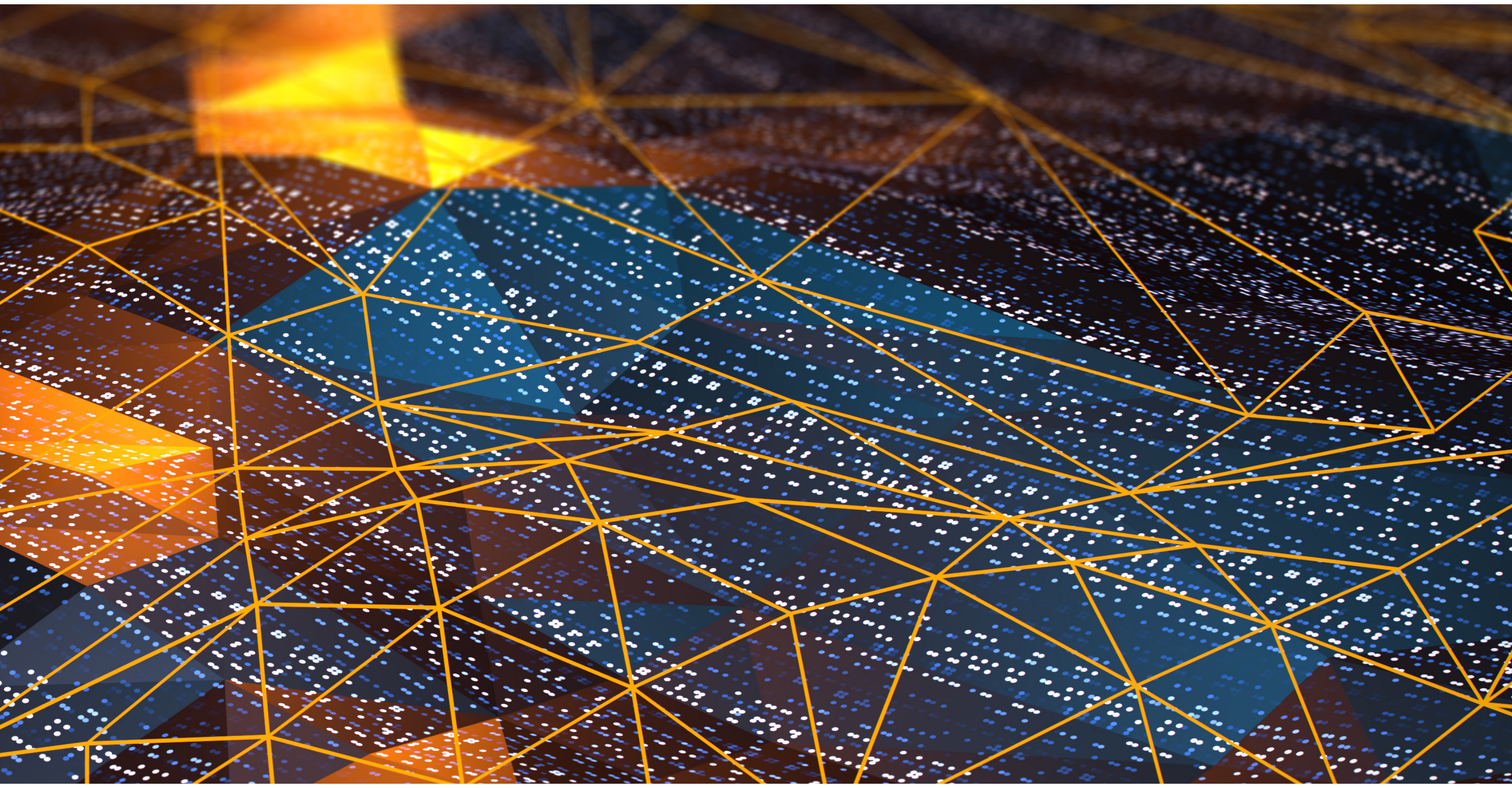
THE BREAKTHROUGH AGENDA REPORT 2022



Accelerating Sector Transitions Through Stronger International Collaboration

UN Climate Change High-Level Champions
in collaboration with:

International Energy Agency (IEA)

The IEA is at the heart of global dialogue on energy, providing authoritative analysis, data, policy recommendations, and real-world solutions to help countries provide secure and sustainable energy for all. Taking an all-fuels, all-technology approach, the IEA recommends policies that enhance the reliability, affordability and sustainability of energy. It examines the full spectrum issues including renewables, oil, gas and coal supply and demand, energy efficiency, clean energy technologies, electricity systems and markets, access to energy, demand-side management, and much more. Since 2015, the IEA has opened its doors to major emerging economies to expand its global impact and deepen cooperation.

International Renewable Energy Agency (IRENA)

IRENA is the lead intergovernmental agency for global energy transformation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewables. With 168 Members (167 States and the European Union) and 16 additional countries in the accession process and actively engaged, IRENA promotes the widespread adoption and sustainable use of all forms of renewables in pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

UN Climate Change High-Level Champions

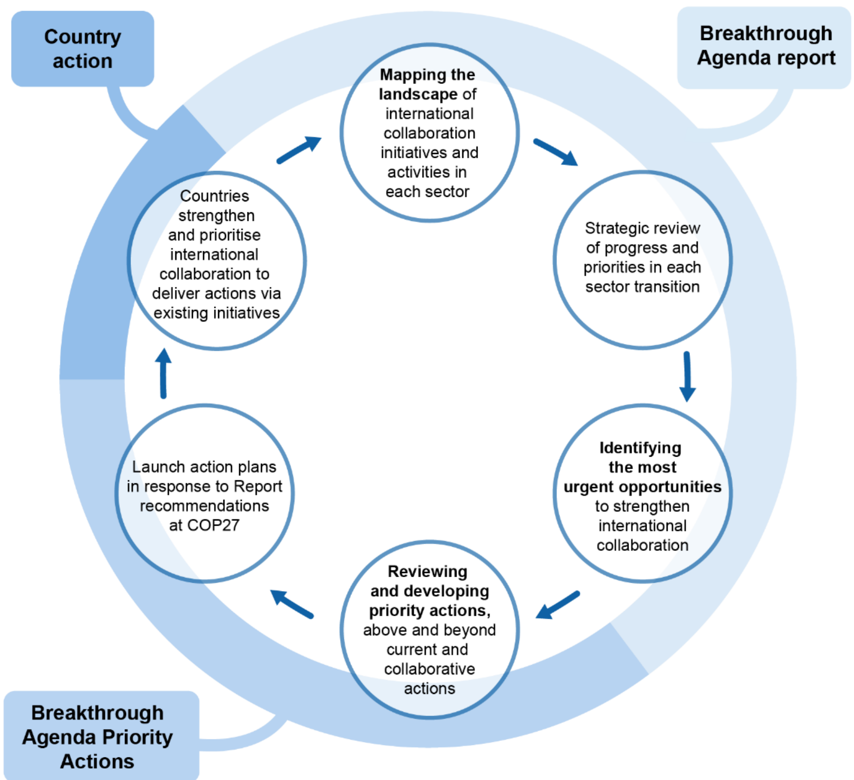
The UN Climate Change High-Level Champions mobilise non-state actors for stronger and more ambitious climate action. Mandated by Parties of the Paris Agreement, and working with the Marrakech Partnership, the two serving HLCs Dr. Mahmoud Mohieldin and Mr. Nigel Topping build on the legacy of their predecessors to engage with non-state actors and activate the ‘ambition loop’ with national governments, connecting policy with the many voluntary and collaborative actions taken by cities, regions, businesses and investors, and nations. Their work is fundamentally designed to encourage a collaborative shift across all of society towards a decarbonised economy so that we can all thrive in a healthy, resilient and zero carbon world. The Climate Champions Team (CCT) is the delivery arm of the UN Climate Change High-Level Champions.

Disclaimer

About this report

The Breakthrough Agenda was launched by 45 world leaders at COP26 and is a commitment to work together this decade to accelerate innovation and deployment of clean technologies, making them accessible and affordable for all this decade. To kick start this Agenda, countries endorsed Breakthrough goals to make clean technologies and sustainable practices more affordable, accessible and attractive than their alternatives by 2030 in the power, road transport, steel, hydrogen and agriculture sectors.

The Breakthrough Agenda establishes an annual cycle to track developments towards these goals, identify where further coordinated 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, IRENA and the UN Climate Change 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.

This document, the 2022 Breakthrough Agenda Report, is the first of these annual reports. It provides an assessment of progress towards each Breakthrough goal and a framework for tracking progress in the future, a pathway of coordinated international actions through to 2030 and a set of specific recommendations on the most urgent and high impact opportunities to strengthen international collaboration that can accelerate progress across each Breakthrough sector.

Breakthrough Agenda Signatories:

As of the 1st September 2022 the Breakthrough Agenda signatories are: Australia, Azerbaijan, Belgium, Cabo Verde, Canada, Chile, China, Denmark, Egypt, European Union, France, Germany, Guinea Bissau, Holy See, India, Ireland, Israel, Italy, Japan, Kenya, Latvia, Lithuania, Luxembourg, Malta, Mauritania, Morocco, Namibia, Netherlands, New Zealand, Nigeria, North Macedonia, Norway, Panama, Poland, Portugal, Senegal, Serbia, Slovakia, South Korea, Spain, Sweden, Republic of Türkiye, United Arab Emirates, United States of America and United Kingdom.

FOREWORD

At the UN Climate Change Conference (COP26) in Glasgow in November 2021, leaders of 45 nations asked our organisations to produce an independent assessment of the status of the global transitions in five major greenhouse-gas-emitting sectors and make recommendations for strengthening international collaboration to drive urgent progress.

The ambition those leaders set out was not only to reduce emissions, but to make clean technologies and sustainable solutions the most affordable, accessible and attractive option in each major emitting sector of the global economy before the end of this decade.

We commend these leaders for their vision, their recognition that this opportunity can only be realised through greater practical collaboration, and their commitment through the Breakthrough Agenda to work together to accelerate progress in each sector.

The world is facing multiple and compounding crises. The effects of climate change are intensifying. The availability and affordability of both energy and food are at risk in many countries, contributing to a broader cost-of-living crisis. The response must not be to slow down the transition to sustainability but to move even faster. A massive scaling up of clean energy investment and deployment worldwide is needed to enhance energy security, affordability and access, and the transition to sustainable land use is essential to protect our food systems against future shocks.

This report is a joint product of the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA) and the UN Climate Change High-Level Champions. Each organisation has brought its own expertise to deliver clear recommendations for the actions that governments and companies need to take. We have also drawn on expertise generously shared by governments, businesses and civil society organisations active in each of the sectors we have considered.

In each sector – power, hydrogen, road transport, steel and agriculture – we see rising investment in clean technologies and sustainable solutions and also growth in the number of collaborative international initiatives. But at the same time, global emissions continue to rise, and progress is not yet fast enough to meet the goals that countries have agreed under the Breakthrough Agenda.

We find that in each of these sectors there is significant scope for stronger international collaboration – more focused, more sustained, with greater commitment and greater participation – to accelerate progress.

Many now see the opportunities of the low-carbon transition and are competing to lead the development of new technologies. This is to be welcomed. The opportunity is for countries, businesses, communities and citizens to work together to accelerate the growth of global markets for clean technologies and sustainable solutions while continuing to compete to supply them.

We look forward to supporting governments, businesses and civil society organisations in their efforts to implement the recommendations of this report in order to make the transition to sustainability faster, easier and more affordable for all.

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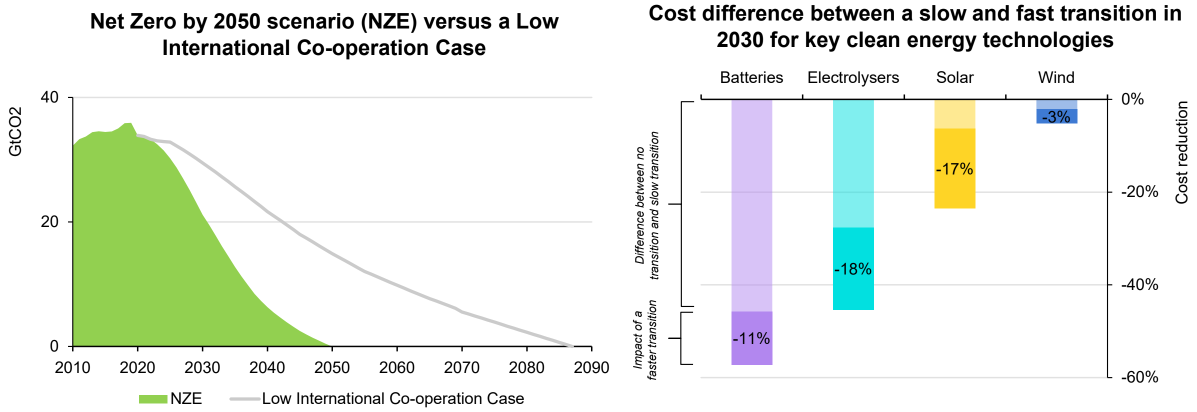
EXECUTIVE SUMMARY

STRENGTHENING INTERNATIONAL COLLABORATION TO ACCELERATE TRANSITIONS

The world remains far off track to meet internationally-agreed climate change goals, despite action being taken in many areas. The Nationally Determined Contributions that countries have put forward in the UN climate change negotiations imply a lower emissions trajectory now than they did before, and most countries have committed to achieving net zero emissions by around the middle century, as have many businesses. Yet, global emissions, which must be halved this decade to limit temperature rise to 1.5°C, are still increasing. The energy crisis and threat of a global food crisis that the world now faces underline the equal urgency of increasing the affordability, accessibility, resilience, and security of supply of humanity's most essential commodities and services. Transitions to sustainability can reduce the likelihood of such crises occurring in future.

International collaboration will be critical to success, given the global scale and fast pace of change required. Action by governments and businesses individually is necessary, but not sufficient. Well-targeted international collaboration can make low carbon transitions faster, less difficult, and lower cost. By aligning and coordinating actions internationally, countries and businesses can accelerate innovation, create stronger signals for investment and larger economies of scale, and establish level playing fields where needed to ensure that competition is a driver of the transition, and not a brake. International assistance, finance, and the sharing of best practice can support widespread adoption of effective policies and available technologies. International infrastructure can enable cross-border flows of clean energy. Without international collaboration, the transition to net zero global emissions could be delayed by decades.

Figure 1 International cooperation and technology cost reduction

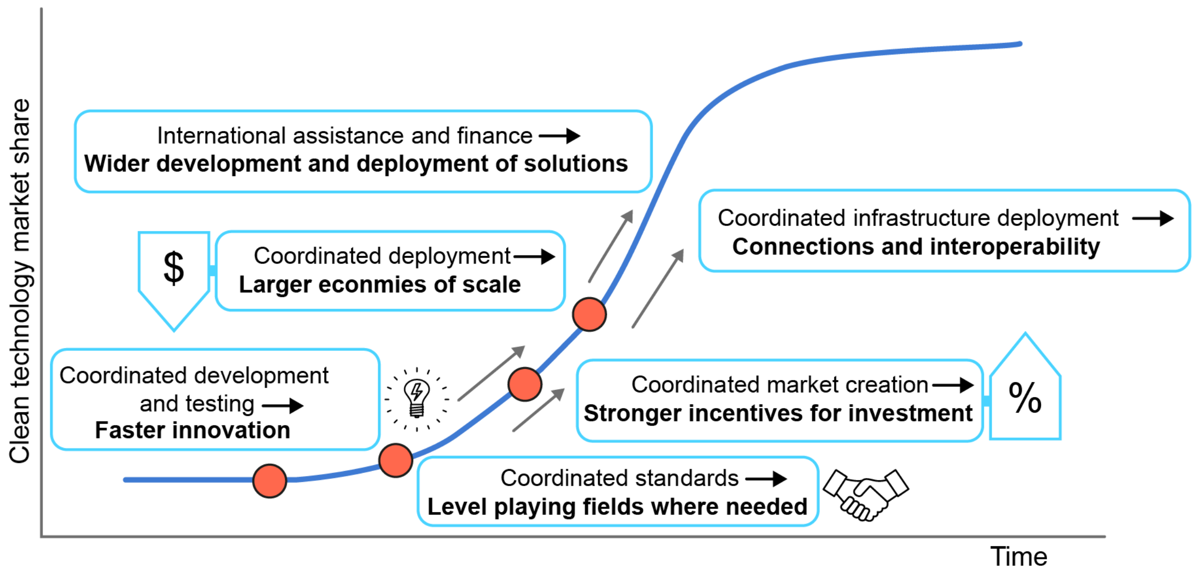


Sources: IEA, 2021, Way et al., 2022.

Without international collaboration, the transition to net zero global emissions could be delayed by decades. The costs of critical low carbon technologies could be significantly lower in a fast global transition, which can only be achieved by the collective action of many countries.

There is a huge opportunity, and need, to strengthen international collaboration in each of the major greenhouse gas emitting sectors of the global economy. Many valuable international initiatives exist, led by governments, businesses and civil society, and their number and diversity has increased notably over recent years. However, current efforts are far from exploiting the full potential of collaboration to accelerate progress. In each sector, collaboration must go beyond sharing of best practice, and include deliberate alignment of action in areas such as technology development, standards and trade, complemented by strong support to developing countries. Participation must expand to include more countries in each sector, to make this a truly effective global effort. Collaboration must be sustained over years to have its full impact, not sporadically started and stopped. Serious, sustained and focused international collaboration of this kind could greatly increase the chances of limiting the rise in global temperatures to 1.5°C, as well as positively contributing to economic development. This will help generate an additional 14 million jobs and prevent 2 million premature deaths globally from air pollution by 2030 (IEA, 2021).

Figure 2 How international collaboration can accelerate progress at each stage of the transition



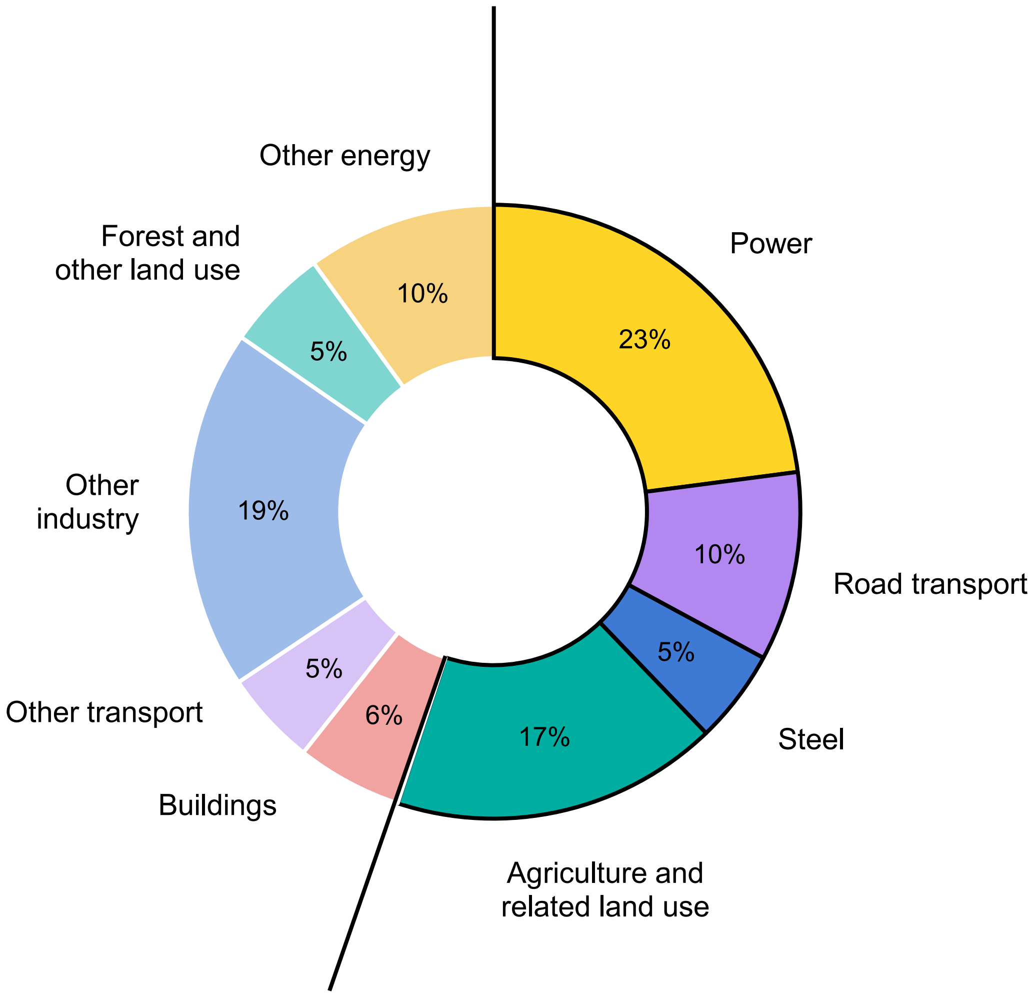
Source: Adapted from Victor, Geels & Sharpe, 2019.

International collaboration can accelerate progress at each stage of the transition

The Breakthrough Agenda is designed to strengthen international collaboration where it is most needed. Leaders of 45 signatories (44 countries plus the European Union), which represent over 70% of global GDP, committed at COP26 to work together to make clean technologies and sustainable solutions the most affordable, accessible and attractive option in each of the emitting sectors before the end of this decade. They agreed on collective goals with the intention of focusing attention on critical problems to solve in each emitting sector. The annual process to identify priorities for stronger collective action to accelerate transitions and then tracking progress on delivery, of which this report is a major part, can help to increase the impact of international action over time.

Action in the five sectors for which the signatories have so far agreed on goals under the Breakthrough Agenda – power, hydrogen, road transport, steel, and agriculture – is essential to achieving international climate goals. Global greenhouse gas emissions have now reached almost 60 $GtCO_2e$ and these sectors today account for over 50% of that total (IPCC, 2022). Clean technologies and sustainable solutions are not yet the most affordable or accessible options in these sectors except in the power sector; and even in the power sector, this is not yet the case in all countries. Meeting the Breakthrough Agenda goals in these sectors will require concerted action from governments, businesses and civil society. And doing so could enable all countries to make faster progress, greatly increasing the chances of avoiding more dangerous levels of climate change and meeting the Sustainable Development Goals.

Figure 3 Greenhouse gas emissions by sector, 2019



Source: IPCC, 2022.

The five sectors for which countries have agreed goals under the Breakthrough Agenda account for over 50% of current global emissions.

PRIORITIES FOR STRENGTHENED INTERNATIONAL COLLABORATION IN THE FIVE FOCUS SECTORS

The power sector accounts for around 13 $GtCO_2e$, or 23% of total emissions. This has risen by around 10% since 2010. These need to fall by over 50% by 2030.

Emissions from the power sector should fall by around 8% each year to 2030.

Electricity access should reach 100% by 2030, if not before.

Investment will need to grow 25% each year, reaching USD 2 trillion per annum required by 2030.

Hydrogen production and use accounts for around 0.9 $GtCO_2$ of emissions, or 1.5% of total emissions.

Renewable and low carbon hydrogen production currently accounts for less than 1% of total.

Targets and commitments to use low carbon and renewable hydrogen are equivalent to 3% of current total hydrogen demand.

15% of ammonia and 28% of methanol is internationally traded.

The road transport sector accounts for around 6 $GtCO_2e$, or 10% of total emissions. That's risen by 13% since 2010. These need to fall by nearly a 1/3 by 2030.

In the **power sector**, the immediate focus for international action must be growing, coordinating and improving the accessibility of support to developing countries. This will be vital to mobilise investment in the additional 7.4 – 8 TW of renewable power capacity that is needed globally by 2030, as well as in other clean power options. At the same time, there must be more dedicated international support for developing countries, and exchange of best practice among all countries, on the socioeconomic challenges of the transition. Countries should reassess the opportunities for interconnectors to support the integration of larger shares of low-cost clean power, while reinforced international action is needed now to coordinate the demonstration and testing of power system flexibility solutions, including long-term storage, that will be needed to enable fully net zero power in future years. A concerted international effort to agree on strong minimum energy performance standards for high energy consuming appliances will be essential to help cut costs as well as emissions, reducing the necessary increase in power generation capacity.

To increase the availability and affordability of renewable and low carbon **hydrogen,** the immediate priority is for countries and companies to work together to create larger markets for its deployment and trade, including through purchase commitments. This will also incentivise investment in production, which must scale up from less than 1 Mt in 2020 to around 140-155 Mt per year by 2030. Stronger international action on two fronts is essential: countries and companies should coordinate measures to move away from production based on unabated fossil fuels in sectors where hydrogen is already used, and share best practice in deployment in new applications for hydrogen such as steel, shipping, and energy storage. The number and geographical distribution of demonstration projects should be increased, along with deeper sharing of learning, and should be backed by targeted technical and financial assistance. This will be important to make hydrogen solutions available and affordable for more countries at an earlier date. International efforts to agree safety, operational and emissions standards should be accelerated, since these will be critical to enabling widespread deployment and trade.

In **road transport**, countries and manufacturers should align target dates for all new vehicles to be zero emission, to shift investment more quickly towards the new technologies and accelerate their cost reduction. Zero emission vehicles accounted for around 9% of global car sales in 2021; this should reach about 60% by 2030. An even greater

Public charging infrastructure needs to increase 10-fold by 2030.

If major markets align their policies with 100% ZEV sales by 2035, cost parity between ZEVs and ICE vehicles could be reached several years earlier.

Over 60% of the vehicles added to the roads in Africa each year are imported used vehicles.

The steel sector accounts for around 3 $GtCO_2e$ of emissions, or 5% of total emissions. That's risen by around 15% since 2010. These need to fall by around ¼ by 2030.

Global average direct emissions intensity of steel production needs to fall by around 30% by 2030.

114 Mt of conventional, high emission plants are currently underway or in the planning stage.

Agriculture and related land use accounts for around 10$GtCO_2e$, or 17% of total emissions. Of those about 7 GtCO2e come from direct, farm-gate emissions.

Farm-gate emissions have increased by 0.6% per year since 2000. These need to fall by around 20% by 2030 and agricultural expansion needs to halt.

Smallholder farmers produce about 30% of global food production.

27% of all agriculture and land use emissions can be attributed to agricultural products that are internationally traded.

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acceleration of deployment is needed for zero emission heavy goods vehicles, given the earlier state of current deployment, and in many countries the transition to zero emission two- and three-wheeled vehicles will also be important. More systematic exchange of best practice is needed to promote effective policies to mobilise investment in charging infrastructure, narrowing the wide gap between the countries furthest ahead in this regard, and the rest. Technical and financial assistance to developing countries should be greatly increased, to enable wider sharing of the benefits of the transition. Harmonised standards will be essential to ensure sustainability in battery supply chains. Regulatory coordination between used vehicle importing and exporting countries is needed to take the most inefficient vehicles out of international trade, saving costs as well as cutting emissions.

In the **steel** sector, the immediate opportunity is for aggregation of demand to mobilise investment in the production of near-zero emission steel. Less than 1 Mt of primary near-zero emission steel per year is currently produced, whereas over 100 Mt per year will be needed by 2030. Joint procurement commitments by groups of countries and companies should be greatly increased, and be supported by measures such as advance purchase commitments, to mobilise the needed investment. Collaboration on commercial-scale pilot projects is needed in all major steel producing regions, to accelerate learning. A strategic dialogue on trade should be launched at the earliest opportunity, including the leading producer and consumer countries, to agree ways to ensure near-zero emission steel can compete in international markets – removing what could otherwise be a significant obstacle to the transition. Common definitions and standards for low emission and near-zero emission steel must be agreed, as important enablers of collaboration on procurement and trade.

In **agriculture**, an immediate priority for international collaboration must be to improve access to finance for smallholder farmers in developing countries – by increasing the flow of public finance, and its leverage of private finance. This is needed both to reduce emissions and to increase productivity and resilience. Current agricultural practices are depleting natural resources as well as contributing over a fifth of global emissions, and this must be reversed. Global investment in research, development and demonstration of technologies and practices for resilient and sustainable agriculture needs to be increased, reversing the declining trend of recent years that threatens to undermine positive international efforts. A long-term process should be established to share learning on reorienting agriculture policies towards sustainability, to accelerate progress away from harmful practices. Countries should also begin focused discussions on how to ensure international trade facilitates, and does not obstruct, the transition to sustainable agriculture.

PUTTING THE WORLD ON TRACK TO MEET THE PARIS GOALS

Countries and businesses should work together in each emitting sector to increase the chances of meeting the Paris Agreement goals, in line with the Breakthrough Agenda commitment. There are likely to be significant opportunities for well-targeted international collaboration to accelerate low carbon transitions in sectors beyond the five discussed in detail in this report, such as in buildings, cement, shipping and aviation. Action in each sector can support progress in others, for example by scaling up the deployment of clean technologies and reducing their costs. International collaboration is of course an addition to, not a replacement for, the necessary action by individual countries and businesses.

In each emitting sector, there needs to be at least one international forum in which actors with strong influence and interests in the sector collaborate to accelerate the global transition. Governments and companies should work to agree the international fora through which to take forward the recommendations of this report for each Breakthrough sector, within existing frameworks wherever possible. This will help provide greater clarity for new and existing participants, reducing barriers to collaboration, and enabling international efforts to develop greater strength and depth over time.

Technical and financial assistance must be made more available in all sectors. In many sectors there is a need to agree priorities, massively scale up climate finance and coordinate international efforts to provide more timely and accessible support, responding to the needs of developing countries. This needs to include a range of instruments, including innovative approaches to finance that take into consideration and overcome key barriers, notably debt risks and budget and financial constraints. The assistance should include both capacity building and support for technology development, demonstration and deployment, in line with broader economic and social objectives.

In trade-exposed sectors where clean technologies or sustainable solutions are at a cost disadvantage to high emitting technologies or practices, level playing fields in international trade will be needed. The success of international efforts in this regard will critically depend on involving countries with the largest production or consumption in the relevant sectors, and on ensuring that any international measures support, and do not obstruct, broader economic and social objectives of developing countries and local communities. Countries can build mutual confidence in these sectors by collaborating on issues including technology demonstration, standards, and the creation of markets for first deployment.

Coordinated efforts to research, develop and demonstrate technologies can support progress in many sectors. Testing clean energy technologies and sustainable agriculture solutions across multiple regions and markets can bring them to widespread commercial deployment more quickly, especially when supported by commitments and processes to ensure sharing of learning.

Coordinated international deployment of low carbon infrastructure such as electricity interconnectors, hydrogen gas pipelines, and refuelling or recharging facilities for shipping, aviation, and heavy-duty vehicles, can increase the availability of clean energy and the feasibility of decarbonisation.

TABLE OF RECOMMENDATIONS

Power	
1	Governments, working with companies, multilateral development banks (MDBs) and investors, should agree a clear set of strategic priority projects to demonstrate and test power system flexibility solutions, including but not limited to energy storage, in a wide variety of contexts. This should build upon existing initiatives and involve the systematic sharing of learning from different geographical, climatic and market settings. *This will increase confidence in delivering net zero power systems in a broader set of markets, supported by increasingly affordable and effective technologies.*
2	Donor governments, working with key institutions, initiatives, and funds, should increase the scale, coordination, transparency and accessibility of international support for the power sector transition, building on established frameworks and successful models. Along with other forms of support, donor countries should, where requested, facilitate more power sector experts working within developing country governments, to strengthen their capacity to make use of international support, implement policy and regulatory reforms and leverage private finance. *This will provide developing countries with the resources they need to deliver on a rapid acceleration towards a net zero power system.*
3	Donor governments and MDBs should work together to more strongly align development funding with targeted support for local jobs, skills, and investment, for the repurposing of fossil fuel assets and for environmental restoration, in the fossil-fuel-dependent regions and communities. Civil society, governments and industry should contribute to creating international centres of expertise on the just transition, within existing institutions. *This action will be vital to ensure inclusive and participatory transition processes, effective social protection for affected workers and communities, and better economic and environmental outcomes*.
4	Governments should work together to reassess the opportunities for cross-border and regional power interconnection and smart grids to support the transition to clean power systems, including opportunities that have been previously considered but not taken forward, given the improving technology, falling costs, and increasing need for system flexibility. Countries and investors should support international efforts to identify top regional priorities for interconnection, and to replicate successful approaches to technical agreements. *In doing so, countries can access new opportunities to integrate larger shares of renewables and improve system reliability.*
5	Countries, in consultation with industry, should collectively agree to higher minimum energy performance standards for high energy-consuming appliances, supported by awareness campaigns and incentives, such as energy efficiency retrofit programmes. Improved technical assistance should facilitate the implementation of effective standards in developing countries. *This will help to cut energy costs and reduce emissions, as well as mitigate future electricity demand growth, easing pressure on renewables and electricity infrastructure deployment.*

Hydrogen	
1	Governments and companies should coordinate internationally to increase commitments for the use of low carbon and renewable hydrogen in sectors where hydrogen is currently used, supported by specific policies and purchase agreements to collectively send a strong demand signal and mobilise investment in production. In new priority application sectors, countries should share learning to accelerate early deployment. *This should be done in a manner that ensures a level playing field in international trade.*
2	Governments and companies should agree a comprehensive portfolio of international standards and associated certification schemes for renewable and low carbon hydrogen, addressing emissions accounting, safety, and operational issues, including leakage. This should be supported by a programme that provides a clear direction and sufficient resources to relevant technical bodies. *This will be vital for supporting a series of other actions, most notably high-quality demand commitments and trade agreements.*
3	Governments and companies should work together to dramatically increase the number and geographical distribution of hydrogen demonstration projects and to ensure that these appropriately cover each of hydrogen's high-value end use sectors, including maritime shipping, heavy industry, and long-duration energy storage. Governments and the private sector should agree on principles to guide a deeper and more rapid sharing of knowledge from these demonstrators, including a commitment to share the lessons learned from all publicly funded projects. *Doing so will help overcome technology availability barriers and accelerate the pace of deployment in multiple regions in parallel.*
4	Donor governments and multilateral development banks should make increased levels of concessional finance available for well-targeted, catalytic uses that can mobilise large-scale private investment in hydrogen production, distribution and end-use projects in developing countries. This should be supported by a process in which countries work with donors and lending institutions to identify viable projects that are being delayed by high costs of capital, and to assess obstacles to investment, and by technical assistance programs to assist governments with policy design. *This will provide much-needed support for the first-wave of low carbon and renewable hydrogen projects, ensuring that a wider set of countries can deploy the technologies required.*

Road transport	
1	Governments should agree on a timeline by which all new road vehicle sales should be zero emission, with interim targets for countries taking into account their level of economic development and ability to scale up infrastructure, and should align policies with this target. Pathways compatible with 1.5 °C indicate that a target date should be around 2035 for cars, for example. Vehicle manufacturers should commit to the same timelines for 100% zero emission vehicle production. *This will send a clear signal to industry and unlock larger economies of scale and faster cost reductions, making the transition more affordable for all countries.*
2	Governments should collectively agree a common understanding of the technologies that are consistent with the goal of zero emissions road transport, in order to send a clear and unambiguous signal to industry. *This will accelerate economies of scale for key technologies, accelerating the pace of innovation and cost reduction, making ZEVs affordable sooner for more people.*
3	Governments should exchange best practice in policy to mobilise investment and accelerate deployment of charging infrastructure, in consultation with vehicle manufacturers and infrastructure investors. This should be complemented by a broader scaling up of technical and financial assistance to developing countries at city, provincial, national and regional levels. *This will help to mobilise private investment, and ensure all countries are able to access the benefits of the transition to zero emission vehicles.*
4	Governments should work together and with industry to avoid further divergence of standards for charging infrastructure. There are already several competing charging standards for light-duty vehicles; for heavy-duty vehicles, avoiding further divergence could limit wasteful investments in multiple charging types, and accelerate the adoption of zero emission trucks. Aligning standards for hydrogen refuelling stations can reap similar benefits. *Doing so will decrease costs and facilitate the transition in vehicle importing countries.*
5	Governments should work together and with industry to agree harmonised standards to ensure sustainability and social responsibility along the electric vehicle battery supply chain, including the extraction and processing of minerals and the recyclability of battery modules. As a priority, these standards should minimise batteries' lifecycle emissions and the adverse social and environmental impacts associated with their production, seek to extend their durability and promote reuse, repurposing and recycling of their components. Similar standards on fuel cell value chains, including information on platinum and other catalyst materials' content and origin, should be put in place. *Harmonised standards will send a clearer signal to the global market, and facilitate compliance by battery and vehicle manufacturers that sell to multiple markets.*
6	Vehicle importer and exporter countries should agree on harmonised regulations on vehicle trade to improve vehicle efficiency and safety in international trade in used vehicles. These rules should govern trade in zero emission vehicles as well as internal combustion engine vehicles, supported by strong mechanisms to enforce compliance. *This will help prevent 'vehicle dumping', locking developing countries into higher emitting vehicles.*

