on hydrogen and ammonia can be a useful starting point. A number of voluntary ammonia certification initiatives exist or are under development - such as those from Bureau Veritas, the Climate Bonds Initiative and the Fertilizer Institute, which relies on ISO 14067. However, their voluntary nature limits their prominence, and they are best seen as complementary to future regulatory frameworks. On the regulatory side, Canada has developed guidelines for its Investment Tax Credit that include ammonia, while the EU Renewable Energy Directive (RED) provides a methodology that could, in principle, be applied to ammonia used as feedstock. At the international level, the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), in collaboration with the International Organization for Standardization (ISO), has led efforts to define a common methodology for calculating the carbon footprint of hydrogen production. ISO 19870-3, currently under development, will provide a technical specification for assessing the GHG emissions associated with ammonia production. However, this standard is not expected to be finalised until 2026 or 2027 and does not cover the conversion of ammonia into nitrogen fertilisers. A complementary standard that encompasses the full fertiliser value chain is needed, ensuring consistency and interoperability with existing low-emissions hydrogen and ammonia standards. This should also be applicable to non-nitrogen fertilisers.

Valuable lessons can also be drawn from the steel and cement sectors. Stakeholders have been working since at least 2019 to define what constitutes low- and near-zero emissions production based on lifecycle emissions accounting and principles that are compatible with net zero emissions (see Success Statements: Steel and Success Statements: Cement and concrete). These efforts aim to create the necessary basis for public procurement, investment decisions and trade policies. One key lesson is that this process takes time, involving many different stakeholders and interests, making it essential to start early. Another is the need for broader international alignment on definitions and thresholds, as well as on the development of certification infrastructure that is both credible and interoperable. In many cases, certification systems remain fragmented or limited in scope, and the integration of standards into trade frameworks and investment criteria is still evolving. The process of making near-zero emissions cement and concrete definitions compatible – since they are products in the same value chain – can also be an example for hydrogen, ammonia and fertilisers. These lessons underscore the importance of designing fertiliser standards with global applicability, transparency and mutual recognition in mind from the outset. Particular attention is also needed to address methane leakage from natural gas supply in CCS-based technologies, for which better data availability is critical for credible standards.

On the demand-side, there is momentum around the inclusion of soil health indicators through soil information systems to inform regional strategies. Recent initiatives, such as the recommended suite of indicators for North America developed by the Soil Health Institute, the Coalition of Action 4 Soil Health Monitoring Brief, and the 2025 African Union Development Agency-New Partnership for Africa's Development Guidance Note for Advancing Africa's Soil Health Monitoring to Support the Nairobi Declaration and CAADP Kampala Agenda, can be leveraged to develop an international framework for soil health monitoring. To assess and track soil health, land degradation and vegetation diversity, the Land Degradation Surveillance Framework (LDSF) has been implemented in over 45 countries across the tropics. This includes implementation of the first-ever systematic survey of sub-Saharan Africa, funded by the Gates Foundation.

To better understand soil health and tailor fertiliser use to the specific context, a robust evidence base is essential. Due to the variability across farms and landscapes, fertiliser and soil health approaches must be tailored and targeted to minimise trade-offs and maximise synergies across productivity, profitability, environmental and social/human indicators, necessitating a strong evidence base. Without such an approach, increases in productivity alone may not be profitable and may have trade-offs for the environment, especially around fertiliser run-off from overapplication. There are examples at the national level, such as Fertilizer Canada's guidance on the 4R Practices, which recognises the need for context-specific recommendations. These types of tables, data, and site-specific guidance need to be expanded globally.

Brazil's action on organics and biologicals shows example of how countries can cut imports and reduce emissions

Brazil is the world's fourth-largest nitrogen fertiliser user, accounting for around 5% of global demand. The vast majority of the country's fertiliser demand is currently met through imports, meaning that the price increases seen in the past few years have had a strong economic impact.

In response, the Brazilian government launched the National Plan for Fertilizers (PNF) in 2022, aiming to reduce imports from 85% to 45% by 2050. Earlier, in 2011, Brazil's Low-Carbon Agriculture (ABC) Plan set ambitious targets including the restoration of degraded land and the application of biological inputs on 13 million hectares. The bio-input industry is growing four times faster in Brazil than the global average, highlighting an opportunity for investment and development of locally produced biofertilisers that can significantly reduce emissions. The Brazilian market for speciality fertilisers saw revenues increase 19% year-on-year in 2024, demonstrating interest from the agricultural sector in alternative technologies. For example, a recent initiative from Yara drew on multi-stakeholder collaboration to reduce the carbon footprint of coffee production in Cooxupé by 40%, working with 20 000 coffee-farming families. The initiative resulted in a fertiliser with 90% lower emissions, produced using renewable resources.

WHAT MORE NEEDS TO BE DONE

The fertiliser sector can build on experiences in other sectors and move quickly to establish its own standards, definitions and certification frameworks for fertiliser production. This includes developing harmonised lifecycle emissions accounting methodologies that cover the full production chain, from hydrogen and ammonia synthesis to final product formulation. These methodologies should be closely co-ordinated with the Hydrogen Breakthrough and other relevant initiatives to maintain consistency across interconnected value chains and comparability across different production technologies and feedstocks. An internationally recognised certification and labelling system is also needed to verify compliance with emissions thresholds and enable consistent product differentiation. Such a system should incorporate chain-of-custody (CoC) tracking and be designed for interoperability across jurisdictions. While traditional physical traceability is clearest, alternative CoC models – such as mass balance or book-and-claim – can offer market flexibility during the early stages of technology scale-up. However, these models must be used judiciously and governed by strong oversight, including robust third-party verification and clear, transparent communication. Without such safeguards, there is a risk of double counting, loss of credibility, and investment being misdirected away from truly transformational technologies. Guardrails will be needed to ensure that these approaches support, rather than undermine, the broader goal of scaling low-emissions fertiliser production.

Establishing global guidance on soil health can help ensure sustainable soil management. Several regional and national initiatives are working to bring soil health into national-level policies, but there is interest and a need to share experiences to develop global standards and certification schemes for soil health. While there are an increasing number of national soil health policies (such in Australia, Kenya, the United Kingdom and Canada), regional efforts (such the Nairobi Declaration), and several sub-national strategies (such as those across Brazil for promoting soil conservation), there is no overarching global framework. A global set of guidelines to promote soil health could support implementation of soil health strategies and initiatives. This would also enable the implementation of a common indicator framework for measuring and assessing soil health to prioritise interventions. The Coalition of Action 4 Soil Health is currently taking stock of multi-stakeholder feedback into such a process to align international, national and sub-national policies on soil health. Such an overarching framework could provide guidance, for example on integrating soil health into national climate policies. This could be aligned with the development of performance validation protocols that incentivise appropriate fertiliser management practices and associated positive outcomes.

Global alignment and guidance could benefit alternative agricultural inputs besides nitrogen. This is especially true for biologicals, including organic fertilisers, biopesticides, and soil health enhancers, which offer alternatives to conventional agricultural inputs. In addition, new kinds of fertilisers would require internationally agreed safety standards to allow for wider trade and use. For example, biologicals have the potential to increase soil health and resilience, decrease the need for nitrogen inputs, and sequester carbon in the soil. Despite these benefits, the scaling and use of biologicals is currently hindered by the lack of globally recognised standards and certification.

Recommendation

Governments should convene a multi-stakeholder process to move towards common understandings of definitions for low- and near-zero emissions fertilisers that encompass the full fertiliser production chain from hydrogen and ammonia synthesis to final product formulation. This should look to develop harmonised lifecycle emissions accounting methodologies, establish an internationally recognised certification and labelling system, and make use of these methodologies and systems within relevant policies. The process should be closely co-ordinated with relevant work from initiatives in the hydrogen sector to ensure compatibility across value chains.

Governments and initiatives should agree to establish a global set of guidelines that define metrics and thresholds to promote and track soil health. This should include efforts to systematically report and monitor indicators of soil health, crop productivity, and fertiliser use, as well as an agreement to share information.

Separately, governments, research organisations and companies should agree to establish global standards for biologicals, including performance validation protocols to foster trust, enable cross-border trade and accelerate uptake.

Demand creation and management

Overview

Creating demand for low-emissions fertilisers is critical to accelerate the decarbonisation of global agriculture and the chemical industry. Establishing early long-term demand for fertilisers produced using low-emissions processes would reduce market risk for first movers, support early commercial projects, and unlock cost reductions through scale and learning. In the absence of targeted demand signals, low-emissions fertiliser producers face uncertainty about offtake and pricing, which – if "supply-side" policies are insufficient – can delay or deter investment in cleaner production technologies. As highlighted by the World Business Council for Sustainable Development, given the price premium currently associated with lower-emissions products, cross value-chain co-ordination mechanisms are needed to pull through demand from food companies and end-users.

Governments and companies can help address this gap by creating incentives for low-emissions fertiliser uptake across agricultural value chains. Public procurement is one of the most direct tools available. Governments – particularly those that subsidise or purchase fertilisers for public distribution or agricultural extension activities – can use their buying power to prioritise low-emissions products. Similarly, quotas or mandates could require large-scale fertiliser-consuming businesses to source a minimum share of low-emissions fertilisers; this approach is more difficult to apply to individual farmers, who are typically too dispersed and numerous for fertiliser use to be directly regulated. In parallel, enabling multi-year offtake agreements is important, since firm demand signals help production facilities to reach FIDs. Aggregating demand can provide the scale and certainty needed to unlock investment in new production capacity.

Another potential option open to policy makers is to mandate blending of low-emissions ammonia for nitrogen fertilisers production. Given that such mandates can raise production costs in a trade-exposed and internationally competitive sector, a co-ordinated approach across countries would likely be necessary to avoid undermining competitiveness. Such measures would offer a clear signal to producers and investors that a market will exist, creating confidence to move forward with low-emissions production facilities. End-use subsidies can also play a role, particularly in cost-sensitive regions. By offering financial benefits to farmers or distributors that use low-emissions fertilisers in effective and efficient ways, governments can directly increase uptake and drive market penetration during the early deployment phase. In addition to mandatory policies, voluntary tools like labels and third-party certifications can further support market development by enabling buyers to identify and choose low-emissions fertilisers.

Some supply-side policies, while not targeted at demand creation, also influence market dynamics. Carbon pricing, carbon contracts for difference and production subsidies can reduce the cost gap between conventional and low-emissions fertilisers, thereby improving their competitiveness. However, while these measures can support supply, they do not guarantee demand unless they completely eliminate any cost gap. Policies that specifically require or incentivise use of low-emissions fertilisers can therefore complement supply-side policies as part of a holistic policy package that includes coherent demand and supply measures. Policies that set embodied carbon limits, such as carbon-based product requirements, also help by restricting products with high emissions and driving demand for lower-emissions alternatives. Importantly, all such measures should be designed and implemented in a manner consistent with international trade obligations.

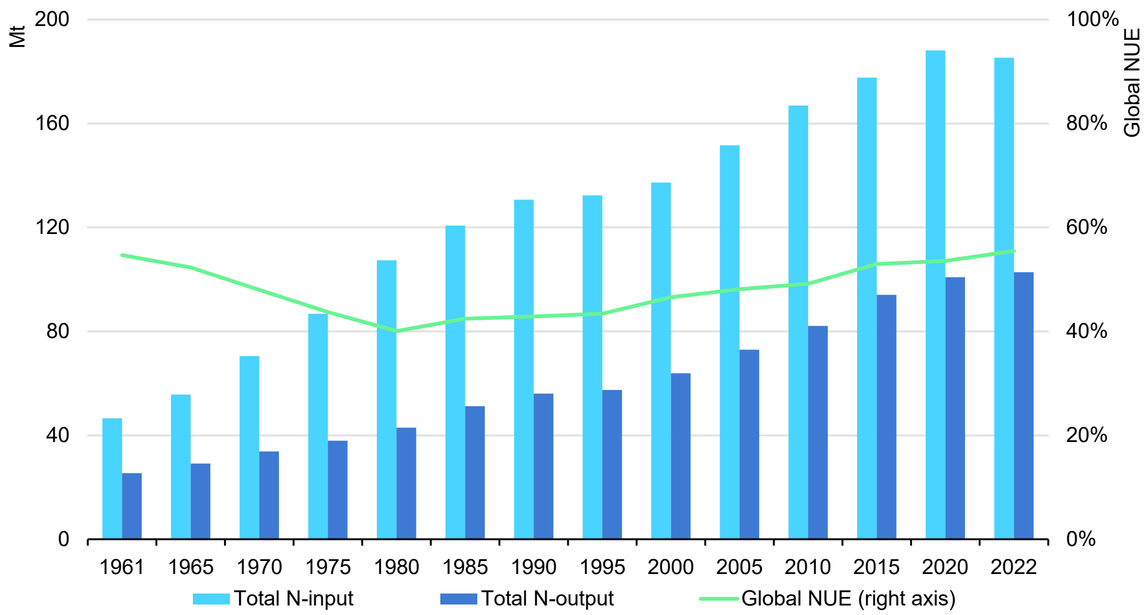
Managing demand for fertilisers is just as important as creating demand for low-emissions options, and a key part of this effort is in increasing nutrient use efficiency. Nutrient use efficiency is a useful indicator to determine the efficiency of fertiliser management. Following a considerable decline in global nutrient use efficiency in the 1960s and 1970s, nutrient management has been gaining traction and there has been an upward trend in efficiency in recent decades. While there may be regional agreement on strategies to improve nutrient use efficiency (i.e. in the European Union), there is often a lack of consistency in how it is measured and of agreement on the optimum levels, which can limit the implementation and scaling of good land management practices.

What progress has been made

Currently, international co-operation on demand creation for low-emissions fertilisers is limited. The Hydrogen Council's Low-Emission Ammonia Fertilizer Lead Market Initiative is a first-of-its-kind, sector-wide effort aligning leading food, agriculture, fertiliser, sustainable fuel and manufacturing companies to unlock scalable production of low-emissions ammonia-based fertilisers and strengthen supply chain resilience. Synergies with other international efforts, especially those related to hydrogen, including the Hydrogen Breakthrough, can also offer a foundation to build on, given that ammonia is the primary use case for low-emissions hydrogen today. The H2Global mechanism – built around a two-way competitive auction – awarded its first long-term offtake agreement for renewable ammonia through the 2024 pilot procurement auction, helping address the supply-side investment barrier and providing early price signals; a corresponding competitive sales auction, expected in 2026, will enable demand-side price discovery, with any gap between purchase and sales prices covered by public funding. However, such schemes are not currently designed to ensure that the resulting ammonia is channelled into fertiliser production. With growing competition for ammonia from shipping, power and industrial applications, it is possible that low-emissions ammonia supply could be diverted away from fertiliser use unless dedicated demand-side strategies are developed. More recently, the International Hydrogen Trade Forum (IHTF) under the Clean Energy Ministerial Hydrogen Initiative has identified lead market creation for sustainable products – including fertilisers – as one of the three priority areas ahead of COP 30. This is an encouraging development, signalling growing international recognition of the sector's relevance. Nevertheless, action remains at an early stage, and specific mechanisms for fertiliser demand are yet to be implemented.

There are multiple ways to measure nutrient use efficiency, and the choice of metric should be tailored to its intended purpose. Fertiliser efficiency is often assessed using recovery efficiency – the amount of increase in nutrients taken up by crops relative to the amount applied. Monitoring nutrient use efficiency at different scales and over time is important. The FAO, in collaboration with the IFA, tracks cropland nutrient balance statistics to assess the impact of fertilisers use in relation to crop production needs, providing information on individual input and output components of the nutrient balance and use efficiency. Although total nitrogen input on cropland has increased nearly fivefold since 1961, rising crop yields and better practices have resulted in an increase of nutrient use efficiency to about 55% at present from a low of about 40% in 1980. However, there is room for further improvement, as there is still a large annual cropland nitrogen surplus of 80 Mt, and data gaps still need to be addressed to build a complete picture on cropland nutrient balance. Given the variability in metrics and limited data, governments – working with technical institutions – should further align on international guidance for measuring nutrient use efficiency and a globally accepted range. This could provide a basis for countries to pledge commitments toward achieving it within a specified timeline.

Figure 3.3 Nitrogen input, output and efficiency of global cropland, 1961-2022



Notes: N = Nitrogen; NUE = nitrogen use efficiency.
Source: UN FAO Cropland Nutrient Balance Database.

WHAT MORE NEEDS TO BE DONE

Joint public procurement commitments or demand aggregation platforms supported by groups of countries could create demand for low-emission fertilisers on a scale sufficient to mobilise investment and accelerate cost reduction. International regulatory co-operation or alignment could be essential given the trade-exposed nature of both fertiliser production and its downstream use in globally competitive agri-food supply chains. Without co-ordination across major markets, national-level measures – such as blending mandates or consumption quotas – risk raising costs for producers or food companies in one jurisdiction while leaving international competitors unaffected, undermining both competitiveness and the broader effectiveness of such policies. The private sector also has a key role to play in driving demand; in particular, the food industry can help stimulate demand by prioritising low-emissions fertilisers in its sourcing strategies. The current lack of intergovernmental initiatives in the fertiliser space may be due to the unique characteristics of the sector: fertiliser end-users are predominantly smallholder farmers, making large-scale co-ordinated purchasing more difficult and limiting the applicability of conventional first-mover approaches. Initiatives that bring together both public and private actors, including agricultural retailers, food processors and major brands, could help overcome market fragmentation and broaden demand creation efforts across the fertiliser value chain.

There is an opportunity to build on the momentum of ongoing transitions to low-emissions hydrogen and ammonia and extend it across the fertiliser value chain, from production to end use. A targeted international effort to create demand for low-emissions fertilisers would not only support emission reductions in a major industrial sector but also contribute to sustainable food systems and global development goals. Stronger co-operation among governments, businesses and different stakeholders in the value chain – including farmers - is needed to realise this potential and ensure that low-emissions fertilisers become the default choice in all markets.

Importantly, demand creation for low-emissions fertilisers should complement ongoing efforts to improve the efficiency of fertiliser use. Fertiliser overuse is already a significant concern in some regions. The primary goal must be to displace high-emission products, not necessarily to expand fertiliser consumption overall. Demand creation strategies should therefore be embedded in broader sustainability frameworks that promote efficient nutrient use and minimise environmental impacts. Organic fertiliser use can contribute to this broader aim, but global data on availability and scalability remain limited, and organic sources are unlikely to offset a substantial share of global nutrient demand. Furthermore, organic nutrient suppliers are often local businesses, as transportation over long distances is uncompetitive due to their high weight per nutrient ratio. At present, no international initiatives focus on expanding organic fertiliser demand at scale.

Greater collaboration is needed to align on a NUE level that balances soil health with crop productivity. Optimal NUE will vary between farms, depending on a range of factors unique to the crop and local environment, but a balanced approach is needed to ensure efficient crop production. Very high NUE (over about 90%) may actually be harmful, signalling depletion of soil nutrients or “soil mining”. On the other hand, a very low NUE is not only harmful to the environment – through nutrient run-off or emissions – but can also reduce farm profitability.

RECOMMENDATION

Governments should co-ordinate joint public procurement, demand aggregation or regulatory measures to create demand for near-zero emissions fertilisers at a scale sufficient to drive investment, innovation and cost reduction.

The private sector should complement these efforts and establish commitments for their use, including through collaborative procurement and joint purchasing agreements. Where appropriate, these efforts should be linked to broader hydrogen and ammonia lead market initiatives to ensure fertiliser applications are included in supply allocation.

Governments, in collaboration with technical institutions, should agree to align on international guidance for measuring nitrogen use efficiency (NUE), with a view to establishing a globally accepted NUE range, and should encourage countries to sign a pledge to reach that level within a specified timeline.

INTERNATIONAL FINANCE AND INVESTMENT

OVERVIEW

Low-emissions fertiliser production is likely to remain significantly more expensive than conventional methods in the near- to medium-term. Average production costs may range from 30% higher to more than triple those of unabated alternatives. While this could raise farmers' fertiliser costs significantly and increase crop prices, the impact could end up being less than 1% on the cost of some consumer food products. There is currently limited willingness to pay a premium for low-emissions fertilisers, and few policies exist at the scale and level needed to incentivise their uptake. Domestic policy plays an important role here in levelling the playing field between low-emissions and conventional fertiliser production, but countries should work together to align policies to mitigate the risks facing first-mover countries and companies, such as industries relocating or trade flows being diverted to lower-cost, higher-emitting competitors. The risks also extend to farmers, who may face higher input costs while competing with lower-cost imports produced under lower environmental standards. However, one consideration relevant to implementation of revenue certainty mechanisms is that fertiliser produced using dedicated renewables may be less exposed to price volatility than traditional production or imports.

EMDEs face another set of considerations, such as the high cost of capital, additional risk, and vulnerability to higher food prices. In EMDEs, where rising demand gives opportunities to scale up low-emissions fertiliser production, targeted international financial assistance will be crucial to de-risk low-emissions projects in different regional contexts, mobilise capital at scale, and ensure that development of low-emissions fertiliser production supports equitable and sustainable growth. However, the transition also carries the risk that higher production costs could translate into increased fertiliser prices, which would have a disproportionate effect on smallholder farmers and food affordability in low-income contexts. While global analyses suggest limited average impacts on final consumer prices, these averages may underestimate the impact in specific cases. Countries should be willing to work together to manage potential price increases so that any related food security risks in EMDEs are addressed, and the cost of food for society's poorest does not rise.

There are systemic barriers to investment as fertiliser technologies are often not included in sustainable finance frameworks or green taxonomies. Low-emissions ammonia and related products are sometimes absent from funding criteria, limiting their eligibility for climate-aligned capital. Their inclusion could help unlock private investment, particularly in advanced economies, by establishing clear benchmarks and sending strong market signals. The industry's engagement with efforts such as the Science Based Targets initiative (SBTi) is encouraging, although current frameworks focus narrowly on ammonia rather than the full fertiliser value chain. This misalignment may hinder integration into emissions-reduction strategies increasingly used by investors to guide funding decisions.

Financial incentives also need to be carefully crafted to avoid overapplication of fertilisers. Agricultural subsidies aimed at increasing farmers' access to fertiliser, seeds and other inputs need to be designed carefully to avoid adverse consequences from overapplication. For example, a recent study by the World Bank found that up to 17% of nitrogen pollution in waterways (such as hypo-toxicity and algal blooms) has been linked to inefficient fertiliser subsidies. Overapplication of subsidised fertilisers has also been linked with increased emissions, contamination of drinking water, air pollution and soil degradation, calling for the revision of agricultural support to mitigate such effects.

Policies should incentivise a systems approach to agriculture. Research shows that transitioning to regenerative agricultural practices, including improving soil health, can take between 3 and 7 years, meaning that smallholder farmers, especially the rural poor, require targeted financial and technical support to help bridge the gap. Understanding the constraints facing farmers globally, as well as the perceived risks, is critical to provide the tailored support needed. In 2024, the World Bank produced a toolkit to provide guidance on repurposing agricultural support policies for a sustainable food system, aiming to promote efficiency, resilience and environmental impact for sustainable agrifood systems.

WHAT PROGRESS HAS BEEN MADE

Financing has begun flowing to low-emissions fertiliser production projects, but remains limited and fragmented. Some relevant initiatives are already underway, largely through hydrogen-focused programmes. The World Bank's 10 GW Lighthouse Initiative, launched under the Hydrogen Breakthrough, is designed to accelerate low-emissions hydrogen deployment in EMDEs by supporting mid- to large-scale projects through concessional finance and capacity-building. Although the initiative does not currently prioritise fertilisers, its tools and financing structures could be adapted to support low-emissions ammonia production. Similarly, H2Global offers a potential model for de-risking early low-emissions ammonia production through price support mechanisms (see above). The Climate Investment Funds (CIF) Industry Decarbonization Program channels concessional funding to developing countries to break down investment barriers, spur innovation and prove new technologies. The Accelerate to Demonstrate (A2D) Facility, implemented by the United Nations Industrial Development Organization and funded by the UK Government, supports early-stage industrial decarbonisation efforts. A pilot project in Namibia demonstrates how renewable hydrogen can be integrated with ammonia production and fertiliser manufacturing, specifically ammonium sulphate, showing a full value chain approach in an African context. Such demonstration projects are valuable, but they also illustrate the need to transition from pilots to commercial-scale projects. Although not an international initiative, it is worth highlighting the first auction conducted by the Solar Energy Corporation of India (SECI) for the procurement of renewable ammonia.

Co-operation to date has generally occurred within broader frameworks for industrial decarbonisation or hydrogen development and has not yet extended to a comprehensive, fertiliser-specific strategy. Partnerships tend to be bilateral or regional in scope, rather than global. Initiatives like the United Kingdom-Brazil Industrial Decarbonisation Hub may offer models for collaboration, but are limited in number and scale. Multinational knowledge-sharing and co-ordination across jurisdictions, which could help align financial and technical resources, is still nascent.

Financing programmes at multilateral development banks offer support for countries to improve soil health. The African Development Bank's Africa Fertilizer Financing Mechanism provides innovative financing solutions required to improve production, procurement and distribution of organic and inorganic fertilisers, and soil health interventions. In 2025, it was reported that the Mechanism had supported hundreds of thousands of smallholder farmers in 2024 though USD 10 million in credit guarantees across Kenya, Uganda, Mozambique and Zimbabwe. It is now considering the launch of a USD 500 million facility that will deploy multiple financial instruments to smallholder farmers, including trade credit guarantees, first-loss coverage, blended finance mechanisms, and origination incentives to reduce the high transaction costs of serving enterprises, complemented by technical assistance.

Existing global dialogues facilitate exchanges on funding mechanisms relevant to soil health. For example, the global Policy Dialogue for Sustainable Agriculture, an initiative launched by the government of the United Kingdom and the World Bank in 2021, provides a forum to share experiences and learning, facilitate partnerships and build global ambition on reforms. The initiative published a report in 2023 that aimed to facilitate exchanges between countries engaged in the Agriculture Policy Dialogue and with other global initiatives on how funding mechanisms – specifically payments for ecosystems services made to landholders – could improve soil health. The FAO's Global Soil Partnership was established in 2012 to enhance collaboration between land users and policy makers.

What more needs to be done

To reduce risk and attract capital for low-emissions fertiliser production projects in EMDEs, international co-operation on finance must increase and become more targeted. Building on existing hydrogen finance mechanisms, future efforts should explicitly include low-emissions fertiliser production within their scope, particularly in EMDEs where concessional finance and de-risking tools are most needed. Investment frameworks should support not just technology development but also the broader infrastructure and market systems necessary to scale low-emissions fertiliser value chains.

At the same time, efforts are needed to align financial standards and eligibility across jurisdictions. Recognising low-emissions ammonia and fertilisers in the Climate

Bonds Initiative Agriculture Criteria and national or regional taxonomies, such as the EU taxonomy, would help ensure these technologies are considered to be aligned with climate goals and bankable (where necessary policies are in place). Clarifying eligibility for green finance can stimulate demand and innovation by improving access to both public and private capital.

Financial incentives can support soil health outcomes by mobilising and aligning public and private funds. Multilateral development banks (MDBs), climate finance institutions, and donor countries need to scale up funding for soil restoration, de-risk investments, and promote results-based financing. Blended financing options that combine government incentives with loans and support from MDBs could also allow smallholder farmers to adopt sustainable agricultural practices to improve soil heath. Other incentives can include capacity-building support, and targeted solutions may include continuous cover cropping, reduced tillage and livestock integration. Global partnerships for pooling financial resources and targeted mechanisms to reward farmers for restoring and maintaining healthy soils can accelerate positive environmental outcomes.

Sharing best practices on financing mechanisms can enable effective implementation of policies. While several organisations have made the case for repurposing public support to agriculture, highlighting the global momentum behind incentivising food system transformation, gaps in implementation still remain. Collaboration can help in sharing best practices in policy implementation across countries, developing financial mechanisms and strengthening monitoring and reporting systems to build trust among stakeholders. Such co-ordinated action could stimulate and encourage widespread implementation of policies incentivising promotion of soil health and food system transformation. This includes opportunities for integrating soil health across climate, biodiversity and environmental policies to create an enabling environment for cross-sectoral investment in soil health.