Steel	
1	Governments and companies willing to lead the transition in the steel sector should agree on common definitions for low emission and near-zero emission steel, along with a timeframe for the adoption of standards by the mid-2020s. *This is an important market signal and will be vital for unlocking a series of subsequent actions, most notably high-quality demand commitments and trade agreements.*
2	Governments and companies should increase the scale of near-zero emission steel procurement commitments to cover a significant share of their future steel demand. These commitments should be high quality, supported by appropriate legal and implementation frameworks, such as advance purchase commitments. Countries and companies should consider joining public and private sector initiatives where these commitments are aggregated. *This will strengthen the global demand signal for near -zero emission steel, increasing the incentives for industry to invest in its production.*
3	Governments should urgently launch a strategic dialogue, including the leading producer and consumer countries, with the purpose of agreeing ways to ensure near-zero emission steel can compete in international markets. This is needed to prevent trade acting as a brake on the transition. *This may be supported by agreements to cooperate on data, standards, comparability of policies, R&D, finance and procurement.*
4	Governments and companies should identify several commercial-scale pilot projects, in all major steel producing regions, where international collaboration can support shared technology learning, business case development and policy support. Collaborative networks should deliver operational projects in these countries by the late 2020s at the latest. Emerging markets and developing countries' participation in key R&D and demonstration initiatives should be increased in support of this aim. *This will help eliminate technology availability issues, providing multiple case studies for a large group of countries and companies to further improve upon.*
5	Donor countries and MDBs, led by the priorities of developing countries, should significantly increase funds supporting industry transition to near-zero emission technologies in emerging and developing countries. *This will provide much needed near-term technology and financial support to unlock additional private sector capital for the first wave of near zero emission projects in key steel producing countries, especially for EMDEs.*

Agriculture	
1	Governments and companies should work together to deliver higher levels of investment in agricultural research, development, and demonstration (RD&D), to be maintained over the course of this decade. The scale and diversity of collaborative international RD&D initiatives and programs should also be increased. Priority should be given to innovations that can reduce food waste, limit emissions from livestock and fertilisers, improve alternative proteins, develop climate-resilient crops and livestock, and protect soil and water resources. *This will accelerate the development and eventual cost-effective deployment of technologies and solutions that can reduce emissions across multiple regions.*
2	The level of international climate finance directed at agriculture should be sharply increased, in line with its importance to global emissions, adaptation and resilience and food security. Governments, multilateral development banks and private sector investors should work together to make finance available to small- to medium-sized enterprises (SMEs) and smallholder farmers in developing countries on a far larger scale than has been achieved so far. Finance should be accompanied by assistance with the adoption of practices that increase productivity and resilience while reducing emissions and protecting natural habitats. *This will support economic development, resilience, and food security, as well as reducing emissions.*
3	Governments, research institutions, international organisations and the private sector should commit to a long-term process to test, develop evidence, and share learning on approaches to redirecting policies and support for agriculture towards sustainability and climate resilience. This should involve all of the world's largest agricultural producer countries, whose policies heavily influence global markets, as well as countries representing a diverse range of environmental and economic conditions. *This will help countries identify the most effective and feasible ways to incentivise the transition to sustainable agriculture.*
4	Governments should begin a strategic dialogue on how to ensure international trade facilitates, and does not obstruct, the transition to sustainable agriculture. International organisations can advise on options to ensure a level playing field so that policy measures essential to drive a transition to climate-resilient, sustainable agriculture do not put a country's agricultural sector at a competitive disadvantage in international trade. Early priority should be given to agreeing sustainability standards for the agricultural commodities that contribute disproportionately to deforestation. *A level playing field in international trade will give countries and companies greater confidence and ability to move ahead in the transition.*
5	Countries and international organisations should develop internationally agreed standards for monitoring and reporting on the state of natural resources on which agriculture depends, including soil carbon content and health, and pollinator health, as well as on the geographical extent of agriculture. *International measurement standards will help support high-quality knowledge sharing on policy effectiveness and enable international trade to play a positive role in supporting the transition.*

Cross-cutting	
1	Countries should work to agree the international fora and institutions through which they will take forward each of the recommendations for collaborative action contained in this report, and should then invest in those fora both politically and financially. Existing institutional frameworks should be used wherever these are appropriate to the task. *This can help to establish the institutional underpinnings needed for strong and sustained international collaboration over the course of this decade.*
2	Governments, philanthropies, financial institutions and delivery partners, should together review the state of international assistance in each major emitting sector, identify the gaps in assistance that are most important to address, and coordinate efforts to provide responsive and accessible support in these areas, led by the needs of developing countries. *This will ensure that assistance is appropriately targeted and available to support countries in relation to each of the major low carbon transitions.*
3	Governments, companies and relevant international organisations should establish high-level, strategic dialogues in each sector that is highly exposed internationally and where competition risks being a barrier to the transition, to develop a common approach to reaching a level playing field. This should include, where relevant, actions on data, standards, procurement, technology collaboration and technical and financial assistance, as well as trade. *This will help to focus dialogue on areas where collaboration is most urgent, and ensure that competition accelerates transitions, and does not hold them back.*
4	Governments and companies should greatly increase spending on clean technology demonstration projects, working together to bring new technologies to commercial-scale deployment as soon as possible. Early deployment projects should be supported by matchmaking forums and ensuing commitments and processes in all regions. *This will help ensure deep and sustained sharing of experiences gathered with these projects between countries, including those with limited resources.*
5	Wherever not already agreed, governments in each region of the world should agree the top priority common infrastructure projects that can support near-term growth in the deployment of clean solutions, such as interconnectors and hydrogen pipelines. In each of the land, sea and air transport sectors, countries and companies should identify specific international routes to be prioritised for the coordinated first deployment of zero emission charging or refuelling infrastructure. *This will support earlier deployment of infrastructure that unlocks accelerated deployment of clean technologies and solutions in multiple countries and regions.*

Chapter 1. Context: Closing the Collaboration Gap

Countries collectively accounting for over 90% of global GDP have committed to reach net zero greenhouse gas emissions by around the middle of this century (Net Zero Tracker, 2022). This is a remarkable degree of alignment: there is no doubt about our shared goals for moving to a resilient, low-carbon economy. To achieve these goals, purposeful, collaborative and structural change in the global economy is required at a pace and scale unprecedented in human history.

It is clear that we are not yet on track to meet those goals. Global emissions are still rising, yet they need to be halved within the course of this decade to put the world on course for limiting the rise in global average temperatures to 1.5°C. As countries all over the world increasingly suffer from extreme weather events, the need for faster progress in adaptation and resilience is more urgent than ever.

Where the right policies have already been put in place, progress has, in some cases, exceeded expectations. Driven by successively stronger deployment policies, solar power costs have fallen by a steep 85% between 2010 and 2020 (IRENA, 2021) and are now the cheapest source of electricity in history (IEA, 2020a). Its global deployment in 2020 was more than ten times higher than governments' targets only fifteen years earlier had suggested (IRENA, 2021). The growth in wind power has similarly outpaced expectations. Helped by falling battery costs, supportive policies, and increased industry investment, electric vehicles are set to be the next chapter in clean energy successes. These achievements show that rapid change is not impossible.

Nevertheless, much more remains to be done to put all emitting sectors on a path consistent with the 1.5°C goal. The Breakthrough Agenda agreed at COP26 aims to do just this. Designed to help trigger tipping points and stimulate international collaboration involving both the public and private sectors, the Breakthrough Agenda has set ambitious goals for 2030 to dramatically accelerate the innovation and deployment of cost-effective clean technologies and sustainable solutions, with the initial focus on five key emitting sectors of the economy – power, road transport, steel, hydrogen, and agriculture.

Importantly, international collaboration will not only enable faster progress among emitting sectors in meeting agreed climate change goals but it will also make significant contributions to other critical social and economic objectives. The global shift to low-cost, low-carbon energy sources can increase energy access, affordability and security. Equally, a faster transition to resilient, sustainable agriculture is essential to global food security. The transformational change required in many sectors to achieve net zero global emissions involves a multitude of challenges, but it also provides abundant valuable opportunities – for innovation, job creation, societal development and economic growth, among many others.

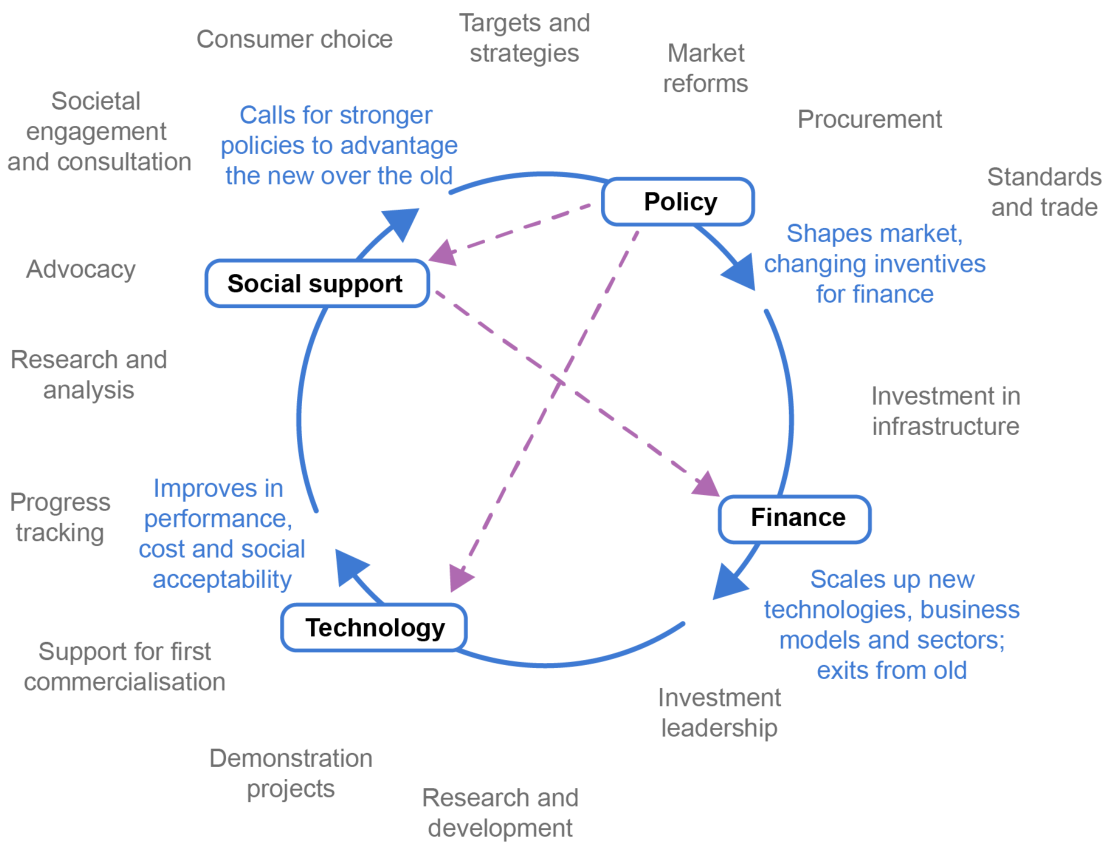
PULL ALL LEVERS TO ACCELERATE TRANSITIONS

The Intergovernmental Panel on Climate Change (IPCC) has described what it is needed to reach net zero as 'system transitions' in each of the emitting sectors of the global economy (IPCC, 2018). Essentially, this requires the replacement of one set of technologies, practices, business models, infrastructures and institutions with another. In most sectors these changes, if well designed, will not only reduce emissions but also contribute to increasing resilience and energy security.

Policy interventions at all points in the system are required to accelerate these transformational changes: funding research and development, reform of market structures, investment in new infrastructure, and support for workers and communities in attaining new skills and opportunities as part of a just transition.

Actors of all kinds can and must contribute to accelerating the deployment of clean technologies and sustainable practices. The effect of mutually supporting actions can create an 'ambition loop' for technology development and deployment: a reinforcing feedback cycle in which policy reallocates finance towards clean technologies; businesses innovate; technologies improve; and social support for the transition grows, enabling the next round of policies to move the transition forward (see Figure 1.1).

Figure 1.1 Reinforcing feedback or 'ambition loop' between policy, finance, technology and social support



Source: Adapted from Victor, Geels and Sharpe, 2019.

For example, in the case of solar power, early research and development was supported by government funding. Later, policies such as feed-in tariffs, tax credits and mandates supported the deployment of solar panels in electricity systems, initially on a small scale and at high cost. The existence of this market allowed businesses to access investment, innovate, and improve their products. This innovation reduced the cost of solar power, increasing its appeal, leading to more demand and more investment. Meanwhile, the growth in deployment of solar power was supported by investments in new infrastructure, strengthening electricity grids and providing new connections, and by market reforms that made electricity systems better able to incorporate intermittent sources of power. Civil society organisations have built support for many of these policies, and the more affordable solar power has become, the more they have been able to push for faster progress in its adoption. We need to learn from this success in order to replicate this effect deliberately and quickly in all emitting sectors.

This is not to suggest that technological progress always follows the example of solar power. The pace of innovation and cost reduction is very much influenced by attributes such as unit size, modularity, the service that is offered to consumers, and various other factors (IEA, 2020b). Moreover, a low-carbon transition is not simply a change in technologies. It also involves significant changes in labour markets, in the distribution of its costs, in the geopolitics of energy and resource security, and in the structure of supply chains. These broader implications are already very clear in the power sector and increasingly so in others; in each sector, managing these multiple issues becomes ever more important as the low-carbon transition moves forward.

COLLABORATE INTERNATIONALLY TO INCREASE THE ECONOMIC GAINS OF TRANSITION

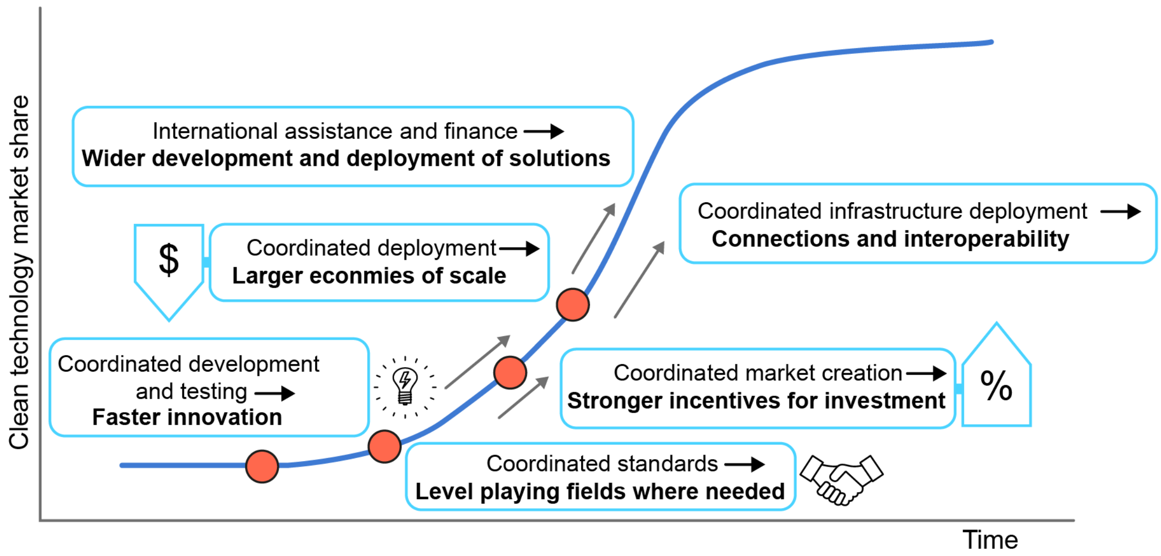
Well-targeted international collaboration can amplify the effect of national government and private sector efforts and rapidly advance progress, making structural change on the global scale quicker, easier, and lower cost. Without widespread collaboration, the transition to net zero could be delayed by decades. To put it another way, without strong international collaboration, achieving a resilient net zero emission global economy by around mid-century is likely to be unachievable. The potential gains from international collaboration are large. They include:

- **More widespread adoption of effective policies** to deploy available solutions at scale, which is essential for halving emissions over the coming decade. This can be enabled by the sharing of knowledge, and by international technical and financial assistance. Support to developing countries in this regard is particularly important.
- **Faster innovation**, which can result from the deliberate alignment of research, development and demonstration activities, the sharing of learning and building confidence. This is particularly important given that around 50% of the global emission reductions needed for net zero are likely to come from technologies that are not yet fully commercialised (IEA, 2021).

- **Stronger incentives for investment**, which can arise through coordinated actions to create a larger and more stable market for the first deployment of new clean technologies. This is especially valuable early in a transition when investment in the production of new technologies represents a high-risk decision for industry.
- **Larger economies of scale**, which can be generated by the alignment of technology choices and deployment policies. There is strong historical evidence that mass deployment of clean energy technologies such as solar PV, wind or electric vehicles leads to significantly lower cost, and that similar effects are likely to be achieved with new and emerging technologies such as hydrogen electrolysers.
- **Level playing fields**, where needed, which may be established by the coordination or harmonising of regulations or carbon prices (and supported by the removal of fossil fuel subsidies, and the reorientation of agricultural subsidies). In sectors where zero-emission solutions are more expensive than their fossil fuel equivalents, such as energy intensive industries and long-distance transport, the establishment of a level playing field internationally can prevent competition acting as a brake on a low-carbon transition, and instead allow it to act as an accelerator.

These gains imply a different focus for international collaboration at each stage of the transition (see Figure 1.2). They will only be realised in full if the efforts are appropriately targeted, substantial and sustained.

Figure 1.2 How international collaboration can accelerate progress at each stage of the transition



Source: Adapted from Victor, Geels & Sharpe, 2019.

International collaboration is a complement, not an alternative, to competition. Competition is an important driver of innovation, and as such a critical ingredient of successful global low-carbon transitions. Its positive effect will be all the more powerful if countries work together on the goals, direction, pace of change and, where appropriate, on the rules of engagement. Countries, and businesses too, can collaborate to grow the markets for clean technologies and sustainable solutions, and at the same time compete to supply them.

FOCUS ON INTERNATIONAL COLLABORATION IN ALL SECTORS

Significant reductions in both the cost and the difficulty of transitions can be achieved when international collaboration is a major strategic focus within each of the emitting sectors of the global economy. While there are important connections, commonalities and synergies among them, which this engagement should seek to exploit, each sector is unique in its technologies, markets, industrial, financial and social structures, political economy, and the nature of its global connections. Consequently, there is a need for dedicated international collaboration within each sector, targeted to address its unique characteristics, to speed its transition.

Important foundations for such collaborations are already in place. The United Nations negotiations on climate change have established a strong consensus for action, and a large number of countries have committed to significant individual actions through their Nationally Determined Contributions. A great many initiatives for practical global engagement are already operating, and involve governments, businesses, international and multilateral organisations, civil society organisations, and investors. The number and diversity of collaborative international initiatives has grown remarkably over recent years, and many of these have already made important contributions to the progress in low-carbon transitions.

Going forward, there is a critical need to strengthen international collaboration to meet the net zero emissions targets and to capture all the benefits for societies. Critically, expanding global engagement will increase access to affordable energy and at the same time reduce the damaging impact on health from air pollution. It will also lead to new industries and job creation, underpinning economic growth. According to one estimate, an energy transition aligned with limiting global temperature increase to 1.5°C could create close to 85 million additional jobs by 2030 compared to 2019, more than offsetting losses of 12 million jobs, mainly in the fossil fuel industries, while supporting increased global GDP (IRENA, 2022). In agriculture and land use, international collaboration is as important to achieving resilience and food security as it is to reducing emissions. In every sector, international flows of financial assistance and knowledge will be essential to enabling all countries to benefit from the social and economic advantages of the transition. The Breakthrough Agenda provides a global mandate to close the collaboration gap and opens a new pathway for accelerating progress.

THE CONTRIBUTION OF THE BREAKTHROUGH AGENDA

The leaders of more than forty countries, representing over 70% of global GDP, formally launched the Breakthrough Agenda at COP26 in November 2021. They were united in their commitment to work together 'to make clean technologies and sustainable solutions the most affordable, accessible and attractive option in each emitting sector globally before 2030' (COP26, 2021).

The Breakthrough Agenda is designed to make three important contributions:

1. Countries committed to work together to fast-track low-carbon transitions in each emitting sector over the course of this decade. This is the first widely supported high-level political commitment to collaborate internationally in each emitting sector. If properly implemented, this could access the gains from international collaboration described above – of broader adoption of effective policies, faster innovation, stronger incentives for investment, larger economies of scale, and level playing fields where they are needed – all of which will facilitate progress towards a resilient net zero emission global economy.
2. Countries agreed goals that focus on tipping points, where clean technologies and sustainable solutions become the most affordable, accessible and attractive option in each of the emitting sectors. These goals are designed to focus attention on the most critical problems that need solving. As clean power becomes the most affordable and reliable option for electricity generation, more countries are choosing it instead of coal or gas. When near-zero steel becomes the preferred choice in global markets, the incentives for industry will be unambiguously aligned with the transition. All actors can help to move transitions towards tipping points, and when they are reached, progress can accelerate dramatically (Sharpe and Lenton, 2020).
3. A process was established for continually tracking and strengthening collaboration over time. This is crucial to establish and maintain the cooperative structures to enable rapid progress to 2030 and beyond. It involves making a number of critical assessments: to distinguish between sharing information and aligning action; from side-events to sustained collaboration; and coalitions of first movers versus the critical mass that can shift global markets. Without such assessments, necessary changes are not made visible.

This inaugural report, envisioned to be repeated annually, along with meetings among countries, businesses and leaders of international initiatives in each sector, is part of that process of assessment. It aims to set out a clear pathway for international collaboration in each sector over the course of this decade, highlighting the priority near-term actions that could have the greatest impacts. Even more important is the response: the success of the Breakthrough Agenda will depend on the extent to which governments, businesses, investors and civil society act to take advantage of the opportunities for stronger collaboration that have been identified.

THE STRUCTURE OF THIS REPORT

This report focuses on the five sectors for which countries have so far agreed collective goals as part of the Breakthrough Agenda, and in which the process to assess and strengthen international collaboration has begun. The focus sectors are power, road transport, steel, hydrogen, and agriculture.[1] They are significant for their impact on greenhouse gas emissions (together accounting for over half of the global total), but also for their potential to contribute to growing a resilient low-carbon global economy, and for opportunities to strengthen international collaboration and accelerate progress in the near-term. Given their different stages of maturity and diverse characteristics, together they also help to illuminate the wide range of ways in which international collaboration can rapidly advance low-carbon transitions.

The report devotes a chapter to each of these five sectors, in which the following points are addressed:

Sector goals and the state of the transition. We set out the Breakthrough Agenda goals in quantitative metrics, provide details on what is needed to meet this goal by 2030, and assess the current state of progress.

Enabling conditions for the transition (or 'how do we get there?'). We outline the conditions necessary for a faster transition – such as market structures, finance and investment, requirements for new or improved infrastructure and supply chains, social considerations, and trade conditions – and provide recommendations on how they need to evolve over the course of this decade. The aim of this report is not to describe all the actions that governments and companies can take individually. Instead, these summary descriptions of the enabling conditions for the transition provide the context for how international collaboration can accelerate progress.

Priorities for international collaboration. We assess the current state of international collaboration, identify the most significant and urgent areas where this could be strengthened, in order to accelerate the transition; and recommend specific steps that can be taken now to realise those opportunities. This assessment is informed by dialogues with countries, businesses, and organisations active in international collaboration in each of these sectors, convened this year as part of the Breakthrough Agenda process, as well as drawing on wider literature and consultation with experts.

In a concluding chapter, we highlight how interventions in different sectors can be mutually reinforcing. We also consider opportunities to strengthen international collaboration that have cross-cutting relevance to many sectors. These include ways to deepen collaboration

[1] The hydrogen sector represents more a collection of technologies than a coherent economic sector at present, but to reach the goals of the Paris Agreement it will become an important sector of the low carbon economy.

on research and development, improve the availability and effectiveness of practical and financial assistance, establish critical international infrastructure, and to use trade agreements in support of transitions. Finally, opportunities are outlined for stronger international collaboration to advance progress in sectors where countries have not yet agreed collective goals under the Breakthrough Agenda.

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CHAPTER 2. POWER

"Clean power is the most affordable and reliable option for all countries to meet their power needs efficiently by 2030." -- *Power Breakthrough goal.*

KEY MESSAGES

- The power sector transition is underway, with significant shifts observed over the last two decades, driven by the increasing pace of renewables deployment and their dramatic cost reductions. Installed renewable capacity increased by 1.7 TW (8.7% per year) from 2011-21, while non-renewable sources grew by 1 TW (2.2% per year) over the same period. The share of low-carbon capacity (renewables and nuclear) in 2021 accounted for 43% of the global total.
- The pace and scale of decarbonisation must increase urgently, driving emissions from the power sector down by more than 7% each year to 2030. This requires the deployment of readily available low-carbon technologies, coupled with the rapid phase out of polluting fuels, particularly coal.
- To meet the dual challenge of growing demand and decarbonisation, 7.4-8.0 TW of additional renewable capacity is required by 2030, quadrupling today's deployment rate. Moreover, the current rate of decline in the energy intensity of the global economy should double from 2% to 4% per annum, along with the increasing deployment of other low-carbon solutions such as nuclear.
- Infrastructure upgrade, modernisation and expansion is a high priority in the coming decade as the share of renewables grows, requiring system flexibility and modern grids. Infrastructure developments should be aligned with long-term plans and reflective of broader strategies, including regional market integration.
- In 2021, annual expenditure in the power sector reached USD 900 billion, from which USD 400 billion went to renewables and around USD 300 billion to power grids. A doubling of this annual energy investment is required by 2030, with substantial funds flowing towards the modernisation of ageing infrastructure and meeting growing energy demand. Planned investments, especially coal, will have to be reassessed and redirected to low-carbon technologies.
- To drive progress at the required pace and scale, national action by public and private sectors is essential. International cooperation is vital to leverage and amplify national action, support a just transition that leaves no one behind and strengthen the international flow of finance, capacity and technologies.

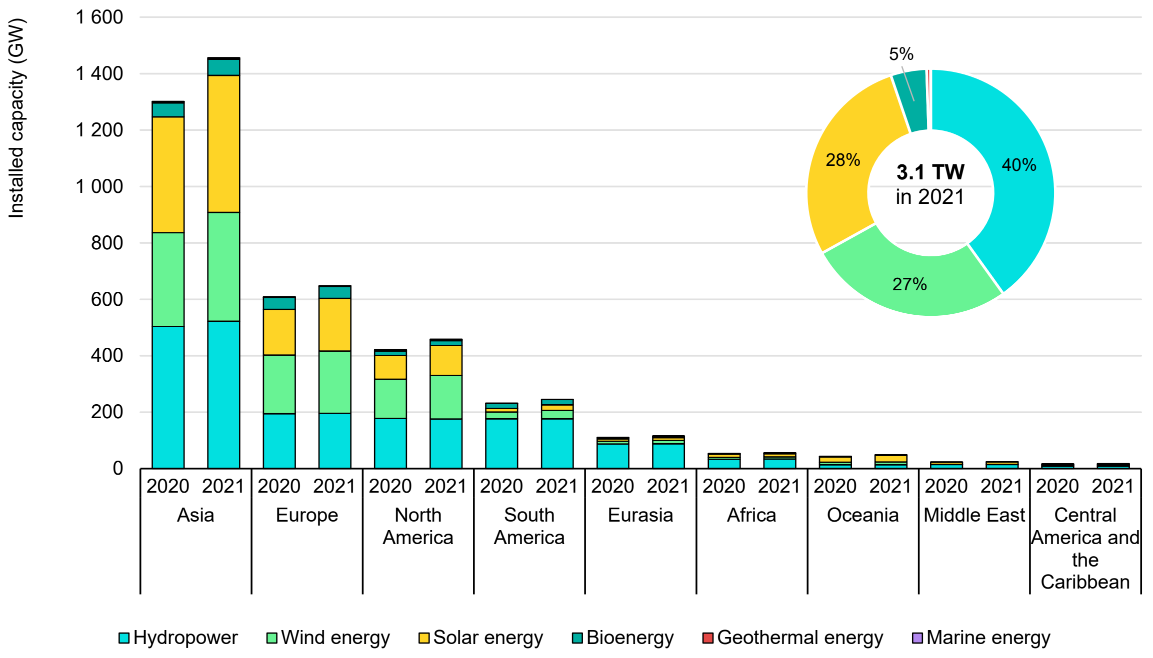
- Five areas stand out as priorities for strengthening international collaboration toward the 2030 Breakthrough goal over the next 1-2 years, where we recommend the following actions:
  - Governments, working with companies, multilateral development banks (MDBs) and investors, should agree a clear set of strategic priority projects to demonstrate and test power system flexibility solutions, including but not limited to energy storage, in a wide variety of contexts. This should build upon existing initiatives and involve the systematic sharing of learning from different geographical, climatic and market settings. *This will increase confidence in delivering net zero power systems in a broader set of markets, supported by increasingly affordable and effective technologies.*
  - Donor governments, working with key institutions, initiatives, and funds, should increase the scale, coordination and accessibility of international support for the power sector transition, building on established frameworks and successful models. Along with other forms of support, donor countries should, where requested, facilitate more power sector experts working within developing country governments, to strengthen their capacity to make use of international support, implement policy and regulatory reforms and leverage private finance. *This will provide developing countries with the resources they need to deliver on a rapid acceleration towards a net zero power system.*
  - Donor governments and MDBs should work together to more strongly align development funding with targeted support for local jobs, skills, and investment, for the repurposing of fossil fuel assets and for environmental restoration, in the fossil-fuel-dependent regions and communities. Civil society, governments and industry should contribute to creating international centres of expertise on the just transition, within existing institutions. *This action will be vital to ensure inclusive and participatory transition processes, effective social protection for affected workers and communities, and better economic and environmental outcomes.*
  - Governments should work together to reassess the opportunities for cross-border and regional power interconnection and smart grids to support the transition to clean power systems, including opportunities that have been previously considered but not taken forward given the improving technology, falling costs, and increasing need for system flexibility. Countries and investors should support international efforts to identify top regional priorities for interconnection, and to replicate successful approaches to technical agreements. *In doing so, countries can access new opportunities to integrate larger shares of renewables and improve system reliability.*
  - Countries, in consultation with industry, should collectively agree to higher minimum energy performance standards for high energy-consuming appliances, supported by awareness campaigns and incentives, such as energy efficiency retrofit programmes. Improved technical assistance should facilitate the implementation of effective standards in developing countries. *This will help to cut energy costs and reduce emissions, as well as mitigate future electricity demand growth, easing pressure on renewables and electricity infrastructure deployment.*

SIGNIFICANCE OF THE SECTOR

The power sector contributes to around a quarter of all global greenhouse gas emissions and almost 40% of global energy-related CO_2 emissions. In 2020, low-carbon technologies generated nearly 40% of electricity. Renewables generated 28% of electricity, while nuclear energy produced 9.9%. Over the past decade (2011-21), renewable installed capacity increased by 1.7 TW or 8.7% per year, while non-renewable sources grew by 1 TW or 2.2% per year, including 18 GW of nuclear power (IRENA, 2022a). Due to the growth of renewables and a decline in energy demand in recent years, the carbon intensity of power generation fell by 8.4% since 2015 (IEA, 2021a).

To date, investment in the energy transition has been predominantly focused on the power sector, and relatively geographically concentrated. In 2021, 84% of investment[1] related to the energy transition was in China, Europe, India, Japan and the United States. However, out of over USD 2.8 trillion of cumulative renewable energy investment made globally between 2010 and 2020, only 2% was in Africa, despite the region's massive power needs and abundant resources (IRENA, 2022b).

Figure 2.1 Renewable generation capacity by region and technology, 2020-21



Source: IRENA, 2022a.

A widespread effort will be important, as the speed and scale of the power sector transition have implications beyond decarbonisation. It will not only limit CO_2 emissions, but also

[1] Estimate includes energy efficiency; hydrogen; CCS; energy storage; electrified heat; electrified transport; and renewable energy.

reduce air pollution and expand energy access to achieve SDG7 on energy and, by extension, the United Nations Sustainable Development Agenda for 2030.

SECTOR GOALS

As other major emitting sectors electrify at an increasing rate over the 2020s, and the efforts on universal access intensify, the low-carbon electricity supply must keep pace, avoiding lock-in of emissions from fossil fuel assets. Emissions from the power sector need to fall by more than 7% each year out to 2030, from 13.5 $GtCO_2$ in 2020 (IEA, 2021a). Electricity production may need to grow 2.5-3 times by 2050, underscoring the significance of the sector's rapid decarbonisation in this decade (IEA, 2021b; IRENA 2022c). Coordinated international action will be critical to overcoming key policy, regulatory, technology and financial bottlenecks for the next phase to deliver the cost-effective, secure operation of carbon-free power systems globally by 2040.

The IPCC, among others, outlines the major options that can contribute to power sector decarbonisation, including decommissioning and reducing the utilisation of existing fossil fuel-based power sector infrastructure, retrofitting existing installations with carbon capture and storage (CCS), switches to renewable power and low-carbon fuels, and cancellation of new unabated coal installations. This might include repurposing some existing facilities, taking advantage of the existing infrastructure and providing local jobs to help offset those lost. The most appropriate strategies will depend on national and regional circumstances, including resource and technology availability (IPCC, 2022).

Many countries are already on a path to low-carbon power systems, with significant commitments enshrined in Nationally Determined Contributions (NDCs) and other national plans. Renewable energy and energy efficiency are chief among the solutions reflected in these plans. For example, the United Nations Framework Convention on Climate Change (UNFCCC) NDC Synthesis report notes that "domestic mitigation measures for renewable energy generation were most frequently mentioned by Parties, followed by measures for energy efficiency improvement" (UNFCCC, 2021). By November 2021, of the 144 NDCs that had a quantified renewable energy target, 109 focused on power. Among those, only 23 Parties committed to a share higher than 60% of installed capacity by 2030 (IRENA, 2022d).

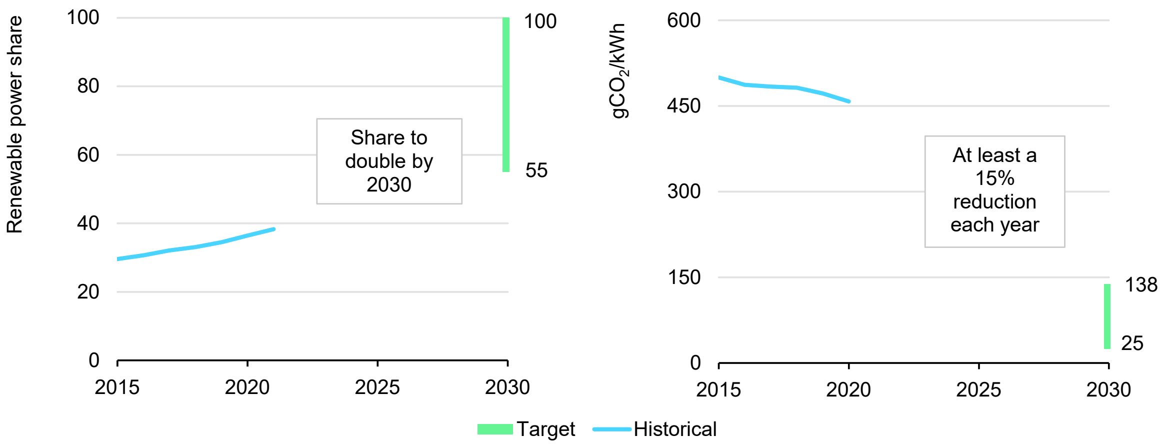
To put the sector on a Paris-aligned pathway, countries and companies will need to meet the Breakthrough goal, which 42 countries, representing over 40% of the global power sector (by electricity consumption), endorsed at COP26:

"Clean power is the most affordable and reliable option for all countries to meet their power needs efficiently by 2030."

This will require a significant buildout of clean[2] power generation assets by 2030, alongside supporting smart grid infrastructure and flexibility measures. Scenarios aligned with international climate goals suggest that by 2030:

- Renewables, as a share of total generation, should rise from around 28% today to between 61-65%. This requires additional 7.4-8 TW of renewable capacity by 2030 (IEA, 2021b; IRENA, 2022c). Other low-emission sources can complement the leading role of renewables, with nuclear power generation rising 40% by 2030 (maintaining a 10% share of total generation) and some carbon capture technologies beginning to be deployed (IEA, 2022a). Power sector emissions intensity should fall from 458 gCO_2/kWh in 2020 to between 25-138 gCO_2/kWh by 2030, a reduction of over 60%.
- Electricity as a share of total final energy consumption should increase from 20% to between 26-30% over this decade (IEA, 2021b; IRENA 2022c).
- Electricity access should become universal, reaching 100% of the population worldwide by 2030.

Figure 2.2 Renewable power (% share of total generation) and power sector emissions intensity (gCO_2/kWh), 2015-2030



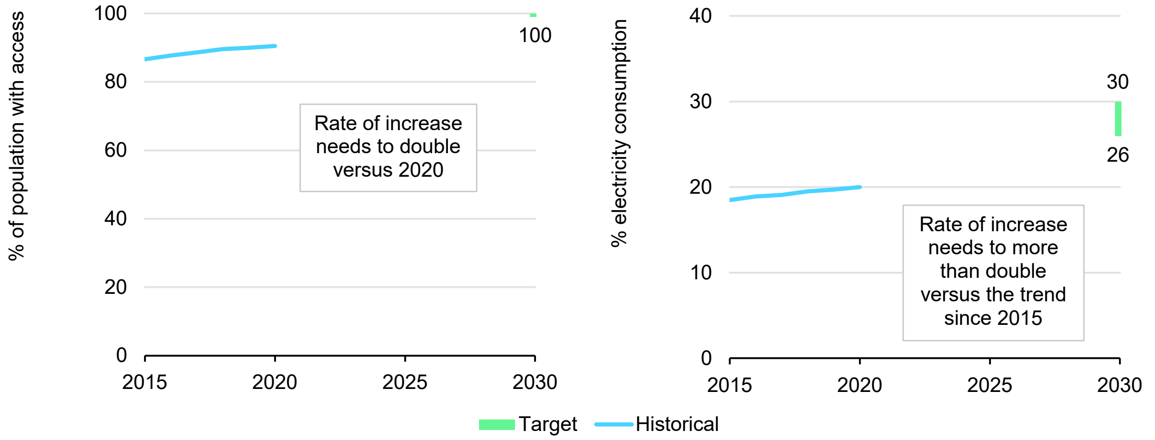
Sources: IEA, 2021b; IRENA, 2022c.

Investment in the power sector will need to increase substantially to deliver on these outcomes. In 2021, annual expenditure in the power sector reached USD 900 billion, from which USD 400 billion went to renewables and around USD 300 billion to power grids. However, annual investments in the power sector need to reach an estimated USD 2 trillion by 2030 on a net zero by 2050 pathway, including around USD 1 trillion for renewable power and USD 650 billion for grids (IEA, 2022b).

[2] For the purposes of this report and how data are analysed, "clean power" is related to near-zero carbon emissions from producing electricity. As such, it includes renewable energy (as defined in the IRENA Statute meaning hydropower, solar energy, wind energy, bioenergy, geothermal energy, and marine energy), nuclear energy, and fossil fuels with very high carbon capture rates. Effectively, the data here reflect renewables and nuclear power due to the negligible carbon capture capacity in the world today.

Energy access remains an important priority. In 2020, 91% of the global population had access to electricity. While the historic rate of access has increased, between 2018 and 2020 it fell to 0.5 percentage points per year – mainly due to the complexity of reaching the remaining unserved populations and the potential impacts of Covid-19. At the current rate, only 92% electrification is expected by 2030, underscoring the need for faster deployment to reach 100 million people annually.

Figure 2.3 Access to electricity (% of population with access) and electricity consumption (% share of total final energy consumption), 2015-2030



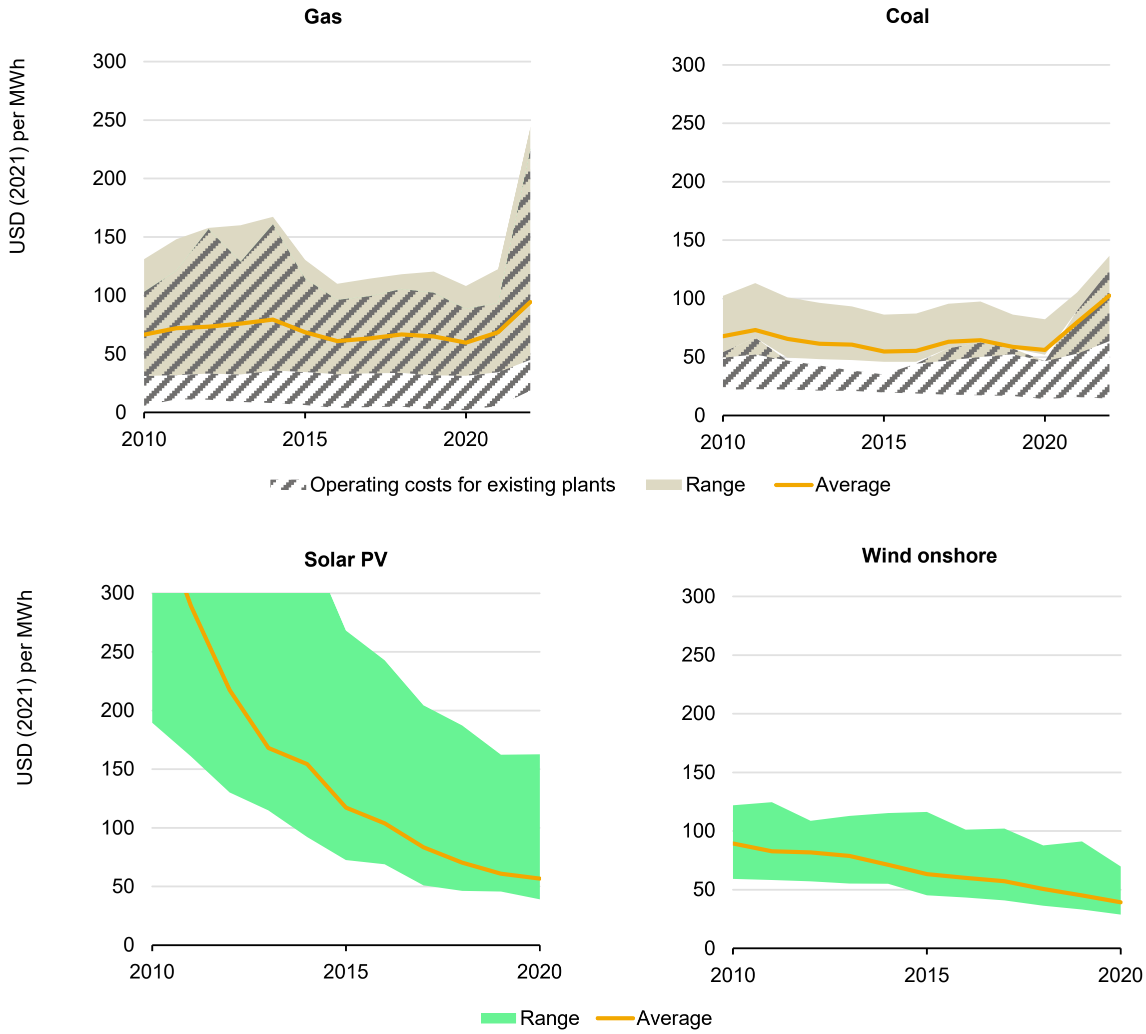
Sources : IEA, 2021b; IRENA, 2022c.

Renewable power is now the cheapest form of new electricity generation in most countries (IRENA, 2022e), making it the centrepiece of cost-effective energy transitions. Many countries are now approaching a second tipping point, where it is cheaper to generate power from newly-installed renewables than from the continued operation of existing coal- and gas-fired plants. The global weighted-average levelised cost of electricity (LCOE) of onshore wind projects commissioned in 2021 declined by 15% compared to 2020, to USD 33/MWh, while offshore wind decreased by 13% to USD 75/MWh, and utility-scale solar PV fell by 13% to USD 48/MWh. However, the cost declines in 2021 may not continue into 2022 as supply chain constraints were already being felt in late 2020, and commodity prices increased further in 2021 (IRENA, 2022e).

Alongside renewables, nuclear is also likely to play an important role in making the transition faster and more secure. There is currently 413 GW of nuclear capacity operating in 32 countries, with 70% of this capacity located in advanced economies. This is set to change, with stronger growth for nuclear power planned in emerging market and developing economies (IEA, 2022a). Of the nearly 60 GW of nuclear capacity under construction, over 80% is located in emerging markets or developing countries (IAEA, 2022).

Energy efficiency will also be vital to ensure that that new clean power capacity is put to best use. Faster action on energy efficiency can help avoid around 96 EJ of final energy demand by 2030, 5% lower than today (and 23% lower than a scenario where no additional action is taken) (IEA, 2021d).

Figure 2.4 Levelised costs of electricity production for key technologies, 2010-2020/22



Source: IEA, 2021e; IRENA, 2022e.

HOW DO WE GET THERE?

Action is required in the 2020s in all countries and regions to advance decarbonisation of the sector to reach the Breakthrough goal by 2030, and to pave the way for net zero emissions by 2050. The availability of cost-effective renewables worldwide, supported by an acceleration in energy efficiency, make this possible. In the short- to medium-term, for many countries this should translate technical and economic challenges into a set of investment, regulatory, and societal actions that can contribute to decarbonisation and create millions of jobs.

The focus of near-term action must be a step change in the deployment of renewables to quadruple installation rates, enabled by investment in system integration and infrastructure (IEA, 2021b; IRENA 2022c). In many countries, renewables are already the cheapest source of electricity. The challenges over the 2020s will be integrating rising shares of variable renewables, overcoming bottlenecks such as permitting and ensuring systems become increasingly flexible. The intelligent use of distributed energy resources (DERs), supported by growing digitalisation of the electricity system, will be increasingly important as end uses are electrified. As a result of these systemic changes, annual investments in the electricity network and overall electricity system flexibility need to more than double by 2030 (IEA, 2021b; IRENA 2022c).

In parallel, governments and regional bodies will need to collaboratively assess options for new interconnectors to facilitate increased electricity trade between countries. This can also provide another important source of system flexibility, supported by improving technology options and falling costs. Examples include the African Union's Continental Master Plan focused on an integrated continental power transmission network or the India-led One Sun, One World, One Grid initiative, which aims to facilitate regional connections in South Asia.

Governments, together with multilateral development banks, will need to expand and strengthen international assistance to ensure that developing countries can access, adapt, and rapidly deploy low-carbon technologies to meet their needs and priorities. This will require increasing the funding levels and improving the coordination and focus of financial and technical assistance. Working with key institutions, funds and initiatives will help guarantee that all new generating capacity is low carbon in all markets.

Governments and companies should further increase investments in research, development and demonstration (RD&D). Considerable innovation opportunities remain, including novel renewable generation technologies, long-term power system flexibility, and digitalisation (Mission Innovation, 2021). Priorities for RD&D need to address the differing requirements of countries and contexts, and technology RD&D must be closely integrated with innovations in business models, system design and markets. Learning should be shared proactively between countries and companies as the first large-scale projects are delivered. Delivering many of these outcomes sooner, at a lower cost, will help accelerate the pace of transitions at the rate needed for a net zero goal.

Governments and companies should develop and implement plans for managing the transition away from high-carbon power systems and associated supply chains, working closely with local communities and workers. This will include repurposing obsolete assets, environmental restoration, and investment in local jobs and skills, particularly in fossil fuel-dependent regions and communities.

While clear national targets, implementation strategies and timetables are necessary starting points, achieving the best outcomes will require broad stakeholder engagement and holistic policy frameworks to anticipate risks, maximise socioeconomic benefits and value creation. By 2030, renewables alone have the potential to add 26.5 million jobs globally, with an additional 58.3 million jobs in energy efficiency, power grids and flexibility, and hydrogen (IRENA, 2021a). It will be important for governments to ensure that strategies for retraining can use existing skills in the energy sector, where possible, and do not exacerbate inequalities as fossil fuel jobs wind down.

Governments must set out detailed strategies for net zero power systems as progress accelerates over the early 2020s, sending a strong long-term signal for companies and civil society. These should be supported by appropriate electricity market reform and long-term contracts and auctions, as the technology options for net zero power systems become clearer. Governments should also consider institutional changes and agreements to support low-carbon power systems. Examples from countries leading the way in this area should be shared internationally to increase the uptake rate for successful policies and strategies.

As power systems approach higher shares of variable renewables in the late 2020s, governments will need to scale-up the deployment of mid- and long-term energy storage options, drawing on the successful RD&D activities from earlier in the decade. It will be important for countries and companies to share learning from early large-scale projects, supporting different power systems as they advance toward net zero.

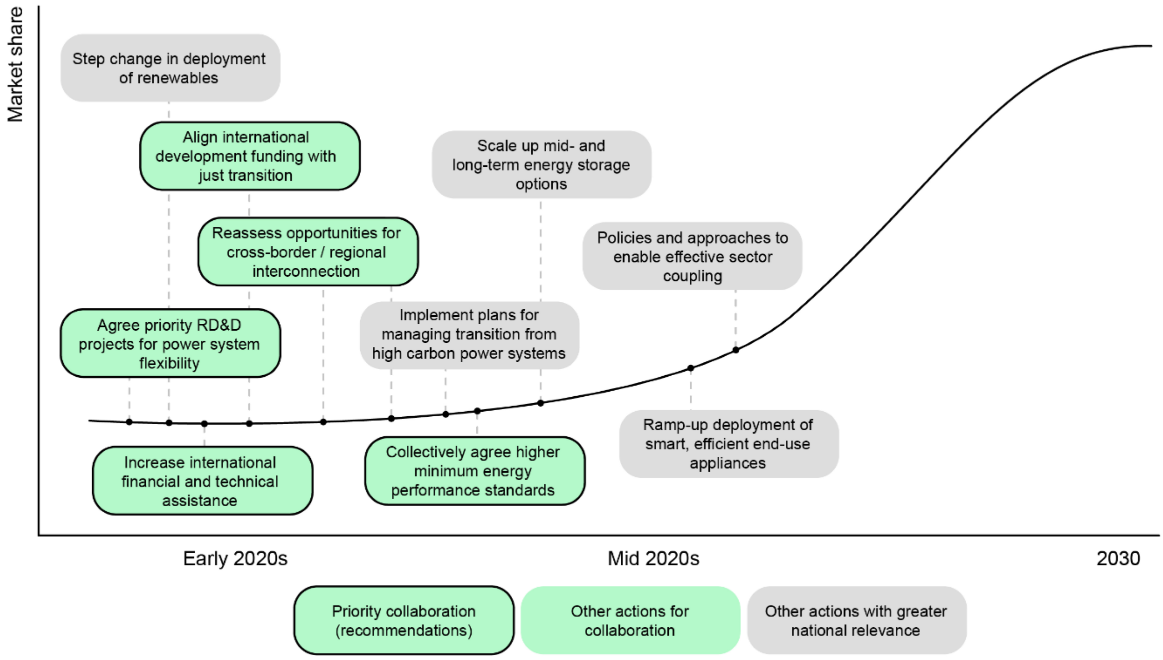
International cooperation will have a significant impact in this decade to achieve the Power Breakthrough goal. Collaborative efforts should focus on those essential levers that can accelerate the deployment of low-carbon solutions worldwide or otherwise there will be a bottleneck in the medium- to long-term. Only with effective international collaboration will it be possible to ensure that the transition can occur at the pace and scale required, making clean power affordable and accessible to all.

Recommended reports

We recommend the following reports for more detailed descriptions of the technologies for power sector decarbonisation and of the actions that countries and businesses can take individually.

- Net Zero by 2050 (IEA, 2021).
- Making Clean Electrification Possible (ETC, 2021).
- World Energy Outlook 2021 (IEA, 2021).
- World Energy Transitions Outlook (IRENA, 2022).
- Renewable Power Generation Costs in 2021 (IRENA, 2022).
- RE-organising Power Systems for the Transition (IRENA, 2022).
- Nuclear Power and Secure Energy Transitions (IEA, 2022).

Figure 2.5 Critical path to 2030 for the power sector



CURRENT STATE OF INTERNATIONAL COLLABORATION

International collaboration on power sector decarbonisation and wider supporting areas is at a relatively developed stage compared to the other major sectors assessed in this report, with almost two decades of work in many areas in several global and regional settings. IEA and IRENA are established platforms for international cooperation on the power sector, and several streams of work have emerged from the G7 and G20 collaborative efforts. Regional entities including the Association of Southeast Asian Nations (ASEAN), African Union (AU), European Union (EU) and Organización Latinoamericana de Energía (OLADE) all have dedicated streams of work on low-carbon power, with increasing efforts toward regional integration. Several initiatives and campaigns also exist under the umbrella of the Clean Energy Ministerial, including Power System Flexibility; Flexible Nuclear Campaign; Nuclear Innovation: Clean Energy Future; and Carbon Capture Utilization and Storage. Significant collaborative work is also undertaken by the industry bodies such as Global Wind Energy Council, Global Solar Council, Long Duration Energy Storage Council and Global Power Systems Transformation Consortium.

There are also collaborative efforts to increase the share of renewables in the most vulnerable countries, such as the Climate Vulnerable Forum where 55 developing countries committed to 100% renewable pathways. Another example is the Africa Renewable Energy Initiative (AREI) launched at COP21 in Paris with the goal of 300 GW of renewables by 2030. The SIDS (Small Island Developing States) Lighthouses Initiative facilitated by IRENA, which comprises 38 SIDS and 32 partners, is working to reach 10 GW of renewable energy installed capacity in all SIDS by 2030. In addition, there are several technology-focused initiatives, including the International Solar Alliance, Global Geothermal Alliance and the Global Offshore Wind Alliance founded by Denmark, GWEC and IRENA. The IEA Technology Collaboration Programme (TCP) supports the work across a wide range of energy technologies and related issues, with over 6 000 experts worldwide representing over 300 public and private organisations in 55 countries. Another example is the Desert to Power initiative led by the African Development Bank and endorsed by heads of state focusing on the 11 countries of the Sahel to increase solar generation capacity by 10 GW and contribute to providing access to electricity to 250 million people.

In recent years, the number of collaborative initiatives focusing on energy transitions has increased. For instance, the IEA's Clean Energy Transitions Programme (CETP) leverages the organisation's expertise across all fuels and technologies to accelerate global clean energy transitions, particularly in major emerging economies. The Energy Transition Council (ETC) was established to create a closer link between political dialogue and technical and financial assistance, with the aim of making low-carbon and sustainable power the most affordable and reliable option for countries to meet their power needs efficiently, supporting the transition away from coal power, and improving energy access. The Green Grids Initiative intends to accelerate the construction of the new infrastructure needed for a world powered by low-carbon energy. The Green Powered Future Mission (GPF) involving 15 governments and 13 companies and organisations has the goal of demonstrating that by 2030 power systems in different geographies and climates are able to effectively integrate up to 100% variable renewable energies in their generation mix and maintain a cost-efficient, secure and resilient system. Finally, the recent addition of the Regulatory Energy Transition Accelerator (RETA), co-founded by the IEA, IRENA, the UK’s Ofgem[3] and the World Bank, reflects the multifaceted nature of the power sector transformation and the benefits of collective learning and international cooperation for faster progress.

In summary, collaboration in the power sector is well-established and wide ranging, and the institutions and initiatives needed to deliver are in place. However, the level of effort and resources devoted to collaboration is low compared to both the scale of the challenge and of the opportunity. Countries and companies should resist establishing more initiatives and should provide a more robust alignment of effort and increased support to existing initiatives to ensure they are focused and delivering. Greater transparency on who does what can help improve coordination, along with pressure on initiatives to collaborate more effectively. This can in part be facilitated by the Power Breakthrough process, crowding-in more countries and companies behind the most critical leading initiatives, joining-up between public-private initiatives and plugging key gaps in the landscape where they exist.

[3] The Office for Gas and Electricity Markets (Ofgem) is the UK’s energy regulator.

Figure 2.6 Landscape map of key international power sector decarbonisation initiatives

Note: The diagram summarises the roles of many public and private sector initiatives in this sector. Initiatives have been included if they have a global scope, with active members from multiple regions of the world, and have at least one significant work programme specifically focused on accelerating emissions reduction in that sector. The list is not exhaustive and will be updated over time.

Priority areas for international collaboration

The transition to clean power has already significantly benefited from the alignment of many country, regional, and international actions, especially in support of the deployment of solar and wind power. With each doubling of their cumulative deployment, the cost of solar PV has fallen around 28%, and wind power by around 15% (BNEF, 2020). The limited time left to 2030 accentuates the need for a change of pace, which can be achieved only if underpinned by strong and focused international cooperation. Five areas stand out as particularly important for further strengthening: research and innovation; international assistance and finance; effective and wide-ranging engagement; cross-border trade; and demand creation and management.

Increasing research and systemic innovation in key challenge areas to unlock affordable, resilient and widespread net zero power systems

Research and innovation within the power sector is key to achieving system-wide synergies and unlocking solutions for net zero. If the power system is to constantly balance demand and supply, while also relying on large shares of renewable electricity from wind and solar, electricity systems need to be flexible. Leveraging only existing flexible generation will not be enough to ensure that variable renewable energy represents a large share of electricity supply in every region. Solutions such as electricity storage, interconnections, and demand-side flexibility – including sector coupling (i.e. power-to-mobility, power-to-heating and cooling, and power-to-gas) – are key. Best practices from systems operating with large shares of solar and wind today can set the path for others to follow for power sector transformation in the next decade.

Attaining net zero power systems with high shares of renewables requires a suite of innovations. International cooperation will be essential to fill the gaps, scaling-up the innovation process, and broadening adoption. While it is positive that global investment in energy RD&D has been rising steadily in recent years (to USD 38 billion in 2021, 90% of which was low-carbon energy RD&D) (IEA, 2022b), more widespread demonstration programmes will be required.

Innovation processes must also extend to decentralised systems for universal access to energy. Beyond technology, innovations in business models and market design play a critical role.

As the share of variable renewables grows, flexibility-related solutions will increase in importance. For instance, energy storage will be used to improve the low-carbon dispatchability of the system. There are many pilot projects, but countries would benefit from systematic exchange of learning from successful and scalable demonstration projects to help accelerate collective learning and encourage investment in replicable projects.

Moreover, creation of a piloting environment that permits the initial deployment and testing of innovative products and services could offer impactful learning opportunities and allow the highest performing solutions to mature in a learning-focused environment. Innovations are not only technological; they also include innovations in market designs, system operation and business models. Collaboration among a broad spectrum of existing and new players inside and outside the power system greatly enhances the chances of success. Policy makers, utilities, transmission and distribution system operators, and unions need to work in tandem to realise the necessary change.

There exist well-established platforms and initiatives for facilitating collaboration in power sector innovation, such as the Green Powered Future Mission (of Mission Innovation). In 2021, its members set out a roadmap identifying 100 innovation priorities that need to be tackled this decade across system flexibility, data and digitalisation, and improved variable renewable energy technologies. However, widespread practical learning between major world-leading projects and respective members is yet to reach the scale required.

Together, public and private funding of RD&D needs to foster innovation across the various dimensions of the power sector value chain encompassing technology, infrastructure, financing, business models, market design, regulation, governance, and institutional frameworks. Given the relative maturity of power sector transitions, the private sector should be the primary funder of RD&D. However, public funding for RD&D is needed to address systemic issues, including market failures and outdated structures.

Recommendation 1

Governments, working with companies, MDBs and investors, should agree a clear set of strategic priority projects to demonstrate and test power system flexibility solutions, including but not limited to energy storage, in a wide variety of contexts. This should build upon existing initiatives and involve the systematic sharing of learning from different geographical, climatic and market settings. *This will increase confidence in delivering net zero power systems in a broader set of markets, supported by increasingly affordable and effective technologies.*

International Assistance and Finance

To meet the 2030 Breakthrough goal, levels of investment in low-carbon power generation need to increase significantly from the USD 400-440 billion in 2021 to USD 1 trillion per year (IRENA, 2022c). The bulk of this investment will come from the private sector - in 2019, USD 1.6 trillion in energy assets were financed by private sources, accounting for 80% of total energy sector investment. Public financing, however, will play a crucial role in catalysing private investment, as markets alone are not likely to move rapidly enough. Public funds are also needed to create an enabling environment for the transition and to ensure: 1) that it occurs fast enough to meet climate goals, and 2) it unfolds in a just and inclusive way, with the best possible socio-economic outcomes. International collaboration can play an important role in this by supporting policy frameworks, transition-related funds, concessional finance and de-risking mechanisms.

In support of the development of clean energy infrastructure, countries and multilateral finance institutions dedicated over USD 100 billion to international development assistance over the period 2002-2019. A large share of this has been focused on the power sector. To date, these financial flows have been concentrated in a limited number of countries and regions, with 80% going to just 30 countries from 2010 to 2019 (Aid Atlas, 2022).

International assistance has, in some cases, been difficult for developing countries to access, involving long and burdensome application processes. The profusion of programmes in the sector can lead to duplication of efforts and lack of clarity from both donors and recipients regarding the assistance being provided, for what purpose, and whether or not it is relevant or effective. Importantly, they often have been a burden on already-limited local capacities. While highly valuable to transfer knowledge and develop local expertise, technical assistance efforts can also underperform when they are not linked to on-the-ground realities since significant policy reforms typically require political leadership and commitment, and the buy-in of local stakeholders such as utilities.

In recent years, there have been improvements in the structures for international assistance in the power sector to make it more coherent and effective. At the UN Climate Action Summit in 2019, the Climate Investment Platform was launched by IRENA, SE4ALL and UNDP in cooperation with GCF, with the aim of “decluttering the finance landscape” by matching available funds and developing country needs. In 2020, the Energy Transition Council (ETC) was launched by a group of countries, multilateral development banks, and international organisations to bring scaled-up practical and financial assistance for the power sector transition together with political dialogue. The ETC includes a Rapid Response Facility, in which experts from leading institutions aim to provide practical assistance in response to developing countries' requests within short timelines. Similar assistance could be tapped through the Climate Technology Centre and Network (CTCN) and the Clean Energy Solutions Centre hosted by the National Renewable Energy Laboratory (NREL). At COP26, the Global Energy Alliance for People and Planet was launched, offering more flexible finance through a combination of philanthropic grants and development bank lending.

For the transition to low-carbon power to proceed at the necessary pace, efforts need to be continued, streamlined and strengthened. The support available to developing countries must be made clearer, easier to access, and more responsive. It also should be inclusive, to ensure all who need to play a role are at the table. Accompanying this assistance with political dialogue is essential to build the confidence that developing countries need to implement significant policy reforms and integrate climate action in national budgets and strategies, and that development partners will require to commit to higher-risk investments.

Donors should strive to better align their efforts to respond to the urgent needs to accelerate deployment of low-carbon power solutions, while avoiding duplication of effort and the unnecessary burden on already limited human resources. Such streamlining of support should be done along three dimensions: 1) greater upfront engagement and coordination to better identify local priorities and needs; 2) upon request, strengthening in-country capacity (including, for example, by embedding advisers in the ministry responsible for power who can provide technical advice and support donor coordination); and 3) creating an accessible and transparent system that makes clear what technical and financial assistance may be available to each developing country.

Recommendation 2

Donor governments, working with key institutions, initiatives, and funds, should increase the scale, coordination, transparency and accessibility of international support for the power sector transition, building on established frameworks and successful models. Along with other forms of support, donor countries should, where requested, facilitate more power sector experts working within developing country governments to strengthen their capacity to make use of international support, implement policy and regulatory reforms and leverage private finance. *This will provide developing countries with the resources they need to deliver on a rapid acceleration towards a net zero power system.*

Ensure effective and wide-ranging engagement and acceptance of transition plans across the power sector and associated supply chains

Social support for the transition to low-carbon power is important in all countries, but especially so in countries and regions where many people are employed by the fossil fuel industry. The global project pipeline of proposed new coal power plants has been reduced by over 75% since 2015 (E3G, 2021), and the cost gap between coal and renewables is only going to widen in renewables' favour. In 2019, 56% of utility-scale renewable capacity added already cost less than the cheapest new coal option (IRENA, 2022e). These trends, bolstered by the political commitment of all countries at COP26 to phase down the use of unabated coal power, accentuate the need for a carefully managed transition.

Research indicates that investing in renewable energy creates more jobs than investing in fossil fuels (IRENA, 2021a). Thus, as the energy transition unfolds, it is likely that most countries will be able to create growing energy sector employment. However, there may be a variety of misalignments, since new jobs may not be created on the same timescale or the same geographies as the loss of old jobs. In regions of high economic dependence on fossil fuel-related industries, the potential loss of many jobs, as well as local tax revenues, can pose substantial risks to social wellbeing, economic development, and the political feasibility of energy transition policies. Therefore, it is essential to design and implement a set of just transition policies that help affected workers and communities successfully navigate through the energy transition, and that give them a strong voice along the way.

Box 2.1 South Africa's Just Energy Transition Partnership

South Africa has the most coal-intensive economy of the G20 - depending on it for 87% of its electricity. The Just Energy Transition Partnership (JET-P) was developed in cooperation with South Africa and France, Germany, the European Union, the United Kingdom, and the United States, who agreed to provide an initial commitment of USD 8.5 billion through just transition interventions, power sector decarbonisation, and economic diversification into future energy sectors, including electric vehicles and green hydrogen.

In June 2022, the G7 agreed on the implementation plan, with the view to having the final JET-P investment plan signed off by November. Also, the G7 affirmed their intent to move forward in negotiations with Indonesia, India, Senegal and Vietnam on JETPs to support energy policy reforms, with a view to decarbonising energy systems and increasing energy efficiency.

This process will require social dialogue[4] and adherence to existing labour standards, supporting the strengthening of social security and protection provisions, providing technical assistance for the repurposing of fossil fuel infrastructure, investing in regional revitalisation programmes and providing targeted regional development finance to support the creation of new jobs and industries. New jobs in clean energy must be jobs that pay well and adhere to occupational health and safety standards. The National Offshore Wind Agreement between Ørsted and the North America's Building Trades Unions (NABTU) represents a positive example to learn from (Ørsted, 2022).

Historically, most of the international assistance in the power sector has focused on more technical market reform issues. Recently, this has begun to change. In the European Union, the Just Transition Mechanism will provide EUR 55 billion over 2021-2027 to support the most coal-intensive regions through the transition (EC, 2019). Since 2019, the European Bank for Reconstruction and Development (EBRD) has provided support for coal transitions in countries neighbouring the EU, including for retraining of workers and economic diversification (EBRD, 2020). The World Bank provides support for coal mine closures, investment and regional development. In 2021, the Climate Investment Funds (CIF) launched the Accelerating Coal Transition Investment Program (CIF, 2021), which will support repurposing of fossil fuel infrastructure, retraining of workers, and planning for economic and social development, beginning with pilot projects in four countries. International cooperation and targeted support to countries on just transitions is also

[4] See, for example, the International Labour Organization's (ILO) Guidelines for a Just Transition report negotiated in 2015.

provided by expert organisations, including the International Labour Organization (ILO), IRENA, the International Trade Union Confederation, and initiatives such as the IEA Global Commission on People-Centred Clean Energy Transitions, and the Sustainable Energy Jobs Platform, among others.

Exchange of best practices and experiences already takes place in these fora. However, given the scale of the challenge, there is a clear need to increase international cooperation systematically and comprehensively. It is essential to recognise that regions and countries face markedly different contexts with varying starting points, socio-economic development priorities and resources. Strong institutions will be needed to coordinate structural and just transition policies and manage potential misalignments. Importantly, achieving a just transition will depend on healthy international flows of finance, capacity and technology. MDBs, in particular, are well placed to target development assistance where it is most needed and should aim to support governments in developing plans and mobilising investment for economic diversification, institution-building, retraining of workers, and social security through the course of the transition.

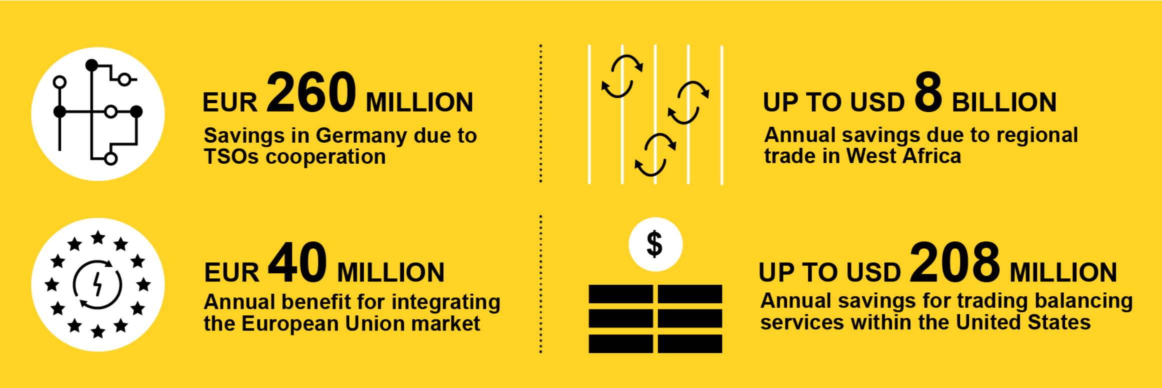
RECOMMENDATION 3

Donor governments and MDBs should work together to more strongly align development funding with targeted support for local jobs, skills, and investment, for the repurposing of fossil fuel assets and for environmental restoration, in the fossil-fuel-dependent regions and communities. Civil society, governments and industry should contribute to creating international centres of expertise on the just transition, within existing institutions. *This action will be vital to ensure inclusive and participatory transition processes, effective social protection for affected workers and communities, and better economic and environmental outcomes.*

PROMOTE ELECTRICITY TRADE THROUGH INTERCONNECTIONS

Cross-border or regional cooperation is often essential to boosting efficiencies and bringing about economies of scale in the deployment of low-carbon energy technologies. Adopting an integrated approach to trans-boundary energy issues – such as planning, trade, regulatory frameworks and policies, regional power infrastructure and other factors – allows countries to benefit from access to a wider range of resources at affordable prices. Importantly, an integrated approach facilitates the investment at scale that is necessary for countries to meet their development and climate targets.

Figure 2.7 Impact of interconnections and regional markets on operation costs



Source: IRENA, 2020.

Creating a regional market by building or taking advantage of interconnections between countries is also an effective way of increasing flexibility in power systems. Increased transmission capacity and interconnections allows electricity to be transported more readily, meaning that more resources can be used to help balance supply and demand. Consequently, operators in different systems can buy and sell electricity and other grid services from one another, creating regional markets. By sharing resources over larger regions, the need for operating reserves, as well as curtailment requirements and costs, are reduced.

There are several regional interconnections currently operational in the world. The largest is the European interconnection managed by European Network of Transmission System Operators (ENTSO-E), trading around 445 TWh of electricity across 35 countries in 2019 (UNSD, 2022). A number of other projects are under development. For instance, the African Continental Power Systems Master Plan (CMP) is an ongoing initiative led by the African Union Development Agency (AUDA-NEPAD) that aims to establish a long-term continent-wide planning process for power generation and transmission involving all five African power pools (IRENA, 2021). The economic case for these projects is only strengthening as the technology of interconnectors continues to improve.[5]

While there is plenty of room for innovation and technical improvement of cross-border and regional interconnections, the current solutions already provide increased grid flexibility and stability to the countries where in use. The techno-economic feasibility of multiple new regional interconnections has been demonstrated, but the implementation is lagging, in large part due to lack of political support. Regional interconnections are complex projects that require agreements between national governments, transmission system operators (TSOs), market regulators, and electricity producers, among others. Traditionally, many of these stakeholders operate in strictly national settings so creating new or leveraging existing regional agreements and entities to devise rules for the interconnection is crucial for success.

[5] For example, ultra-high-voltage direct current (UHVDC), high-voltage direct current (HVDC), voltage source converters (VSC), and smart grids.

International cooperation can help overcome barriers and create blueprints across areas to accelerate progress in the ongoing efforts. Countries should identify and prioritise non-technical barriers for regional interconnections that are usually the most common and most difficult to overcome, and that often require diplomatic support and international cooperation for platforms/institutions. Existing regional institutions should help harmonise the rules of all participating markets. Given the need for substantial infrastructure investment, MDBs should be an active player in supporting the planning and resource mobilisation efforts.

RECOMMENDATION 4

Governments should work together to reassess the opportunities for cross-border and regional power interconnections and smart grids to support the transition to clean power systems, including opportunities that have been previously considered but not taken forward given the improving technology, falling costs, and increasing need for system flexibility. Countries and investors should support international efforts to identify top regional priorities for interconnection, and to replicate successful approaches to technical agreements. *In doing so, countries can access new opportunities to integrate larger shares of renewables and improve system reliability.*

RAPIDLY MOVE THE LARGEST MARKETS FOR KEY ELECTRICAL APPLIANCES TO HIGHER COMMON MINIMUM ENERGY EFFICIENCY STANDARDS

Energy efficiency will be vital in enabling all new demand for power to be met by low-carbon sources, particularly within emerging economies. A doubling of the current rate of decline in the energy intensity of the global economy from 2% to 4% per year over this decade is required for a 1.5°C aligned pathway, and yet rates of energy efficiency improvements have slowed in recent years. Compared to the current policies, a doubling of the current rate of energy intensity improvement has the potential to avoid 96 EJ a year of final energy consumption; equivalent to the current final energy consumption of China (IEA, 2021b).