Recommendation

Governments, multilateral development banks and development finance institutions should scale up dedicated financing for low- and near-zero emissions fertiliser production and expand investment in innovative financing mechanisms that help smallholder and commercial farmers adopt practices that improve soil health. Financing should be paired with technical assistance, advisory services and monitoring tools. These programmes should build on existing funding mechanisms for low-emissions hydrogen and be expanded to explicitly support fertiliser-related projects.

Financial incentives, such as agricultural subsidies for fertilisers, need to be tailored to encourage optimal fertiliser use, including increased use of biologicals, and promoting soil health. Cross-border collaboration needs to be enhanced for pooling financial resources, mobilising international climate finance and sharing best practices for implementing effective policies for incentivising soil health, and equitable access to financial resources.

Research and innovation

Overview

International knowledge exchange and capacity-building can advance research and innovation. A range of international initiatives have been established to advance research on sustainable and innovative fertiliser production, in areas such as low-emissions hydrogen production, non-Haber-Bosch ammonia manufacturing, improving non-nitrogen-based fertiliser manufacturing, novel fertiliser formulations, sustainable feedstocks (including recycled and bio-based inputs/sourcing in raw materials) and exploring alternative sources of plant nutrition.

There is a need to better understand the nexus between climate change, soil degradation and crop productivity, centred around fertiliser and nutrient use efficiency. Despite more than a century of agronomic studies and trials, there are still gaps in knowledge on the impact of land/farm management on crop productivity under a changing climate. For example, neither crop nor climate models incorporate land/soil degradation status, despite their close interconnections. There is also an opportunity to improve crop and climate models by including soil degradation indicators, such as on soil erosion, to improve the accuracy of yields and to develop effective strategies for resilient agriculture.

What progress has been made

While not specific to fertilisers, innovations related to low-emissions hydrogen can have a large impact on reducing the carbon footprint of fertilisers. A large number of international initiatives are working on low-emissions hydrogen, such as Mission Innovation's Clean Hydrogen and Net-Zero Industries missions, the Clean Ammonia Alliance by the Hydrogen Council and IPHE, CIF Industry Decarbonization Program, and Clean Hydrogen Partnership Europe, all working on technology development, pilot plants and scaling up innovations. The Hydrogen Breakthrough is further expanding on these initiatives, and ensuring strong international co-ordination between all stakeholders and actors. While the fertiliser sector needs to engage in these initiatives to ensure representation, there is little need for new international R&D platforms focused on fertilisers. Stronger engagement can also help to ensure that innovations from outside of the sector feed in and are spread rapidly; however, this is likely to happen naturally as technology developers and industrial producers seek a competitive edge. The IFA Cultivate Challenge is the one active initiative specific to fertilisers; one of the challenge's three themes is how to halve energy intensity of nitrogen fertiliser production.

Some ongoing research and innovation aims to optimise low-emissions ammonia production via the Haber-Bosch process. Several low-emissions ammonia production facilities are being planned or under construction worldwide, but efforts are still needed to scale up facilities, integrate intermittent renewable energy sources and reduce costs. For example, the Policy Dialogue on Transition to Sustainable Agriculture includes as a key topic the promotion of greener production of fertilisers, particularly through supporting energy efficiency and technological innovation in industrial production. Innovation programmes could also explore the value of smaller-scale and modular low-emissions ammonia production facilities, especially where there are difficulties with accessing traditional mineral fertiliser supply chains, though economies of scale can be important.

International collaboration on research on alternatives to the traditional Haber-Bosch process is already taking place. Examples include research between researchers in Australia and the United States on plasma-catalysis, between China and Canada on photochemical ammonia synthesis, and between Australia and Korea on electrochemical synthesis. While traditional research networks already offer opportunities for international research collaborations, these can disappear when the technologies scale towards pilot and demonstration stages. At this stage, easy access to active international collaboration, potentially through innovation programmes jointly funded by multiple governments, can help to ensure that projects can continue and learning is shared.

Some joint efforts are looking at improving non-nitrogen-based fertilisers (primarily phosphate [P] and potassium [K] based). Joint ventures in Morocco, which has around 70% of the world's reserves of phosphate rock, and Algeria, are primarily investigating mining-to-phosphate fertiliser integration, whereas initiatives such as the European Sustainable Phosphorus Platform are focusing on phosphorus efficiency and nutrient recycling technologies. International collaboration – through joint research programmes, pooled funding mechanisms, and mutual sharing of insights from national R&D efforts – has a role to play to aid R&D on eliminating hard-to-abate emissions like the process emissions from phosphate fertiliser production.

Other initiatives are concentrating on the production of more effective fertilisers. Enhanced efficiency fertilisers (EEFs) are one example of these, and are currently supported by initiatives under the Efficient Fertiliser Consortium and IFA's Innovation Hub, which includes corporates, start-ups and other partners. EEFs have added compounds that enable controlled nutrient release, lowering nitrogen losses and N_2O emissions, and improving nutrient uptake by plants, thereby reducing the need for excessive fertiliser application. However, the use of some EEFs, particularly polymer-coated urea, raise environmental concerns related to potential plastic pollution that may impact soil health, which must also be considered. There is a need for independent evaluation of such technologies, using standardised protocols for yield and environmental performance across diverse conditions to guide product improvement, identify where such technologies will have the highest potential for success, and understand potential trade-offs, including ensuring reduced emissions during microbial processes. There are efforts underway to improve the accuracies of the inventories that can be built on and scaled. While international collaboration could help in this area, particularly through jointly funded international basic research programmes, production of these fertiliser formulations is likely to be commercially important for the entities developing them, and so collaboration could be limited by sensitivity and competition requirements.

Some initiatives are working on producing fertilisers from alternative raw materials, and others focus on improving the supply of organic fertilisers. The IFA's Innovation Hub also includes organic fertilisers initiatives. Circular approaches, such as nutrient recovery, increased use of by-products of fertiliser production and recycling through processed organic and organo-mineral fertiliser are also encouraged by numerous initiatives such as the Policy Dialogue on Transition to Sustainable Agriculture, IFAD and others. Through programmes like Horizon Europe, the European Union has also funded numerous projects aiming at producing fertilisers from alternative materials. For both recycled and organic approaches, the local context is particularly important, meaning that learning from international research programmes needs to be translated into local realities.

Over the past three decades, there have been multiple large-scale initiatives focused on soil health and landscape restoration. The results of these need to make more of an impact through cross-learning and scaling. Examples include:

- N2Africa, a large-scale science-based "research-in-development" project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in Africa.
- EU Soil Mission: A Soil Deal for Europe, with a goal to establish 100 living labs and lighthouses to lead the transition toward healthy soils by 2030, and an associated Soil Manifesto.
- International Fertilizer Development Center is leading a consortium of partners to implement Soil Values, a 10-year programme (2024-2034) financed by the Netherlands Directorate-General for International Cooperation (DGIS), which aims to improve the soil fertility and productive capacity of 2 million hectares of farmland in the Sahel, fostering resilience and well-being among 1.5 million farmers, with an emphasis on women.
- Regreening Africa, a research-in-development project to restore 1 million hectares of land across eight countries in sub-Saharan Africa, where more than 60% of agricultural land is degraded.
- The Living Soils Initiative of the Americas was launched by the Inter-American Institute for Cooperation on Agriculture in December 2024, with the aim to translate science into action to protect and rehabilitate soil.
- The Efficient Fertilizer Consortium is a recently founded public-private partnership that funds research to advance enhanced efficiency and novel fertiliser products that improve crop production and reduce nutrient losses.

WHAT MORE NEEDS TO BE DONE

Knowledge-sharing and transparency can broaden the impact of innovation. Several companies are now taking important steps by investing in cleaner technologies and low-emission production methods. To scale up their impact, openly sharing successful strategies (where possible and of limited commercial sensitivity) can help to accelerate progress, reduce costs, and improve long-term prospects for the sector as a whole.

International collaboration will continue to be a vital enabler, not only in early-stage R&D but increasingly in pilot and demonstration projects, where funding gaps and risks are often greatest. Jointly funded international innovation programmes – particularly those that can bridge the transition from lab-scale breakthroughs to industrial deployment – are essential to accelerate progress. Sharing infrastructure and knowledge across borders can significantly de-risk investments by reducing duplication and enabling cost-effective scaling. Strategic prioritisation is also needed to focus efforts on areas with the highest emissions reduction potential and where international knowledge-sharing can offer the most value.

For fertiliser use, there is a need to establish an international network of long-term monitoring sites across diverse agroecosystems to fill critical knowledge gaps, such as on the impact of land management on soil health and productivity. This includes generating the evidence on the effectiveness of fertiliser management, identification of beneficial application techniques and long-term strategies to improve soil health. In particular, there is a significant opportunity to fill knowledge gaps in soil and land health data to drive strategic implementation and scale up initiatives to improve soil health. Collaboration towards this aim could build on existing networks such as the Long-Term Ecological Research Network, which has 27 sites globally, as well as the long-term trials hosted by the CGIAR, the Rodale Institute Farming Systems Trial and the long-term experiments at Rothamsted, and fill key gaps around different agroecologies.

While significant progress has been made in the development of microbial formulations and digital agronomic tools, critical knowledge gaps remain. Key research priorities include the long-term validation of biologicals across diverse agroecologies, the development of climate-resilient microbial strains tailored to specific soil and crop contexts, and robust metrics to quantify their contributions to nitrogen substitution, carbon sequestration, and ecosystem resilience. International collaboration is essential to address these gaps through joint research platforms, shared microbial libraries, and co-ordinated field trials. It is also needed to define science-based regulatory pathways, harmonised data protocols, and monitoring frameworks for assessing biological performance. Brazil's leadership in this field (see box above) demonstrates how frontier science can translate into measurable impact, but realising the full potential of biologicals will require co-ordinated global efforts across public, private and academic stakeholders.

There is a need for the development of innovations that support circular bio-economies for nutrient management, especially those that limit trade-offs across lifecycle analyses. R&D should focus on creating organo-mineral fertilisers that are rich in nutrients. More broadly, there is an opportunity to expand research on novel fertilisers by applying systematic monitoring protocols to identify priority areas for investment. Novel microbials and EEFs, for example, will likely have an important role in sustainable agriculture, but many current products are not delivering the expected results.

Recommendation

Leveraging existing platforms for innovation collaboration, governments should work together to support the scale-up of promising low- and near-zero emissions fertiliser technologies, prioritising pilot and demonstration projects in EMDEs.

Governments, in collaboration with the private sector, should agree to establish a network of long-term monitoring sites across diverse agroecosystems, with data-sharing arrangements, to address persistent knowledge gaps on the links between fertiliser use, soil health and climate resilience, and promote innovative programmes to support circular bio-economies for nutrient management.

Chapter 4. Deep Dives

This chapter presents four focused deep dives into sectors where co-ordinated action can unlock faster progress. The deep dives provide practical insights into what effective collaboration looks like on the ground. Drawing on case studies from diverse geographies and stakeholders, they highlight mechanisms that have helped overcome systemic barriers and build momentum in critical areas.

Whether improving grid integration across borders, scaling up road corridors for zero-emission vehicles, exploring international offtake agreements for near-zero emissions iron, or building resilient, decarbonised supply chains that could enable economic opportunities for emerging economies, the examples shared offer lessons for replicability and scale.

By identifying successful models and emerging opportunities, the chapter supports the Breakthrough Agenda's goal of making clean technologies the most affordable, accessible and attractive option in each emitting sector by 2030 – everywhere in the world.

HEAVY-DUTY ROAD TRANSPORT

The transition to zero-emission vehicles in the heavy-duty road transport sector is still at an early stage, especially when compared to passenger cars; more than 20% of new car sales were zero-emission in 2024. In contrast, buses reached around 5% of new sales, and trucks[1] just below 2%. However, while global averages remain low, several regional markets are seeing fast uptake of zero-emission buses and early momentum on truck deployment. Zero-emission trucks include both electric vehicles (battery electric vehicles [BEVs] and plug-in hybrid vehicles [PHEVs]) and fuel cell electric vehicles (FCEVs). As in other segments, BEVs currently dominate the market for zero-emission trucks, due to their lower costs and higher model availability.

This deep dive presents two examples of how collaboration across international road freight corridors can accelerate the transition. While these opportunities apply to both BEVs and FCEVs, the case studies draw primarily on experiences with BEVs, for which data and implementation examples are more readily available.

WHY IS THIS IMPORTANT?

Trucks and buses emit more than one-third of road transport CO_2 emissions, despite representing less than one-tenth of the global vehicle fleet (excluding 2-3 wheelers), due to their heavier payloads and longer travel distances. The transition in heavy road transport faces technical challenges: large batteries reduce truck payload capacity when compared to conventional trucks. Longer charging times affect logistics and delivery schedules. However, the technology is rapidly improving: in 2024 there were nearly 800 electric heavy-duty models available; ranges are increasing and the first megawatt-scale chargers are being deployed, enabling faster charging. Operations are predominantly commercial, meaning that truck operators are highly sensitive to the economics of the transition.

In 2023, only around 1% of trucks sold worldwide were zero-emission vehicles. In 2024, this share doubled as global sales of electric trucks grew by almost 80% to reach nearly 100 000. Growth is fastest in China, where electric trucks represented 4.5% of all truck sales in 2024. In the first half of 2025, the Chinese market for heavy-duty and tractor-trailers grew again, by 180% year-over-year.

There are also signs of change in other regions; over the same period, sales of zero-emission trucks in Europe increased by nearly 50%, despite a 15% contraction in the truck market overall. The medium-duty truck segment stood out in particular, with 15% of sales being electric – more than double the share over the same period in 2024. This rapid growth highlights that electrification can accelerate quickly in specific use cases.

Nevertheless, the transition faces two critical hurdles: the upfront cost of zero-emission trucks, and the availability and cost of refuelling/charging infrastructure. These two challenges are linked; in the case of battery electric trucks, for example, charging costs can account for 15-40% of the total cost of ownership (TCO), reflecting the wide variability of use cases. The price of electricity is a particularly powerful determinant, with the price

[1] This deep dive focuses on trucks, specifically medium- and heavy-duty (MHDV) vehicles with a gross vehicle weight (GVW) of over 3.5 tonnes.

charged at high-power, public charging stations often far higher than typical industrial rates. Hydrogen refuelling infrastructure for fuel cell trucks faces a similar, albeit distinct, infrastructure challenge, with the price of low-emissions hydrogen being a strong determinant of overall costs. Hydrogen is also expected to have significantly higher distribution and refuelling costs than electricity.