There is renewed interest from countries to prioritise energy efficiency, particularly when facing the challenge of electrifying major end-use sectors such as heating, cooling, and transport, alongside growing energy security concerns. Rapid adoption of the best available end-use technologies enables a faster transition to low-carbon power systems, allowing low-carbon power generation to supply a greater share of demand.

Best practice efficiency policies, such as standards and labelling, have already halved energy consumption of high energy using appliances and are delivering a reduction of 15%

of total current electricity consumption in countries that have adopted them. In nine countries covered in an analysis of such policies, energy efficiency programmes reduced annual electricity consumption by around 1 580 TWh in 2018. This is a similar order of magnitude to the total electricity generation of wind and solar energy in those countries in 2018 (IEA, 2021d).

The principal organisations and initiatives involved in facilitating international collaboration around energy efficient electrical appliances are the IEA's Energy-Efficient End-use Equipment initiative (4E) and the CEM's Super-Efficient Appliance Deployment initiative (SEAD).

4E was established under the IEA's Technology Collaboration Programme (TCP) in 2008, with representatives from 15 countries regularly engaging in detailed, technical discussions around energy efficient appliances.

SEAD was established in 2009 and has been active in facilitating international collaboration on energy efficiency. Current membership covers 22 governments, plus the EU. At COP26, SEAD launched the Product Efficiency Call to Action, with the goal of doubling the efficiency of four priority products by 2030, which account for 40% of global electricity consumption, and includes air conditioners, refrigerators, motors, and lighting.

Countries should build on the Product Efficiency Call to Action under SEAD and work to agree higher minimum energy performance standards (MEPS) for the highest energy-consuming appliances, aiming to cover a majority of the global market. This would send a clear signal to industry, moving markets towards higher efficiency products that reduce costs as well as emissions.

Higher MEPS should also be complemented by wider information and incentives programmes, such as awareness raising around energy consumption for different consumer groups, and energy efficiency retrofit incentive programmes. Bringing all appliances in the economy in line with MEPS takes time, because once new standards are put in place it can be many years before the existing inefficient stock is replaced. This highlights the role of incentives and replacement schemes to remove old, inefficient equipment from use faster, especially in countries with less mature programmes.

To increase the uptake of energy efficient appliances in emerging economies, developed countries should improve the current financial and technical assistance offers to support the implementation of policies such as appliance and equipment standards, incentive schemes and information campaigns. This can facilitate the adoption of these policies in countries which currently lack the resources and or expertise. This needs to be replicated across multiple jurisdictions simultaneously, with coordinated support from donor countries and expert organisations.

Recommendation 5

Countries, in consultation with industry, should collectively agree to higher minimum energy performance standards for high energy-consuming appliances, supported by awareness campaigns and incentives, such as energy efficiency retrofit programmes. Improved technical assistance should facilitate the implementation of effective standards in developing countries. *This will help to cut energy costs and reduce emissions, as well as mitigate future electricity demand growth, easing pressure on renewables and electricity infrastructure deployment.*

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ANNEX

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Long-term vision and action plans	Governments and companies should develop and implement plans for managing the transition away from high-carbon power systems and associated supply chains, working closely with local communities and workers. These long-term plans should start to set out the practicalities of delivering net zero power systems, including details on technology and policy.	56 electricity utilities, independent power producers and energy traders have near-term targets approved by the Science-based Targets initiative (SBTi), in line with 2°C or below.
Demand creation and management	In the early 2020s, governments and companies should continue to build short-term confidence in the demand for low-carbon electricity, through policies and commitments, such as procurement strategies. Beyond creating demand, governments and companies should also take actions to maximise the efficiency of electricity use. This should include aligning regulations across multiple markets, such as minimum energy performance standards. This should be accompanied by incentives and awareness raising campaigns, to accelerate deployment in the early 2020s.	377 members in RE100, committed to 100% renewables.
Infrastructure and supply chains	Investments in grid infrastructure will need to scale rapidly to support increased renewable supply and electrification of end-uses. Governments and companies should work to further diversify vital supply chains, to mitigate against supply-side shocks, such as the world saw during the Covid-19 pandemic.	
Finance and investment	Governments and companies will need to accelerate the recent positive trends in investment in the power sector. This includes continued investments in renewables, as well as supporting infrastructure, such as electricity grids. At the same time, investments in fossil fuel power generation, particularly coal, will need to decline. Governments, together with multilateral development banks, will need to expand and strengthen international assistance to ensure that developing countries can access, adapt, and rapidly deploy low-carbon technologies to meet their needs and priorities by the	Over USD 900 billion in investment in the power sector in 2021. Over USD 100 billion of climate finance provided for the energy sector between 2002-2019.

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
	early 2020s. This will require increasing the levels and improving the coordination and focus of financial and technical assistance.	At least USD 8 billion of climate finance for electricity provided in 2020.
Research and innovation	Governments and companies need to further increase investments in research, development and demonstration (RD&D). In particular, this should focus on deploying novel renewable generation technologies, long-term power system flexibility and digitalisation that will be vital for the delivery of net zero power systems.	TRLs for key technologies Ocean wave – TRL 4 Tidal stream – TRL 5 Compressed air storage – TRL 8 Redox flow batteries – TRL 8
Market structures	Governments will need to implement electricity market reforms to accelerate the shift away from fossil fuel power generation, while ensuring affordable and secure supply. This may require new auction mechanisms, processes for valuing firm, low-carbon supply and minimising the use of fossil fuel power generation.	
Trade conditions	In the early 2020s, governments and regional bodies should assess and or reassess options for new interconnectors to facilitate increased electricity trade between countries. This will help improve grid flexibility and security of supply, supporting further integration of renewables.	
Knowledge, capability and skills	Governments and companies will need to undertake broad stakeholder engagement and holistic policy frameworks to anticipate risks, maximise socio-economic benefits, and value creation in order to achieve desired outcomes. It will be important for governments to ensure that strategies for retraining can use existing skills in the energy sector, where possible, and do not exacerbate inequalities as fossil fuel jobs wind down.	12 million renewable energy jobs in 2020, up from 10 million in 2015.
Social acceptance	Governments and companies, in close collaboration with affected communities, should develop and implement plans for managing the transition away from high-carbon power systems and associated supply chains, working closely with local communities and workers. This will include repurposing obsolete assets, environmental restoration, and investment in local jobs and skills, particularly in fossil fuel-dependent regions and communities.	

CHAPTER 3. HYDROGEN

"Affordable renewable and low-carbon hydrogen is globally available by 2030" -- *Hydrogen Breakthrough goal*

KEY MESSAGES

- Hydrogen only plays a narrow role in today's energy system, mainly as an industrial feedstock in the oil refining process and in the production of chemicals, with almost all hydrogen in use derived from fossil fuels.
- Renewable and low-carbon hydrogen need to replace existing fossil fuel-based hydrogen, and is set to play a vital role in supporting a rapid clean energy transition, primarily in hard-to-abate applications where there are limited alternative clean energy solutions, such as heavy industry, maritime shipping, aviation, seasonal electricity storage, and potentially segments of heavy-duty trucking. We refer to those sectors as "new priority applications".
- Progress to date has been limited, with less than 1 Mt/yr of renewable and low-carbon hydrogen produced in 2020, versus the 140-155 Mt/yr needed by 2030. This implies that production capacity needs to approximately double every year from 2023 to 2030. This in turn will require an accelerated deployment of renewable power. To reach these targets, a sharp escalation in financing across the hydrogen value chain is required.
- Common standards, higher and sustained investment in RD&D, and increased demand commitments for both low-carbon and renewable hydrogen in sectors where unabated fossil fuel hydrogen is currently used and in new priority applications can all contribute to overcoming the challenges to cost-effectively support decarbonisation.
- International collaboration on low-carbon and renewable hydrogen has a long history, with substantial activity since the mid-2000s, although there has been a significant increase in activity over the past 3-5 years.
- Stronger international action across multiple enabling conditions is imperative to accelerate the transition in the hydrogen sector and put it on track for the 2030 Breakthrough goal. Four areas stand out as priorities for strengthening international collaboration over the next 1-2 years, where we recommend the following actions:
    - Governments and companies should coordinate internationally to increase commitments for the use of low-carbon and renewable hydrogen in sectors where hydrogen is currently used, supported by specific policies and purchase

agreements, to collectively send a strong demand signal and mobilise investment in production. In new priority application sectors, countries should share learning to accelerate early deployment. *This should be done in a manner that ensures a level playing field in international trade.*

- Governments and companies should agree a comprehensive portfolio of international standards and associated certification schemes for renewable and low-carbon hydrogen, addressing emissions accounting, safety, and operational issues, including leakage. *This should be supported by a programme that provides a clear direction and sufficient resources to relevant technical bodies. This will be vital for supporting a series of other actions, most notably high-quality demand commitments and trade agreements.*
- Governments and companies should work together to dramatically increase the number and geographical distribution of hydrogen demonstration projects and to ensure that these appropriately cover each of the high-value end-use sectors, including maritime shipping, heavy industry, and long-duration energy storage. Governments and the private sector should agree on principles to guide a deeper and more rapid sharing of knowledge from these demonstrators, including a commitment to share the lessons learned from all publicly-funded demonstration projects. *Doing so will help overcome technology availability barriers and accelerate the pace of deployment in multiple regions in parallel.*
- Donor governments and MDBs should make increased levels of concessional finance available for well-targeted, catalytic uses that can mobilise large-scale private investment in hydrogen production, distribution, and end-use projects in developing countries. This should be supported by a process in which countries work with lending institutions to identify viable projects that are being delayed by high costs of capital and to assess obstacles to investment, along with technical assistance programmes to assist governments with policy design. *This will provide much-needed support for the first wave of low-carbon and renewable hydrogen projects, ensuring that a wider set of countries can deploy the technologies required.*

SIGNIFICANCE OF THE SECTOR

In today's energy system, hydrogen plays a relatively marginal role as an energy vector. It is largely used as an industrial feedstock in the oil refining process and the production of chemicals, such as fertilisers. Hydrogen production currently is almost entirely derived from fossil fuels and emitted around 900 Mt of carbon dioxide in 2020, equating to approximately 3% of global energy-related CO_2 emissions (IEA, 2021).

China accounts for nearly 30% of global demand, followed by the United States and India. These three countries combined use nearly half of the hydrogen produced. About 60% of the production is sourced from natural gas, close to 20% from coal – mainly in China – and 20% as a by-product from industrial processes. The two main routes to produce hydrogen with low greenhouse gas emissions are renewable hydrogen from electrolysis using renewable electricity, and low-carbon hydrogen from fossil fuels with carbon capture, utilisation and storage (CCUS). Both will be needed in a net zero energy system.

Hydrogen is set to play a vital role in supporting a low-carbon future, not least because it has promising potential in new priority applications where emissions are hard to abate, and where there are limited viable clean energy alternatives, including heavy industry, maritime shipping, aviation, seasonal electricity storage, and segments of heavy-duty trucking, which currently account for approximately 30% of global carbon dioxide emissions (IEA, 2020). We refer to those as "new priority applications".

SECTOR GOALS

The production and use of low-carbon and renewable hydrogen is at a very early stage of development. Under 1.5°C-aligned pathways, it is projected that hydrogen could satisfy 12-22% of global final energy demand by 2050, versus less than 1% today (IEA, 2021b; Hydrogen Council, 2022; DNV, 2021; IRENA, 2022a; BP, 2022).[1] While scenarios project demand for hydrogen to accelerate towards 2030, the next couple of years will be highly consequential for laying the groundwork to meet this potential.

Firstly, existing hydrogen use must be decarbonised by the uptake of rapidly increasing shares of both low-carbon and renewable hydrogen. The latter has the largest cost premium compared to today's unabated fossil hydrogen production (see Figure 3.3) and has the greatest potential for cost reduction in this decade. Lower costs will result from the reinforcing feedbacks of learning-by-doing and economies of scale linked to the targeted deployment of low-carbon hydrogen.

While this report does not define a specific carbon intensity limit for low-carbon and renewable hydrogen, both of these production routes 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 carbon dioxide, and that the captured carbon is permanently stored underground to prevent its release into the atmosphere. Additionally, it is critical that methane leakage is minimised to near zero, if not completely avoided. Rigorous measurement, reporting and verification of emissions will be necessary.

Secondly, the large-scale deployment of low-carbon and renewable hydrogen in new priority applications from 2030 onwards hinges on a number of key actions that must be taken this decade. Hydrogen use in those applications remains – to varying degrees – pre-commercial, which means that unlocking this potential will require concerted and globally harmonised efforts relating to RD&D, development of operational standards and guidelines, and targeted supportive policies to spur hydrogen use. Additionally, expanding renewable and low-carbon hydrogen into new priority applications will require the buildout of enabling

[1] This share excludes hydrogen use for refineries since it is not final energy demand.

infrastructure starting in this decade—including renewable electricity projects, electricity transmission, and targeted storage and transportation infrastructure, underpinned by efficient permitting processes.

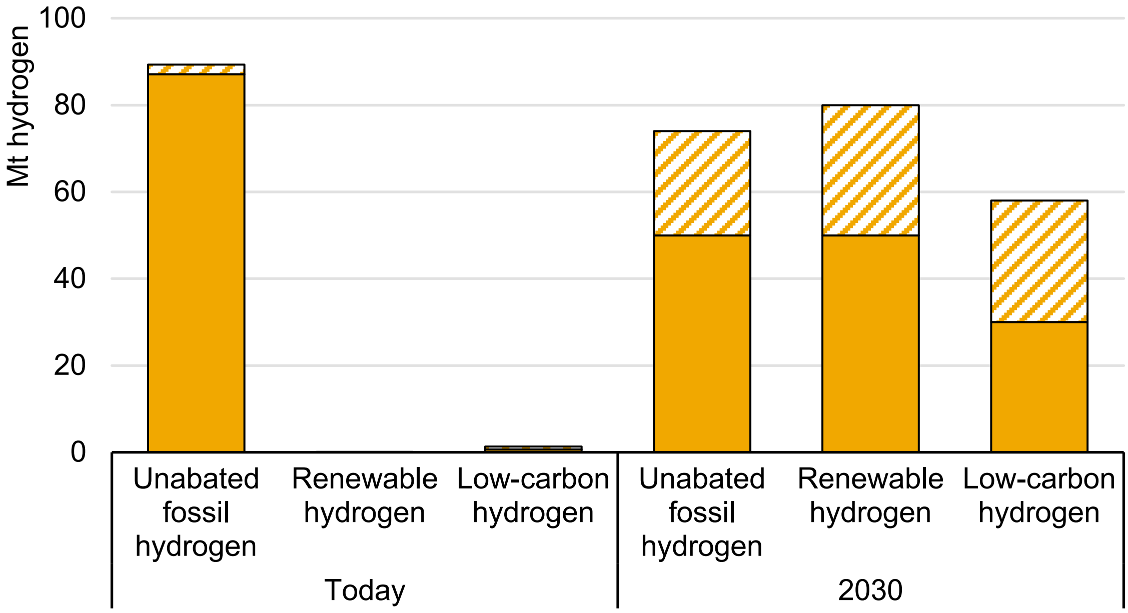
To achieve a Paris-aligned pathway, countries and companies will need to meet the Breakthrough goal for hydrogen, which 35 countries and the European Union, representing more than two-thirds of global hydrogen production and demand, endorsed at COP26:

"Affordable renewable and low carbon hydrogen is globally available by 2030."

This will require a dramatic increase in the supply of renewable and low-carbon hydrogen, meeting growing shares of demand in relevant sectors, accelerated by falling costs. By 2030, scenarios aligned with international climate goals suggest that:

- The supply of renewable and low-carbon hydrogen increases from less than 1 Mt/yr in 2020 to 140-155 Mt/yr by 2030 (see Figure 3.1). This implies that production capacity must approximately double every year from 2023 to 2030.
- The share of hydrogen in final energy demand in the chemicals sector increases from around 28% in 2020 to up to 44% in 2030 (see Figure 3.2). The rate of growth required is even higher in other sectors where there is no current use of hydrogen and where renewable and low-carbon hydrogen needs to reach shares up to 10% by 2030.
- The production cost of renewable hydrogen falls by 40-55% over the course of this decade, to almost USD 1/kgH_2 in the most favourable locations (see Figure 3.3).

Figure 3.1 Supply of unabated fossil, low-carbon and renewable hydrogen, 2020 and in 2030 in 1.5°C-compatible pathways

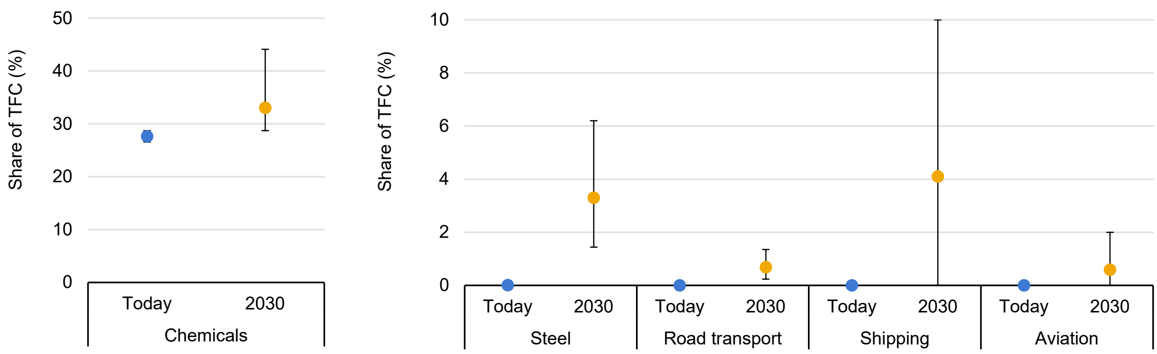


Note: Shaded bars represent the range of supply across various scenarios.
Sources: IEA, 2021b; BNEF, 2021; IRENA, 2022a; and BP, 2022.

There is a large gap to achieve such levels of hydrogen production and use. In 2020, low-carbon hydrogen production was around 0.7 Mt/yr, requiring carbon capture and storage capacity of 10 $MtCO_2$/yr (IEA, 2021a). As for renewable hydrogen, expected to have a large share of production by 2030, electrolyser capacity was less than 0.5 GW in 2020, producing below 0.1 Mt/yr.

The project pipeline for electrolysers is expanding quickly, and stands at around 50-90 GW over the coming decade (a number constantly changing with business decisions), although only a small fraction of the projects under development have reached final investment decision. While this represent a significant increase in the levels of committed projects compared with only a few years ago, it is still well below the 350-850 GW of electrolysis by 2030 that is needed to produce the 50-80 Mt/yr of renewable hydrogen projected under 1.5°C-compatible scenarios (see Figure 3.1) (IEA, 2021b; Hydrogen Council, 2021a). The upper bound of this estimate would require electricity equivalent to the entire current global wind and solar capacity.

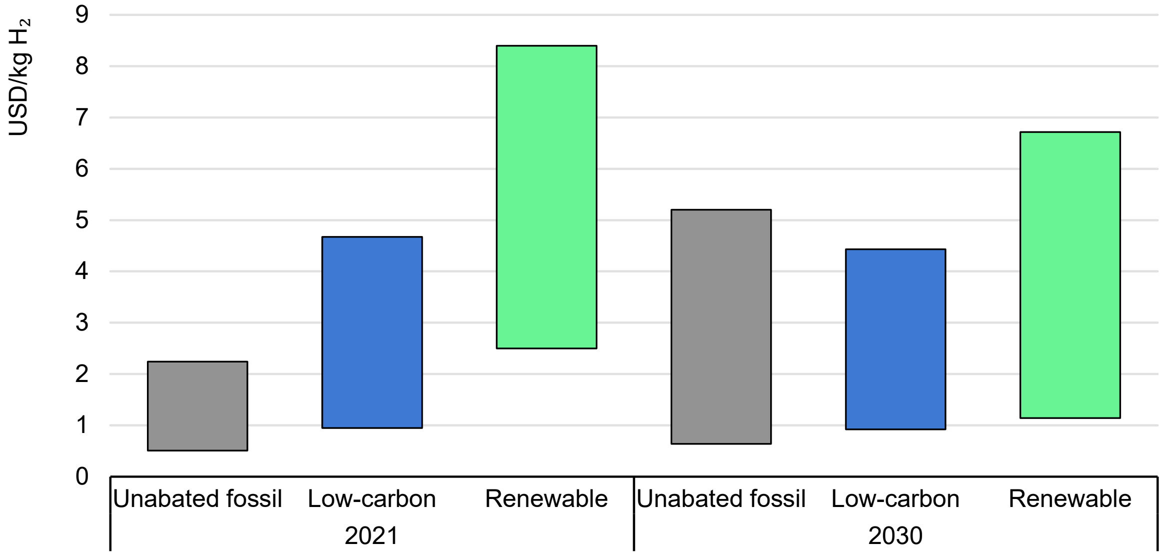
Figure 3.2 Share of total final energy consumption in selected sectors met by hydrogen today and in 2030 in 1.5°C-compatible pathways



Notes: Shipping and aviation include hydrogen derivatives. Hydrogen used for direct reduction of iron with natural gas is excluded.
Sources: IRENA, 2022a; BP, 2022; IEA, 2021b; and BNEF, 2021.

Hydrogen production from renewables was 3-5 times more expensive than hydrogen from unabated fossil fuels before the high gas prices experienced in late 2021 and 2022, but it also offers the greatest opportunities for large cost reductions (see Figure 3.3). Based on gas prices as of mid-2022, the cost of unabated fossil hydrogen could reach up to USD 10/kg H2. If ambitious action to scale-up renewable hydrogen production is taken, costs could fall by 40-55% by 2030, driven by a reduction in the cost of electricity and in the steep capital costs of the electrolyser. The cost premium for low-carbon hydrogen is currently smaller but still significant with 40-85% higher costs than the unabated route. By 2030, the cost reduction is more modest, between 0-20%, with future natural gas prices being a key uncertainty.

Figure 3.3 Levelised cost of hydrogen production by technology in 2021 and 2030



Notes: All references were published before gas prices started to rise as a consequence of the current energy crisis. Based on gas prices of USD 200/MWh (vs historical averages of USD 15-20/MWh in Europe), the levelised cost of unabated fossil hydrogen could reach up to USD 10/kg H2.
Sources : IRENA 2022c; IEA, 2021a; ETC, 2021; IRENA, 2020; and BNEF, 2020.

HOW DO WE GET THERE?

Ambitious and thoughtfully tailored action across a set of enabling conditions early in this decade will be critical to ensure the requisite production, storage, transportation and end-use technologies can support fast-paced growth in low-carbon and renewable hydrogen supplies. However, there are a multitude of risks and challenges that require careful attention.[2] Beyond increasing affordability and availability, the manner in which the Breakthrough goal is achieved – including the specific low-carbon and renewable hydrogen end uses that are stimulated along the way and the climate impacts of hydrogen deployment – is just as important.

Governments and companies need to create dependable and durable demand to help de-risk near-term investments in capital-intensive low-carbon and renewable hydrogen supply. This includes supportive policy mechanisms and purchase agreements to boost the deployment where hydrogen is already used, such as fertiliser production and oil refining. Potential mechanisms include volume instruments such as minimum quotas for low-carbon hydrogen use, public procurement policies and carbon contracts for differences (CFDs).

Supportive policy mechanisms should also be adopted to increase use in new priority applications where hydrogen and its derivatives are poised to be a more cost-effective decarbonisation solution than alternatives.

[2] Hydrogen production, transport and use incur high energy losses, such that its widespread use across sectors that can be more efficiently decarbonised with alternative clean energy solutions may increase the costs of transitioning to a clean economy. Hydrogen production can be highly emitting absent rigorous and verifiable emissions standards. Hydrogen is an indirect GHG which, when it leaks into the atmosphere, can contribute to climate warming.

Hydrogen deployment must be underpinned by rigorous emission standards. This should complement demand-side actions in the early 2020s, ensuring this deployment is aligned with climate targets, fostering consumer and investor confidence in a low-carbon hydrogen market and harmonising investment signals across jurisdictions.

Alongside emission standards, governments and companies must develop common and robust hydrogen leakage detection and repair protocols and solutions. This should be supported by diligent measurement, reporting and verification schemes to prevent high hydrogen leakage rates contributing to global warming.[3] In addition, globally harmonised safety and operational standards must be developed for new priority hydrogen applications, including maritime shipping, heavy-duty trucks and steelmaking. These should be developed alongside the RD&D programmes and demand-side commitments associated with these applications. This should result in technologies reaching commercial-scale for new end uses by the mid- to late-2020s.

Governments and companies will need to increase investments in research, development and demonstration to accelerate the advancement of hydrogen and its derivatives in new priority applications. Hydrogen use in those applications is largely pre-commercial today and requires concerted RD&D to reach commercial viability. Many of the relevant technologies should be demonstrated to reach commercialisation by the mid-2020s (e.g. steel), and all should be commercially viable by no later than 2030.

This will require adequate and sustained financing across the hydrogen value chain. Hydrogen deployment consistent with a 1.5ºC-aligned pathway will require an annual investment of around USD 60-130 billion through to 2030, relative to the less than USD 1 billion invested annually, on average, over the last decade (IEA, 2021a; IRENA, 2022b; Hydrogen Council, 2021a; BNEF, 2021; ETC, 2021). While the bulk of this investment must come from the private sector, governments have a key role to play in mobilising investments by putting in place policies that can de-risk early projects and support private sector engagement. As the pace of deployment increases, governments and companies will need to develop long-term plans for supporting infrastructure. This needs to include renewable electricity generation, electricity and gas transmission and distribution, and carbon capture, storage and infrastructure. These should make best use of existing assets, where possible, including the repurposing of natural gas infrastructure.

Governments and companies will need ensure major ports are ready to handle hydrogen (and derivatives), facilitating the global trade of renewable and low-carbon hydrogen. Again, there will be opportunities to reuse existing infrastructure to reduce costs. Through the mid- to late-2020s, this will support the signing of long-term contracts for the trade of hydrogen, further building confidence in supply chains.

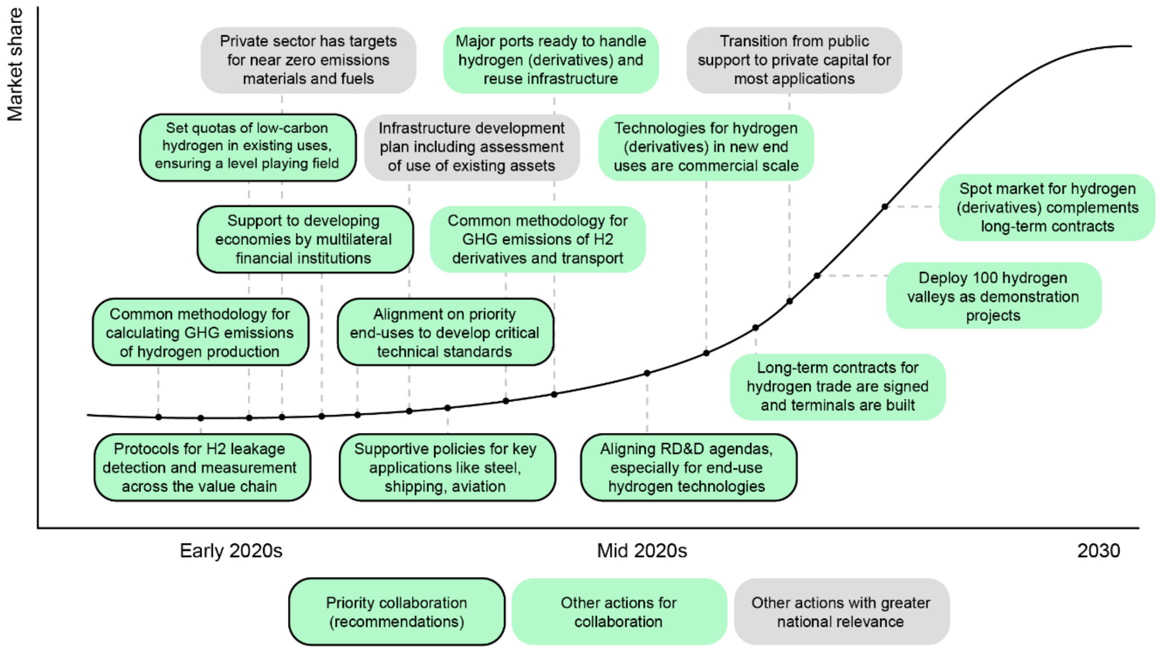
Recommended reports

We recommend the following reports for more detailed descriptions of the actions that countries and businesses can take individually to bring low-carbon and renewable hydrogen to scale.

[3] Hydrogen has an indirect global warming potential equivalent to 11 +/- 5 for a 100-year horizon (Warwick et al., 2022).

- The Future of Hydrogen (IEA, 2019).
- Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy (Energy Transitions Commission, 2021).
- Global Hydrogen Review 2021 (IEA, 2021).
- Methodology for Determining the Greenhouse Gas Emissions Associated With the Production of Hydrogen (IPHE, 2021).
- Geopolitics of the Energy Transformation: The Hydrogen Factor (IRENA, 2022).
- Global Hydrogen Trade to Meet the 1.5°C Climate Goal: Green Hydrogen Cost and Potential (IRENA, 2022).
- International Trade Rules for Hydrogen and its Carriers: Information and Issues for Consideration (IPHE, 2022).

Figure 3.4 Critical path to 2030 for low-carbon and renewable hydrogen and derivatives



CURRENT STATE OF INTERNATIONAL COLLABORATION

International collaboration on low-carbon and renewable hydrogen has a long history. Its initial focus was on setting long-term visions on the role of hydrogen in the energy sector, defining common standards, and research, development and demonstration.

Since 2003, the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), has been sharing information and facilitating work on standards and safety issues, more recently emphasising collaborative work on GHG quantification methodologies.

International collaboration on research and development began under the IEA's Hydrogen Technology Collaboration Programme (TCP) in 1977, covering 26 Contracting Parties (24 countries, the European Commission and UNIDO) and seven private Sponsor Members. The Hydrogen TCP publishes regular reports with the research outcomes of the tasks in which its network of researchers collaborate. The Advanced Fuel Cells TCP (16 members) conducts analyses and shares knowledge on stationary, transportation and portable applications of fuel cells. In 2021, Mission Innovation launched the new Clean Hydrogen Mission, which focuses on catalysing cost reductions by increasing research and development in hydrogen technologies and industrial processes.

Over the past five years, there has been rapid growth in both public and private sector collaboration on hydrogen. The Japan-led Hydrogen Energy Ministerial was established in 2018, and this was followed by the launch of the Hydrogen Initiative under the Clean Energy Ministerial in 2019 (24 members), and the Collaborative Framework on Green Hydrogen, from IRENA (with 168 members) in 2020.

With these new initiatives, collaboration on hydrogen has expanded from research and development into exchange of policy best practice, accelerating near-term deployment, and defining international market principles. While interest in hydrogen during the 2000s largely focused on its use as a road transport fuel, more recently the scope of collaboration has encompassed end-use applications including steel, aviation, and power system balancing. And while much of the initial activity took place among advanced economies, developing countries are now also launching collaborative initiatives. For example, the members of the Africa Green Hydrogen Alliance, founded by Egypt, Kenya, Mauritania, Morocco, Namibia and South Africa, are collaborating on public and regulatory policy, financing and certification, to mobilise green hydrogen production for domestic and international use. As governments start to implement hydrogen strategies, collaboration in these fora has become more meaningful, allowing countries to learn from real-world examples of successful technology deployment of policy support.

Key private sector initiatives include the Hydrogen Council, which has over 130 members representing all parts of the supply chain. The Hydrogen Council has been proactive in publishing reports about the status and perspectives of hydrogen technologies, policy instruments to support their deployment and coordinating member advocacy to shape government policy. The Green Hydrogen Organisation, Green Hydrogen Catapult and First Movers Coalition are three examples of additional private sector initiatives that aim to create lead markets for low-carbon and renewable hydrogen. The Green Hydrogen Organisation, which also engages extensively with civil society organisations, has recently presented a first of a kind green hydrogen certificate to be voluntarily adopted by hydrogen projects. Additionally, the WEF Accelerating Clean Hydrogen Initiative aims to remove key barriers, boost the hydrogen economy towards a fully realised net zero economy, and expedite the pathway of projects from announcement to operation.

Figure 3.5 Landscape map of key international hydrogen initiatives

Long-term Vision & Action Plans	Hydrogen Energy Ministerial (HEM); CEM Hydrogen Initiative; IRENA's Collaborative Framework on Green Hydrogen; Mission Innovation's Clean Hydrogen Mission; Hydrogen Council
Demand Creation & Management	First Mover Coalition; WEF's Accelerating Clean Hydrogen Initiative; CEM Hydrogen Initiative; Hydrogen Council; Green Hydrogen Catapult; H2Global; Mission Innovation's Clean Hydrogen Mission
Infrastructure & Supply Chains	CEM Hydrogen Initiative; Hydrogen Council; Green Hydrogen Catapult; IEA's Hydrogen TCP; IRENA's Collaborative Framework on Green Hydrogen
Finance & Investment	[Activities of DFIs and MDBs e.g. World Bank]; WEF's Accelerating Clean Hydrogen Initiative; Green Hydrogen Organisation; Hydrogen Council
Research & Innovation	Mission Innovation's Clean Hydrogen Mission; IEA's Hydrogen TCP and the Advanced Fuel Cells TCP; Green Hydrogen Catapult
Market Structures	International Partnership for Hydrogen & Fuel Cells in the Economy; CEM Hydrogen Initiative; Green Hydrogen Organisation; WEF's Accelerating Clean Hydrogen Initiative
Standards & Certification	International Partnership for Hydrogen & Fuel Cells in the Economy; IEA's Hydrogen TCP; Green Hydrogen Organisation; IRENA's Collaborative Framework on Green Hydrogen; Hydrogen Action Pact; Hydrogen Council; Hydrogen Energy Ministerial (HEM)
Trade Conditions	International Partnership for Hydrogen & Fuel Cells in the Economy; CEM Hydrogen Initiative; Green Hydrogen Organisation; Hydrogen Action Pact; WEF's Accelerating Clean Hydrogen Initiative; IRENA's Collaborative Framework on Green Hydrogen
Knowledge, Capability & Skills	International Partnership for Hydrogen & Fuel Cells in the Economy; CEM Hydrogen Initiative; Mission Innovation's Clean Hydrogen Mission; Green Hydrogen Organisation; UNIDO Global Programme for Green Hydrogen in Industry; Hydrogen Energy Ministerial (HEM); IEA's Hydrogen TCP & Fuel Cell's TCP
Social Engagement & Impact	Green Hydrogen Organisation
Landscape Coordination	Hydrogen Breakthrough in partnership with the initiatives above

Note: The diagram summarises the roles of many public and private sector initiatives in this sector. Initiatives have been included if they have a global scope, with active members from multiple regions of the world, and have at least one significant work programme specifically focused on accelerating emissions reduction in this sector. The list is not exhaustive and will be updated over time.

In summary, international collaboration around hydrogen is well established and wide ranging, and the institutions and initiatives needed to deliver are largely in place. That said, additional resources and stronger collective actions within this structure will be necessary to make faster progress in the development of the sector.

PRIORITY AREAS FOR INTERNATIONAL COLLABORATION

There are four key areas that stand out as immediate priorities for strengthening international collaboration: demand creation; standards and certification; research and innovation; and financial and technical assistance. These represent priorities for international collaboration over the next 1-2 years, which can unlock further actions and faster progress later in the decade.

COORDINATING ACTION TO CREATE TARGETED DEMAND FOR LOW-CARBON AND RENEWABLE HYDROGEN, STARTING WITH EXISTING INDUSTRIAL APPLICATIONS

As noted previously, almost all hydrogen produced today is sourced from fossil fuels. And in some of the sectors where it may be most useful for decarbonisation, hydrogen is barely used at all. As a result, an entirely new set of demand creation policies, trade structures, regulations and business models are needed for a renewable and low-carbon hydrogen market.

Strong demand creation policies are a key pillar for low-carbon and renewable hydrogen in sectors where unabated fossil-fuel hydrogen is currently used, and for hydrogen and its derivatives in applications where it is not yet used. At the national level, governments can create demand using policies that either act on price (to close the cost gap with fossil fuel alternatives) or on volume. Volume-based policies include public procurement and mandates that require a minimum share of renewable and low-carbon hydrogen use in specific sectors. The private sector, similarly, can support demand creation through commitments to use a fixed volume (or achieve a certain share) of hydrogen in specific applications, and by investing in hydrogen-using assets.

International collaboration can support faster growth in demand for low-carbon and renewable hydrogen in three ways: exchanging policy best practice; aggregating demand to accelerate cost reduction; and creating level playing fields in competitive sectors.

Exchanging best practice on policy design and implementation. Understanding what has worked in specific countries and settings can help to replicate successes and avoid mistakes. Countries are already developing and implementing a diverse range of policy approaches: the United Kingdom is proceeding with a contractual producer-focused hydrogen business model which also encourages end-user uptake; Germany is considering (carbon) contracts for difference to promote hydrogen use in industry; Portugal and India are testing auctions for hydrogen supply; and the United States is considering a production tax credit to reduce the cost of low-carbon hydrogen production. Comprehensively sharing the lessons learned from the design and implementation of these and other policies could help many countries identify more quickly the approaches that will be effective in their own national circumstances.

Several international initiatives already support mutual learning between countries on hydrogen policy. Faster progress could be supported by a more concerted effort to share learning between international initiatives that have differing regional or thematic focus areas. For example, some initiatives focus on the conditions of a particular geographic region, and aim to tackle local barriers to hydrogen deployment. While each of these can be valuable, regional initiatives cannot easily tap into the experience and lessons learned in more distant markets. This leaves knowledge to percolate gradually from one region to another through international companies, or through bilateral relationships. A more systematic linking of efforts across regions—building on existing efforts—could lead to less duplication of effort and faster shared learning. Industry can also support this process by sharing its insights on why some policies have proven more effective than others.

Aggregating demand to accelerate cost reduction. Countries acting together can achieve the volumes of hydrogen production needed for significant cost reductions more quickly. Coordinated action on this front will enable reaching the required demand with lower individual effort. Coordinated deployment can reduce risks as well as costs, by sending a stronger signal to investors, and by allowing the testing of a range of business models and applications. This opportunity applies equally to the public and private sectors.

In addition, coordinating efforts to promote low-carbon and renewable hydrogen demand can be beneficial for infrastructure development. Pipelines, facilities at ports and trading routes all benefit from economies of scale. By working together, several users can plan the conversion or construction of hydrogen transport, storage or refuelling facilities, increasing the value and reducing the risks of investing in such infrastructure. The benefits include lower transport costs, access to sites with lower production costs, and greater resilience of the system (as more suppliers can be connected in a network, avoiding reliance on a single one).

Many international initiatives are working on demand creation in ways that support both the sharing of lessons learned related to policy implementation, and the reduction of costs through increased market size. Mission Innovation has a target of 100 hydrogen valleys by 2030 covering production, storage, and end use worldwide. The Hydrogen Initiative of the Clean Energy Ministerial has set up a Global Ports Hydrogen Coalition aimed at driving demand for low-carbon hydrogen technologies and hydrogen-based fuels in ports and surrounding areas, recognising that ports present opportunities to bring multiple hydrogen uses together and to build upon good connectivity and infrastructure. The World Economic Forum's (WEF) First Movers Coalition brings private sector actors together to set explicit targets for the use of low-carbon technologies and fuels including hydrogen across aviation, shipping, aluminium, carbon dioxide removal, trucks, and steel. WEF and IRENA have issued enabling measures roadmaps (for Europe and Japan) that provide an overview of the different ways governments can support demand creation. The Green Hydrogen Catapult initiative focuses on increasing the supply of green hydrogen (targeting 45 GW of electrolysis and a USD 2/kg cost target) but also aims to aggregate demand in 'hydrogen hubs'.

Each of these initiatives, among others, are helping to build the global market for low-carbon and renewable hydrogen, and some are successfully aggregating efforts across multiple actors. However, the overall level of confirmed demand remains low: announced targets and commitments would create a demand for less than 3 Mt of low-carbon and renewable hydrogen (CEM, 2022; IRENA, 2022c). This corresponds to around 3% of the current global hydrogen demand. Such a low level of demand creation will not achieve the full extent of cost reduction that is possible over the coming years. To accelerate cost reduction, countries and companies should agree on stronger near-term targets for the deployment of low-carbon and renewable hydrogen, translating these into specific policies and purchase commitments to mobilise investment in hydrogen production. In the near term, the largest opportunity to increase deployment and drive down costs is in the sectors where hydrogen is already used – including fertilisers, chemical manufacturing and refining.

Creating level playing fields in competitive sectors. Some of the sectors where there is the greatest opportunity for near-term deployment are significantly exposed to international trade. These include ammonia (for fertilisers) and methanol, of which 15% and 28% of global production is traded internationally, respectively (UNSW, 2021; IRENA, 2022d). Given the currently higher cost of low-carbon and renewable hydrogen compared to unabated hydrogen, there is a risk that first mover countries and companies could be penalised, with industries relocating or trade flows being diverted to lower cost and higher emitting competitors. Deployment of low-carbon and renewable hydrogen could stall as a result. Over the longer-term, the same risk applies to some new end use sectors for hydrogen, such as steel.

Countries can mitigate this risk by coordinating hydrogen deployment policies in the relevant sectors. This could involve alignment either of quantity-based policies, such as sectoral mandates, or of carbon pricing. Either approach could be used to establish a level playing field, with similar cost premiums for low-carbon hydrogen products across regions. Countries that are significant producers of ammonia and methanol or that have interest in scaling-up production should initiate discussions aimed at agreeing coordinated measures in these sectors as an immediate priority. Over time, the participation of a larger group of countries in such an agreement is likely to be needed, to avoid the risk of first movers on low-carbon and renewable hydrogen deployment being undercut in global markets.

Recommendation 1

Countries and companies should coordinate internationally to increase commitments for the use of low-carbon and renewable hydrogen in sectors where hydrogen is already used, supported by specific policies and purchase agreements, to collectively send a strong demand signal and mobilise investment in production. In new priority application sectors, countries should share learning to accelerate early deployment. *This should be done in a manner that ensures a level playing field in international trade.*

Urgently agreeing common standards for hydrogen emissions, safety and operations

Robust and globally harmonised standards relating to emissions, safety, and operations are essential for hydrogen's potential in the low-carbon economy to be fully realised. International collaboration on hydrogen standards has so far largely focused on safety and operational protocols in traditional hydrogen-using sectors such as refining and chemicals. The wider range of hydrogen uses in the low-carbon economy now requires a new and broader set of standards to be agreed. This is a critical enabler of many of the other policies and priorities for international collaboration.

There are already several international initiatives active in the development and implementation of hydrogen standards. The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) is notable as an intergovernmental forum with the potential to support the development of common and harmonised hydrogen standards and regulations. Its focus is on the research and identification of priorities related to hydrogen emissions, safety and operational protocols and guidelines, which subsequently inform Standards Development Organisations (SDOs) such as the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), among others.

However, these efforts have not received the levels of political attention and resources that are needed to make rapid progress. There is insufficient funding allocated to the pre-normative research that supports the development of standards.[4] Many of the gaps in standards identified by technical bodies have not yet been addressed, and processes in SDOs are often protracted.[14] More concerted efforts, including political commitment and funding, are needed to make progress in two areas: measurement of emissions; and safety and operations.

Standards for the measurement of emissions. Since hydrogen can be produced through a wide array of technological methods, from unabated fossil fuels to renewable-powered electrolysis, a broad range of emissions intensities of production is possible. Emissions can also be created in hydrogen's transport and use.

To support the rapid growth of markets for low-carbon and renewable hydrogen, it will be important to have standards for the measurement of emissions created by hydrogen production, delivery and use, accompanied by certification schemes. These are needed to give public or private sector buyers of hydrogen and its derivative goods and services confidence in what they are buying. Over time, there may also be advantages to extending these standards and certification schemes to cover other sustainability criteria, such as land and water use, air pollution and social development.

International collaboration is critical in this area. Urgent agreement between governments on a common and harmonised methodology for GHG accounting can support international

[4] Pre-normative research (or pre-standardisation research) refers to the technical and scientific knowledge that is required to inform the development of standards.

trade in low-carbon and renewable hydrogen and can provide a foundation for international efforts to coordinate deployment, as described above. Conversely, absence of an agreed standard would likely be an obstacle to international trade. The adoption of differing methodologies with varying degrees of rigor and transparency could undermine investor and consumer confidence in the low-carbon hydrogen market and complicate the operations of hydrogen companies that operate across international borders.

A related and essential need is for international collaboration on methods to detect and repair hydrogen leakage. New scientific research suggests that hydrogen is more potent as an indirect greenhouse gas than previously assessed (Warwick et al., 2022), and that current leakage detection practices and technologies do not provide sufficiently accurate measurements. Internationally agreed guidelines and protocols for the measurement and reporting of hydrogen leakage, and for the verification of measures to address it, will be urgently needed to maintain confidence in any systems for the measurement and certification of hydrogen emissions, and in hydrogen's role as a climate solution.

Safety and operational standards. Internationally agreed safety and operational standards will be crucial to enabling the use of hydrogen in sectors where it has not been used before. In the long-term, these are the sectors where hydrogen is likely to make the greatest contribution to decarbonisation. Priorities include:

Shipping: Standards and guidelines to ensure the interoperability and safety of vessels powered by hydrogen or hydrogen-based fuels, and for the storage and bunkering of hydrogen and hydrogen-based fuels at ports. Standards should also be consistent with existing International Maritime Organization guidelines on vessel design and operational measures, e.g. guidelines related to reducing underwater radiated noise from maritime vessels (IMO, 2014).

Road transport: Safety protocols for hydrogen refuelling stations for heavy-duty trucks, in particular as it relates to requisite setback distances (minimum distance from other structures).

Steel production: Operational and safety standards for the use of hydrogen in the direct reduction of iron.

Countries should align on all those priorities and work together through fora such as IPHE and SDOs to accelerate the development of standards. The private sector can greatly support those efforts by pressing for the development and implementation of priority standards, and advancing the technological innovation needed to underpin standards development.

Governments should also work towards greater alignment between the activities of international bodies focused on standards and regulations (such as IPHE and SDOs), and those focused on research and development (such as Mission Innovation and the Hydrogen TCP). This will ensure that the development of harmonised operational and safety standards closely follows the development of relevant technologies. Stronger alignment could be achieved through the creation of joint task forces focused on developing the needed technologies as well as the safety and operational standards for hydrogen use in new priority applications, including maritime shipping, heavy duty trucks and steelmaking.[5]

RECOMMENDATION 2

Governments and companies should agree a comprehensive portfolio of international standards and associated certification schemes for renewable and low-carbon hydrogen, addressing emissions accounting, safety, and operational issues, including leakage. This should be supported by a programme that provides a clear direction and sufficient resources to relevant technical bodies. *This will be vital for supporting a series of other actions, most notably high-quality demand commitments and trade agreements.*

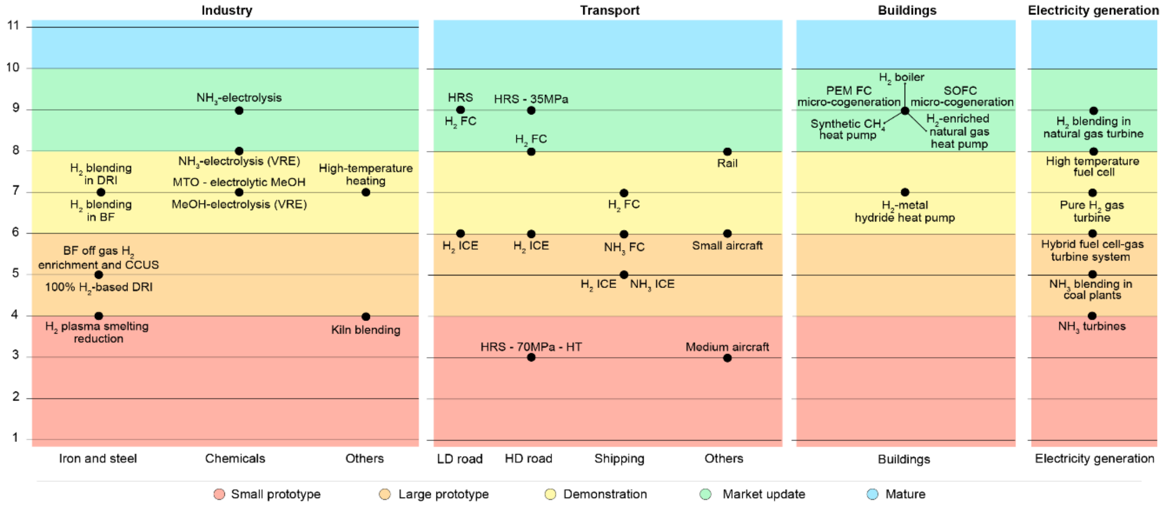
ACCELERATING THE RESEARCH, DEVELOPMENT AND DEMONSTRATION OF HYDROGEN TECHNOLOGIES

Research, development and demonstration is important both to demonstrate the viability of the next generation of hydrogen technologies, and to support continued cost reduction. On the supply side, innovation will be required to reduce the costs of renewable and low-carbon hydrogen production, storage and transport, including its conversion into other carriers (such as ammonia or liquid organic hydrogen carriers) and their reconversion back to hydrogen. Innovation will also be needed to improve the sustainability of manufacturing of key hydrogen technologies such as electrolysers, including by decreasing the demand for critical materials, which may be achieved both by improving the design of the equipment and by facilitating the recovery and recycling of these materials at the end of their lifetime.

On the end use side, while the near-term opportunities for renewable and low-carbon hydrogen deployment are concentrated in the sectors where it is already used, the potential for its larger deployment over the longer-term will only be realised after technologies for the use of hydrogen and its derivatives in new priority applications have been fully demonstrated. Most of these technologies are at pilot or demonstration stage, with only a few exceptions that are at the very early stages of commercialisation.

[5] The International Association for Hydrogen Safety (HySafe) has mapped state-of-the-art and recent progress in normative research to support standards development and identified and ranked pending research needs. Similarly, the IPHE has put together a compendium of high priority standards that must be developed.

Figure 3.6 Technology readiness levels of key hydrogen and hydrogen-derivatives end-use technologies



Notes:BF = blast furnace. DRI = direct iron reduction. FC = fuel cell. HRS = hydrogen refuelling station. HD = heavy-duty. HT = high throughput. ICE = internal combustion engine. LD = light-duty. MeOH = methanol. MTO = methanol to olefins. PEM FC = polymer electrolyte membrane fuel cell. SOFC = solid oxide fuel cell. VRE = variable renewable electricity. Cogeneration refers to the combined production of heat and power. TRL classification based on Clean Energy Innovation (2020), p. 67.

Source: IEA, 2022.

In the net zero scenario, a significant fraction of renewable and low-carbon hydrogen demand in 2030 onwards comes from new priority applications where hydrogen use is not yet commercialised. An urgent priority is therefore to demonstrate these new technologies in time to ensure their commercial viability before the end of this decade, allowing their deployment to significantly accelerate thereafter. This implies a strong prioritisation of the demonstration of:

The use of renewable hydrogen in refining, and the production of chemicals (methanol and ammonia) and synthetic fuels. While this presents lower barriers relative to new hydrogen uses, there remain challenges with the operation of chemical plants under variable inputs of hydrogen—which would be the regime when using renewable hydrogen. This may require the demonstration of innovative processes to deal with variable operation regimes or new business models to address high storage needs to smooth out the variability.

- The use of hydrogen, methanol and ammonia fuel in maritime shipping and the development of vessel technologies using such fuels that simultaneously reduce vessel-radiated underwater noise.
- The use of low-carbon and renewable hydrogen in the direct reduced iron (DRI) production process for steelmaking.
- The use of hydrogen in heavy duty trucks, including high throughput refuelling stations.
- The use of renewable hydrogen for long-duration energy storage of power and the development of turbines capable of being powered by 100% hydrogen and ammonia, to support power system balancing and seasonal electricity storage.

- The large-scale production of synthetic hydrocarbons that can be used as sustainable aviation fuels and the development of technologies for the direct use of hydrogen in aviation.
- The use of renewable and low-carbon hydrogen in high-temperature heating operations in industry.
- The use of porous reservoirs such as rock caverns for underground storage of large quantities of gaseous hydrogen.
- Lower energy consumption for hydrogen (re)conversion to (from) hydrogen carriers such as liquid hydrogen, ammonia, and liquid organic hydrogen carriers.

There are three major international initiatives focused on the research and development of renewable and low-carbon hydrogen technologies: the IEA's Hydrogen and Advanced Fuel Cells TCPs and Mission Innovation's Clean Hydrogen Mission. The IEA's Hydrogen and Advanced Fuel Cells TCPs are the main source of scientific knowledge, bringing together the largest pool of leading researchers across the world, whereas the Clean Hydrogen Mission aims to promote research, development, and innovation and deploy at least 100 clean hydrogen valleys.

Ongoing efforts are bringing certain technologies closer to commercialisation. In heavy-duty road transport there is a scattered set of demonstration efforts, mainly in China, Europe and the United States (FuelCellsWorks, 2021; IVECO, 2020; Truckinginfo, 2021). In shipping, there are several ongoing demonstration projects for the use of hydrogen in small, short-distance vessels, and major industry stakeholders have announced plans to make 100% ammonia-fuelled maritime engines available by as early as 2023 (Wärtsilä, 2021). In industry, however, there is only one operational pilot for the production of ammonia from renewable hydrogen (Iberdrola, 2022), one demonstrator for the use of renewable hydrogen in direct reduction of iron (Hybrit, 2022), and a limited number of trials for the use of hydrogen in high-temperature heating. International efforts to create hydrogen valleys are currently highly concentrated in Europe and the United States, and there is a lack of emphasis on industrial and maritime applications.

Although these efforts are encouraging, they are insufficient to develop the knowledge, operational experience and confidence needed to bring these technologies to commercial scale and begin their large-scale deployment before the end of this decade. Governments should work together to develop a critical mass of demonstration projects in each of the areas listed above. Aligning efforts with respect to areas of focus, objectives, and timelines, can significantly accelerate innovation. The private sector should participate in this process, informing the definition of common objectives, and helping governments understand what support is needed to bring new technologies to the market.

The benefits of internationally coordinated research, development and demonstration efforts will be greater if there is deeper sharing of knowledge between countries. Knowledge that is useful to share includes not only the results of testing hydrogen technologies in different applications, but also the lessons learned in the project management, planning and implementation of large-scale demonstrators, which tend to be complex 'first-of-a-kind' projects. Knowledge sharing is particularly valuable for industrial applications of hydrogen that are capital intensive, where perceived high risk can prevent private investment.

Knowledge sharing is already encouraged and supported by initiatives including the IEA's Technology Collaboration Programme (TCP), which normally publishes a report after the conclusion of major tasks, and the Clean Hydrogen Mission of Mission Innovation. However, the quality of information shared depends on the openness of participating countries. From our discussions with stakeholders, we believe there is significant scope for deeper sharing of knowledge, without prejudice to countries' national industrial interests.

We suggest that governments should agree a set of knowledge sharing principles that include, at a minimum, mandates for the production of 'lessons learned' reports from all publicly-funded demonstration projects, addressing issues of project management as well as technical performance. Deeper knowledge sharing can also be enabled by opening national research programmes to the participation of experts and companies from other countries, rather than limiting them to national participation as is the most common practice at present.

International cooperation of this kind can particularly benefit emerging economies that are likely to deploy hydrogen technologies after developed economies. To support faster global progress, knowledge sharing should be extended as much as possible to all countries active in the development and demonstration of hydrogen technologies, not only those that participate in the IEA TCPs and Mission Innovation.

Aside from the development of technologies, there is also a need for international collaboration to measure the extent of hydrogen leakage from infrastructure (especially repurposed natural gas infrastructure), to better understand hydrogen's global warming potential,[6] and to develop best practice in hydrogen leakage, detection and repair (LDAR) systems. Governments and companies should participate in these efforts, supported by international hydrogen initiatives, to ensure that effective leakage, detection and repair systems are widely adopted as soon as possible.

Stronger collaboration and priority alignment is necessary between research and development and knowledge-focused bodies such as the IEA's TCPs, Mission Innovation's Clean Hydrogen Mission and IRENA's Collaborative Framework on Green Hydrogen, as well as standards-focused bodies such as the IPHE. Enhanced collaboration can be accomplished through the creation of joint tasks focused on research for the development of norms and standards to mobilise a large pool of scientific resources and experts to rapidly close research gaps that are necessary for the development of safety and operational standards for hydrogen use in new priority applications.

[6] According to recent research, the global warming potential of hydrogen over a 100-year time horizon is in the order of 11±5

Recommendation 3

Governments and companies should work together to dramatically increase the number and geographical distribution of hydrogen demonstration projects and to ensure that these appropriately cover each of hydrogen's high-value end use sectors, including maritime shipping, heavy industry, and long-duration energy storage. Governments and the private sector should agree on minimum reporting principles to guide a deeper and more rapid sharing of knowledge these demonstrators, including a commitment to share the lessons learned from all publicly funded demonstration projects. *Doing so will help overcome technology availability barriers and accelerate the pace of deployment in multiple regions in parallel.*

Rapidly scale-up investments in renewable and low-carbon hydrogen production, and support the development of the sector in emerging economies

Making renewable and low-carbon hydrogen affordable and globally available by 2030 requires an enormous increase in investment. Around USD 60-130 billion per year is likely to be needed until 2030. Currently, less than USD 1 billion per year is invested in the production of renewable and low-carbon hydrogen and its derivatives, and in the required infrastructure (IEA, 2021a).

Private sector investment can be mobilised by putting the right policies in place. According to the Hydrogen Council, private sector commitments for hydrogen investments are growing rapidly and projects announced from now through 2030 account for more than USD 160 billion across production, infrastructure and end uses (Hydrogen Council, 2021b). However, most of these relate to projects that are still in feasibility or pre-feasibility stages; only a third are associated with projects that are in planning or at a more advanced stage of development. Converting these into actual projects requires a rapidly growing flow of investment and strong demand creation policies, as well as demonstration of key technologies.

This can be achieved by the adoption of targeted policies and supporting mechanisms, as discussed above. Some governments are already taking the initiative by deploying novel financing mechanisms, such as the H2Global instrument of the German government, based on a mechanism similar to contracts for difference, the US Department of Energy loan guarantees or the European Green Hydrogen Acceleration Center, which supports projects with an industrial vision and a whole value chain scope at early stage of development (DOE, 2022). Sharing and promoting successful best practices can facilitate their widespread adoption and speed up project deployment, increasing investor confidence.

Mobilising investment can be more difficult in emerging markets and developing economies, which typically suffer from higher costs of capital and may have more difficult business environments. Many such countries are interested in developing the hydrogen economy as a source of jobs, exports, and clean energy, and there is growing interest in the opportunity for renewable hydrogen to meet domestic demand for products such as fertilisers while shielding consumers from the high price of imported gas. Some developing countries have locations and resources that are particularly well suited to the production of low-cost renewable and low-carbon hydrogen.

International assistance can help developing countries mobilise finance for the hydrogen economy by providing technical assistance with policy design and project preparation, and by providing targeted concessional finance for first-of-a-kind projects. At present, assistance of this kind appears to be sparse. Multilateral development banks have provided support for governments to develop strategies outlining the role of hydrogen in their decarbonisation plans, and to some extent for the design of policies to implement these strategies, but so far they have provided no financial support for renewable and low-carbon hydrogen projects.

This is a substantial gap that needs to be closed. Financial assistance should also be complemented by technical assistance programmes that address issues including the policies and finance models that are most effective at mobilising private finance and minimising the government's share of total project costs; and approaches to risk-sharing among the various actors along the hydrogen value chain.

Recommendation 4

Donor countries and multilateral development banks should make increased levels of concessional finance available for well targeted, catalytic uses that can mobilise large-scale private investment in renewable and low-carbon hydrogen production, distribution and end use projects in developing countries. This should be supported by a process in which countries work with lending institutions to identify viable projects that are being delayed by high costs of capital and to assess obstacles to investment, along with technical assistance programmes to assist governments with policy design. *This will provide much-needed support for the first wave of low-carbon and renewable hydrogen projects, ensuring that a wider set of countries can deploy the technologies required.*

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ANNEX

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Long-term vision and action plans	By early 2020s, governments should put in place a supporting policy framework to promote the uptake of low-carbon and renewable hydrogen in existing industrial applications. This includes policy instruments to tackle the higher cost, creating a level playing field for trade-exposed commodities (such as ammonia) to prevent carbon leakage and setting a clear timeline for decarbonisation of these applications including the use of sectoral quotas. Countries should also have an international platform to share lessons learned from early implementation of demand-pull policies to inform policy design across countries. Leading countries have identified hydrogen valleys with different conditions that can trigger initial demand and economies of scale for common infrastructure. At the same time, the private sector should set targets for near zero emissions materials and fuels that promote demand for low-carbon and renewable hydrogen (derivatives).	17 countries plus the European Union have hydrogen strategies, including targets for production and use.

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
	By mid-2020s, governments should put in place a supporting policy framework to promote the uptake of low-carbon and renewable hydrogen in key applications such as steel, international shipping, aviation, and long-term storage. This includes using policies that promote fuel shift rather than only incremental emission reductions since the hydrogen pathways are new in these applications. By the end of the decade, all governments should have regulatory frameworks in place to make sure that demands in new sectors are met only with renewable and low-carbon hydrogen. All developed economies have defined a strategy to phase out unabated fossil-based hydrogen production for existing industrial applications. Efforts should be aligned to meet Mission Innovation's Clean Hydrogen Mission of delivering at least 100 large-scale hydrogen valleys globally.	
Demand creation and management	By early 2020s, all developed and major emerging economies should have assessed whether hydrogen can play a role in their long-term decarbonisation plans and defined a hydrogen strategy accordingly and integrated within an overarching strategy for decarbonising the energy system. These should be accompanied by short-term action plans that can be fully implemented before 2030, with milestones to track progress. These strategies should also incorporate plans to share lessons learned with emerging economies during their development and implementation. This would facilitate that all economies have developed a vision for the role of hydrogen in their energy systems by 2030 and adopted an implementation plan. Government action should be complemented by a response from the private sector, which needs to develop its own vision on how to adopt renewable and low-carbon hydrogen as a decarbonisation tool.	Announced commitments and targets cover 3 Mt of hydrogen demand.
Finance and Investment	Leading countries need to put in place in early 2020s policies, regulatory frameworks and novel financing mechanisms to help the private sector to de-risk investment in renewable and low-carbon hydrogen projects. They should create a cooperation platform for sharing and promoting those best practices that are proven more efficient in unlocking investment. By mid-2020s, governments and the private sector should increase annual investments in renewable and low-carbon hydrogen above USD 50 billion. Developed economies should make available international finance for renewable and low-carbon hydrogen projects in emerging economies. Financial institutions should understand risks and mitigation measures associated with various business models for hydrogen.	Total investment in electrolysers reached USD 200 million in 2021.

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
	By the end of the decade, the risk perception for the most conventional parts of the value chain like electrolysis or transmission should be low enough to compete with a cost of capital premium in line with equivalent projects in the chemicals and electricity sectors. At this stage, the most advanced applications (e.g. ammonia production) are transitioning from mainly relying on public capital to private.	
Research innovation	As soon as possible, governments in advanced economies should take decisions about funding and actions for mitigating investment risks associated with demonstration at scale of end-use technologies for hydrogen and its derived fuels. Public hydrogen R&D agendas across countries should be aligned, maximising synergies and coordination gains, and targeting those applications for hydrogen and its derived fuels where it should be prioritised due to the lack of other efficient low-carbon technology alternatives. By mid-2020s, technologies such as the production of ammonia and methanol using variable renewables or the use of ammonia and methanol engines for maritime applications should have been demonstrated and be ready for commercialisation. By 2030, the use of 100% hydrogen reduction in DRI for steel production and liquid hydrogen ships should reach full commercial scale. In addition, research gaps related to safety protocols for liquid hydrogen storage and use, materials compatibility or leak detection should be filled as soon as possible to build the necessary evidence for the development of robust standards and regulations. Knowledge transfer, particularly for public-funded projects, should be guaranteed to facilitate and accelerate deployment, especially in emerging economies.	TRLs for key technologies Alkaline electrolysis – TRL 9 PEM electrolysis – TRL 9 Solid oxide electrolysis – TRL 7 AEM electrolysis – TRL 4 Steam methane reforming with CCUS – TRL 8 Autothermal reforming with CCUS – TRL 8 Partial oxidation – TRL 7 Methane pyrolysis – TRL 6 For other technologies (including infrastructure and end uses of hydrogen) see forthcoming Global Hydrogen Review 2022.
Market structures	By the mid-2020s, a long-term emissions reduction policy framework is in place to provide certainty for new renewable and low-carbon hydrogen production capacity. Alongside initial demand-side measures such as contracts for difference and procurement, this should also include mass-market carbon pricing and emissions performance standards that will limit the production of high emission hydrogen.	

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Standards and regulations	A globally harmonised methodology for calculating GHG emissions for all major hydrogen production pathways should be urgently agreed. The methodology should extend to hydrogen transport and use later in the decade. Countries should urgently collaborate to develop and test at scale hydrogen leakage measurement technologies and leakage detection and repair (LDAR) best practices. Governments and organisations should regularly participate in information-sharing regarding hydrogen leakage research and LDAR best practices. By 2030, leakage measurement, detection, and repair systems should be widely adopted. By the mid-2020s, there are globally harmonised standards and guidelines that guarantee interoperability across countries and jurisdictions (I.e. vessels need to be able to refuel with the same hardware in all the calling ports). In particular, there are globally synchronised safety protocols, guidelines and regulations for the storage and bunkering of hydrogen and hydrogen-based fuels at ports, as well as for the on-board storage of hydrogen and hydrogen-based fuels in maritime vessels. Furthermore, there are globally agreed safety and operational standards for the use of hydrogen in the direct reduction of iron for steelmaking, and in heavy-duty trucking.	
Supply chains and infrastructure	By early 2020s, the largest global ports have mapped out the infrastructure to handle hydrogen (derivatives) on a scale aligned with net zero targets. Countries that have an existing natural gas network have assessed the suitability of the network for repurposing to hydrogen, the techno-economics and risks of conversion (including hydrogen leakage) and, if suitable, have identified a roadmap for conversion. Storage capacity around the world for various types of reservoirs is well understood along with storage needs. By mid-2020s, there are clear guidelines for regulation, including cost recovery, operation, access, and planning of the hydrogen network. Leading economies have already started financing and building the hydrogen infrastructure needed to cater for the long-lead times and make sure it is ready for later stages. Major ports around the world are ready to handle hydrogen derivatives and have a plan for ramping down fossil fuel infrastructure while maximising repurposing for hydrogen to reduce costs. Electrolyser and fuel cells are manufactured globally with a diversified and robust supply chain. The project pipeline is expanding quickly, and stands at around 50-100 GW for electrolysers and 270 GW for fuel cells over the coming decade (a number constantly changing with business decisions), although only a small fraction of the projects under development have reached final investment decision (IRENA, 2020; IEA, 2021a).	Zero ports that have terminals ready for reception of hydrogen (derivatives) and their inland distribution Zero hubs that handle hydrogen flows larger than 1 MtH_2/yr

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
	By the end of the decade, leading countries are building hydrogen pipelines to connect the main hydrogen clusters.	
International markets and trade	By early 2020s, the conditions that make each transport pathway (shipping, pipelines, hydrogen carriers) attractive and the steps needed to reduce their costs have been defined. There are regional coalitions of ports established and international platforms for knowledge exchange between ports. Importing and exporting countries should align the timeline for development, sizing, and characteristics (carriers) of the trade infrastructure to enable the development of a widespread and reliable network of ports that can facilitate hydrogen trade and reduce costs. By mid-2020s, regional price benchmarks are being established differentiated by production process. The first long-term contracts for low-carbon hydrogen and ammonia are signed and import/export terminals are starting to be built. All countries that have identified trade as a relevant part of their system are setting explicit targets for import/export of hydrogen (derivatives) in their hydrogen strategies. By now, codes, import custom duties, taxes, and more broadly, rules within the WTO framework have been adapted to cater for hydrogen and promote early emergence of trade. By the end of the decade, the main hydrogen hubs have several suppliers and users, there are established price benchmarks across regions that guide future investment, there is a standardised guidance for drafting new contracts. There is a parallel (emerging) spot market for hydrogen (derivatives) that complements the long-term contracts. There is consistency between the scope of regulation and decarbonisation targets which facilitates the linking of different markets and hydrogen trade between them.	0 Mt of import and export flows from countries Zero long-term supply contracts signed Today the largest project is the Hydrogen Energy Supply Chain demonstration which can export up to 300t H_2 per year from Australia to Japan.
Knowledge, capability & skills	Representatives from all interested developing countries (as well as from initiatives focused on developing countries) are active participants in major global hydrogen and energy-related initiatives. By the mid-2020s, all national education systems have developed plans (including technical and university degrees) for training a specialised workforce of professionals able to respond to the challenges of adopting a new energy vector. These plans include inter-country exchange programmes to ensure that the knowledge developed in more advanced countries is shared and does not create gaps with lagging countries. Capacity-building and training programmes are accessible to all and cover relevant skill sets including construction, equipment manufacturing, facility operation, and regulatory requirements. Special attention is placed on capacity-building and training programmes in	

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
	communities experiencing displacement from fossil fuel intensive sectors and in historically underserved communities. By 2030, there is a robust pool of qualified and experienced professionals in hydrogen deployment as it relates to its full value chain. There are high quality careers in the clean hydrogen sector in both developed and developing countries. There are sustainable jobs in construction projects, operations and maintenance, and along the hydrogen supply chain, from production to end use. By 2030, the knowledge gap between countries has significantly closed and there are established platforms across countries to transfer lessons across policies, project execution, manufacturing, and regulation.	

CHAPTER 4. ROAD TRANSPORT

"Zero-emission vehicles are the new normal and are accessible, affordable, and sustainable in all regions by 2030." -- *Road Transport Breakthrough goal*

KEY MESSAGES

- Transport has the highest level of reliance on fossil fuels of any sector today, which supply about 95% of its final energy demand. It accounts for more than 20% of global energy-related direct CO_2 emissions, and produces a significant share of air pollution and related threats to public health.
- The transition to zero-emission road transport is at a relatively early stage in terms of global market adoption, but progress is accelerating rapidly, with substantial take-up of electric cars, urban buses, and two- and three-wheelers in many countries.
- That progress, while welcome, falls short of what is required to put the sector on a Paris-aligned pathway. Just over 1% of cars on the road in 2021 were zero-emission vehicles (ZEVs), versus 20-25% needed by 2030. In 2021, ZEVs accounted for under 9% of new car sales globally; by 2030, about 60% of new cars sold will need to be zero emission. Zero-emission trucks, which have only just begun to enter the market in appreciable shares, will need to constitute at least 35-40% of new sales by 2030. Zero-emission buses will also need to rise from nearly 14% of new sales in 2021 to 60% by 2030.
- Eliminating emissions from road transport will also need policies to reduce unnecessary travel and encourage modal shifts to the least carbon-intensive option and energy efficiency measures to reduce the carbon intensity of all transport modes. International collaboration on road transport decarbonisation is growing rapidly, both at national and subnational levels, with new initiatives focused on a range of political and technical challenges.
- Action across multiple enabling conditions, further strengthened by international collaboration, is urgently required to accelerate the transition and put it on track for the 2030 Road Transport Breakthrough goal. Six areas stand out as priorities for strengthening international collaboration over the next 1-2 years, where we recommend the following actions:
  - Governments should agree on a timeline by which all new road vehicle sales should be zero emission, with interim targets for countries taking into account their level of economic development and ability to scale up infrastructure, and should align policies with this target. Pathways

compatible with 1.5°C indicate that this target date should be around 2035 for cars, for example. Vehicle manufacturers should commit to the same timelines for 100% zero-emission vehicle production. *This will send a clear signal to industry and unlock larger economies of scale and faster cost reductions, making the transition more affordable for all countries.*

- Governments should collectively agree a common understanding of the technologies that are consistent with the goal of zero-emissions road transport, in order to send a clear and unambiguous signal to industry. *This will accelerate economies of scale for key technologies, accelerating the pace of innovation and cost reduction, making ZEVs affordable sooner for more people.*
- Governments should exchange best practice in policy to mobilise investment and accelerate deployment of charging infrastructure, in consultation with vehicle manufacturers and infrastructure investors. This should be complemented by a broader scaling-up of technical and financial assistance to developing countries at city, provincial, national and regional levels. *This will help to mobilise private investment, and ensure all countries are able to access the benefits of the transition to zero-emission vehicles.*
- Governments should work together and with industry to avoid further divergence of standards for charging infrastructure. There are already several competing charging standards for light-duty vehicles; for heavy-duty vehicles, avoiding further divergence of standards could limit wasteful investments in multiple charging types, and accelerate the adoption of electric trucks. Aligning standards for hydrogen refuelling stations can reap similar benefits. *Doing so will decrease costs and facilitate the transition in vehicle importing countries.*
- Countries should work together and with industry to agree harmonised standards to ensure sustainability and social responsibility along the entire electric vehicle battery supply chain, including the extraction and processing of minerals and improving the recyclability of battery modules. As a priority, these standards should minimise batteries' life-cycle emissions and the adverse social and environmental impacts associated with their production, seek to extend their durability and promote reuse, repurposing and recycling of their components. Similar standards on fuel cell value chains, including information on platinum and other catalyst materials content and origin, should be put in place. *Harmonised standards will send a clearer signal to the global market, and facilitate compliance by battery and vehicle manufacturers that sell to multiple markets.*
- Vehicle importer and exporter countries should agree on harmonised regulations on vehicle trade to improve vehicle efficiency and safety in international trade in used vehicles. These rules should govern trade in zero-emission vehicles as well as internal combustion engine vehicles, supported by strong mechanisms to enforce compliance. *This will help prevent 'vehicle dumping', locking developing countries into higher emitting vehicles.*

SIGNIFICANCE OF THE SECTOR

Transport has the highest level of reliance on fossil fuels of any sector and accounted for 40% of CO_2 emissions from all end-use sectors at 7.7 $GtCO_2$ in 2021, with road transport alone accounting for three-quarters at 5.9 $GtCO_2$ (IEA, 2022a). It offers the largest markets in which to quickly scale-up the deployment of batteries, bringing down their costs and thereby supporting the decarbonisation of the power sector. Furthermore, as the largest market for oil, a rapid transition in road transport can help incentivise faster diversification of investment in the energy industry towards clean technologies.