Opportunities for and examples of international collaboration

This deep dive provides two examples of how international collaboration can address these two barriers to deployment. Firstly, it considers how regulatory alignment in major markets could accelerate the reduction in TCO of zero-emission trucks. Secondly, given that many road freight corridors cross national borders, it looks at how co-ordination between countries on investments in charging infrastructure deployment and related policies can help to ensure that affordable infrastructure is available.

Aligning regulations to accelerate cost reduction

While in one leading market – China – the TCO of battery electric trucks is already lower than that of diesel trucks, this is not yet the case in other markets. Typically, the purchase costs of battery electric trucks are around 2 to 2.5 times those of diesel trucks, while higher financing costs and potential lower resale values can also play a significant role. Nevertheless, the lower operating costs of electric trucks help reduce their overall lifetime costs.

This difference in purchase cost is shrinking as technology improves, battery prices decline, economies of scale grow, and supportive policies are implemented. In leading markets other than China, heavy-duty electric trucks could approach parity with diesel trucks in TCO around 2030. Hydrogen fuel cell trucks, however, continue to have a higher TCO than battery electric trucks. To reach parity with battery electric trucks by 2030, hydrogen fuel cell and tank costs would need to fall by approximately 60% from 2024 levels.

Regulatory policies can incentivise manufacturers to produce electric vehicles in greater volumes, driving innovation and economies of scale that bring down costs. Simulation modelling suggests that strong zero-emission vehicle mandates are more effective for accelerating cost reductions for electric trucks than other policies. These effects are amplified if the policies are implemented across a larger share of the global market.

Through the Global Memorandum of Understanding on Zero-Emission Medium- and Heavy-Duty Vehicles (Global MoU), 40 countries have committed to work together to enable all new truck and bus sales to be zero-emission vehicles by 2040, with an interim goal of reaching a 30% share of sales by 2030. This commitment has also been endorsed by a range of subnational governments and businesses. Countries that are signatories of the Global MoU or that have made similar commitments accounted for around one-fifth of global HDV sales in 2023.

If some of the countries and jurisdictions with the largest markets were to align their regulatory policies with the goal of the Global MoU, the decline in electric truck costs could accelerate significantly, as higher production volumes would drive economies of scale and innovation would further push prices down. It has been estimated that if China, Europe, India, Canada, California and other selected US states implemented regulatory policies aligned with the Global MoU, TCO parity between electric and diesel light and heavy-duty trucks in major markets could be brought forward by several years, and the difference in purchase price could be substantially reduced.

The accelerated cost reduction that could arise from aligned action among the major markets would be to the benefit of all countries. By reducing the barriers to adoption of electric trucks, it would also reduce emissions and air pollution, and – as the costs of zero-emission vehicles fall below those of diesel vehicles – improve economic productivity.

Gains from co-ordinated action on charging infrastructure on international road freight corridors

Cross-border freight corridors that are heavily used by trucks are where co-ordinated international action on electric truck charging infrastructure is most necessary – and most likely to make an impact. Concentrating investment in power infrastructure and charging stations along major trade arteries that connect ports, industrial hubs and cities in different countries can create a base from which to expand long-haul electric trucking more widely. The business case for charging infrastructure investment depends heavily on utilisation rates. For example, high utilisation of electric or hydrogen refuelling stations could bring down the refuelling costs significantly, nearly 50% and 30%, respectively. The potential for high utilisation rates could be reached more quickly if countries along the route also use fiscal or regulatory policies to simultaneously increase demand for electric trucks, as outlined in the previous section.

Co-ordination in the timing of public investments or policies to incentivise private investment in charging infrastructure can help to ensure that charging facilities are available in different countries along the same route. This will be important in giving truck operators the confidence to switch from diesel to zero-emission trucks. Creating pooled, multi-country investment packages can enable larger and more diversified deals, allowing institutional investors and multilateral development banks to enter with lower perceived risk and longer-term debt, thereby reducing the cost of capital.

The high capacity (megawatt-scale) charging infrastructure needed for electric trucks on high-usage routes often requires investment for additional grid infrastructure for local distribution networks, substations, transformers, feeder lines and advanced control systems for load balancing and demand response. Collaborative, cross-border planning involving utilities can facilitate development and reduce costs, and is especially necessary in cases where fast charging creates a need for network upgrades in different segments of the grid.

Grid upgrades and expansion can have long lead times, and international co-ordination can support anticipatory planning. By using detailed scenarios that integrate both transport and power system modelling, the risk of power grids becoming a bottleneck for truck charging can be reduced. This will also continue to be relevant into the future, in order to prepare for the impacts of electric trucks on the local grid; when fleets reach very high stock shares (over 50%), they can increase average line utilisation by up to 5%.

Greater grid interconnectivity and joint planning to increase grid flexibility can enable countries to share infrastructure costs and to maximise mutual benefits. In addition, installing battery energy storage systems at charging stations can further increase flexibility. Co-ordination on smart charging can reduce peak electricity demand by 6-9%, and avoid up to 25% of network reinforcement costs.

Harmonised technical standards and operational protocols are important to make charging technology interoperable across borders, facilitating international zero-emission road freight. Harmonisation also brings cost savings: when countries agree on common charging connectors, power levels and communication standards, manufacturers can build one version of a truck or charger for all markets, thus reaching greater volumes and lower unit costs.

For battery electric trucks, two different charging systems are emerging, one led by the European Union and the United States, and the other by China and Japan. In 2023, the European Union and the United States issued a joint statement recognising the Megawatt Charging System as adopted by international standardisation bodies, including the International Electrotechnical Commission (IEC), SAE International and International Organization for Standardization (ISO). Elsewhere, China has adopted the ChaoJi-1 end of 2023 and is further developing ChaoJi-2.

China has also begun deploying battery-swapping stations with a standard that provides a common "physical and digital socket" for batteries in heavy trucks. There could be advantages to agreeing an international standard for battery-swapping before approaches diverge. Similar standardisation challenges exist for hydrogen refuelling standards and connectors.

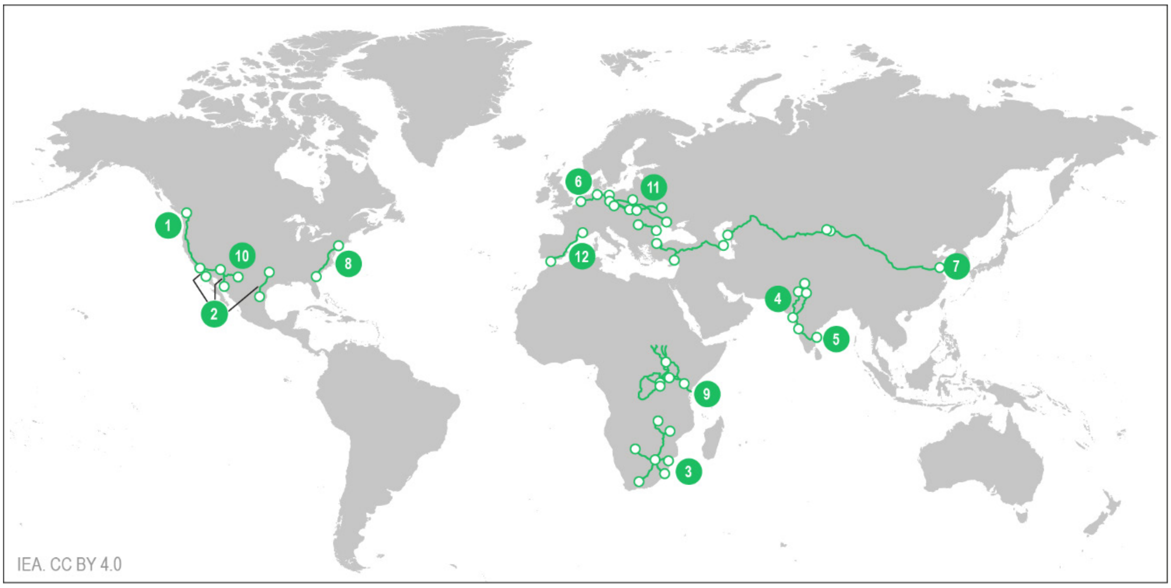
For charging point users, interoperable payment systems can allow a truck to travel across countries using a single billing account, with data-sharing enabling authentication, billing, and live information on charging station availability across operators and borders, reducing complexity for truck operators. This can also support higher charger utilisation rates. Cross-border market design (such as time-varying tariffs) could help signal when and where to charge to minimise effects on the grid.

Centralised data-sharing frameworks can also allow charge-point operators to align infrastructure development with actual demand patterns, ensuring investments are made where they are most needed, and avoiding under-utilised chargers or capacity shortages. For example, the Poland-Germany Zero Emission Freight Corridor benefited from a high-level Electrification Plan based on trucking data received from participating shippers and carriers over 250 million kilometres travelled in the course of a year, collected by the Smart Freight Centre and PragmaCharge.

CASE STUDIES OF INTERNATIONAL ROAD FREIGHT CORRIDORS

The Global Green Road Corridors Initiative is a multistakeholder initiative to support the establishment of a set of zero-emission road freight corridors for medium- and heavy-duty vehicles. The initiative is currently focused on twelve corridors; the first eight are shown in Figure 4.1. The corridors include both national and international routes, and are being developed by diverse coalitions, including private-led consortia and government partnerships. The stakeholders involved have identified conditions necessary for the corridors' success, which include sufficient freight volumes; policies supportive to the deployment of zero-emission vehicles; strong demand signals via government purchase incentives or private sector demand aggregation initiatives (which may be complemented by supply-side regulations); and effective co-ordination and governance among stakeholders to build the required infrastructure. Other enabling factors include public investment in infrastructure, targeted roadmaps for route development, engaged stakeholders, zero-emission vehicle availability at competitive prices, and strategic development of the route, starting from freight hubs.

Figure 4.1 First eight zero-emission road freight corridors envisaged by the Global Green Road Corridors Initiative



Notes: 1. FIFA 2026 Corridor (Canada–United States–Mexico). 2. United States–Mexico border corridors (California – Baja California, Texas – Nuevo Leon, Arizona – Sonora). 3. Southern Africa Container Corridor (Port of Durban, including South Africa, Lesotho, Eswatini, Zimbabwe, Botswana and Zambia). 4. India Corridor I (Mumbai–Delhi and Delhi–Jaipur). 5. India Corridor II (NH48: Delhi – Mumbai – Chennai). 6. European Corridor to Zero (the Netherlands, Germany, Poland and Ukraine). 7. Trans-Caspian International Transport Route (TITR) Corridor (China, through Kazakhstan, Azerbaijan, Georgia and Türkiye to Europe). 8. United States I–95 Corridor (Georgia – New Jersey).

Source: Global Green Corridors Initiative.

The corridors that are the focus of this initiative are at different levels of maturity, from concept and planning to implementation and operation. Two examples are described below.

Case study 2: Europe: The Clean Transport Corridor Initiative

The European Union has created a Clean Transport Corridor Initiative as part of its Industrial Automotive Action plan. This initiative aims to identify infrastructure and investment needs for key Trans-European Transport Network (TEN-T) corridors, which together carry around 80% of the European Union's road freight. Two major routes have been selected as initial priorities: the Scandinavian–Mediterranean Corridor, and the North Sea–Baltic Corridor.

The EU Alternative Fuels Infrastructure Regulation mandates a unified approach to infrastructure along these routes. By 2030, all EU member states are required to install truck chargers with a capacity of at least 350 kW every 60 km along the TEN-T corridors, with standardised connectors and payment access. This is backed by dedicated funding to support infrastructure investment.

For each corridor, different private initiatives are now co-ordinating roll-out. For example, Milence, a joint venture between three large truck manufacturers that are pooling resources to invest in truck charging infrastructure across the continent, has received over EUR 100 million in EU funding in support of a project to invest in 70 charging hubs across 10 European countries. Three of these hubs are located along the 700 km Barcelona–Lyon stretch of the Scandinavian–Mediterranean Corridor, connecting one of Europe's largest ports with France's second–largest logistics centre. Other business consortia include the Iberdrola, Disfrimur, Primafrío and BP-Pulse coalition working on corporate demand aggregation and charging infrastructure investment between France and Spain, and the BP-Pulse Germany and Ekoenergetyka partnership expanding into Eastern Europe.

These initiatives are reinforced by strong regulatory policy driving the transition. The European Union has stringent requirements for the reduction of vehicles' CO_2 intensity, with financial penalties for non–compliance. The penalties start from 2025 onwards at EUR 4 250 per g CO_2/tkm. These measures help to ensure the supply of electric trucks, contribute to demand for charging infrastructure, and create confidence for infrastructure investors.

Case study 2: East Africa: The Northern Corridor trade route

The Northern Corridor is a multimodal trade route which includes nearly 13 000 km of road networks across Burundi, the Democratic Republic of the Congo, Kenya, Rwanda, South Sudan and Uganda. The corridor is governed through a supranational governance framework dating back to 1985, which has enabled harmonisation of policies and procedures, infrastructure management, and standardised services across different member states, providing a strong foundation for the development of international zero-emission freight corridors.

In 2024, the Northern Corridor Transit and Transport Coordination Authority adopted a Green Freight Strategy 2030, which aims to transform the trade route into a climate–resilient corridor. As part of this initiative, a Green Freight Transport Network was developed to bring together regional representatives from transport ministries, logistics divisions, freight associations, and civil society organisations to co-ordinate efforts in support of electrified road transport across the participating countries.

An "electrification readiness study", to be undertaken in the six countries along the corridor, was launched in July 2025. This will involve consultation with stakeholders – including relevant government ministries, freight businesses and truck manufacturers – on topics including the co-ordination of standards, deployment of charging infrastructure, availability of clean power, and vehicle regulation or diesel truck phase-out plans. The study is intended to provide a roadmap for the implementation of the green freight strategy by member countries, including policies for the deployment of zero-emissions medium- and heavy-duty vehicles.

Stakeholders in the Green Freight Transport Network are also supporting business-led battery electric truck and fuel cell truck demonstration projects and a pre-feasibility study to identify potential charging stations and mechanisms. The Smart Freight Centre is developing guidance for truck operators and fleet owners on transitioning to electric vehicles and investing in charging solutions.