Cars and vans currently contribute the largest share of road transport CO_2 emissions at around 60%, but heavy-duty vehicles (HDVs)[1] also contribute a large share, at more than 35%, despite accounting for less than 5% of the vehicles on the road (IEA, 2022b). In some countries, two- and three-wheelers also make up a significant share of vehicles on the road, such as Indonesia, where they consume in aggregate nearly as much gasoline as cars, or Viet Nam, where they consume more than 50% more gasoline than cars. These vehicle types are likely to be decarbonised at different rates, as technology maturity varies markedly between them, with two- and three-wheelers first (overwhelmingly battery electric), followed by cars and light-duty commercial vehicles (mostly battery and plug-in hybrid electric) and urban buses (largely battery electric, with some fuel cell electric sales). HDVs and intercity buses are at an earlier stage, with zero-emission models (mostly battery electric, with some plug-in hybrid and fuel cell electric models) only just beginning to enter the market.

Decarbonisation of road transport will require the implementation of a broad set of policies, often summarised as a hierarchy of actions, as “avoid, shift, improve” (IRENA, 2021a). The frequency and distance of discretionary car trips can be reduced (“avoid”) through policies that provide alternatives to private car trips, reduce distances, and make car travel more expensive. Modal shifts to the least carbon-intensive travel options can similarly be encouraged through a range of push and pull policies (“shift”), Finally, “improve” measures can target operational and technical energy efficiency measures to reduce the CO_2 intensity of all transport modes, and the scale-up of zero-emission vehicles and low-emission fuels.[2] Simultaneously, continuing investments in road, rail, and other transport infrastructures are needed to ensure equitable access to mobility, and that diverse mobility options and vehicles operate efficiently.

Government and industry targets point towards a decarbonisation of the road transport sector dominated by a transition towards electric mobility (plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs). This will

[1] Throughout the text, “cars and vans” is used synonymously with “light-duty vehicles”. “heavy-duty vehicles” includes all medium- and heavy-duty commercial vehicles (“trucks”) with greater than 3.5 tonnes Gross Vehicle Weight.

[2] The Road Transport Breakthrough focuses on ZEVs, which is a key shift measure. However, in general context, decarbonisation of road transport also requires “avoid” and “shift” to be in place, for example, replacing cars with public transit.

require policy interventions to stimulate investment in the supply of electric vehicles and charging infrastructure and to incentivise consumer uptake, as well as to address other technological and market barriers.

SECTOR GOALS

Road transport is more advanced in its low-carbon transition compared to other transport subsectors, such as shipping and aviation. There are already nearly 18 million zero-emission cars, light commercial vehicles, buses and trucks on the roads, plus more than 36 million electric two- and three-wheelers. In 2012, just 120 000 electric cars were sold worldwide but by 2021 more than that number were sold each week, totalling 8.7% of global sales; yet, there remains a long way to go (IEA, 2022a). The ZEV share of car sales in 2021 was over 85% in Norway, and between 10% and 30% in other leading large markets in the European Union (EU), as well as China, and the state of California. However, it was much lower in most developing countries,[3] and less than 9% globally. Adoption of electric heavy-duty vehicles or trucks (HDVs) is at a much earlier stage, with a share of global sales at less than 0.5%. With the right policies to stimulate their adoption, however, zero-emission vehicle technologies are poised to gain market share rapidly.

There is an imperative to significantly increase the uptake of zero-emission vehicles and their enabling infrastructure.[4] Paris-aligned pathways make clear that road transport operations must be almost entirely decarbonised by 2050 (Khalil et al., 2019; IEA, 2021a; IRENA, 2022). The IEA, for example, has highlighted the need to quickly signal the end of sales of new internal combustion engine (ICE) cars globally by 2035.

To ensure that the pace and scale of deployment continues to ramp-up over the 2020s, especially in developing countries, coordinated international action will be required. To put the road transport sector on a Paris-aligned pathway, countries and companies will need to align their policies with an accelerated transition to 100% ZEV. Thus far 28 countries and a number of subnational governments, representing more than 16% of global passenger vehicle sales in 2020, have announced policies in line with this.

The Breakthrough goal for road transport endorsed at COP26 is:

"Zero emission vehicles are the new normal and are accessible, affordable, and sustainable in all regions by 2030."

Meeting this goal will require rapid progress on deployment, cost reduction, availability, and sustainability. By 2030, scenarios aligned with international climate goals suggest that:

[3] It is estimated that almost all of vehicle stock growth and two out of three vehicles will be found in low- and middle-income countries in 2050. The majority of this growth is likely to be ICE vehicles in the absence of additional policies promoting their electrification.

[4] A zero-emission vehicle is capable of operating without emitting CO_2 or other pollutants from the tailpipe when relying on an onboard source of power, and includes battery electric vehicles (BEVs) plug-in hybrid electric vehicles (PHEVs)] and fuel cell electric vehicles (FCEVs). Note that greenhouse gas emissions may be incurred to produce the electricity or hydrogen that fuels zero-tailpipe vehicle operations; hence it is critical to move to low-carbon power generation and hydrogen production in tandem with rolling out zero-emission vehicles.

- ZEV sales will need to reach 60% of global car sales, 60% of buses, at least 80% of two- and three-wheelers and around 35-40% of heavy truck sales by 2030. All new car sales should be zero emission by around 2035 globally (IEA, 2021a).
- It will be essential for publicly available charging infrastructure to keep pace with zero-emission vehicle deployment, requiring a network of 18 million publicly accessible charging points, about 10 times the stock of publicly available charging points in 2021. As the utilisation of chargers increases, this will support an even faster growth in the number of EVs on the world's roads (meaning that the ratio of EVs per charger will roughly double).
- Costs of ZEVs will need to fall to achieve total cost of ownership (TCO) parity, as well as purchase price parity (for most operations except for some long-distance bus and truck operations).

Figure 4.1 Shares of ZEV sales and stock, affordability and accessibility metrics, 2021 and 2030

Metric		2021				2030			
	Shares by	2/3-Ws	cars & vans	buses	trucks	2/3-Ws	cars & vans	buses	trucks
Share of ZEVs	Sales	17%	8.7%	13.8%	0.3%	>80%	60%	60%	35-40%
	Stock	6.2%	1.3%	4.3%	0.1%	50%	20-25%	25-30%	10-15%
Purchase price gap / TCO parity		10-20% higher purchase price	30% higher purchase price	TCO parity for urban transit	0-50% TCO gap (depending on operations)	purchase price parity	purchase price parity	TCO parity for intercity buses	TCO parity for most operations
EV:Public charger / kW:EV ratio		--	10:1 / 2.4 kW	--	--	--	18:1 / 2.7 kW	--	--

Sources: IEA, 2021a; IRENA, 2022.

The current gap in the purchase price of a battery electric vehicle (BEV) versus an internal combustion engine (ICE) vehicle varies considerably by segment and across markets. The price of the average BEV is estimated to be 20% higher than that of the average conventional vehicle in China, compared to about 45-55% in Europe and the United States (IEA, 2022a). Zero-emission cars are likely to become less expensive than conventional cars in terms of total cost of ownership within the next few years, and in advanced markets, cheaper in terms of purchase price before the end of the decade. For HDVs, parity in total cost of ownership could be reached in the next few years for certain truck duty cycles and operations, depending on fuel and electricity prices (MPP, 2022). These cost parity tipping points need to be brought forward, and realised across all regions, to enable the Breakthrough goal to be met.

HOW DO WE GET THERE?

Action across multiple 'enabling conditions' is required to accelerate the transition to net zero emissions in the road transport sector, putting it on track for the 2030 Breakthrough goal.

Governments need to set clear timeframes by which all new road vehicle sales should be zero emission, along with interim targets taking account of their level of economic development. This action is crucial to create greater levels of confidence in the pace and direction of the transition to ZEVs in all markets. A range of analyses suggest that this should be around 2030 for two- to three-wheelers, 2035 for cars and vans in leading markets and 2040 for the rest of the world, and during the 2040s for HDVs (IEA, 2021a; IRENA, 2022; ICCT 2021a).

Near-term actions are essential to rapidly accelerate the supply of vehicles to ZEVs and to strengthen demand, supplementing the longer-term vision. Sales requirements (often referred to as 'ZEV mandates') are particularly effective for shifting supply, ensuring ZEV models are available in all market segments, and rapidly increasing their market share (ICCT, 2019). Purchase incentives such as capital grants or 'feebates' (a combination of tax and subsidy) can be effective in increasing demand. These measures were successfully adopted in Germany, the United Kingdom, and Italy, building upon previous success in Norway and France.[5] Developing countries can fast-track the transition to ZEVs by aggregating demand across similar and proximate markets, thereby leveraging buying power, harnessing economies of scale and de-risking investments.

Favourable financing terms to reach total cost of ownership (TCO) parity faster, **supported by international development banks and by government policy, can further stimulate uptake,** particularly in EVs for commercial or municipal use. Procurement commitments from governments and companies, which guarantee a pipeline of demand, can also help to support manufacturers' investments, and may be particularly important to stimulating the transition in HDVs. Governments will also need to support vehicle manufacturers in making the required investments in re-tooling their assets to deliver ZEVs in large numbers.

Governments and companies will need to work closely with infrastructure providers to ensure a rapid scale-up of high-quality charging options, providing consumers with the confidence to make purchase commitments. This includes ensuring that charging points are maintained and always operating, as well as that they are easy to use and payments are transparent, secure and simple. A further goal should be to provide smart charging infrastructure that can reflect differentiated pricing and variable charging rates based on wider system electricity demand, which will require extensive availability of time-of-use or real-time retail electricity prices for residential and businesses consumers. By the mid-2020s, governments and industry should aim to make smart charging available in major markets with ZEVs contributing to a greater share of power system flexibility by 2030.

In the same time frame, governments should integrate and simplify regulatory frameworks to de-risk private-sector investment and develop regulations to streamline international and/or regional charging standards for LDVs and HDVs. Agreement on standards for hydrogen refuelling stations, and sharing experiences in deploying fuel cell electric buses and trucks can similarly help countries to ensure that investments in these technologies are targeted to applications where they are economically and technically most viable. The expansion of fuel cell supply chains will also be required to support the decarbonisation of HDVs.

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[5] Ramji, A., Fulton, L., Sperling, D. (2022). Vehicle Feebate Designs: Lessons for a ZEV Transition from Europe. Institute of Transportation Studies, University of California Davis.

A range of complementary policy measures can support the transition. Implementing more stringent fuel economy and tailpipe emissions standards can help to reduce the emissions of fossil fuelled cars. In developed markets where zero- or low-emission vehicles have become widely available, discontinuing fossil subsidies in a way that takes the needs of the poorest parts of the population into account, and shifting the burden of road and fuel taxes onto the most polluting vehicles, can help to align incentives with the transition. Other measures, such as low- and zero-emissions zones in cities can support the transition while also improving public health. Lowering emissions would also benefit from a holistic rethinking of the way people move, including by reducing the frequency and distance of travel though better urban planning, and by policies to promote shifts to more efficient and lower emitting modes, such as public transit, walking and cycling. Governments can promote the transition to zero-emissions mobility in cities by making ZEV procurement common practice for public transit operators and municipal fleets, with an aim to reach 100% ZEV procurement by well before 2030.

Governments will need to coordinate actions with companies and civil society to ensure an orderly transition of the existing ICE supply chains, contributing to the scale-up of new material supply chains for ZEVs. This includes steps to avoid the dumping of old ICE vehicles in developing countries, which can be highly polluting and unsafe. Nonetheless, many developing countries rely on second-hand ICE vehicles to meet growing mobility needs. Hence, coordinated regulations that set age limits and/or emissions technology minimum standards should be implemented by vehicle importing and exporting countries.

Tracking of international used-vehicle flows can bring much needed transparency to support the development and implementation of the necessary regulations. Alongside anti-dumping policies, developed countries should also expand ZEV-dedicated financing facilities via existing and new programmes, providing effective technical and financial assistance to developing countries to support the manufacture and purchase of new ZEVs, alongside support for the buildout of charging infrastructure.

As the scale of ZEV deployment accelerates through the mid-2020s, securing material supply chains will become increasingly important. Governments should implement supply chain standards for ZEVs and key components (e.g. batteries) to encourage upstream suppliers to adopt sustainable practices and foster feasible downstream battery reuse or recycling. Regulations on battery product information will be required to ensure they are sourced responsibly, to measure and report the carbon footprint of their production, and to promote a circular value chain. The European Union's draft regulation on batteries provides a useful example of this kind of regulation which should be implemented globally by the mid-2020s (EC, 2020).

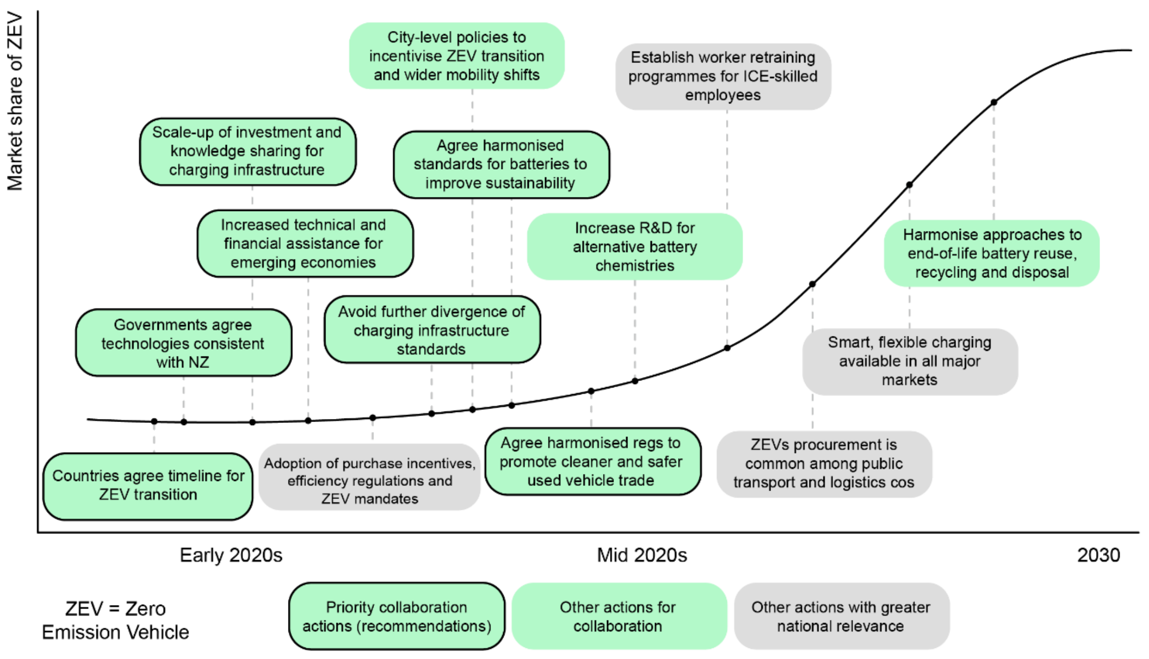
Governments and companies should also increase their support for RD&D of alternative battery chemistries, as supply chain standards shift to support more sustainable practices. This will be necessary to reduce reliance on critical minerals that are in limited supply, such as cobalt, and meet the increasing needs for lithium while improving battery performance and reducing production costs.

Governments and companies must work to ensure comparable employment opportunities are provided, supported by retraining and recertification programmes and look for synergies with new jobs in EV supply chains. The decline of the ICE vehicle industry will have a major impact on the communities that currently benefit from employment in associated supply chains. At the VW Zwickau plant in Germany, for example, a major training initiative was successful in preparing 3 000 production workers to make the shift from producing ICE cars to electric ones. Such policies and measures to ensure a just transition should be adopted by all major vehicle producing countries by the mid-2020s.

Governments and industry should take actions to develop standards and regulations to ensure the safety, quality and sustainability of batteries' end-of-life management, ahead of the first wave of battery electric vehicles coming to the end of their lifetime in the mid- to late 2020s. This includes repurposing EV batteries for their second life (e.g. stationary storage and home energy storage), as well as the recycling of materials.

By 2030, the transport sector will need to be firmly on track for reaching net zero emissions by mid-century as the uptake of ZEVs increases worldwide. Governments and companies are confident in the positive role that they will play in decarbonising the sector, incentivising more investments and further accelerating the pace of deployment in all regions. Coordination in key areas such as battery standards, financial and technical assistance, and charging infrastructure can help close the gap between progress in developed and developing countries, ensuring sustainable, efficient ZEVs are affordable and accessible to all.

Figure 4.2 Critical path to 2030 for the transport sector



RECOMMENDED REPORTS

We recommend the following reports for more detailed descriptions of the technologies for road transport decarbonisation and of the actions that countries and businesses can take individually.

- Decarbonizing Road Transport by 2050: Effective Policies to Accelerate the Transition to Zero-Emission Vehicles (ICCT, 2021)
- Decarbonising road transport by 2050: Accelerating the Global Transition to Zero-Emission Vehicles (ICCT, 2021)
- Renewable Energy Policies for Cities: Transport (IRENA, 2021)
- Global EV Outlook 2022 (IEA, 2022)

CURRENT STATE OF INTERNATIONAL COLLABORATION

International collaboration on road transport decarbonisation is less extensive than in the power sector or land use, but is more advanced than several other sectors at earlier stages of their transitions, such as steel. Governments exchange best practices on road transport ZEV policy in several initiatives, including through the Zero-Emission Vehicle Transition Council and its International Assistance Taskforce, the Global EV Advisory Council, the International Zero Emission Vehicle Alliance, and the Climate Group's EV100 initiative. There are also several important international conferences where governments work together on transport issues, including the OECD's International Transport Forum and the annual China EV100 Forum.[6]

An early step towards coordination on the pace of the transition was taken in 2017 by the 10 countries (now 14) participating in the Electric Vehicle Initiative of the Clean Energy Ministerial, which committed to achieving a 30% ZEV share of car sales by 2030. In 2020, members of the Zero Emission Vehicles Transition Council (ZEVTC), which brings together ministers from governments that represent over 50% of the global car market and one quarter of the global truck and bus market, have committed to overcoming strategic, political and technical barriers, and to rapidly move forward on the production of zero-emission vehicles and increase economies of scale. More recently, the COP26 ZEV declaration on accelerating the transition to 100% zero-emission cars and vans was signed by almost 40 national governments and many other stakeholders. Signatories pledged to work towards all sales of new cars and vans being ZEVs globally by 2040, and by no later than 2035 in leading markets. Also, at COP26, stakeholders from governments signed a Global Drive to Zero pledge, committing to enabling and expediting the growth of ZEVs with the "vision that ZE technology will be commercially competitive by 2025 and dominant by 2040 in specific vehicle segments and regions".

The main initiative promoting ZEV adoption in heavy-duty vehicles is the Drive to Zero Initiative. Its members, including national and subnational governments, manufacturers, fleet operators, and infrastructure providers have agreed to work together to identify viable pathways and supportive implementation action for deployment of Zero Emission Medium- and Heavy-Duty Vehicles (ZE-MHDVs) and related infrastructure that enable ZE-MHDVs to reach 30% of sales of new MHDVs by 2030, as well as enable a full transition to ZE-MHDVs in new fleets by 2040.

Business-led initiatives have played an important role in creating early demand for ZEVs. Notably the Climate Group's EV100' initiative, which includes large fleet-owning companies

[6] China EV100 is an industry and expert body in China, and is not the same as the Climate Group's EV100 initiative.

that have committed to achieving entirely zero-emission fleets by 2030. There are now several initiatives looking to mobilise private-sector buying power in the same way to catalyse the transition to zero-emission HDVs, including the World Economic Forum's First Movers Coalition (FMC).

There has also been significant international collaboration on ZEV infrastructure, with initiatives such as the ZEV Transition Council, the Green Grids Initiative, and the World Business Council on Sustainable Development's Mobility Decarbonization Initiative which aims to accelerate the deployment of charging infrastructure and ZEVs. On battery supply chain sustainability, countries have worked together on platforms such as the Global Battery Alliance (GBA) and European Battery Alliance (EBA).

In the used car trade, there are several existing international initiatives aiming to promote sustainability. These include the UN Economic Commission for Europe's (UNECE) Road Safety Fund (RSF), the UN's Environment Programme's Partnership for Clean Fuels and Vehicles (PCFV), and the Global Fuel Economy Initiative, each of which aim to promote the introduction of cleaner, more energy efficient vehicles in developing and transitional countries.

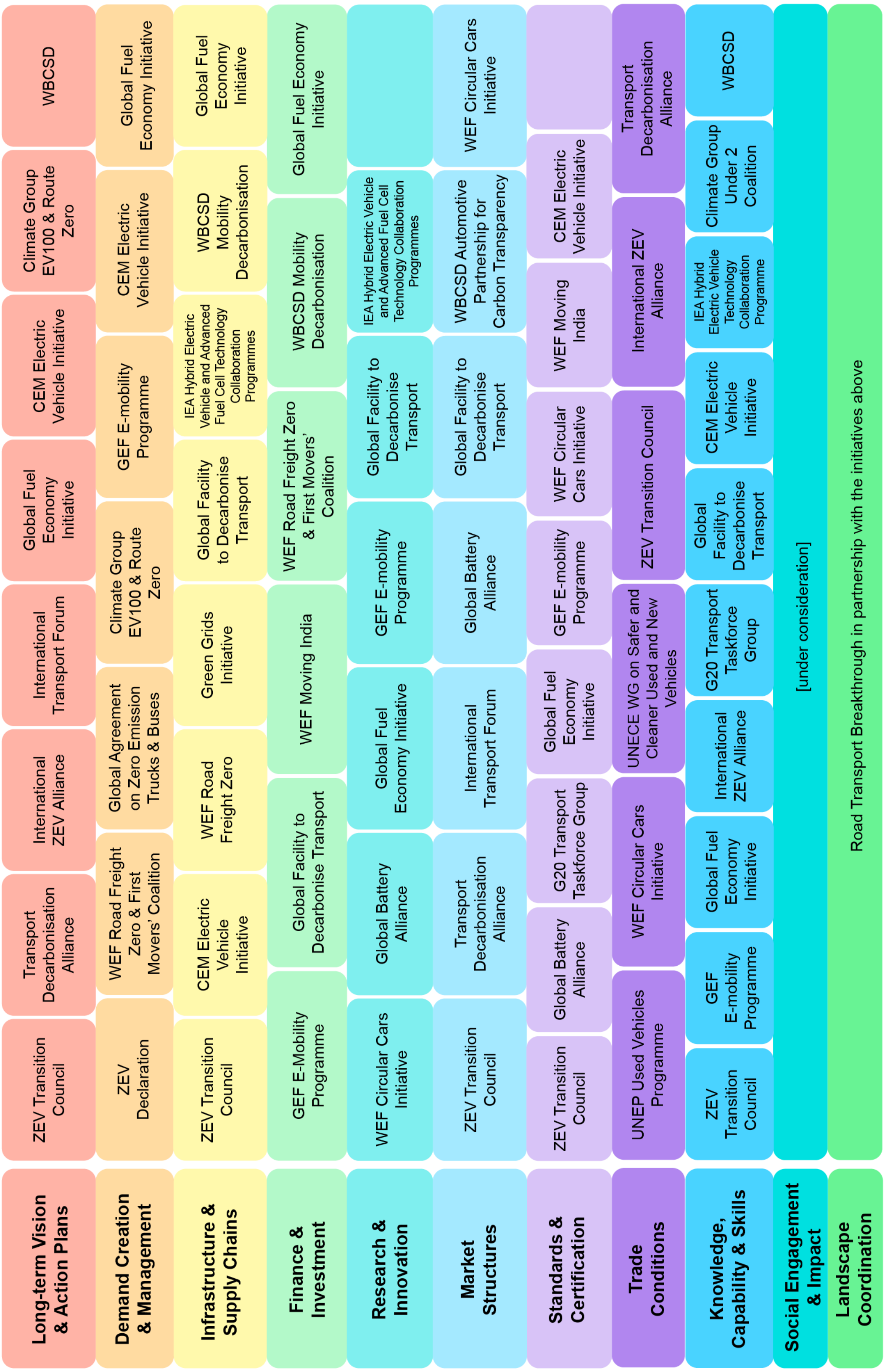
At the UNECE's World Forum for Harmonization of Vehicle Regulation, governments representing more than 90% of global road vehicle production discuss and agree globally unified technical policies including regulations and other instruments relating to pollution, safety, security and technical standards for the automotive sector. The forum has developed and adopted several regulatory instruments to ensure the safe and sustainable deployment of ZEVs.

Support to developing countries has been provided by initiatives such as the Global Environment Facility (GEF-7) project and the World Bank's Global Facility to Decarbonize Transport, launched at COP26. There are numerous other projects funded by donors such as the European Union, global foundations or through bilateral development aid organisations such as the German Society for International Cooperation (GIZ) and the US Agency for International Development (USAID). Nonetheless, compared to the scale of the challenge for the road transport transition, the level of international assistance is still relatively low. Many more countries could benefit from increased technical and financial support.

Since 2020, governments of most of the largest car markets have met at the ministerial level for strategic discussions on many of the above topics under the Zero Emission Vehicle Transition Council. This initiative may be seen as an indication of countries' willingness to take seriously the need and opportunity for stronger international collaboration in the sector. In addition, civil society and business-led initiatives such as those already mentioned are increasingly aligning their efforts to promote fully zero-emission vehicle manufacturing and fleets on timelines consistent with international climate goals.

In summary, international collaboration around zero-emission road transport is increasing rapidly, covering demand creation, infrastructure, trade and alignment of targets for the pace of transition. In each of these areas, however, there are significant opportunities to further strengthen international collaboration and improve coordination in ways that will lead to faster progress towards the Breakthrough goal.

Figure 4.3 Landscape map of road transport decarbonisation initiatives



Note: The diagram summarises the roles of many public and private sector initiatives in this sector. Initiatives have been included if they have a global scope, with active members from multiple regions of the world, and have at least one significant work programme specifically focused on accelerating emissions reduction in this sector. The list is not exhaustive and will be updated over time.

PRIORITY AREAS FOR INTERNATIONAL COLLABORATION

Six areas stand out as priorities for strengthening international collaboration: the pace of the transition to ZEVs; the choice of technologies to needed to achieve zero-emission goals; investment in charging infrastructure and alignment of standards; financing for developing countries; standards governing the electric battery supply chain; and regulation of the international trade in used vehicles.

ALIGNING THE PACE OF THE TRANSITION INTERNATIONALLY TO SHIFT INVESTMENT AND ACCELERATE COST REDUCTION

For many countries, the higher cost of ZEVs compared to ICE vehicles is a barrier to a faster transition. International collaboration will be key in driving currently more expensive technologies, such as batteries, down the cost curve. Until recently, the cost of a typical electric vehicle battery pack fell by around 18% with each doubling of cumulative global deployment (BNEF, 2019). Consequently, if large markets align their policies with a fast transition, the cost of ZEVs is likely to fall more quickly, benefiting all countries.

Analysis suggests that if the governments of the three largest car markets (China, the EU, and the United States) implement policies ensuring a transition to 100% ZEV car sales by 2035, from which larger economies of scale and faster innovation can be achieved, then cost-parity between ZEVs and ICEs could be reached several years earlier in these markets than without such a coordinated effort (Lam and Mercure, 2022).

To put the road transport sector on a zero-carbon trajectory, countries and companies will need to align their policies with an accelerated transition for all new car sales to be ZEVs. Some 28 countries, as well as a significant number of subnational governments, representing more than 16% of global passenger vehicle sales in 2020, have announced policies in line with making all new car sales zero emission globally by 2040, and in leading markets by 2035. Automakers representing 32% of the car market in 2020 have also committed to this pathway (BEIS and DfT, 2022). Strong, collective commitments on the pace of transition will have a positive effect not only in the automotive sector, but across the EV ecosystem, including companies in the supply chain for batteries, as well as grid planners and charging infrastructure installers and operators.

The transition to zero-emission HDVs is at an earlier stage than that of cars. Nevertheless, coordination on the pace of the transition can send an important signal to the market. At COP26, 16 countries, supported by over 30 other subnational governments and private-sector companies, including vehicle manufacturers and fleet operators, signed a Memorandum of Understanding that commits country signatories to achieving 100% zero-emission new truck and bus sales and manufacturing by 2040, with an interim goal of 30% for new medium-duty and HDV sales by 2030. Subnational governments and private-sector companies that have endorsed the MoU now total 42. The signatories have since held a series of discussions on HDV technologies, policy and infrastructure.

RECOMMENDATION 1

Governments should agree on a timeline by which all new road vehicle sales should be zero emission, with interim targets for countries taking into account their level of economic development and ability to scale up infrastructure, and should align policies with this target. Pathways compatible with 1.5°C indicate that this target date should be 2035 for cars, for example. Vehicle manufacturers should commit to the same timelines for 100% zero emission vehicle production. *This will send a clear signal to industry and unlock larger economies of scale and faster cost reductions, making the transition more affordable for all countries.*

AGREEING A COMMON POSITION ON TECHNOLOGIES CONSISTENT WITH THE GOAL OF ZERO EMISSIONS

Coordinating agreement around technologies compatible with zero emissions can unlock larger economies of scale, driving faster innovation. Analysis of life-cycle emissions suggests that only two currently commercialised technologies can be fully consistent with the long-term goal of zero emissions from the road transport sector: battery-electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs). Although achieving this goal will depend on decarbonisation of the power sector (or hydrogen supply), deployment of BEVs already saves emissions even in countries where the power supply is dominated by coal as a result of their high energy efficiency compared to ICEs. The emissions saving will continue to increase as the power sector is decarbonised (Knobloch, 2020).

Plug-in hybrid electric vehicles (PHEVs), which can run without emitting CO_2 when drawing solely on their battery, can play an important role in reducing emissions and transitioning to full ZEVs in road transport, provided the right regulatory framework is put in place. However, they are not consistent with the goal of net zero emissions if they continue to burn fossil fuels for a substantial portion of their energy. The emissions savings from their deployment vary widely depending on their use, and in some cases appear to be modest (ICCT, 2020; ICCT 2022). Conventional hybrid-electric vehicles, which use a battery to recover energy losses from braking, can reduce fuel consumption by 30% relative to conventional ICE vehicles, and hence can continue to contribute to reducing oil dependence and emissions in the short term, especially in developing countries, but are not a viable mid- to long-term technology option to decarbonise road transport.

The blending of biofuels and biomethane appears to have limited potential for emissions savings for cars and vans, with life-cycle greenhouse gas emissions estimated to be reduced by a maximum of 9% compared to ICE vehicles, based on current policies and projected changes in biofuel blends to 2030, according to a detailed study of their actual and potential use in Europe, India and the United States (ICCT, 2021b). Larger life-cycle emissions reductions could be achieved by moving to more advanced and sustainable blends, but supply of these blends would take time to ramp up. Moreover, a key factor is the limited global supply of sustainable biomass feedstock, and a greater need for it in sectors where there are fewer viable alternatives, such as long-haul aviation and the chemical industry (ETC, 2021).

Electrofuels (E-fuels) could in principle be consistent with the zero emissions goal, but their early stage of development and very high production costs, together with the lower life-cycle efficiency of their production, transport, and combustion in vehicles, limits their ability to contribute substantially to the global emissions reductions required over the course of this decade (ICCT, 2021b).

All of the above considerations regarding technology options apply to HDVs as much as to LDVs.

Governments inevitably influence technology choices through the design of policies to support the road transport transition, including regulations, incentives, and investments in charging or refuelling infrastructure. If countries align support with the technologies that are compatible with their long-term goal of decarbonisation of road transport, vehicle manufacturers worldwide will be able to concentrate their resources on improving these technologies, yielding faster progress, and avoid making wasteful investments that result in stranded assets. The more countries support the deployment of BEVs, for example, the faster the cost of batteries will come down, thereby making the technology more affordable for a broader set of consumers.

Policies in major markets are not yet fully aligned with choices consistent with a zero emissions goal. While recognising differing national circumstances and preferences, countries should aim to reach agreement on the issue of which technologies are consistent with zero emissions, since stronger alignment of policy in this respect would provide important support to accelerating the global transition.

Recommendation 2

Governments should collectively agree a common understanding of the technologies that are consistent with the goal of zero-emissions road transport, in order to send a clear and unambiguous signal to industry. *This will accelerate economies of scale for key technologies, accelerating the pace of innovation and cost reduction, making ZEVs affordable sooner for more people.*

Working together to mobilise investment in charging infrastructure

The availability of charging infrastructure for electric vehicles is likely to be one of the strongest determinants of the pace of the transition. Even among advanced markets, there is a wide gap between countries that have gone the furthest in installing charging infrastructure, and those that have done less. The Netherlands has around one public EV charger for every five EVs, while the average across Europe is one charging point for every 15 EVs (IEA, 2022a). Wide differences in this ratio, and in the ratio of kW of public charging capacity per EV, mean there is great potential for countries to learn from each other on what level of public charging is required at different stages of EV deployment, while accounting for differences in regional EV usage and regional context. We recommend countries collect a wide range of data needed to share the lessons from their own experiences, and support in-depth analysis that compares countries' experiences to identify in detail the policies that can most effectively support rapid deployment of charging infrastructure. (This will need to take into account differences between countries related to road typology, driving patterns, grid network capacity and accessibility).

Cooperation on knowledge and data sharing can be valuable in relation to the deployment of electric charging or hydrogen refuelling infrastructure for HDVs. Estimates suggest there could be between six million and eleven million zero-emission HDVs on the road globally by 2030. These numbers will require a dense network of charging and refuelling infrastructure that has yet to be built, including around two million overnight depot chargers, 0.6-0.7 million public high-speed chargers for battery electric vehicles, and 16 000 to 25 000 hydrogen refuelling stations (IEA, 2021a; IRENA, 2022; BNEF, 2022). International coordination will need to be strengthened to support this massive infrastructure investment in regions where there are significant volumes of cross-border road freight.

In emerging market and developing economies, except for some large EV markets such as China and India, the challenge of attracting investment in charging infrastructure may be greater as a result of smaller market size, lack of technical capacity in government, higher costs of capital, and other factors. There is a clear role for international assistance to play in providing technical support for policy development and concessional finance to catalyse early private investments. This may be useful not only for investment in BEV chargers, but also in infrastructure for two- and three-wheelers and battery swapping in some cases. This will need to be linked to support in the power sector, given the critical importance of upgrading electricity grids. This support should be a high priority, since without the appropriate infrastructure networks, countries will be unable to participate in the transition and share its benefits. The World Business Council for Sustainable Development is developing a global roadmap for charging infrastructure deployment, accompanied by an action prioritisation tool that identifies regional investment readiness and provides regional recommendations of financing mechanisms. This could be a useful guide to support international investment and assistance.

RECOMMENDATION 3

Countries should exchange best practice in policy to mobilise investment and accelerate deployment of charging infrastructure, in consultation with vehicle manufacturers and infrastructure investors. This should be complemented by a broader scaling-up of technical and financial assistance to developing countries at city, provincial, national and regional levels. *This will help to mobilise private investment, and ensure all countries are able to access the benefits of the transition to zero-emission vehicles.*

PROVIDING INTERNATIONAL ASSISTANCE AND FINANCE TO SUPPORT DEVELOPING COUNTRIES IN THE TRANSITION

There are important opportunities for international assistance and finance to support developing countries in the transition to zero-emissions road transport. These include:

- Policy design and investment in electric vehicle charging infrastructure, including support for smart charging systems and electricity grid upgrades.
- Development of comprehensive strategies and policy packages to support the deployment of ZEVs.
- Development of local supply chains, including both localised manufacturing and assembling of imported parts.
- Technical assistance, coordinating among financiers and private and public-sector stakeholders, integrating electrification into a broader framework of plans for sustainable urban mobility, and bundling of subnational projects, to enable the procurement of fleets of ZEVs for public transport (including two-and three-wheeler taxis, as well as minibuses and buses).
- Support for innovation, incubators and small businesses in developing countries to catalyse the development of locally appropriate road transport solutions.