Nevertheless, the East African market for zero-emission trucks is still nascent, with only a few dozen units having been sold across the region. For example, in Rwanda, OX Delivers is operating 29 zero-emission light-duty electric trucks and four logistics hubs. Regional initiatives on truck electrification are also now emerging, such as the Green Freight Support Program in Eastern Africa, initiated by the Kühne Climate Center and Smart Freight Centre. This programme brings together shippers, carriers and other freight stakeholders to collaborate on introducing electric trucks on the Northern Corridor.

The multinational governance of the Northern Corridor creates a strong foundation for information exchange and co-operation among stakeholders for road freight electrification. This has been internationally recognised, and efforts are underway to replicate its governance structures in other corridors.

Next Steps

International co-ordination on zero-emission road freight corridors could reduce infrastructure costs and accelerate the deployment of charging networks for zero-emission trucks. This is likely to require multi-country investment packages and co-ordinated grid planning in order to achieve the utilisation rates necessary for commercially viable charging infrastructure. Intergovernmental agreements on technical standards and corridor governance, such as those highlighted by the Global Green Road Corridors Initiative, could also give infrastructure investors additional confidence to deploy capital. Policies such as zero-emission vehicle mandates, harmonised charging standards, and public infrastructure investments will be important to ensuring seamless cross-border operations and accelerating the transition from diesel trucks to zero-emission vehicles.

REGIONAL INTERCONNECTION PROJECTS

Grids are the backbone of today's electricity systems, delivering power to households, businesses and industry. Over time, countries have been collaborating on cross-border projects to connect their power systems, allowing access to more resources to balance supply and demand and increase system efficiencies. Regional interconnection projects can take years, however, highlighting the need for strong regional planning and agreements between a diverse set of stakeholders that can ultimately attract the investment needed for deployment.

WHY IS THIS IMPORTANT?

Expanding and modernising grids is essential for a secure, affordable, resilient and sustainable energy system. Regional integration of power systems is a key element of this, and one that requires stronger international collaboration to enhance and build out regional interconnections.

A 2023 IEA analysis found that the world must add or replace 80 million kilometres of grids by 2040 – equal to all grids globally today – to meet national climate targets and support energy security. This would require annual average investment in grids to nearly double by the end of the decade, reversing years of stagnation at the global level. The investment needs for grid infrastructure are particularly acute in emerging markets and developing economies (EMDEs) other than China, which account for only 20% of global investment in transmission.

When designed well, interconnected grids can improve grid stability, increase energy security and enhance flexibility in managing power supply and demand fluctuations. When paired with integrated power markets, interconnected grids can lower total operating costs. For example, in Europe, cross-border trade of electricity is estimated to have delivered welfare benefits worth EUR 34 billion in 2021, compared to a situation with isolated national markets. to export it to areas with higher demand.

Yet regional interconnection projects continue to face financial, technical and political challenges. Differences in power market structure

Interconnected grids can also enable the integration of variable renewable energy sources, such as wind and solar, allowing regions with excess clean energy s, policy objectives, technical specifications, institutional structures and grid capabilities can further complicate the ability of countries to work together on these capital-intensive projects.

Regional interconnections, and the regional markets that support cross-border trading of electricity, are complex projects that require agreements between governments, transmission system operators, market regulators, electricity producers and others. Achieving the benefits of regional integration requires not only financing and building the necessary physical infrastructure to connect power systems, but also co-operation across borders to establish agreements between jurisdictions and co-ordinate the stakeholders that will operate the interconnected system.

For regional interconnections to operate successfully, projects must meet institutional, political and technical requirements. There are several examples of collaboration within the European Union on cross-border projects that successfully address requirements across all of these three pillars, and with the establishment of a dedicated regional fund, the Connecting Europe Facility, more funding is available to finance cross-border projects of common interest to EU member states. While some lessons can be shared from these experiences, collaboration between countries outside of the European Union can look very different. This deep dive provides two case studies on how countries have successfully worked together in Central America and Southeast Asia to develop the necessary institutional and political frameworks to realise regional interconnection projects.

Opportunities for and examples of international collaboration

Case Study 1: Central American Electrical Interconnection System (SIEPAC)

The SIEPAC is an interconnection project that links the power grids of six Central American countries: Panama, Costa Rica, Honduras, Nicaragua, El Salvador and Guatemala. The project, which connects around 50 million consumers, was initiated in 1987 and became operational in 2013.

SIEPAC was initially created to stimulate the development of a regional electricity market that would facilitate private sector participation in the build-out of electricity generation capacity in the region. The backbone of the project is a 1 790 km 230 kV transmission line from Guatemala to Panama, with connections to substations and the national power grids of the six participating countries.

Following a series of concept studies funded by the Inter-American Development Bank (IADB), SIEPAC was formalised in an intergovernmental agreement (the "Marco Treaty") that provided the legal foundation for the establishment of a regional market and the supporting institutional and physical infrastructure. Under the Marco Treaty, the project successfully put in place subsequent agreements and frameworks to build the necessary cross-border transmission infrastructure to allow energy trading across the region.

Two key elements made this success possible: the development of an institutional framework and the availability of finance from inception to deployment.

Institutional framework

The creation of an institutional framework for the SIEPAC project (the "Framework Treaty") established regional institutions responsible for developing the physical, regulatory and market infrastructure. Under the Framework Treaty, regional entities were created to develop the necessary transmission infrastructure and market operation functions (regional operating entity, or EOR), establish an independent regulatory agency (Regional Commission for Electrical Interconnections [CRIE]), and co-ordinate regional energy policy (Council of Ministers of Energy).

The international transmission line company (EPR) formed under the framework was mandated by participating governments to design, finance, construct and maintain the physical transmission infrastructure for the interconnection of the electricity systems in the region. The company was structured so as to spread the development risk of the transmission line across the countries in the region. Organised under a public-private partnership model, EPR is made of six regional state-owned utilities and three extra-regional shareholders, each with an 11.1% holding in the parent company.

Finance from inception to deployment

The total cost of the 230 kV transmission line amounted to around USD 505 million, the financing of which was made possible through a mix of development finance institutions and private banks that were involved from inception to deployment.

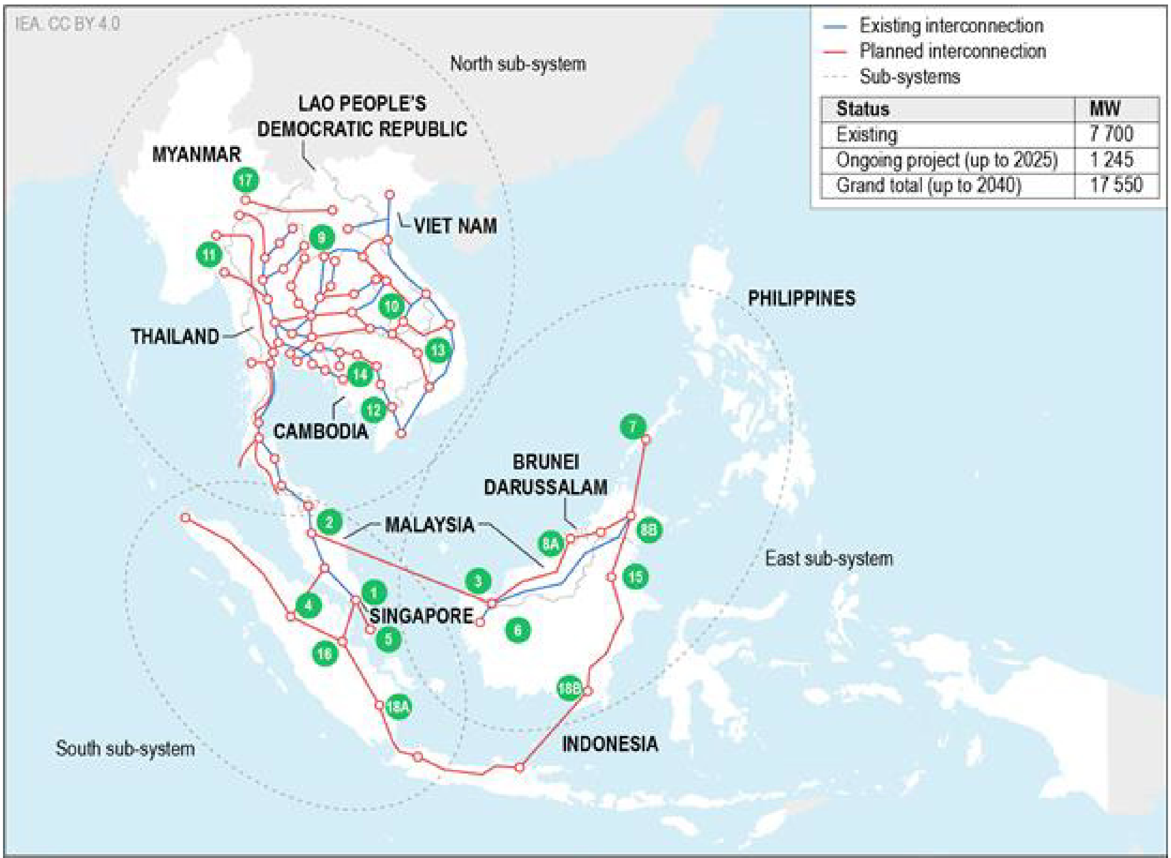
The first interconnection feasibility study was conducted by Spanish utility Endesa in 1987 to evaluate the economic benefits of interconnection. This found that physical interconnection alone would not be economically practical unless a level of regional electricity trade was introduced to reap the full benefits of the interconnected system. This sparked a series of technical studies funded by the United Nations Economic Commission for Latin America and the Caribbean, the IADB and the Spanish government to prove the feasibility and potential benefits of the SIEPAC project, in turn allowing other sources of finance to be used for construction and development.

The IADB was the main source of financing for the construction of the 230 kV transmission line, providing over USD 250 million in loans to electricity companies and technical assistance resources to support the establishment of a regional market. Additional debt financing was secured with the Central American Bank for Economic Integration, Banco de Desarrollo de América Latina (formerly Corporación Andina de Foment), Bancomext and Banco Davivienda.

Case Study 2: ASEAN Power Grid

Southeast Asia is one of the fastest-growing regions in the world in terms of electricity demand. The Association of Southeast Asian Nations (ASEAN) countries have put forward an ambitious project for regional development to support economic growth and the integration of higher shares of renewable energy. Central to this effort is the integration of the region's power systems and the establishment of cross-border electricity trading. The ASEAN Power Grid (APG) is an initiative to connect the region, initially on cross-border bilateral terms, then gradually expanding to the sub-regional level and finally to a totally integrated Southeast Asia power grid system. While relatively few interconnections exist today in the region, the APG initiative shows how the political will and leadership of governments can set the stage for, and build on, bilateral co-operation to pilot and test what broader regional integration would look like.

Figure 4.2 Association of Southeast Asian Nations Power Grid Map



1. 275 kV Plentong - Senoko | 9.2 km | Existing 1 050 MW
2. 110 kV Gurun - Khlong Ngae | 110km | Existing 300 MW
4. 500 kV Telok Gong Malaka to Perawang | 234 km (50 km subsea) Year connect: 2030 | 2 000 MW
5. Singapore - Batam subsued to Sumatra - Singapore Interconnection
6. 275 kV Mambong - Bengkayang | 126 km Existing 230 MW | Expand to 830 MW
7. 275 kV Kudat - Palawan 230 km (190 km subsea) Year to connect: 2040 | 200 MW

8A. 275 kV Kuala Belait to Miri/Tudan | 45 km Year to connect: 2025 | 100 MW

8B. 275 kV Lawas - Mengalong Sipitang | 31 km Existing 100 MW | Expand to 150 MW

9. 1. 115 kV Nong Khai - Dongphosy
   2. 115 kV Bueng Kan - Pakxan
   3. 115 kV Nakhon Phanom - Thakhek
   4. 115 kV Mudhakan - 2 Pakbo
   5. 115 kV Sirindhorn - Bangyo
   6. 115 kV Tha Li - Paklay

   115 kV Mae Chan - Ton Phueng | 60 km
   Year to connect: 2025 | Expand 900 MW
   up to 1 300 MW

10. 220 kV Nam Mo - Ban Ve | Existing 570 MW 500 kV Hax Tan - Pleiku | 94 km Year to connect: 2040 | Expand to 620 MW
11. 500 kV Hutgyi (Myanmar) to Phitsanulok | 300 km Year to connect: 2040 | 1,250 MW
12. 220 kV Chau Doc to Takeo| Existing 400 MW 500 kV Savy Antor - Tay Ninh Year to connect: 2035 | 250 MW
13. Bypass at Lao Border from Don Sahong generation | Exisiting 300 MW New: Banhat to Stung Treng | 85 km Year to connect: 2030 | Expand up to 200 MW
14. 115 kV Aranyaprathet to Poi Pet| Existing 240 MW 500 kV Prachin Buri to Siem Reap | 300 km Year to connect: 2025 | Up to 250 MW
15. 275 kV Malinau - Kalabakan | 140 km Year to connect: 2030 | Up to 200 MW
16. 250 kV Paranap - Singapore| 260 km (100 km subsea) Year to connect: 2030 | Up to 1 600 MW
17. 115 kV Tonpheun to Tachilcik | Existing 30 MW 230 kV from Muang Long to Ken Tung | 300 km Year to connect: 2035 | Up to 350 MW

18A. 500 kV Muara Enim (Sumatra) to Bogor 500 km (40 km subsea) Year to connect: 2030 | Up to 6 200 MW

Source: IEA (2024) Southeast Asia Energy Outlook.

A 2019 IEA analysis found that optimising cross-border flows through multilateral trade based on the existing cross-border infrastructure in the region could reduce the annual operating costs of the ASEAN power sector by USD 1 billion. Expanding the region's interconnection infrastructure could enhance the economic benefits and accommodate higher shares of variable renewable energy, resulting in operational cost savings of USD 4-5 billion per year.

The prospects for an integrated ASEAN power sector remain promising, but achieving the full potential of a regional power grid will require significant investments and well-co-ordinated governance. Key to enabling further development is political will and leadership among ASEAN member states, which have already supported development of the institutional and technical pillars of the regional initiative.

Political support

In 1997, ASEAN heads of state called for the establishment of an APG through an interconnection arrangement between the region's utilities. A decade later, in 2007, ASEAN ministers signed a Memorandum of Understanding (MoU) that outlined a broad framework through which countries would collaborate to develop the APG. Central to the MoU was a common understanding of the objective of enhancing energy security and sustainability in Southeast Asia.

This MoU, which entered into force in 2009 and is set to be renewed and enhanced at the end of 2025, has set the stage for regional co-operation and enabled additional agreements at the sub-regional and project level that detail the steps towards implementation. Subsequent agreements focused on specific sub-regional interconnection projects. For example:

- An intergovernmental agreement, followed by two MoUs for power trade among the six Greater Mekong Subregion countries, was signed in 2004 to continue development towards the envisioned multilateral power trade initiative. This involves Cambodia, China, Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand and Viet Nam, and aims to establish a regional power market, creating regulatory and technical standards for cross-border electricity trading.
- Another intergovernmental agreement, the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project's (LTMS-PIP) Joint Statement, was signed in 2014. The statement established a working group to study the technical viability, policy, legal, regulatory and commercial aspects of cross-border power trade from Lao PDR to Singapore. Designed to operate as a pilot, the LTMS-PIP is now the most advanced multilateral power trading arrangement of the region. In 2022, it began trading 100 MW of hydropower from Lao PDR to Singapore via Thailand and Malaysia using existing transmission infrastructure. This electricity import made up about 1.5% of Singapore's peak electricity demand and proved the technical and economic feasibility of multilateral electricity trade in the region. In 2024, the agreement was expanded to double the trade capacity to 200 MW and extended through 2026.

In addition to specific project-level agreements, partnerships with multilateral institutions are working to leverage implementation and financial support.

- In August 2025, ASEAN ministers welcomed a proposal by the World Bank and Asian Development Bank to develop the ASEAN Power Grid Financing Initiative, an initiative to mobilise financing and provide technical support to the APG. The banks have so far pledged more than USD 12 billion to support the effort.

- In September 2025, the ASEAN Centre for Energy and the United Nations Economic and Social Commission for Asia and the Pacific signed an MoU to support the implementation of the region's energy planning, including energy connectivity through the APG.

NEXT STEPS

Improving and expanding grid infrastructure in countries worldwide will require stronger international collaboration. Intergovernmental agreements can act as a first and crucial step towards regional interconnection and market integration, and establish a foundation for further collaboration down the road. However, political agreements alone do not lead to the development of regional interconnection projects, and their successful implementation depends on several factors that require collaboration.

- **Improved co-ordination**: Successfully interconnecting regions requires a broad range of stakeholders to be engaged, from relevant government and regulatory bodies to grid utilities, as well as affected local and regional governments, merchant investors, renewable energy developers and civil society. Planning interconnections together with expansion of renewable and other clean electricity generation is also emerging as a key priority for international collaboration. Well-interconnected countries will also need to ensure co-ordinated planning and operations with neighbours for transition plans that increase the reliance on trade for renewables integration and generation adequacy.
- **Institutional frameworks**: International experience shows that multilateral trading and regional integration more broadly are best supported by regional institutions and their frameworks. When it comes to regional interconnection, it is important to clearly define the roles and responsibilities linked to cross-border assets. Regional organisations tasked with planning and overseeing implementation must be formalised, given proper authority and adequately resourced.
- **Technical and cost harmonisation**: Alignment of technical requirements covers a broad range of topics essential to ensuring electricity can flow seamlessly and safely across borders. For example, harmonised grid codes help to ensure that power system operations across interconnected systems are not in conflict with one another. Similarly, the need for standards to ensure interoperability between grid components from different manufacturers, particularly for DC technology, is becoming more relevant during energy transitions, especially with the increased development of meshed offshore grids. Harmonised methodologies for charges across the system (such as wheeling charges) are also necessary to adequately compensate those jurisdictions that are affected by new interconnections and to quantify the benefits. Explicitly valuing domestic spot prices (even as a shadow price without an actual market) can quantify interconnector benefits, allowing usage fee recovery in relation to them.
- **Accessible financing options**: While several advanced economies have established mechanisms to finance interconnection projects, EMDEs often face a much higher cost of capital and can struggle to attract necessary investment. In regions that rely on state-owned utilities to own and/or operate transmission infrastructure, collaboration with development finance institutions is a crucial element of the financial sustainability of a project, from the project's inception through to construction. In regions where portions of the grid are tendered to private entities, a strong regional regulatory framework is needed to attract private sector participation. In addition, new and creative financing approaches are essential to address the unique cross-border nature of interconnectors, which often includes shared infrastructure like subsea cables. Blended finance is one approach that could be used to de-risk commercial investment in grid infrastructure, combining concessional funds from donors with commercial funds from private investors and development finance institutions. Various blended financing instruments, such as concessional equity or loans, can address common constraints and increase the flow of private capital to EMDEs by rebalancing the risk return profile of investments.

INTERNATIONAL OFFTAKE AGREEMENTS FOR NEAR-ZERO EMISSIONS IRON

WHY IS THIS IMPORTANT?

THE STEEL TRANSITION REMAINS AT AN EARLY STAGE

Steel production today contributes approximately 7-8% of CO_2 emissions from the global energy system every year, making the steel sector an important priority for the industry transition. Today, around 70% of global steel production is through the emissions-intensive blast furnace-basic oxygen furnace (BF-BOF) route, of which 15-25% is from recycled scrap steel and the remainder from iron inputs. The remaining 30% of steel production comes from electric arc furnace (EAF) routes, either charged solely with recycled scrap steel directly to an EAF, or produced using a mix of scrap and iron produced through the gas- or coal-based direct reduced iron-electric arc furnace (DRI-EAF) routes. Across these different steel production routes, 68% of total metallic inputs come from iron and the remaining 32% from recycled scrap. Overall, only about 0.1% of global steel production is from near-zero emissions technologies, highlighting the early stage of steel decarbonisation.

The most technologically advanced options for near-zero emissions iron-based steel production are hydrogen direct reduced iron followed by an electric arc furnace (H_2-DRI-EAF), and BF-BOF or DRI-EAF with carbon capture and storage (technology readiness level 5-8). Projects in the pipeline for near-zero emissions iron production by 2030 have capacity for about 10 Mt, and the first commercial-scale plant is due to begin operation in 2026. An additional 80 Mt of announced capacity is near-zero emissions capable[1] but currently lacks clear timelines or details regarding full near-zero emissions operation.

One of the largest barriers to further deployment of near-zero emissions iron-based steel production today is its cost premium when compared to conventional steel production, which is among the key contributions to relatively low demand to date. Compounded by current limitations on access to low-emissions hydrogen and low-emissions electricity, this represents a significant barrier in a highly competitive international marketplace. In the absence of policy support, the IEA estimates the cost of production for early commercial plants using H_2-DRI-EAF with low-emissions hydrogen to be around 50-140% higher than the cost of production through the BF-BOF route, depending on location, cost and availability of renewable energy, and other factors.

HOW NEAR-ZERO EMISSIONS IRON TRADE COULD ACCELERATE THE TRANSITION TO NEAR-ZERO EMISSIONS STEEL

Rather than producing steel in integrated iron and steel plants, DRI-EAF and Direct Reduced Iron-Smelting-Basic Oxygen Furnace (DRI-SMELT-BOF) production routes allow for the decoupling of iron and steel production, opening the opportunity for trade of near-zero emissions iron. The cost of producing near-zero emissions steel through the above

[1] See definition of "near-zero emissions capable" provided in the Steel dashboard.

processes is likely to be significantly lower if the first stage of production – ironmaking with DRI – takes place in regions with cheap and abundant low-emissions energy resources or access to cheap CO_2 storage. The cost of low-emissions hydrogen production is an important determinant of the overall cost for the hydrogen-based route. The opportunity for lower-cost near-zero emissions or "green" iron production is greatest in locations that have both high-grade iron ore and/or low levelised cost of energy.

Forthcoming IEA analysis shows that in countries with less favourable renewable resources, the cost of steel production with H_2-DRI-EAF could be reduced significantly if the near-zero emissions iron is imported from regions where it can be produced most cheaply, instead of being produced domestically within an integrated iron and steelmaking plant. This saving arises mainly from the difference in production cost of H_2-DRI. Importing low-emissions hydrogen rather than near-zero emissions iron is also a possible strategy for countries. However, shipping near-zero emissions hot briquetted iron (HBI) is technically simpler and economically cheaper than importing low-emissions hydrogen as ammonia and then converting it back to hydrogen at the destination port and injecting it in the pipeline for transportation to the steel plant, resulting in potentially considerable savings in transportation costs. Per tonne of crude steel, the cost of transporting near-zero emissions iron is likely to be several times lower than that of transporting iron ore and hydrogen separately.

Today, the key challenge is to deploy the first wave of near-zero emissions iron-based steel production facilities. Strategic partnerships that decouple iron and steel production, with near-zero emissions iron produced in the most cost-competitive locations, could facilitate this in two ways. Firstly, they could reduce the magnitude of policy support required, whether in the form of subsidies or carbon prices, for near-zero emissions iron-based steel to be commercially viable. Secondly – and perhaps more importantly – they could give industry more confidence about the long-term competitiveness of new facilities, increasing willingness to invest. Such partnerships could provide new opportunities for both exporting and importing countries, building momentum and lowering the overall cost for the steel sector transition.

ADVANTAGES FOR NEAR-ZERO EMISSIONS IRON EXPORTER COUNTRIES

For countries with iron ore reserves and favourable renewable energy resources, there is an opportunity to move up the value chain to produce and export near-zero emission iron, a higher value-added product than iron ore. This could attract investment, generate jobs and economic growth, and increase export revenues. For example, at prices equivalent to the estimated costs of producing near-zero emission iron in Europe in 2050, Africa could export almost 15 Mt of iron worth around USD 6 billion per year – more than four times the value of the same tonnage of iron ore exports at today's prices.

The opportunity may be largest for the current top four iron ore exporters – Australia, Brazil, Canada and South Africa. However, others could also become exporters of near-zero emissions iron, particularly countries with strong potential for low-cost renewable energy. Key enabling factors include a well-established iron and steel sector, access to iron ore deposits, existing domestic demand, proximity to large markets that may be interested to purchase near-zero emissions iron (e.g. Europe), a trained workforce, robust transport infrastructure and a favourable business environment. Countries that may be well placed for producing and exporting near-zero emissions iron include parts of Southeast Asia such as Viet Nam, Malaysia and Indonesia; Egypt and Morocco in Africa; and Chile and Mexico in Latin America.

The scale of the future market opportunity for near-zero emissions iron exports depends on various uncertain factors, including the pace of the transition to near-zero emissions steel and the potential to restructure global supply chains. The higher end of the opportunity can be illustrated by the IEA Net Zero Emissions by 2050 Scenario (NZE Scenario); analysis from Energy Technology Perspectives 2024 shows that the total global market for near-zero emissions iron-based steel reaches more than USD 800 billion in 2050. While much of the iron inputs may be used for domestic steel production, such a growing market also represents a potential for export opportunities. This is especially true for regions like Africa, where, for example, iron production in the IEA's High Potential Case grows to 55 Mt in 2050, mainly using near-zero emissions technologies such as H_2-DRI. In this scenario, over one-quarter of Africa's production is exported in 2050, destined primarily for Europe (around 60%) and Japan (around 35%).

Advantages for near-zero emissions iron importer countries

The considerations facing potential near-zero emissions iron importer countries are more complex. Importing near-zero emissions iron rather than producing it domestically could lead to job losses associated with the first stage in an integrated iron and steel plant in the near term.[2] However, this would come against a backdrop in which traditional steel-producing countries are facing growing pressures such as high energy prices, and would need to be balanced against the possibility that global value chains could shift in the context of a global technology transition in the sector. In this context, there is no certainty that domestic steel production as a whole in these regions will be competitive in future global markets for near-zero emissions materials, and the economic risks may be lower if strategic trade partnerships are pursued. Ironmaking accounts for only small share of the steel sector's employment: 80-90% of jobs in the steel sector are concentrated in the steelmaking stage and downstream industries.

Countries with high energy costs could increase the competitiveness of their steel industries by importing DRI from regions where it can be produced at lower cost, instead of producing iron domestically. Forthcoming IEA analysis estimates that significant cost savings in steel production could be achieved in this way, in regions such as Europe and Japan. Several other studies have estimated cost savings, considering examples including the potential for Germany to import near-zero emissions iron from Brazil, and Japan to import iron from Australia or Canada. These cost savings would complement the existing industrial strengths and comparative advantages of established steelmaking countries, which include advanced technology capabilities, specialised workforces, strong logistics and transport systems, and proximity to demand.

An additional benefit from importing DRI could be the reduced need for new infrastructure construction. Avoiding the need to build greenfield domestic low-emissions hydrogen and iron production facilities would free up capital and workforce capacity for other development

[2] Jobs associated with primary iron production are generally falling in all countries due to labour productivity improvements and automation.

projects. It would also reduce the necessary expansion of electricity generation capacity, which may be particularly valuable in countries facing grid constraints.

Finally, importing iron could strengthen energy and resource security by building more diverse and resilient supply chains (compared to maintaining all domestic iron production but relying on a concentrated source of energy inputs), while retaining domestic steelmaking capacity that is closely tied to national supply chains for sectors such as defence and transportation.

Policies that could enable near-zero emissions iron production and trade

While importing HBI from favourable locations could reduce the cost of producing near-zero emissions iron-based steel through the DRI-EAF route, it is unlikely to fully eliminate the additional cost compared to producing high-emissions steel through the conventional BF-BOF route, at least in the near term. To invest in new DRI-EAF production facilities, industry is likely to need confidence that its output will be commercially viable as soon as it is ready to be sold – which would require either an existing robust market for near-zero emissions iron and steel, or confirmed demand for the output of the plant. Some private sector buyers may be willing to enter into long-term offtake agreements that cover the cost premium, and mechanisms may develop in the medium to long term to pass the premium along the value chain, where the cost uplift for end-use products would be relatively minimal. However, demand of this kind may be insufficient to balance the risks of investing in a new facility. Particularly in the near term, government policy is likely to be needed to accelerate widespread market formation.