In addition to supporting policy and infrastructure development at the national level, in many countries there is an opportunity for international assistance to facilitate action at the province or city level. Many cities are interested in purchasing and operating fleets of zero-emission buses or electric two- and three-wheelers, for example, but to do so they need access to financing, and support with project preparation. Often, there is a mismatch between the scale of finance required for these projects, which may be in the tens of millions of dollars, and the typical size of loans given by MDBs, which are at least an order of magnitude larger. At the same time, vehicle manufacturers sometimes lack interest in small fleet purchase orders from developing country markets.

Aggregating subnational projects to the national or regional level may help, but this approach on its own is unlikely to be sufficient. These projects are complex, since they require coordination across diverse networks of public sector entities (e.g. transport and urban planners), and private sector actors (e.g. fleet providers and operators, utilities, vehicle manufacturers). Cities need support with this coordination, preparing viable investment plans, enhancing grids and charging infrastructure, and, more broadly, with policy and planning for sustainable transport.

One example of how subnational projects can be successfully coordinated at a national or regional level is the work of the UN Environment Programme, the IEA, the Asian Development Bank, the European Bank for Reconstruction and Development, and the Centro Mario Molina Chile under the Global Electric Mobility Programme, and the GEF-7 project. Together, these partners have successfully begun to mobilise EV and charging infrastructure supply, investment, and financing for two- and three-wheelers and electric buses across a number of emerging markets and developing countries in Latin America and the Caribbean, Sub-Saharan Africa, East and Southeast Asia, Eastern Europe, and West Asia and the Middle East. The programme is also launching a number of regional support and investment platforms for assistance to be aggregated.

The ZEVTC International Assistance Task Force (IAT), which will report its findings at COP27, has convened stakeholders with the aim of assessing the current status of international finance and assistance for the ZEV transition, identifying both gaps and opportunities to scale-up successful approaches. To date, the IAT has categorised a range of principles for effective international assistance, including:

- The use of a business ecosystem approach for bringing together relevant stakeholders.
- Developing coalitions to accurately communicate ZEV benefits to stakeholders and the public.
- Facilitating knowledge sharing.
- Making information available on details of successful case studies and lessons learned.
- Integrating efforts across multiple cities or countries to create an aggregated regional market for investment.
- Sharing technology and providing technical assistance, and running pilot projects for assessing the feasibility of electromobility and retrofitting technology.
- Collaborating with international manufacturers and other industries for investment in electric public transport.

The World Business Council on Sustainable Development's Mobility Decarbonization project has also established regional business dialogues, developed tools to support investment decisions, and connected public and private partners, including for the GEF-7 project. Other notable projects such as the Zero Emissions Bus Rapid-deployment Accelerator (ZEBRA), the Transformative Urban Mobility Initiative (TUMI), and the SOLUTIONSplus, have all made progress in deploying electric buses.

Despite these valuable initiatives, two key problems remain. First, the overall level of financial and technical assistance dedicated to the transition in road transport, while it has grown in recent years, remains low. The sector has typically received the second largest share of climate finance, after the power sector, but absolute levels remain below what is needed (Aid Atlas, 2022). Second, there remains a difference in scale between the opportunities for investment available at city and regional level as described above, and the funding projects that international development institutions are accustomed to designing.

All actors can play a role in overcoming these challenges. Developed countries can coordinate together and increase funding for programmes that matches technical assistance with targeted financial support. One example of a new funding stream of this kind is the World Bank's Global Facility for Decarbonizing Transport. Multilateral development banks can coordinate activities and develop offers, which includes financing for city and regional level investments, that can be provided as part of their larger support for transport infrastructure. Developing countries can draw on a number of these cross-sector streams of climate finance to support the transition in transport. For example, countries that prepare and implement Nationally Appropriate Mitigation Actions (NAMAs) in the transport sector may be able to secure funding from climate mitigation funding streams such as the UNFCCC's Green Climate Fund (GCF). Support for electricity-grid upgrades may be accessible from a wide range of funds focused on energy transitions in the developing countries, including the Climate Investment Funds. Subnational governments (e.g. cities) in both developing and developed countries can also share experiences and lessons in policies, practices, investments and partnerships to advance the deployment of ZEVs and related infrastructures.

MOVE TOWARDS HARMONISATION OF CHARGING INFRASTRUCTURE STANDARDS

The availability of charging infrastructure is a crucial determinant of the pace of the transition to zero-emission vehicles. The interoperability of charging infrastructure is also a critical success factor. When electric vehicles cannot be charged at available charging points, consumers are disincentivised from making the switch from conventional ICE cars. Harmonised charging standards can reduce the risks for investors in charging stations, as well as increasing convenience and accessibility for consumers.

Chargers can be differentiated across three characteristics, each of which has implications for interoperability: electric current type (AC or DC) and level; socket and connector method; and mode of communication protocol between the vehicle and the charger. Fortunately, the wide diversity of charging types and protocols that characterised the first decade of EV deployment has begun to consolidate in the past couple of years. Within each of the largest car markets, interoperability issues arising from differences in charging connectors have been largely, though not completely, addressed. Public charging stations often offer multiple plugs with different charging standards to accommodate all EV models. In addition, some previously incompatible standards have been made interoperable.

However, significant differences remain between the major markets in the standards that are used. This creates problems for countries that import vehicles from major manufacturers in different regions of the world. At present, these countries are forced to choose between options that are all unsatisfactory: allowing imports of vehicles with only one set of standards, which would limit their domestic market to a subset of vehicle brands; developing a charging network that accommodates multiple standards but which risks requiring overinvestment in infrastructure; or setting one standard for public chargers but requiring drivers to use multiple different adaptors. Any of these options entails trade-offs that could delay the transition, particularly in developing countries.

Adjustments in standards can be difficult to achieve, not least given that nearly two million public chargers and over eight times as many private chargers that have already been deployed worldwide (IEA, 2022a). However, these are a small fraction of the number of chargers that need to be in place by the end of this decade. There remains an opportunity for governments of the largest markets to work towards greater convergence in charging standards, which could have important benefits for developing countries and the transition. International discussions are underway, within fora such as the International Organization for Standardization (ISO), UNECE's World Forum for Harmonization of Vehicle Regulations (WP.29) and the International Electrotechnical Commission (IEC), but progress has been slow.

Installation of charging infrastructure for HDVs has barely begun worldwide. China is the only country to have started to build a network of charging stations at significant scale. Globally, two competing and incompatible standards for HDV charging infrastructure are being developed; namely the Megawatt Charging System (MCS) standard, and co-developers China Electricity Council (CEC) and CHAdeMO's "ultra ChaoJi" for up to several megawatts for heavy-duty ZEVs. At this early stage, there is still an opportunity to avoid the cost, inefficiency, and problems for vehicle importers and international operators created by manufacturers following divergent paths. Countries and manufacturers should work together to take advantage of this window, and aim for the maximum possible convergence of standards and interoperability.

Over time, standardisation of communication protocols (modes) that enable smart charging and bidirectional charging will become increasingly important, so taking a proactive approach now to harmonisation would provide greater market certainty for manufacturers, and encourage more innovation and investment in these new forms of EV charging. This could hasten the economic viability and scale-up of these important demand-side management and energy market flexibility options, which will also contribute to the decarbonisation of the power sector.

Recommendation 4

Governments should work together and with industry to avoid further divergence of standards for charging infrastructure. There are several competing charging standards for light-duty vehicles; for heavy-duty vehicles, avoiding divergence of emerging standards could limit wasteful investments in multiple charging types, and accelerate the adoption of zero emission trucks. Aligning standards for hydrogen refuelling stations can reap similar benefits. *Doing so will decrease costs and facilitate the transition in vehicle importing countries.*

AGREEMENT ON STANDARDS FOR THE SUSTAINABILITY OF BATTERY SUPPLY CHAINS

Sustainable battery supply chains are essential for the transition to ZEVs and to enable them to maximise their contribution to reducing global emissions as well as avoiding social and environmental damage.

Batteries require a number of critical materials, including, in the most common battery types, nickel, copper, cobalt, and lithium. Nickel, for example, typically accounts for 12-15% of the weight of a lithium-ion battery. Owing to high demand and strained supply, the prices of some of these critical materials are increasing. IRENA estimates that demand for cobalt may double between 2020 and 2030, with vehicle batteries accounting for 60% of the total in 2030 (IRENA, 2021b). To realise the ten-fold increase in EV battery capacity by 2030 that would be needed to achieve countries' announced climate pledges, mining of critical battery metals would have to nearly double (for cobalt and nickel), or increase nearly six-fold (for lithium) (IEA, 2022a). Meeting 1.5°C targets will necessitate even more rapid EV adoption, as outlined in the IEA's Net Zero Emissions by 2050 Scenario, which would in turn require even faster scale-up of metals mining and processing. Higher mineral prices could have a significant effect: a doubling of lithium or nickel prices would induce a 6% increase in battery costs. Furthermore, many minerals come from a small number of producing countries. In the cases of lithium, cobalt and rare earth elements, for example, the world's top three producing countries control well over three-quarters of global output (IEA, 2021b; IEA 2022a). These factors not only pose risks to the transition but also offer opportunities to expand or enhance mining and processing operations, especially to regions where the production and processing of critical materials is concentrated.

Poorly managed mineral development can lead to significant GHG emissions, negative environmental impacts and damaging social consequences such as human rights violations and modern slavery. The mining of hard-rock lithium uses extensive amounts of water and energy, resulting in local water stress and up to 15 tonnes of CO_2 emissions for every tonne of lithium produced. Copper and lithium are particularly vulnerable to water stress given their high level of usage, with over 50% of today's production of the two minerals concentrated in areas with high water stress levels (IRENA, 2021b; IEA, 2021b). Other adverse environmental impacts of mining activities include waste generation, reduced biodiversity and contaminated soil. Mining activities for EV battery materials have also been linked to child labour. In the Democratic Republic of Congo (DRC), which provided 68% of global total cobalt production in 2020, 20% of mining activities take place in artisanal mines where child labour and human rights concerns have been identified (USGS, 2022; UNCTD, 2020).

Regulations and other measures are necessary, therefore, to establish environmental, social and governance standards, to minimise the adverse effect of battery supply chains and to promote sustainable practices. While the adoption of corporate responsibility policies and processes has led to mineral supply chain improvements, performance varies significantly within the industry. Local stakeholders, such as governments and civil societies, should be engaged to find ways to maximise socio-economic benefits to the advantage of people living in areas of mining operations.

The pressures on production of critical materials can be lessened by adopting a circular economy approach to battery supply chains. Repurposing end-of-life electric vehicle batteries for energy storage and household appliances is an important opportunity. For example, lithium-ion batteries whose capacity has declined by 70–80% can still be used for stationary energy storage applications in the electricity grid. Recycling is another way to avoid waste of materials. China currently has the most stringent national level regulations for EV batteries, wherein producers are responsible for labelling and tracing batteries following their first use in EVs, and for the creation of recycling channels that include battery collection (IEA, 2020). The European Union similarly puts responsibility for battery end-of-life on battery producers, and is nearing adoption of even more robust battery regulations. In the United States, California leads on developing supportive policies.

Ensuring EV batteries last longer can help ease pressure on demand for critical raw materials and reduce waste. Importantly, the Working Party on Pollution and Energy, a subsidiary body of UNECE's World Forum for Harmonization of Vehicle Regulations, has agreed a standard on electric vehicle battery durability, which many countries have committed to transpose into national legislation.[7]

Several international standards relating to waste batteries have already been developed, and some can be applied to enable the reuse of batteries. The Global Battery Alliance (GBA), for example, works with over 100 governments and organisations to ensure that battery production not only supports energy transitions, but also safeguards human rights and promotes health and environmental sustainability. The Circular Cars Initiative, jointly run by the World Economic Forum and World Business Council for Sustainable Development, works with more than 100 organisations to accelerate the transformation of circular manufacturing and business models within the automotive and mobility industry. The International Electrotechnical Commission has developed standards to provide guidelines for manufacturers and recyclers regarding the end-of-life management and operation of battery recycling. The OECD oversees a number of initiatives for responsible mineral production and sourcing to support a just low-carbon transition, with an emphasis on critical minerals and the role of supply-chain due diligence. Many standards lack binding force, however, unless they are adopted by countries as part of their national or regional regulatory frameworks.

There is an urgent need for a significant increase in the pace and depth of international collaboration to ensure the sustainability and responsible conduct of battery supply chains as global sales of electric vehicles accelerate. Today's battery supply chains are very concentrated: China produces three-quarters of all lithium-ion batteries and is home to 70% of production capacity for cathodes and 85% for anodes (both of which are key components of batteries). Over half of the world's lithium, cobalt and graphite processing and refining capacity is located in China. In contrast, Europe produces over one-quarter of global EVs but it is home to very little supply chain activity apart from cobalt processing at 20%, while

[7] To ensure that batteries meet minimum durability standards, the Working Party on Pollution and Energy (GRPE) adopted in March 2022 UN Global Technical Regulation No. 22 on In-Vehicle Battery Durability, which requires EV manufacturers to certify that the batteries will lose less than 20% of initial capacity over five years or 100 000 km and less than 30% over eight years or 160 000 km. Countries that committed to add it into legislation include Australia, Canada, China, India, Japan, Korea, Malaysia, Norway, Russia, South Africa, Tunisia, United Kingdom and the United States. The European Union also has committed to transpose it into legislation, with the provisions expected to be part of the forthcoming new vehicle emission standards, Euro 7/VII.

the United States accounts for only 10% of EV and 7% of battery production capacity (IEA, 2021b). Working together, countries can influence the incentives for manufacturers throughout the global market. As the transition moves forward, the expansion and diversification of these supply chains would help to increase the sector's resilience.

Finally, as energy transitions gain momentum, security of mineral supply is gaining prominence in the energy security debate. Governments can take a number of measures to broaden supply. Support for geological surveys, and streamlining of planning processes can help. Reducing material intensity and encouraging material substitution via technology innovation can also play major roles in alleviating strains on supply, while also reducing costs.

International efforts should focus on agreeing harmonised international standards for lifetime sustainability, design, operation and end-of-life treatment of EV batteries, to reduce dependency on critical materials from mining and increase sustainability throughout supply chains. Factors to consider include the carbon intensity of power inputs and processing of battery metals, the quantity of water use for battery production, the social responsibility of sourced minerals, and other environmental, societal and economic aspects. This may be enabled by transparency standards that mandate actors along the supply chain to provide fully traceable products, and to ensure that third party independent organisations adopt internationally consistent methods to track, assess and verify the sustainability performance of mining and production practices for battery supply chains. It can also be complemented by harmonising the way that recycling-relevant information is provided, or even setting standards for battery disassembly. Further, international cooperation on recycling processes and technologies could spur their cost-effective and widespread adoption.

Countries should also consider how to ensure security of supply and increase the resilience of battery supply chains. This could include measures to reduce material demand in novel battery chemistry designs, to diversify regional distribution and market players within each step of supply chain, to create coalitions to procure supplies, and to ensure that minerals in used battery re-enter the value chain.

Recommendation 5

Countries should work together and with industry to urgently agree harmonised standards to ensure sustainability and social responsibility along the electric vehicle battery supply chain, including when sourcing critical minerals and increasing the recyclability of battery modules. As a priority, these standards should minimise batteries' life-cycle emissions and the social and environmental impacts associated with their production, ensure minimum cycle and calendar lifetimes and seek to extend battery durability, and promote reuse, repurposing and recycling of their components. Similar standards on fuel cell value chains, including information on platinum and other catalyst materials' content and origin, should be put in place. *Harmonised standards will send a clearer signal to the global market, and facilitate compliance by battery and vehicle manufacturers that sell to multiple markets*.

TAKE THE MOST POLLUTING VEHICLES OUT OF INTERNATIONAL TRADE

The standards governing trade in used vehicles matter greatly to emissions from road transport, as well as to public health and safety.

Nearly ten million used cars were imported by developing countries in 2020. These included countries in Africa (4 million used cars imported), Eastern Europe (2.4 million), Asia Pacific (1.5 million), the Middle East (1.2 million) and Latin America (0.9 million). In Africa, more than 60% of the vehicles added to the roads each year are imported used vehicles. The largest exporters of these vehicles were the European Union, Japan and the United States (UNEP, 2020).

Most used vehicle-importing countries have weak policies to regulate the safety, quality, efficiency and emission performance of imported used vehicles. More than 100 of the 146 countries investigated by UNEP have no regulation on emission standards for used vehicles. Even when importing countries impose standards for quality and environmental performance, their regulations are usually less restrictive than those of the countries in which the vehicles are produced. A study published by the Netherlands Human Environment and Transport Inspectorate (ILT), for example, revealed that many used vehicles exported from Europe to Africa cause significant pollutant and climate emissions and endanger road safety (ILT, 2020).

While most African countries (32 out of 54) have implemented standards on imports of second-hand vehicles, including four that have banned them altogether, the standards vary by country. The most stringent standard, Euro 4, which is applied in Morocco, Rwanda and the 15 Economic Commission of West African States (ECOWAS) countries, was superseded in Europe around a decade ago. A significant share of used vehicles imported to Africa are more than 15-years old (around 30 countries in Africa do not impose any regulatory age limit on cars). These vehicles typically have low safety levels because of missing safety-related components (as well as lacking components for environmental protection). In addition to being highly polluting and often unsafe, older vehicles typically have very low efficiency, resulting in high operational costs (IEA, 2022a).

The export of used cars is similarly under-regulated. A few exporting markets (such as the EU) have regulations in place regarding the export of vehicles as waste, for example, the EU Waste Shipment Regulation EC/1013/2006, and Directive 2000/53/EU on end-of-life vehicles (EC, 2020a, 2020b). However, there are limited regulations in place governing the export of vehicles to the second-hand market, which is usually in developing countries. Neither exporting nor importing countries have effective measures in place to assess and monitor the environmental performance of the traded second-hand vehicles.

There have also been moves by groups of countries to apply standards to imports, including by ECOWAS, which recently adopted the standard of importing only Euro 4 vehicles, and imposed an age limit of five years for imported light-duty vehicles (LDV) and ten years for heavy-duty vehicles (HDV) (Africa Times, 2020). The East African Community (EAC) is in the process of setting minimum standards for imported used vehicles, after which each country will work towards passing these standards into legislation (UNECE, 2021). In addition, the African Organisation for Standardisation (ARSO) has a mandate to unify the region's standards to promote international and inter-African trade. It has been working on a harmonised minimum requirement for the import of vehicles to the Continent, covering both new and used vehicles. Supporting these efforts, UNEP has developed a Global Electric Vehicles Database containing information on fiscal, regulatory and other mobility-related policies (including policies promoting electromobility) in countries around the world (UNEP, 2018).

At a global level, the World Forum for Harmonization of Vehicle Regulations has recently created an Informal Working Group on Safer and Cleaner Used and New Vehicles. This aims to establish harmonised minimum performance requirements for safe and clean vehicles in developing economies.

Despite these important efforts, there are currently few regional agreements and no global ones on environmental sustainability in the trade of used vehicles. There is little harmonisation between importing and exporting countries regarding the regulations on used vehicles. This lack of coordination contributes to air pollution and safety problems, and holds back the decarbonisation of road transport.

There are clear opportunities for international collaboration to bring about trade conditions that more strongly support the transition:

- Individually, exporting countries should test and certify used vehicles before export to ensure they meet appropriate safety and emissions standards. This should include confirming key components such as particulate filters, catalytic converters and airbags are attached and working.
- Importing countries should set age restrictions and/or minimum standards for fuel efficiency for the vehicles they import. Setting an age limit for second-hand vehicle imports is an effective policy instrument for importing countries, as exporters are increasing the stringency of their fuel economy and emissions standards, notably in the European Union. Applying fuel economy standards on all new car registrations and vehicle imports would lead to improvements in the average fuel economy of the fleet. Other measures include providing incentives or tax exemptions for high efficiency or ZEVs and higher taxes for more emissions-intensive vehicles; and strengthening systems for inspection and verification of imported vehicles' safety and environmental performance.
- Together, importer and exporter countries can reinforce each other's efforts by agreeing harmonised regulations to promote cleaner and safer used vehicles in international trade, supported by strong mechanisms to enforce compliance. Enforcement mechanisms could benefit from the international sharing of a common database and regulations mandating the tracking of vehicles imports and exports.

SUPPORT THE EMERGING TRADE IN USED ZERO-EMISSION VEHICLES

Some developing countries see importing electric vehicles as a cost-effective way to begin the transition from internal combustion engine cars to zero-emission vehicles.

The international trade in used electric vehicles is currently very low; having only begun to emerge in recent years, but some countries are encouraging this trade either by providing incentives for the import of used EVs, or by exempting EVs from existing bans on the import of used vehicles. Jordan, Ukraine, FYR Macedonia, Turkmenistan, Sri Lanka, Seychelles, Mauritius, Maldives have introduced fiscal incentives (e.g. favourable duty, registration fee, road tax) to encourage the import of used EVs. Mauritius, for example, provides fiscal incentives for low- or zero-emission vehicles and therefore the volume of imported used EVs has increased. Egypt and Bhutan ban the import of other used vehicles but allows the import of used EVs (UNEP, 2020). The major exporters of electric and hybrid vehicles are Japan and the EU. Japan contributed the majority and exported around 169 000 electric and hybrid electric used LDVs in 2018, representing 32% growth compared with 2017.

This international trade should be encouraged since it can help developing countries access zero-emission vehicles at lower cost. The need to ensure quality and safety is as important for ZEVs as for conventional vehicles, however, and should not be overlooked in import policies. Importing countries will also need to consider to how address challenges of battery replacement, and end-of-life management of batteries.

Global trade of electric two- and three-wheelers is growing rapidly. Africa is a growing market for imports, with Chinese manufacturers dominating the market, and Indian manufacturers also present. Local manufacturing or assembly of electric two- or three-wheelers is also emerging in some countries, such as Kenya, Nigeria, and Rwanda. In many developing countries, electrification of two- and three-wheelers can contribute substantially to both emissions reduction and economic development. Promoting the scale-up of electric two- and three-wheeler industries and sales will require attention to deployment of charging infrastructure, technical and financial assistance, as well as trade.

Recommendation 6

Vehicle importer and exporter countries should agree on harmonised regulations on vehicle trade to improve vehicle efficiency and safety in international trade in used vehicles. These rules should govern trade in zero-emission vehicles as well as internal combustion engine vehicles, supported by strong mechanisms to enforce compliance. *This will help prevent 'vehicle dumping', locking developing countries into higher emitting vehicles.*

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ANNEX

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Long-term vision and action plans	Target date should be around the early 2030s for two- and three-wheelers, 2035 for cars and vans, and in the 2040s for heavy-duty vehicles. Vehicle manufacturers should commit to the same timelines for 100% zero-emission production.	25 automobile (and components) company with a science-based target aligned with 1.5°C. 39 national governments and 13 automotive manufacturers signed the ZEV Declaration, committing to work together towards all sales of new cars and vans being zero emission globally by 2040, and by no later than 2035 in leading markets.
Demand creation and management	By the mid-2020s, governments and companies should commit to high shares of zero-emission vehicle procurement for public transit bus operators, municipal services and logistic companies. Private sector fleet operators should approach 100% of ZEVs, with a clear timeline for phasing-in.	123 companies have signed the EV100 commitment to either transition their fleets to EVs by 2030 or install charging at their facilities.
Infrastructure and supply chains	As soon as possible, governments and industry agree harmonised standards on the sustainability and social responsibility of sourced minerals and along the entire supply chain of electric vehicle batteries, as well as to increase the recyclability of battery modules. Regulations on battery product information (such as the EU's battery passport), including information on manufacturer, durability/warranty, material content and origin of components/materials, and environmental footprint. By the early 2020s, governments mandate that cables that can accommodate EV charging are included in all newly constructed and renovated buildings. By the mid-2020s, smart charging (e.g. stop/start charging based on communications from the power system, facilitated through the e-mobility service provider or through the charging point) is becoming the norm in major markets. The UK's regulation mandating OCPP compliance from 2022, and incentive systems in Belgium and Luxembourg, serves as model policies designed to achieve this goal EVs thereby serve as distributed energy storage, dynamically charging at times when system availability is the highest, while providing additional power supply at peak time	Key initiatives include: IRENA Collaborative Framework on Critical Materials.

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Finance and investment	By the early 2020s, governments of developed countries will need to provide, replicate, and scale-up technical and financial assistance, best practice sharing, and training, from the city and subnational level to the national and regional level to their counterparts in developing countries. By the mid-2020s, once sufficient project scale and capacity has been built up, financing from international assistance funds can target country-level investments to further accelerate the transition to zero-emission vehicles.	Direct spending on EVs in 2021 reached USD 270 billion. Government share of spending fell to 10% in 2021 (from 22% in 2015).
Research and innovation	Countries will need to target public RD&D budgets and other instruments seeking to leverage private investment flows on specific areas of the EV value chain, including mineral mining, mineral processing, cell chemistry and design, vehicle production and battery end-of-life processes.	Four IEA Technology Collaboration Programmes currently underway: Advanced Fuel Cells; Advanced Materials for Transportation; Advanced Motor Fuels; Hybrid and Electric Vehicle
Market structures	Shift from fossil fuel subsidies to taxing transport fuels: By the mid-2020s, all countries adopt fuel taxes that reflect the health and other impacts of local air pollutants, as well as the climate impacts of GHG emissions, among others (e.g. energy security, etc.). Shift from EV subsidies to feebates: Countries leading the adoption of ZEVs have recognised the importance of reducing the purchase price gap to drive consumer adoption. However, as the value proposition of EVs improves, and this purchase price gap closes, countries will need to switch to revenue neutral (or even net-revenue generating) policies to continue to accelerate EV adoption. City-level policies: measures such as licence plate lotteries, restrictions on ICEs, low-emissions zones that favour ZEVs, dedicated/prioritised public parking for ZEVs. Revise power system regulations to ensure that different types of distributed flexibility provider (e.g. aggregators, energy communities, peer-to-peer trading) have access to markets on a level-playing field with traditional flexibility providers, such as power plants or large industry. Focus on key principles of power markets such as right to participate, size of products, rules for control and flexibility measurement.	

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Standards & certification	By the mid-2020s, governments develop regulations seeking to streamline international and/or regional charging standards for LDVs and HDVs. Adopt policies, such as differentiated pricing (at minimum day/night or peak/off-peak tariffs, ideally time-of-use tariffs, or even real-time pricing), and technologies (to control charging time, rate, and duration, based on price signals and/or power system availability). Fuel economy standards: promote the adoption of more efficient vehicles but also benefit the rollout of ZEVs. Tailpipe emissions standards: target reduction of pollutants emitted from ICE vehicle tailpipes, while also improving the competitive prospects of ZEVs.	
Trade conditions	By 2024, major automotive exporting markets agree on regulations and enforcement protocols to restrict export of used vehicles (e.g. age limits). Major vehicle producing countries adopt ZEV mandate regulations, such as ZEV credits, and require manufacturers to put more ZEVs in the market.	Global Trade in Used Vehicles Report Used vehicles and the environment - Progress and updates 2021
Knowledge, capability & skills	Governments and companies to provide retraining and recertification programmes for ICE industry workers. This should also include potential social protection programmes to help affected ICE industry workers and communities cope with a potentially lengthy and difficult transition period. Public investment strategies to finance training and social protection, and to support regional economic development and diversification.	
Social acceptance	By the mid-2020s, dialogues are held with communities in regions most affected by the transition to new ZEVs and any changes in supply chains.	

CHAPTER 5. STEEL

"Near-zero emission steel is the preferred choice in global markets, with efficient use and near-zero emission steel production established and growing in every region by 2030" -- *Steel Breakthrough goal*

KEY MESSAGES

- The steel sector is at an early and critical stage in the transition and, while progress is accelerating, it is significantly behind where it needs to be on a Paris-aligned pathway. Less than 1 Mt of primary near-zero emission steel is produced per annum as of today, versus over 100 Mt needed by 2030, requiring deployment to double every year.
- In many parts of the world, the sector is heading in the wrong direction entirely. As of late 2021, there were approximately 114 Mt of new steelmaking projects currently underway or in the planning stage. The vast majority of these projects are set to use conventional, high-emission steelmaking routes, representing significant potential stranded asset risks.
- Given the long lifetimes of steel plants, 2050 is only one investment cycle away. As such, if near-zero emission steel is to become the default choice in international markets, large-scale action is required now.
- Progress to date has been mostly in Europe, with a recent wave of new announcements from companies planning to deploy novel technologies over the 2020s. However, urgent action is needed in emerging markets and developing countries, which are projected to account for around three-quarters of future growth in steel demand by 2050.
- Companies face multiple challenges, not least technology availability and covering the 'green premium'. At the same time, these challenges offer a unique opportunity to leapfrog to clean solutions, allowing a larger number of companies and countries, particularly in emerging economies, to compete in an international market that will increasingly demand near-zero emission steel.
- There has been a welcome and significant increase in international collaboration on the steel sector's transition to low emissions over the past several years, but this is still at a formative stage.

- To drive progress at the pace and scale required, international collaborative action is imperative to generate the 'enabling conditions' needed to dramatically accelerate the transition in the global steel sector, putting it on track for the 2030 Breakthrough goal.
- Five areas stand out as urgent priorities to strengthen international collaboration over the next 1-2 years that will help put the steel sector on track to meet the 2030 Breakthrough goals. Key priorities include:
  - Governments and companies willing to lead the transition in the steel sector should collectively agree on common definitions for low emission and near-zero emission steel, along with a time frame for the adoption of standards by the mid-2020s. *This is an important market signal and will be vital for unlocking a series of subsequent actions, most notably high-quality demand commitments and trade agreements.*
  - Governments and companies should increase the scale of near-zero emission steel procurement commitments to cover a significant share of their future demand. These commitments should be high quality, supported by appropriate legal and implementation frameworks, such as advance purchase commitments. Countries and companies should also consider joining public and private sector initiatives where these commitments are aggregated. *This will strengthen the global demand signal for near-zero emission steel, increasing the incentives for industry to invest in its production.*
  - Governments should urgently launch a strategic dialogue, including the leading producer and consumer countries, with the purpose of agreeing ways to ensure near-zero emission steel can compete in international markets. This is needed to prevent trade acting as a brake on the transition. *This may be supported by agreements to cooperate on data, standards, comparability of policies, RD&D, finance and procurement.*
  - Governments and companies should urgently identify several commercial-scale pilot projects, in all major steel producing regions, where international collaboration can support shared technology learning, business case development and policy support. Collaborative networks should deliver operational projects in these countries by the late 2020s at the latest. Emerging markets and developing countries' participation in key research, development and demonstration initiatives should be increased in support of this aim. *This will help eliminate technology availability issues, providing multiple case studies for a large group of countries and companies to further improve upon.*
  - Donor countries and MDBs, led by the priorities of developing countries, should significantly increase funds supporting industry transition to near-zero emission technologies in emerging and developing countries. *This will provide much needed, near-term technology and financial support to unlock additional private sector capital for the first wave of near-zero emission projects in key steel producing countries, especially for developing countries.*

SIGNIFICANCE OF THE SECTOR

Steel production accounts for around 7% of global energy-related carbon dioxide emissions (IEA, 2020). The sector is the largest contributor to industrial emissions, which make up around one quarter of the global total. The energy intensity of steelmaking has shown little change in the past few years, and remains reliant on coal, which meets 75% of its energy demand. Steel demand is projected to steadily increase in the coming decades, especially in developing and emerging economies, and will play a vital role in building the infrastructure and products that will enable the energy transition, including the construction of electricity and pipeline infrastructure and the manufacture of electric vehicles.

Steel production is at an all-time high at just below 2 billion tonnes per annum. China produces over half of the world's steel (53%), with the top five producing countries accounting for roughly three-quarters of global production. Three out of the five top steel producing companies include China's Baowu Group, Ansteel Group, Shagang Group, with the other two Luxembourg-based ArcelorMittal and Japan's Nippon Steel (WorldSteel, 2022). The top 15 countries produce close to 90%, which underscores the high concentration of production.

Steel is produced via two routes: primary steelmaking from iron ore, and secondary steelmaking from scrap steel. Primary steelmaking – or more specifically the ironmaking step within this process – consumes the most energy and is far more emissions-intensive (on average producing seven times more emissions versus secondary steelmaking). The blast furnace route (using coking coal) accounts for about 70% of global steel production and around 90% of primary production (IEA, 2020). The majority of the remaining primary steel production follows the direct reduced iron (DRI) route, using natural gas or coal. Secondary steelmaking relies on electric arc furnaces (EAF), which are mainly used to process scrap. The decarbonisation of secondary steel is promising, as it will follow the decarbonisation of the power supply, but its potential is limited by scrap availability. Therefore, decarbonisation of the steel sector will rely on the deployment of an array of low-carbon solutions for primary steel production.

SECTOR GOALS

The steel sector is at an early stage in its transition. Paris-aligned pathways make clear that emissions from steel production need to be drastically reduced by 2050 (IPCC, 2022). Further improving the energy efficiency and material efficiency of processes, alongside applying the principles of circular economy throughout the supply chain, will play a vital role in reducing emissions from steel production. However, these efforts alone cannot deliver the emission reductions required (IRENA, 2020).

Technologies for near-zero emission[1] production have already been developed, and several pilot plants are in operation. However, these are not yet widely deployed at a

[1] Near-zero emission steel (NZS) refers to production which has achieved greater than 85% reduction in direct and indirect emissions versus conventional technologies, such as a blast furnace-basic oxygen furnace (BF-BOF), equivalent to around 400kgCO_2 (IEA, 2022).

commercial scale. With the exception of a natural gas-based DRI plant using CCUS in Abu Dhabi,[2] implementation is lagging, particularly for key technologies with the capacity not only to deliver near-zero emissions steel but also to scale sufficiently to play a significant role in the decarbonisation of the sector globally.

Alongside deploying new near-zero emission technologies, avoiding the construction of high emission steel production is equally important. In many parts of the world the sector is heading in the wrong direction entirely. As of late 2021, there were approximately 114 Mt of new steelmaking projects currently underway or in the planning stage. The vast majority of these projects are set to use conventional, high-emission steelmaking routes, representing significant potential stranded asset risks (OECD, 2021).

Steel facilities have long lifetimes (approximately 40 years), meaning that 2050 is only one investment cycle away (IEA, 2022). In the case of integrated steel plants with blast furnaces, these typically require major investment for relining every 15-20 years (Vogl, Olsson and Nykvist, 2021). Roughly two-thirds of existing blast furnace capacity is projected to need relining before 2030 (Agora Industry, Wuppertal Institute and Lund University, 2021).

This makes near-term action vital, especially given the critical investment window available this decade. This is an important time frame for developed countries, which have older facilities that will be ready for reinvestment during the 2020s, as well as for developing countries, which can benefit from technology leapfrogging and avoid the risk of stranded assets. Coordinated international action will be critical to driving these changes at the speed and scale required.

To put the steel sector on a Paris-aligned pathway, countries and companies will need to meet the Breakthrough goal which 29 countries, representing over 30% of the steel sector (by production), endorsed at COP26:

"Near-zero emission steel is the preferred choice in global markets, with efficient use and near-zero emission steel production established and growing in every region by 2030."

This will require the construction of multiple near-zero emission steel plants around the world, alongside measures to promote its efficient use and greater material circularity. A number of scenarios have been developed to put the sector on the near-zero emissions pathway (IEA, 2021; Bataille, Stiebert and Li, 2021; E3G & PNNL, 2021; MPP, 2021; Agora Industry, 2021). These make the following projections for 2030.

- Primary near-zero emission steel production should reach more than 100 Mtpa by 2030, with some estimates suggesting as much as 500 Mtpa (5-25% of current steel

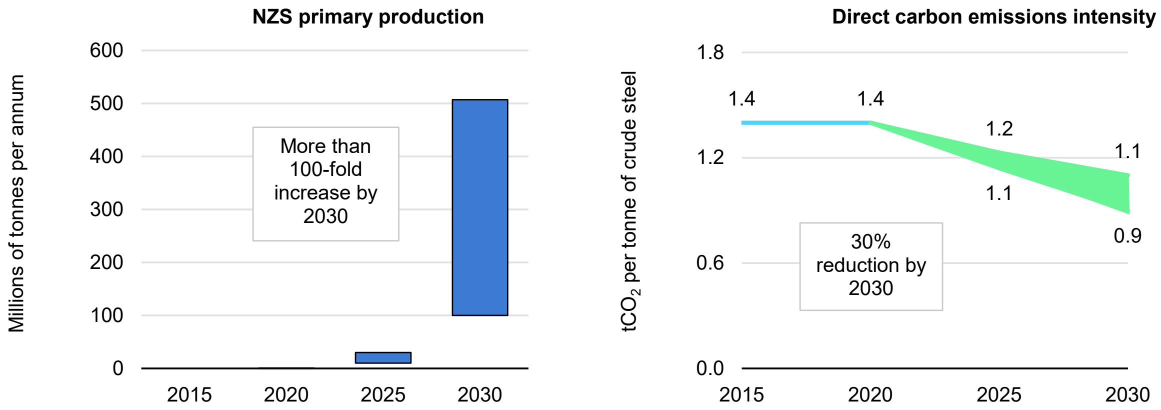
[2] The captured carbon is being used for enhanced oil recovery (EOR).

production).[3] This equates to around 40-200 of typical-sized[4] near-zero-emission steel plants in operation, or 5-25 plants being built each year between now and 2030.