Policy measures that could close the remaining cost gap include carbon pricing in the destination market (which may, in turn, require additional measures to preserve competitiveness if similar levels of carbon pricing are not present in other countries), or subsidies for near-zero emissions iron or steel. At current price levels, carbon pricing is unable to provide the support needed to build a robust business case. Therefore, subsidies for both capital and operating costs are emerging as an alternative and more targeted option in the near term, including mechanisms such as carbon contracts for difference, tax credits, grants and direct subsidies. These can be complemented by targeted public procurement, which creates demand for near-zero emission steel despite its higher costs.

Other policies that may help enable investment include regulatory mandates and national or international concessional financing to reduce the cost of capital for new plants. Investment in the infrastructure to ensure a reliable, low-cost supply of low-emissions electricity or hydrogen, or CCS-related infrastructure, can ensure enabling infrastructure is available. The development of land transport and port infrastructure may also be necessary to enable opening-up of new trade routes.

While policy support is not yet well developed, projects are struggling to reach final investment decisions (FIDs). In Europe, plans for over 10 Mt of capacity for hydrogen-based steel have been delayed or put on hold indefinitely, citing a lack of economic viability for investments, higher-than-expected costs, and inadequate policy support. Notable examples include Thyssenkrupp putting on hold the hydrogen tender for its low-emissions steel plant in Duisburg, Germany; ArcelorMittal suspending its plans to construct DRI-EAF assets at Bremen and Eisenhüttenstadt in Germany; and Salzgitter AG postponing the investment decision on phase 2 of its Salcos project until 2029. While they have not been cancelled, policy certainty and improved market conditions are likely to be needed to move these projects to FID.

Robust and comprehensive enabling policy frameworks that can get projects to FID and eventually operation are likely to include many of the support elements mentioned above, as no single policy can address all barriers. These measures could create a stronger enabling environment for international near-zero emission iron offtake agreements, as well as for domestic steel industry decarbonisation. More illustrative examples and detailed considerations for policy options can be found in Demand and Supply Measures for the Steel and Cement Transition: the case for international co-operation and Policy Toolbox for Industrial Decarbonisation.

OPPORTUNITIES FOR AND EXAMPLES OF INTERNATIONAL COLLABORATION

POTENTIAL ROLE OF INTERNATIONAL OFFTAKE AGREEMENTS

International offtake or advanced purchase agreements, in which a steel producer commits to buy a specified quantity of near-zero emissions iron over a specified period of time, could play a critical role in reducing the risks associated with investment in near-zero emissions iron production to a level that makes such an investment financially attractive. Since the commercial viability of such an arrangement will depend strongly on policy conditions, particularly in the importing country, bilateral agreements and strategic partnerships between the governments of the countries concerned may be important to give businesses the confidence to invest.

The most important element of an intergovernmental agreement would concern the arrangements for eliminating the cost gap to conventional steel production. This could include an agreement on how to share the costs of subsidising near-zero emissions iron or near-zero emission steel production, or a commitment on the part of the importing country to maintain a certain level of carbon pricing, or a combination of both approaches.

Another element that may be necessary to agree are the definitions of “near-zero emissions iron” and/or “near-zero emissions steel”, and associated certification standards and processes. This could provide the businesses involved in bilateral offtake agreements with greater certainty that their products would meet the standards required by the relevant policies in both the exporter and importer countries.

Several definitions of near-zero and low-emissions steel have been proposed, and these are converging on similar emissions intensity thresholds for steel compatible with the net zero endpoint. However, there remain differences in the precise threshold values, as well as underlying emissions measurement methodologies, which can complicate direct comparability. As a consequence, working towards interoperability between these different schemes would help enable uptake of near-zero emissions steel, considering the various actors involved and especially for cross-border transactions. Additionally, there is lack of clarity on the definition of near-zero or low-emissions iron. In support of the use of common terminology, the South African G20 Presidency is aiming to deliver an agreement on common principles that would enable standard terms to be used in offtake agreements for low-emissions hydrogen for use in energy-intensive industries such as steel. Common principles could also be developed for offtake agreements for near-zero emissions iron. Enabling interoperability between definitions, standards and certification schemes, along with other actions, will be important for the successful implementation of several policies.

As a third potential component, international co-operation on technology development and licensing could also ensure that companies in near-zero and low-emissions iron export markets gain access to relevant technologies, while technology providers benefit from global deployment, scale-up and licensing revenues. In some cases, this may take place within multinational companies. Comprehensive agreements which address demand and supply across supply chains, between the countries and key industry players in each chain, could make these agreements more robust.

Nevertheless, there are multiple challenges to be overcome, including policy and regulatory risks, extended supply chains that may be affected by trade measures, and geopolitical risks. In this context, international near-zero emissions iron offtake agreements could be seen as not just individual transactions, but as strategic levers to accelerate steel decarbonisation and economic growth. They would directly address the barrier of uncertain demand, thereby unlocking investment in new near-zero emissions iron production facilities. By guaranteeing a market for near-zero emissions products, these agreements could stimulate innovation and accelerate the scale-up of H_2-DRI technologies.

PIONEER EXAMPLES OF INTERNATIONAL NEAR-ZERO EMISSIONS IRON OFFTAKE AGREEMENTS

Examples of international near-zero emissions iron offtake agreements are already beginning to emerge. Although the full details are, in most cases, not publicly available, the agreements give some indications about the viability of the approach.

In Namibia, the HyIron Oshivela project has signed an offtake agreement with German metals processing firm Benteler to supply 200 000 tonnes per year (tpa) of near-zero emissions iron produced with H_2-DRI. The construction of the plant began in April 2024 and the first phase was inaugurated in April 2025. It will produce 15 000 tpa of near-zero emissions iron in 2025, expanding to 200 000 tpa in 2026, and aims to produce 2 Mtpa in 2030. The project has been funded by the German government with a grant of around EUR 13 million, and funding for its second phase is committed from the Netherlands and the European Union.

Australia's Fortescue metals group and China's Baowu Steel group signed a Memorandum of Understanding (MoU) to develop a "green" iron supply chain in January 2025. A pilot plant in Western Australia will produce 1 500 tpa of H_2-DRI iron, and is intended to commence production in 2025. Details of the offtake agreement are not public. However, the project is likely to benefit from Australia's hydrogen production tax incentive, which provides support worth AUD 2 per kg (Australian dollars) of hydrogen for up to 10 years, starting from 1 July 2027. In March 2025, the Australian government announced an AUD 1 billion green iron investment fund, offering support for capital investment in new projects.

In September, 2025, Thyssenkrupp Materials Trading (Germany) signed an MoU to offtake hydrogen-derived iron from Progressive Green Solutions Mid-West Green Iron project in Western Australia. The planned offtake would cover 100% of the site's output — including both iron pellets and HBI — produced using on-site hydrogen from a 1.4GW electrolyser installation. Phase 1 of the project has a target to export 2.5 Mtpa of near-zero emissions HBI and 3.5 Mtpa "green" iron pellets by Q1, 2030. The project is supported by technology providers SMS group, Midrex, Thyssenkrupp Nucera, which is the electrolyser supplier (50.2% owned by Thyssenkrupp), and financial partner KFW IPEX bank.

In Sweden, Stegra (formerly H2 Green Steel) signed an agreement in 2023 for a multi-year supply of iron ore pellets from Rio Tinto's Iron Ore Company of Canada, for use in its H_2-DRI-EAF plant. As part of the same agreement, Rio Tinto committed to buy a portion of the near-zero emissions iron produced in the plant (with the aim of reselling this, presumably to other steel producers). Production of near-zero emission steel at Stegra's plant (currently under construction in Boden, Sweden) is scheduled to start in 2026, and to rise to 5 Mt per year by 2030. The project has benefited from USD 400 million in subsidies from the Swedish government and EU Innovation Fund, as well as reduced costs of capital due to state-backed loan and import credit guarantees. Carbon pricing under the EU Emissions Trading System has also supported the business case for the near-zero steel offtake agreements signed by the project's owners with various private companies.

Next Steps

International trade in near-zero emissions iron could reduce the costs of near-zero emissions iron-based steel production, creating opportunities for exporters and importers. Offtake agreements that guarantee demand in sufficient quantities can be key to enabling investment in new near-zero emissions iron production facilities. Strategic bilateral or multilateral partnerships (in the form of aggregated demand from public or private buyer coalitions) between potential importers and exporters can enable trade of near-zero emissions iron. Financial derisking tools to lower risks would strengthen industry confidence to invest, while supportive policies such as carbon pricing, subsidies or public procurement will be crucial to ensure the commercial competitiveness of near-zero emissions steel projects.

GLOBAL SUPPLY CHAINS AND OPPORTUNITIES FOR EMERGING MARKETS

WHY IS THIS IMPORTANT?

Access to clean energy technologies is important for achieving climate goals, but their strategic importance now extends well beyond the realm of climate change – they have become central considerations for industrial and economic policy. At the same time, increasing reliance on clean energy technologies presents new challenges related to the complex and interdependent global supply chains that underpin these technologies.

In 2024, the IEA's Energy Technology Perspectives report traced the supply chains and trade patterns for six key clean energy technologies – solar PV, wind turbines, electrolysers, heat pumps, batteries and electric vehicles (EVs). This analysis made clear the significant levels of concentration of clean energy technology supply chains: Today, China, the United States and the European Union dominate manufacturing capacity for these six technologies. Strong reliance on a limited number of suppliers creates vulnerabilities, heightening the risk of disruption and price fluctuations stemming from market imbalances, shocks and market manipulation. In this context, supply chain diversification is essential to ensuring that technology roll-out can continue unhindered, and supporting a well-functioning market that encourages flexibility, transparent pricing and healthy competition.

While supply chains for clean energy technologies are highly concentrated, emerging markets and developing economies (EMDEs) other than China have only a peripheral role today, essentially limited to the supply of critical minerals from some countries. These economies account for less than 5% of the output value from all clean energy technology manufacturing globally. Expanding production in EMDEs can help deliver diversification at competitive costs, while at the same time allowing emerging economies to step up the value chain. With domestic demand for clean energy technologies expected to surge in many EMDEs, moving up the supply chain in clean technology manufacturing represents an important opportunity to drive job creation and catalyse further economic and social development.

To achieve meaningful diversification of clean energy supply chains, strong collaboration across countries and sectors is needed. With successful implementation, such efforts can deliver tangible progress towards security, economic and climate goals, both for countries seeking to expand their market presence and for those relying on dependable access to clean technologies.

Opportunities for and examples of international collaboration

Improving Supply Chain Data

International collaboration can enable – and greatly amplify – efforts to improve supply chain data, which could lead to better-informed decision-making. The ability of governments to conduct risk assessments on clean energy technology supply chains is currently hindered by a paucity of data. Processes for collecting accurate, timely and granular data are limited, and in many cases involve a proprietary data source, or stitching together multiple data sources maintained at differing intervals or in different formats.

There are initiatives underway to improve the quality and quantity of data on clean technology supply chains, and to overcome barriers to data-sharing, but there is room for further progress. In 2022, the European Commission presented SCAN (Supply Chain Alert Notification), a monitoring system that combines different data streams to identify and share notifications about disruptions and anomalies in trade flows. Three supply chain-specific initiatives were launched in 2024. The International Chamber of Commerce Digital Standards Initiative launched its complete digitalisation framework, Key Trade Documents and Data Elements, which allows for the digitalisation and harmonisation of trade and supply chain data. A group of international organisations and development banks led by the Bank for International Settlements launched Project Insight to explore how big data analysis can help monitor developments in global value chains, with the aim of helping policy makers to better track key trends. The United Nations Economic Commission for Europe (UNECE) published the Supply Chain Reference Data Model, a business standard developed to facilitate supply chain data exchanges across governments, banks and other key actors. Beside these dedicated initiatives, other broader frameworks for international co-operation have components relating to supply chain data. For example, the Indo-Pacific Economic Framework, launched in 2022 by the United States and 14 Indo-Pacific partner countries, addresses the need for timely information-sharing between governments and private firms under its supply chain pillar. Initiatives and standards like the Partnership for Carbon Transparency (PACT) facilitate the sharing of supply chain data on emissions, but rarely contain information on stocks and flows of equipment and materials.

While these initiatives are an encouraging sign of recognition of the need for collaboration on supply chain data, there are limitations to the scope (geographical and technology) and extent of the efforts. One recently launched initiative that seeks to improve the data landscape in this area through international collaboration is related to the Supply Chains Mission of the Global Clean Power Alliance (GCPA).

In 2024, the UK-led Global Clean Power Alliance (GCPA) was launched at the G20 Summit in Brazil by more than a dozen countries to strengthen international co-operation and knowledge-sharing in support of renewable energy deployment and energy efficiency goals, organised under a series of "missions". As part of this, the Supply Chains Mission was announced in April 2025. This seeks to address critical supply chain bottlenecks and support more resilient and sustainable clean energy supply chains through enhanced data transparency and international co-ordination. In April 2025, the IEA and the UK Government co-hosted a technical workshop, with participants addressing key issues to improve data availability and co-ordination. The IEA, in on-going collaboration with the

United Kingdom, is exploring ways to strengthen supply chain data, thereby shaping the next phase of implementation of the GCPA Supply Chains Mission.

Technology & Skills Transfer

In countries that have an existing industrial base, skills transfer can help workers to acquire necessary competences to expand into clean technology manufacturing. A range of bilateral and multilateral initiatives are now making strides towards this aim. For example, the 2023 Memorandum of Understanding (MoU) on the EV ecosystem between Indonesia and Korea focuses on providing exchange opportunities and training workers in EV manufacturing and research. The enhanced Australia-India partnership on clean tech manufacturing established in November 2024 aims to deliver workforce training to facilitate large-scale PV ventures. The UN Global Cleantech Innovation Programme, which involves more than 15 countries, aims to help clean technology start-ups bridge the challenging scale-up phase by offering direct support, as well as bolstering clean technology networks.

These initiatives demonstrate some progress on skills transfer, but their depth and geographic coverage remains limited. Analysis of enabling conditions for clean technology manufacturing in EMDEs, focusing on key dimensions such as business climate, industrial capabilities and market potential, can help to identify suitable partners for targeted and effective skills transfer programmes. Finally, clearly specifying key deliverables of technology and skills transfer programmes can help to ensure that efforts yield robust outcomes.

Collaboration on Innovation

For clean energy technologies still at early stages of development, innovation is critical to facilitate commercialisation and cost-reduction. In more mature supply chains, like those for solar PV, batteries and wind power, new materials and processes can reduce dependency on materials with vulnerable supply chains. As such, innovation also has a crucial role to play in diversification efforts. International collaboration can help bridge the substantial capital investment and extended development timelines associated with innovation.

Several well-established platforms enable collaboration on innovation. The IEA Technology Collaboration Programmes (TCPs) on solar PV, wind energy systems, hydrogen and heat pumping technologies provide a well-established platform for collaboration, facilitating knowledge exchange and innovation collaboration. The CETPartnership brings together public and private sector representatives from the European Union and beyond with the aim of building strong innovation ecosystems and reducing fragmentation. Divided into seven main fields, its second transition initiative focuses on improving zero-emissions technologies. The Clean Hydrogen Mission, part of Mission Innovation, works to promote hydrogen technology and disseminate information on the latest technological advances. In 2024, the IEA Energy Ministerial brought together more than 250 entrepreneurs, business leaders, investors and policy makers from 45 countries for the first edition of the Energy Innovation Forum, which discussed how to accelerate clean energy technology innovation efforts. A second Energy Innovation Forum will be co-hosted by the IEA and the Government of Canada on 29 October 2025.

Bilateral initiatives for technology-specific R&D collaborations also exist, with a notable push on batteries in the last few years. In 2023, the United States and Korea launched the Next Generation Critical and Emerging Technologies Dialogue, which works to strengthen R&D collaboration on semiconductors and batteries. Japan and Canada signed a co-operation agreement on battery supply chains, which promotes collaboration on R&D. In Southeast Asia, the government-backed Thailand Energy Storage Technology Association signed an MoU with five partner organisations in Singapore, Malaysia, the Philippines and Indonesia to develop a platform for collaboration and innovation on battery development.

Another notable trend is efforts to connect companies and institutions through matchmaking. The Indo-German Platform for Partnership in Solar PV is connecting research institutions and companies to advance innovation on cell technologies and PV manufacturing. The United Nations Economic Commission for Latin America and the Caribbean has organised matchmaking to foster commercial and technical partnerships in green technologies by connecting science and technology institutions from Europe and Latin America. The United Kingdom-Korea Clean Energy Partnership also emphasises connecting businesses in the two countries to stimulate exchange. Across all such activities, it is critical that new links made through matchmaking are followed up and supported to ensure that matches develop into lasting and mutually beneficial relationships.

It typically takes many years for new advanced materials to reach deployment. There are several collaborative initiatives to accelerate their development and integration into energy systems. The International Iberian Nanotechnology Lab, founded by the governments of Spain and Portugal is an example of such collaboration – one current area of research is the development of efficient ultrathin solar cells. Led by Canada, the European Commission and Germany, The Materials for Energy (M4E) Innovation Community brings together six countries to develop and accelerate adoption of advanced materials.

While collaborative research on battery technologies, and to a lesser extent solar PV, continues to gain momentum, other critical clean energy technologies receive comparatively less attention. For instance, innovation in electrolyser technologies holds significant promise for enhancing technical performance and reducing costs, as well as reducing reliance on materials with vulnerable supply chains.

STANDARDS

Variations in technology products that are driven by divergent regulatory standards across markets can create barriers to trade and hinder the realisation of economies of scale. In contrast, harmonisation of product standards can facilitate trade, thereby enhancing competitiveness and enabling manufacturing scale-up, which can drive down costs. Standardisation is particularly important for pre-commercial technologies, where clear benchmarks can support investment and adoption.

International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO) standards provide a technical foundation for safety, performance and quality across clean energy technology products and systems. The two organisations have well-established standards for solar PV, wind, heat pumps and batteries. With rapid technological advancement, standards must continuously balance the need to integrate new innovations, while remaining stable enough to encourage wide adoption. Finding this balance requires strong pre-normative research, but this is often a costly and resource-intensive endeavour, which makes it a priority area for collaboration. The IEA TCPs support such research by providing platforms for collaborative research and the development of reference cases and recommended practices. Strengthening ties between the TCPs and standardisation bodies could further improve the alignment between innovation and regulation.

Beyond performance and safety standards, standardisation on size and capacity can help promote efficiency in clean technology manufacturing. For example, the IEA TCP on Heat Pumping Technologies is advancing a common heat pump design concept, while the North Seas Wind Standard has raised the issue of inefficiencies resulting from the uncoordinated increase in the size of wind turbines. By favouring standardisation over incremental improvements, greater economies of scale and market certainty can achieve cost reductions. There have also been collaborative efforts to develop concepts and standards for enhanced product circularity. The IEA Photovoltaic Power Systems Programme TCP has developed design guidelines to promote recyclability of PV modules. For EVs and batteries, the ZEvRA project brings together research institutes and companies from the European Union, Norway, Türkiye and United Kingdom to address the fragmentation of the EV value chain and incorporate circular design approaches, as well as establish a common way to measure circularity. Further discussion of collaboration on recycling can be found below.

The opacity of global clean energy technology supply chains has also driven a need for standards that take into account environmental, social and governance (ESG) concerns. For example, in solar PV, the Solar Stewardship Initiative's ESG Standard has developed assessment protocols to verify ethical and sustainability criteria for the industry. Such standards complement technical norms by introducing transparency on labour practices, sourcing and lifecycle impacts.

Well-calibrated standards, backed by conformity assessments, can be a driver of clean technology development where they succeed in balancing the need to provide stability for investors and project developers with the need to incorporate technology improvements. In addition, bridging technical, recycling and ESG standards through enhanced collaboration would help to build trust and reduce fragmentation. Greater co-ordination between technical standard-setting bodies and ESG initiatives could help integrate these dimensions, supporting more sustainable and competitive clean tech manufacturing.

World Standards Cooperation, which is a high-level collaboration between the IEC, ISO and the International Telecommunication Union, provides a good example of progressing voluntary consensus-based standards which are globally acceptable.

End of Life Collaboration

As clean energy deployment accelerates, so too does the urgency to manage technologies at their end of life (EoL). Recycling can create valuable secondary material supply sources and provide management strategies for mounting clean energy technology waste, mitigating environmental impacts from new mining as well as from disposal of EoL technologies into landfill. Broad international collaboration on standards and harmonised rules for EoL technology can create the certainty needed to boost the economic viability of recycling.

Policy frameworks must be carefully designed to enable safe and efficient transboundary movement of e-waste. At COP 15, the Basel Convention expanded its scope on e-waste to include not only waste that is directly hazardous but also non-functional electronics, tightening regulations on transboundary e-waste movement. This represented a critical step toward closing loopholes that have allowed the dumping of irreparable equipment in developing countries that lack safe recycling streams. The UN-led Global Alliance on Circular Economy and Resource Efficiency (GACERE) advances circular economy policies and practices across borders and serves as a key platform for fostering collaboration between governments in both emerging and advanced economies.

There are multiple projects strengthening recycling technology innovation and early-stage deployment. In 2022, the US National Renewable Energy Laboratory and the Faraday Institution in the United Kingdom signed an MoU to deepen battery research collaboration on cathode materials and recycling routes for lithium-ion batteries. The India-European Union Trade and Technology Council arranged matchmaking opportunities in 2024 for Indian and European start-ups specialising in EV battery recycling technologies. In the same year, the United States-led Mineral Security Partnership invested in three projects related to recovery and recycling of critical minerals.

The development of product traceability solutions is also progressing, facilitating coherence, comparability, and the implementation of standards. Progress has been made on Digital Product Passports (DPPs), which include information about materials and ESG compliance. At the start of this decade, the European Union announced its plans for DPPs for batteries to become mandatory in 2027, and the Global Battery Alliance concluded its second pilot of its battery passport in 2024. Together with members and stakeholders, the Alliance has defined a framework to benchmark batteries against sustainability performance expectations anchored in international regulations and voluntary standards, covering 18 ESG issues impacting battery value chain resilience and sustainability. A prototype DPP for solar PV is also under development within the EU-funded RETRIEVE project. Similarly, DecomBlades, a public-private initiative involving several large wind power manufacturers, has launched blade material passports to facilitate recycling. For heat pumps, the IEA TCP on Heat Pumps works on design and dismantling processes and guidelines to facilitate circularity. Going forward, ensuring coherence among emerging frameworks and tools will be critical. To this end, ISO and UNECE have announced a joint initiative on DPPs, providing direction and policy advice to foster alignment and harmonisation among emerging passport schemes.

Addressing loopholes in waste trade and enforcing minimum recycling standards is the first step to promoting circularity and limiting social and environmental risks. Moreover, R&D that holds promise for recycling technology must be accompanied by widely agreed-upon standards that simplify dismantling and recycling, to allow recycling at scale. More ambitious projects to develop standards across markets could allow recycled materials to become a cost-competitive with primary materials.

Driving Inclusive Supply Chain Partnerships

Partnerships between EMDEs and advanced economies can help EMDEs expand their clean technology manufacturing faster, by benefiting from previous learning experiences. For advanced economies, such partnerships can help realise diversification goals. An example of this is the 2023 Indonesia-Singapore MoU on Renewable Energy Cooperation, which promotes investment in clean energy technology manufacturing in Indonesia, targeting win-win outcomes. Another such partnership is the 2022 MoU between Zambia, the Democratic Republic of the Congo and the United States, with plans to develop a complete cross-border EV battery value chain, from minerals extraction to assembly and recycling. Specifying key deliverables on standards, or on skills and technology transfer, can ensure that strategic collaboration agreements yield tangible outcomes.

Stronger co-operation between EMDEs can also help align industrial strategies and provide opportunities for learning and policy support. A recent example is the joint statement between Türkiye and Indonesia, which promotes deepened collaboration on clean energy technology innovation. As part of the Clean Energy Ministerial, the India-led initiative on Transforming Solar Supply Chains promotes global linkages to strengthen the whole PV supply chain. Partnerships which involve wider geographic areas can facilitate learning and create clusters of shared interest, enhancing the development of complete supply chains across regions.

Supporting critical minerals resilience strategies

Building a strong clean technology manufacturing base depends on a resilient and diversified supply of critical minerals. However, the complexity and lack of transparency in critical minerals supply chains often hinder the development of effective policy responses. To address this challenge, several emerging initiatives seek to help governments gain clearer insights and make informed decisions to strengthen their critical mineral supply chain strategies.

Collaborative programmes and initiatives boost government preparedness and responsiveness to critical mineral supply chain disruptions. In 2024, the IEA Voluntary Critical Minerals Security Programme led an exercise for governments to help build emergency preparedness and promote supply chain resilience. Also launched in 2024, the Association of Southeast Asian Nations (ASEAN) – Korea Collaborative Initiative on Critical Minerals Management and Strategy for Sustainable Environment in ASEAN offers capacity-building and training for ASEAN member governments.

Other projects focus on providing better data and insights to policy makers. The IEA's 2025 Critical Minerals Outlook has expanded to feature a wider range of strategic minerals. The Trade in Critical Minerals database by the Asian Development Bank and World Trade Organization allows users to explore trade and tariff data, and the IEA Critical Minerals Data Explorer complements this with demand projections across multiple scenarios and technologies. Finally, the Material Insights Platform provides detailed profiles of raw materials including associated ESG and security of supply issues.

Trade Agreements

Recent trade agreements increasingly reflect a focus on supply chain resilience and often directly reference clean energy technology, highlighting the growing strategic importance of this issue. The recent Chile-European Union interim trade agreement aims to encourage investment in Chilean wind power and lithium supply chains. When ratified, the revised version of the Mexico-European Union free trade agreement will make strides towards standards harmonisation and incorporating ESG considerations. Also pending ratification, the long-awaited European Union-Mercosur trade agreement contains key provisions to guarantee critical mineral supply to the European Union and promote energy-intensive manufacturing in Latin America. In January 2025, the Office of the US Trade Representative detailed new approaches to trade policy, notably including a sectoral trade policy approach aiming to secure supply chain resilience through targeted agreements with trade partners. Meanwhile, the free trade agreement between Korea and the Philippines will see tariffs for EVs and hybrid cars decrease to zero over 5 years. These examples demonstrate an enhanced focus on supply chains in trade policy, and the ambition to achieve mutually beneficial outcomes that strengthen clean energy technology supply chains.

Next Steps

Collaboration on clean energy technology supply chains is gaining momentum across several key areas, including data-sharing, skills transfer and the development of common standards. However, to fully realise diversification goals, more co-ordinated and far-reaching action will be essential.

A key priority is accelerating work to establish reliable, comprehensive data in order to map supply chain vulnerabilities. Several promising collaborative initiatives are already underway to support policy makers in this area. Yet to sustain and scale up these efforts, broader and more visible engagement from key stakeholders is needed. Without this, progress risks stalling.

Transferring clean energy technology manufacturing skills to countries with existing industrial bases is a powerful strategy for delivering on diversification goals, but current initiatives remain geographically limited. Expanding training and capacity-building efforts to a wider range of regions would help close this gap and support more inclusive growth. Future agreements should be more inclusive, outcome-oriented, and designed with concrete, measurable objectives. Integrating such objectives into wider strategic collaboration and trade agreements can help build trust and momentum for deepened collaboration among new partners.

Collaborative R&D efforts are currently concentrated on a limited set of high-profile technologies. Broadening the scope to include emerging and less mature technologies could unlock new breakthroughs and drive cost-competitiveness. Here, well-established programmes such as the IEA TCPs and Mission Innovation can drive targeted action across a broader range of stakeholders.

The development of comprehensive and widely accepted ESG standards, standardised product designs, and fine-tuned quality standards can support broader resilient supply chain goals. Developing standards is resource-intensive and can require sustained investment in research. The IEA TCPs are engaging relevant stakeholders in pre-normative research.

To turn EoL clean technologies into a viable material supply stream, innovation in technology and product traceability must be co-ordinated and disseminated on a wider scale. Here, the UN-led GACERE will be key to promote global co-operation. Similarly, UNECE and ISO's joint initiative to harmonise and provide traceability systems is a key platform for harmonising DPP systems. Further initiatives where countries work together to drive modularity, and simplified designs to optimise recycling, could further speed up the emergence of economically viable recycling of EoL clean energy technology.

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Typeset in France by IEA - October 2025
Cover design: IEA
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