- A reduction in the average direct emissions intensity of steel production - reducing it by around 30%, to below 1 tCO_2 per tonne of crude steel (tcs) in 2030.
- The cost of near-zero emission steel should approach the cost of high emission steel, in the most favourable locations, by 2030.

Developing and deploying new near-zero emission steel (NZS)technologies are essential for meeting these goals. Multiple low-emission primary steelmaking technologies, using hydrogen, carbon capture, utilisation and storage (CCUS), or direct electrification, are being developed and plans are underway to demonstrate these technologies over the 2020s. Several pilot plants are already in operation, including the Hybrit Project in Sweden, which uses hydrogen direct reduction and the 3D project in France, which uses CCUS on a blast furnace, with both operating since 2021.

Figure 5.1. Change in direct carbon emissions intensity and NZS primary production needed to meet climate goals, 2015-2030



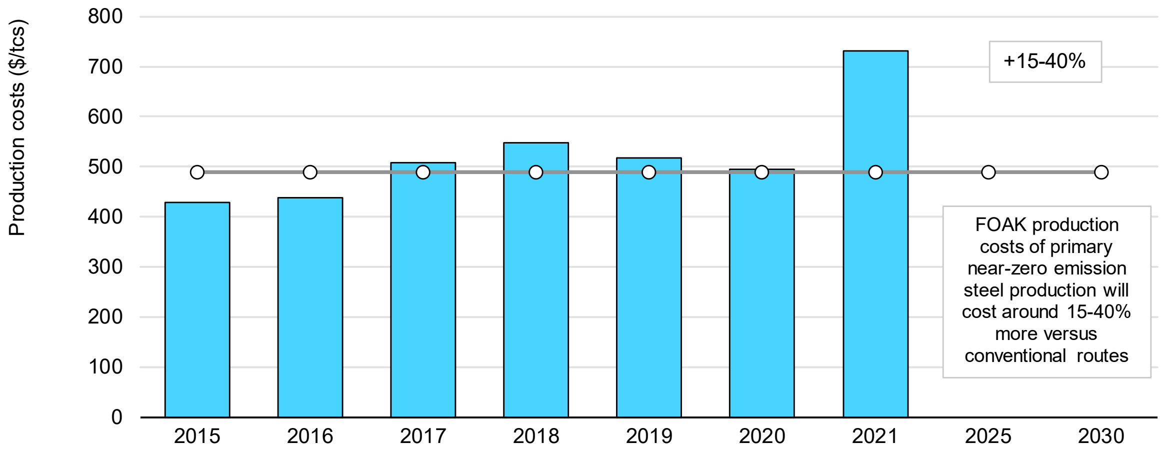
Notes: The change in the direct carbon emissions intensity includes process emissions, and exludes Scope 2 and 3 emissions.
Sources: IEA, 2021; Bataille, Stiebert and Li, 2021; E3G & PNNL, 2021; MPP, 2021; and Agora Industry, 2021.

To begin with, near-zero emission steel will be significantly more expensive to produce than high emission steel, at a premium of between 15-40% for first-of-a-kind (FOAK) plants over the 2020s (MPP, 2021). Much will depend on the cost of high emission steel, which fluctuates significantly (particularly over the past two years, driven by highly variable energy and raw material costs), as well as on progress in reducing the cost of near-zero emission

[3] The range of primary NZS production varies significantly due to uncertainties in the sequencing and scale of various emission reduction measures, such as energy efficiency, material efficiency and the introduction of low-emission technologies versus near-zero emission technologies. The scenarios that inform this range also use different assumptions around technology availability, the steel sector's share of a 1.5˚C emission budget, the availability of scrap, among other factors.
[4] Typical-sized plant assumed to be 2.5 Mtpa.

steel production processes and their inputs. This has been confirmed by currently planned projects, such as H2 Green Steel's plant in Sweden, which is targeting a 25% premium when it begins production in 2025 (Reuters, 2022). Overcoming this cost barrier is a critical challenge for the early phase of the transition. With the right policy support and coordinated international action to channel and mobilise investment and innovation, near-zero emission steel could start to approach cost parity with high emission steel by 2030 in the most favourable regions.

Figure 5.2. Global average steel production costs for BF-BOF (2015-2021)



Notes: Global average production costs are calculated from country-level blast furnace – basic oxygen furnace (BF-BOF) production costs for 13 countries representing close to 90% of global steelmaking capacity. Line represents average historical costs for 2015-2020, before recent price shocks.The 15-40% range of future costs of NZS production is from MPP analysis.

Sources: TransitionZero, 2022; MPP, 2021.

Achieving the Steel Breakthrough goal would produce a radical and enormously beneficial transformation for the sector globally. By 2030, the steel sector should be firmly on track to reach net zero emissions by the mid-century, illustrating that near-zero emission technologies are technically viable at commercial-scale in all regions. Collective action in the sector, reinforced by successes over the 2020s, could create a race to the top, with the most progressive companies being rewarded. Equally, local communities benefit from secure and clean jobs and significantly reduced air pollution.

HOW DO WE GET THERE?

Action across multiple enabling conditions is required to accelerate the transition in the steel sector. To achieve the 2030 vision, a multi-pronged approach – adapted to the different economic and social realities in developed and developing countries – is needed in the coming years.

Urgent action is required to create demand for low and near-zero emission steel, overcoming the barrier created by their cost premium. Assured demand can mobilise investment in low and near-zero emission steel production, and set in train the processes of innovation and improvement that will bring down costs over time. Steel buyers, in both the public and private sectors, can create this demand through measures such as procurement and advance-purchase commitments.

Definitions for low and near-zero emission steel will need to be agreed among major steel producing countries, with a timeline for adoption by the mid-2020s, which will help enable demand creation. These definitions should be supported by robust processes for substantiating these standards, including agreed approaches to the monitoring, reporting and verification of emissions data. This will provide certainty for those companies and governments looking to purchase low and near-zero emissions steel through key procurement initiatives.

In parallel, countries and companies should scale-up RD&D investments to ensure that commercial-scale technology is ready to deploy by the mid-2020s in multiple regions. Beyond investments in near-zero emission steel production technologies, this should also include projects along the value chain, including iron ore processing and finishing processes. Once exploratory RD&D projects have de-risked key deep decarbonisation technologies, governments can support the first wave of commercial-scale plants in the mid- to late-2020s through policy and regulation. As an example of such support, in May 2022, Germany launched an expression of interest for Carbon Contracts for Difference for heavy industry sectors, including steel (BMWK, 2022a).

Governments will need to cooperate towards creating a level playing field for low and near-zero emission steel products, alongside the support for early deployment. This should include coordination on carbon intensity standards and benchmarks, which should be agreed by a significant share of the market by the mid-2020s, to ensure that near-zero emission steel producers have confidence that they will not be undercut by high emission competitors. International cooperation could extend to policy coordination aiming for progressive convergence on carbon intensity regulations or carbon pricing in the steel sector across jurisdictions.

Governments and companies should communicate medium- and long-term strategies and set milestones for deep decarbonisation, as technology and policy pathways become clearer, providing greater certainty on the direction of travel. These strategies should detail the important interactions with other sectors, such as hydrogen and power, which will have a significant impact on the pace of the transition in the steel sector. Alongside policies to boost the deployment of key supply-side technologies, such strategies should also set out policies to encourage material efficiency and circularity, in close consultation with supply chains. This in turn can provide certainty for public and private investors around the technologies and approaches being favoured by the sector.

Governments will need to work closely together to develop effective technology partnerships underpinned by technical and financial assistance, ensuring involvement from all major steel producing regions. As can be observed with already-announced projects, it is likely that companies in Europe and Asia will lead in early deployment of innovative, near-zero emission technologies over the mid-2020s. Beyond these first few projects, additional projects should be taken forward, supported by learning from early examples in the mid-2020s, enabling operation later in the decade.

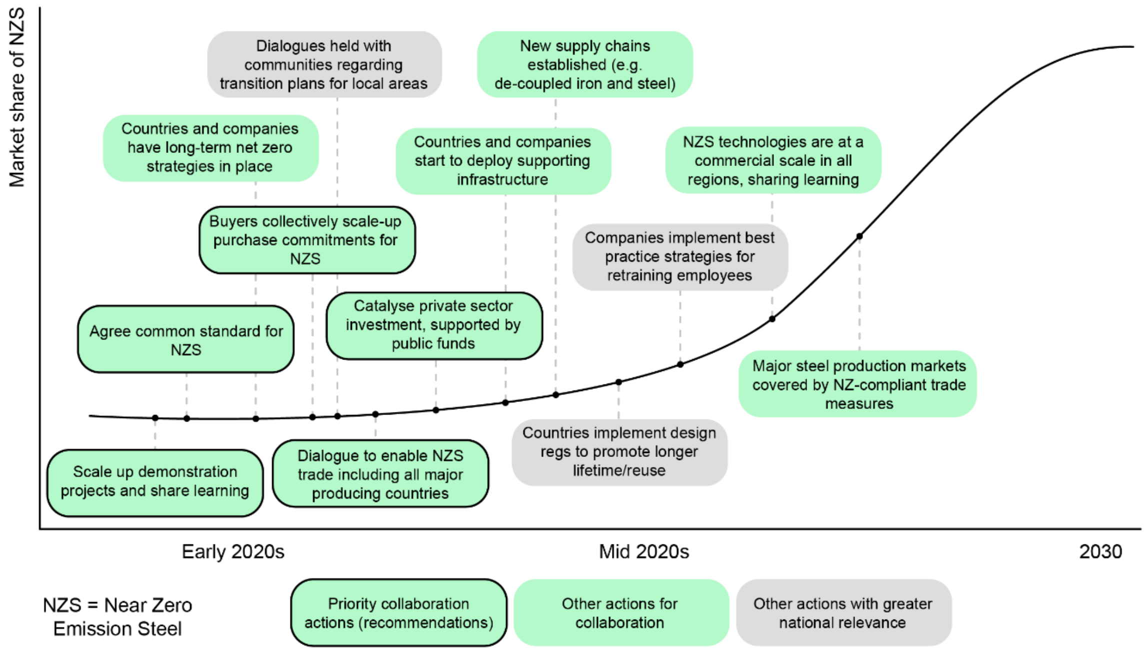
By the late 2020s, commercial-scale projects will need to ramp up across multiple regions, requiring a proactive approach for deploying vital enabling infrastructure, including electricity transmission, and CO_2 and hydrogen storage and transportation. This has the potential to lead to a decoupling of iron and steel production, as countries with abundant land, low-cost renewables and iron ore reserves are able to produce competitively priced near-zero emission iron,[5] which can be exported for processing (Gielen et al. 2020; Trollip, McCall and Bataille, 2022). To support these projects, a significant increase in the availability of skilled professionals will be required, including engineers, metallurgists and renewable energy experts, capable of supporting the deployment of new near-zero emission technologies. This will require both retraining programmes for existing employees, as well an increase in appropriate graduate and early-career training and qualifications.

Governments and companies will need to share early learning on rapid infrastructure deployment, including creative and risk-based approaches to regulations, accelerated permitting, plant operation and renewable energy systems, supply of low-carbon intensity hydrogen and bio-based fuels and feedstock, and/or CO_2 infrastructure integration with the iron and steelmaking process. It is important that such approaches are still inclusive of local communities' concerns and priorities. Rapid feedback loops, supported by international initiatives, can help ensure that near-zero emission plants are built in a series of 'fast follower' countries within a couple of years of the first plants being built in the mid-2020s.

For these actions to be realised, there is a need to focus and coordinate international efforts in the steel sector as well as with other industry sectors. Only with effective international collaboration will it be possible to ensure that the transition can occur at the pace and scale required, and that near-zero emission solutions are affordable and accessible to all.

[5] Near-zero emission iron can be produced from iron ore in DRI facilities supplied with low-carbon or renewable hydrogen and or fitted with CCUS.

Figure 5.3. Critical path to 2030 for the steel sector



Recommended Reports

We recommend the following reports for more detailed descriptions of the technologies for steel sector decarbonisation and of the actions that countries and businesses can take individually.

- Iron and Steel Technology Roadmap (IEA, 2020)
- Reaching Zero with Renewables: Eliminating CO_2 emissions from industry and transport in line with the 1.5ºC climate goal (IRENA, 2020)
- Net Zero Steel Sector Transition Strategy (MPP, 2021)
- Net Zero Steel project (IDDRI, 2021)
- 1.5C Steel: decarbonising the steel sector in Paris-compatible pathways (E3G & PNNL, 2021)
- Achieving Net Zero Heavy Industry Sectors in G7 Members (IEA, 2022)
- Global Steel at a Crossroads (Agora, 2021)

Current State of International Collaboration

International collaboration in the steel sector is relatively limited, although there has been a significant increase in activity over the past several years. Through the Steel Breakthrough process, there is an opportunity to ensure that the international collaborative architecture is established in an organised, focused and efficient way from an early stage, avoiding some of the challenges facing other sectors with a very crowded bottom-up landscape.

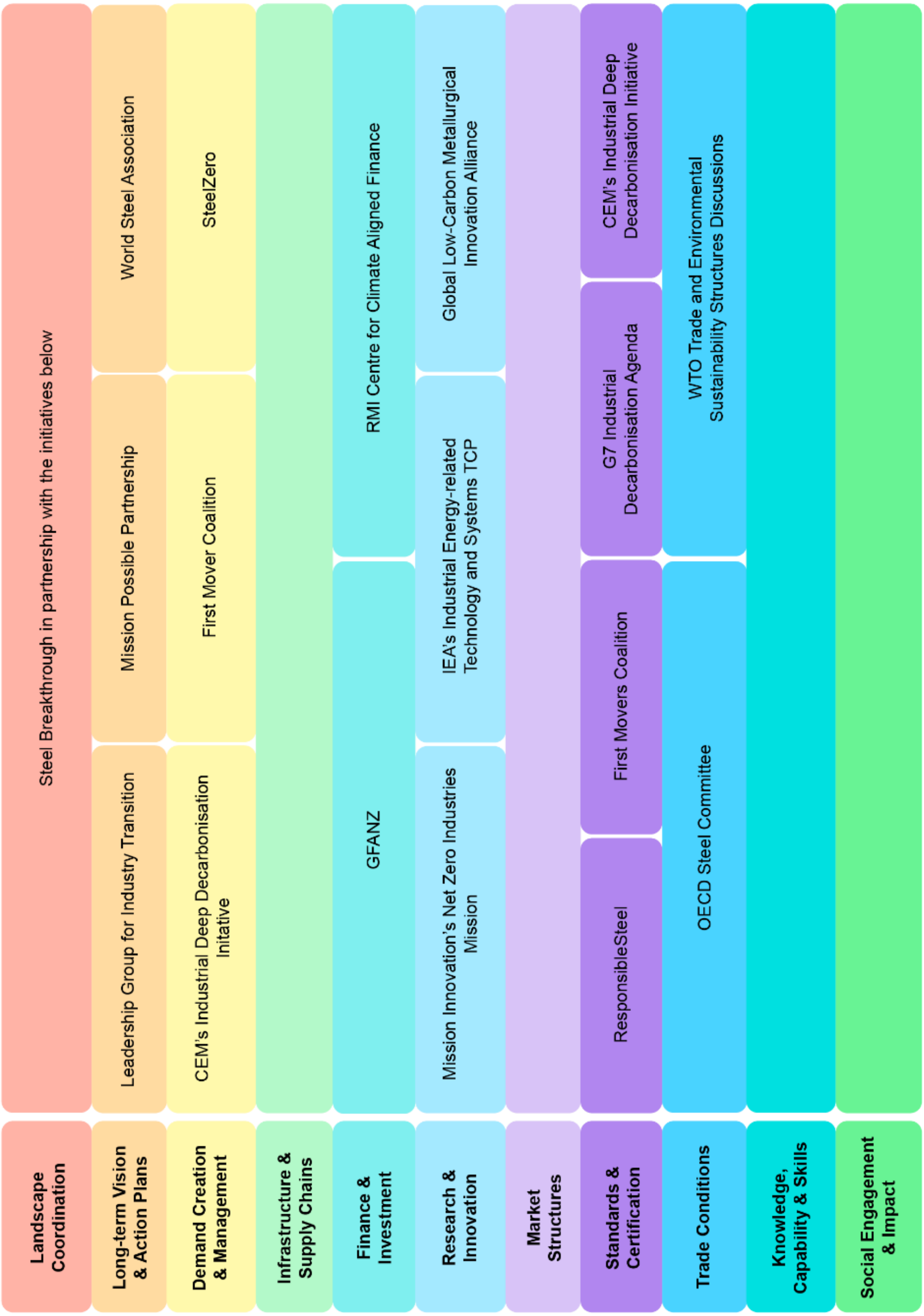
Until recently, international collaboration in the steel sector has largely focused on issues other than decarbonisation. Trade discussions, such as those in the OECD Steel Committee and the Global Forum on Steel Excess Capacity, have been primarily devoted to production (over-) capacity and anti-dumping. There has also been cooperation on energy efficiency (including through the World Steel Association's Benchmarking Systems, and bilateral partnerships, such as between Japan and India), but this has largely contributed to making fossil-fuel-based steel more efficient, and has not focused on starting the necessary transition to near-zero-emission steel production.

However, there are a number of important collaborative initiatives that have been launched in recent years that focus on near-zero emission steel, including innovation (Mission Innovation's Net Zero Industries Mission), data, harmonisation of standards and public and private procurement (Clean Energy Ministerial's Industrial Deep Decarbonisation Initiative, the First Movers Coalition, SteelZero). Other collaborative initiatives cover product and site-level standards (ResponsibleSteel), finance (Climate Bonds Initiative, Centre for Climate Aligned Finance, Glasgow Financial Alliance for Net Zero) trade (the upcoming 'Climate Club', EU-US Global Arrangement on Steel and Aluminium), and more cross-cutting issues (the Mission Possible Partnership, the Leadership Group for Industry Transition and the G7 Industrial Decarbonisation Agenda). There are also growing interactions with several established forums in technology areas, such as hydrogen and CCUS. The rapid growth of these new initiatives, while encouraging, represents a challenge. Steel stakeholders risk being overwhelmed with the wide-ranging, overlapping asks. At the same time, governments' participation in these initiatives does not yet have the strength and depth necessary to enable a rapid global transition.

Despite the growing number of initiatives in the steel sector, there exists no single, authoritative forum in which countries representing the majority of global steel production coordinate on key elements of the transition. The government forum with the highest share of steel production is the OECD Steel Committee, whose members and participants cover 45% of global steel production and 75% of steel exports (including several non-OECD members), is increasingly focusing on the transition to near-zero emission steel (OECD, 2022a). Beyond the steel sector alone, LeadIT has a remit covering industry more broadly, including both governments and companies, with a membership of 16 countries covering 24% of global steel production (LeadIT, 2022a).

In short, there is an opportunity to reinforce this international landscape of collaboration on the steel sector's transition to low emissions. This can be done by facilitating ongoing strategic discussions to coordinate international activity across this agenda (including through the Steel Breakthrough Dialogues), by crowding-in more countries and companies to the most critical initiatives, by strengthening join-up between public and private initiatives and by plugging key gaps in the landscape where they exist.

Figure 5.4. Landscape map of key international steel sector decarbonisation initiatives



Note: The diagram summarises the roles of many public and private sector initiatives in this sector. Initiatives have been included if they have a global scope, with active members from multiple regions of the world, and have at least one significant work programme specifically focused on accelerating emissions reduction in this sector. The list is not exhaustive and will be updated over time.

PRIORITY AREAS FOR INTERNATIONAL COLLABORATION

International collaborative action is vital to jumpstart the nascent transition in the steel sector. There are five actionable areas that stand out as immediate priorities for strengthening international collaboration: standards and certification; demand creation; trade conditions; research and innovation; and finance and investment. These represent priorities that need to be addressed within the next 1-2 years, which can then unlock further actions and faster progress later in the decade.

URGENTLY AGREEING COMMON STANDARDS FOR NEAR-ZERO EMISSION STEEL

Standards are a vital tool for aligning expectations as to the pace and trajectory of the net zero transition in the steel sector. A common definition of low emission and near-zero emission steel production is an important first step, allowing buyers to differentiate between higher and lower emission products, and make it possible for producers to charge a premium in return for their investments.

Measurement standards for evaluating the emissions intensity already exist or are under development, such as ISO 14404, ISO 20915 and the Worldsteel Benchmarking Systems, however, these measurement standards generally do not specify the necessary normative thresholds or target levels for emissions intensities. When defining these thresholds, it will be important to agree complementary definitions for low emission steel, as well as near-zero emission steel, recognising the important interim steps that can be taken to reduce emissions intensity.

Collaboration between countries on this issue is important since steel is part of a highly international market. Most of the largest steel producers and many large consumers, such as automotive firms, sell and buy internationally. Differences by country exist of course, but there is a risk that if countries and companies choose to define their standards differently, this would slow down the pace and scale at which a global, premium market is established. Similarly, it will be difficult for governments to agree coordinated measures on market creation and trade unless they have first agreed how to differentiate between high and low emissions steel.

At present, there is not a widely recognised, common definition of low emission and near-zero emission steel production that has been adopted by a significant share of the market. However, there are several definitions, either already public or currently being developed, which countries could look to adopt over similar time frames to stimulate investments and mitigate carbon leakage. These include definitions from ResponsibleSteel (due for publication later in 2022), ArcelorMittal, the First Movers Coalition and the IEA's definitions proposed in the *"Achieving Net Zero Heavy Industry Sectors in G7 Members"* report (IEA, 2022). The emissions intensity thresholds proposed by each of these efforts are broadly similar, although further work is required to understand the differences in methodology and analytical scope.

Early adopters are already preparing to commit to these standards, with 51 companies from across the supply chain signed up as members of ResponsibleSteel (ResponsibleSteel, 2022). Clear government policy can also pave the way to increase and accelerate the rate of adoption. The most prominent example of international coordination on this front is the G7 Climate, Energy and Environment Ministers' Communiqué of 2022, which includes countries that represent 18% of global steel production. The Communiqué "recognised the definitions proposed in the IEA report as a robust starting point" enroute to agreeing "stable, absolute and ambitious thresholds for near-zero emissions material production" (BMWK, 2022b).

There is growing support to collaborate on the definition and adoption of standards from a broad set of countries, including major emitters. Since this step is an enabler of other, deeper forms of collaboration needed in the steel sector, it is essential for these efforts to be fast-tracked. Countries leading the effort to reach an agreement on standards and definitions, should also include actions to increase data availability and improve the monitoring, reporting and verification of emissions data to support these standards. For the greatest effect, this agreement should include countries that collectively account for the majority of global steel production and consumption. The group could be continually broadened, and the details of the standards adopted could be refined as necessary over time.

Recommendation 1

Governments and companies willing to lead the transition in the steel sector should agree on common definitions for low-emission and near-zero emission steel, along with a time frame for the adoption of standards by the mid-2020s. *This is an important market signal and will be vital for unlocking a series of subsequent actions, most notably high-quality demand commitments and trade agreements.*

Rapid scale-up of high-quality commitments to purchase near-zero emission steel

Significant capital investments are needed for new near-zero emission steel production, either in the construction of new plants, or in the substantial retrofitting of existing facilities. A first-of-a-kind (FOAK) commercial-scale (2.5 Mtpa) hydrogen direct reduction with an EAF plant can be expected to cost around USD 2 billion (SEI, 2020). Steel companies are unlikely to make such large investments, on the necessary scale, unless they have high confidence that there is sufficient demand for the near-zero emission product. Since near-zero emission steel is expected to cost more than high-emission products (+15-40% per tonne for FOAK plants), confidence in its demand is closely related to the question of how this additional cost will be met.

There are a number of options for creating demand for NZS products, including direct offtake agreements, quotas, tax incentives, labelling or Contracts for Difference (CFDs). There is a clear opportunity for international collaboration in this area: the more public and private sector steel consumers align their actions, jointly creating a stronger demand signal than they could individually, the greater the incentives for industry to invest. This is particularly vital given the high levels of international trade in the steel sector, meaning that it may require demand commitments in multiple consumer markets to send a sufficiently strong signal to support production in any one location.

Since 2021, commitments from public and private steel buyers have started to gain momentum. In the private sector, these include arrangements between some steel producers and a range of buyers from across the automotive, construction and appliance sectors. Steel often represents a minor share of the final value of its main end-use products, such as vehicles, buildings and appliances, so a relatively large cost increase in each tonne of production translates into a very small cost increase at the final product level, often less than 1% (MPP, 2021b). The companies taking advantage of this opportunity include steel producers such as SSAB, Salzgitter, Nucor, and H2 Green Steel, and buyers such as General Motors, Mercedes Benz, Volvo, Ørsted, Miele and Lindab. H2 Green Steel is notable in the extent to which their business model is reliant on such commitments, receiving no direct government support to establish a 1.5 Mtpa plant from 2025 (H2 Green Steel, 2022).

Key private sector initiatives to create demand include SteelZero, which focuses on scaling commitments for the mass market, and the First Movers Coalition (FMC), which concentrates on bringing forward the deployment of innovative or breakthrough technologies. Collectively, these initiatives cover over 40 companies, representing a significant share of steel demand from a range of sectors (FMC, 2022).

In the public sector, the principal international collaborative initiative is the Clean Energy Ministerial (CEM) Industrial Deep Decarbonisation Initiative (IDDI), which focuses on construction and infrastructure, and is supported by the UK, India, Germany and Canada. Public procurement typically covers 20-30% of a country's steel demand (UNIDO & LeadIT, 2021); as such IDDI member governments have direct influence over approximately 2-3% of global steel demand.[1] Members have committed to a Green Public Procurement Pledge, where they can choose from three different areas of commitment, including carbon disclosure on major public construction projects by 2025, achieve procurement of net zero construction materials by 2050, and put in place an interim low-carbon target by 2022, to be met in 2030. As well as directly creating demand for near-zero emission steel, it can also influence industry expectations and investment by clearly signalling the direction of government policy. There is strong momentum building in this area, where G7 members 'welcomed the work' of the IDDI in May 2022 (BMWK, 2022c). If all G7 members joined, this would then cover 4-5% of global steel demand.

These are important first steps in the right direction. However, there is an opportunity for these efforts to be greatly strengthened in terms of both quality and quantity of commitments. The quality of demand commitments refers to how specific they are. While the initiatives mentioned above are proving effective in establishing communities of

[1] Total steel demand from IDDI members is around 9% of global steel demand (WSA, 2022), though this covers both public and private buyers. Data on public procurement of steel is incomplete but typically ranges between 20-30%, suggesting current IDDI member governments have direct influence over approximately 2-3% of global steel demand.

practice, as of July 2022 they have yet to result in specific agreements to purchase near-zero emission primary steel. High-level procurement targets reinforce expectations about the sector's direction of travel, but to be effective in incentivising the first investments in commercial-scale near-zero emission steel plants, they will need to be translated into forward purchase agreements with specific producers, covering pre-agreed time frames. Otherwise, industry may perceive the necessary investments as simply too high-risk.

In terms of quantity, giving steel companies the confidence to invest in the scale-up of near-zero emission steel production needed to meet the 2030 goal is likely to require high-quality commitments from across multiple end-use sectors, assuring demand for the first tens of plants, not just the first few. Expanding the country and company membership of demand creation initiatives would be one way to achieve this goal.

To put the sector on track to meet international targets, countries and companies within these initiatives should set standards for procurement in line with a clear 'near-zero emission steel' benchmark. Commitments should require a substantial share of steel purchases to meet that standard before or by 2030, covering both primary and secondary production. The partnership between SteelZero and ResponsibleSteel, with the former mobilising demand commitments based on the standard defined by the latter, is a good example of this – which could be replicated across other public and private sector initiatives. Putting strong targets in place quickly, accompanied by advanced purchase agreements, will be crucial to ensure new steel plants built in the next investment cycle are designed to produce steel with near-zero emissions.

To support the growth in NZS production that is required, countries and companies should rapidly increase the scale of their procurement commitments. Demand commitments from across public and private sector buyers may be enough on their own to support the deployment of the first few near-zero emission steel production plants in each region, allowing producers to quickly deploy several first-of-a-kind plants in the absence of wider policy. However, achieving the pace and scale of transition that can meet the 2030 goals will also require supportive supply-side polices.

RECOMMENDATION 2

Governments and companies should increase the scale of near-zero emission steel procurement commitments to cover a significant share of their future steel demand. These commitments should be high quality, supported by appropriate legal and implementation frameworks, such as advance purchase commitments. Governments and companies should also consider joining public and private sector initiatives where these commitments are aggregated. *This will strengthen the global demand signal for near-zero emission steel, increasing the incentives for industry to invest in its production.*

AGREEING AN APPROACH TO ENABLE THE TRADE OF NEAR-ZERO EMISSION STEEL

Trade is of critical importance for the global net zero transition in the steel sector. Over the past few decades, between 20-30% of steel has been traded internationally (WorldSteel, 2022). While the steel sector is very cyclical, net profit margins are often low, averaging around 4.5% between 1998 and 2020 (OECD, 2022b). Without an agreement that creates a level playing field for near-zero emission steel, first movers will continue to be undercut by producers using cheaper, high-emission alternatives. Short of a collaborative solution, countries are more likely to adopt unilateral and inconsistent approaches, which have the potential to lead to trade disputes and slow the pace of transition.

If countries representing a substantial proportion of the global steel market agree to a common approach to requiring low or near-zero emissions in steel production and imports, this would strengthen the incentive for investments in low or near-zero emission steel production in all countries and mitigate the risks of carbon leakage in any individual country. International competition in the sector would then become an accelerator of the transition, instead of a brake, as it would be focused on improving the quality and reducing the cost of near-zero emission steel.

There are several international fora that could be used to discuss approaches to creating a level playing field for decarbonised steel, but none yet have the necessary focus and participation. In the World Trade Organisation's Trade and Environmental Sustainability Structure Discussions (TESSD), member countries are working towards potential solutions around trade-related climate measures that can avoid challenge under the WTO. This is an important step towards establishing legal clarity on what is permissible, but it is not an attempt to reach an agreement (on steel or any other sector).

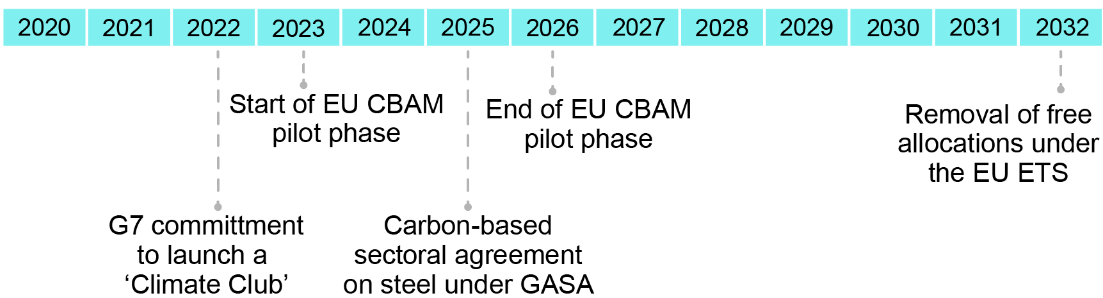
The OECD Steel Committee has historically had a focus on issues of market structure, demand and capacity but is increasingly focusing on the various aspects of decarbonisation. Participation in the Steel Committee goes beyond OECD members and includes other countries such as Brazil, India, Egypt, Malaysia and South Africa (OECD, 2022a). The OECD Steel Committee provides some of the highest quality data and analysis of the steel sector, so is well-placed to provide valuable support to international discussions on steel decarbonisation and trade.

Outside international organisations, some countries are looking to accelerate activity in this area through new bilateral initiatives or agreements. The Global Arrangement on Steel and Aluminium, agreed by the United States and European Union on 31 October 2021, to establish a "carbon-based sectoral arrangement that will drive investment in green steel production in the United States, Europe and around the world". However, the European Union and United States together represent only 12% of global steel production. Japan and the United Kingdom have also reached bilateral agreements with the United States on steel trade, although with less of a focus on decarbonisation. The US-Japan Proclamation agreed to "…cooperate on addressing…carbon intensity in these sectors" and the US-UK joint statement agreed that both parties "will confer on entering into discussions on…carbon intensity of the steel and aluminium industries" (DIT, 2022; The White House, 2022). The inclusion of other major steel producing countries in ambitious agreements on steel decarbonisation and trade will be necessary for an agreement to be reached that is capable of shifting the global market.

The proposed EU Carbon Border Adjustment Mechanism (CBAM) could also contribute to progress in this area. The aim of the CBAM is to provide protection against the risk of carbon leakage, as free allocations of emissions permits are removed from the EU Emission Trading System (ETS). It is due to come into force in 2026 after a three-year pilot starting in 2023, which will cover five sectors, including iron and steel. At current carbon prices of around EUR 80/tCO_2 (USD 84/tCO_2), this could be sufficient to drive investments in the more advanced deep decarbonisation solutions, such as certain hydrogen or CCUS applications, assuming confidence in this price is maintained and Free Allocation is phased out. Additional supporting policies, such as procurement or CfDs, could increase the pace and scale of deployment.

In 2022, the G7 committed to establish a "Climate Club", which would focus on accelerated climate action in industrial sectors, while mitigating risks of carbon leakage and complying with international rules. The club covers three pillars of activity, including advancing climate mitigation policies, jointly transforming industries, and boosting international ambition in developing countries. While the club is yet to be established, it could provide an influential intergovernmental forum to accelerate effective collaboration in the sector. Its effectiveness in driving the global transition is likely to depend significantly on the extent to which it includes, or establishes constructive collaboration with, the major emerging economy steel producers.

Figure 5.5. Timeline of existing trade-related commitments



This is a highly challenging area for countries to collaborate on given the potentially significant impacts on domestic industry. Nevertheless, there are significant benefits to collectively agreeing the conditions for a level playing field for steel, avoiding a series of competing unilateral measures that run the risk of triggering trade disputes, fragmenting the market, and ultimately slowing the pace of transition.

Countries can build mutual confidence by collaborating openly on the key enabling structures for such a deal, including data monitoring, reporting and verification (MRV), definitions and standards, comparability of climate policies, research and innovation programmes, financial support for emerging economies and demand creation policies for near-zero emission steel (see Annex). Collaboration in all these forms will help to build countries' understanding and confidence in near-zero emission steel solutions, increasing the potential for an agreement that successfully harnesses the power of international trade in support of a rapid transition.

RECOMMENDATION 3

Governments should urgently launch a strategic dialogue, including the leading producer and consumer countries, with the purpose of agreeing ways to ensure near-zero emission steel can compete in international markets. *This is needed to prevent trade acting as a brake on the transition. This may be supported by agreements to cooperate on data, standards, comparability of policies, RD&D, finance and procurement.*

IMMEDIATELY INCREASING PUBLIC AND PRIVATE FUNDING FOR RESEARCH AND INNOVATION, SUPPORTED BY EFFECTIVE COLLABORATIVE NETWORKS

Most of the key technologies required for near-zero emission steel production have not yet been deployed commercially at scale. These are principally technologies for the near-zero emission reduction of iron ore, the most emissions-intensive part of the steel production process. These include hydrogen direct reduction, and CCUS on the blast furnace or direct reduction furnace. CCUS has reached the commercial operation stage for direct reduction furnaces technology readiness level 9 (TRL 9) but is still at pre-commercial stage for high rates of CO_2 capture from the blast furnace (TRL 5). Hydrogen direct reduction, using close to 100% hydrogen, is at an earlier stage, with only large prototypes having been deployed so far (TRL 6). Additional direct electrification technologies, such as iron ore electrolysis (IOE), are at an earlier stage of prototype (TRL 4) but could play a vital role in the future (IRENA, 2021; IEA, 2021a).

It is also important to note the vital role of research and innovation in other parts of the supply chain, beyond steelmaking. This is particularly true for the direct reduction route, which currently requires a high grade of iron ore, when paired with an electric arc furnace (EAF). These grades are currently limited in their availability and so further work will be required to better understand processes to upgrade iron ores (beneficiation) to support an expansion in low emission and near-zero emission production via the direct reduction route. Projects in Austria and Australia show early signs of success but the scale of production needs to increase rapidly to support the 2030 goals (Primetals, 2021).

There has been a wave of recent announcements of projects using various innovative technologies, especially hydrogen direct reduction. In addition to the one DRI-EAF plant with carbon capture operating at commercial scale in the United Arab Emirates today (with a capture rate of 0.8 $MtCO_2$ per year), announcements for future capacity additions of conventional scrap-based EAF and natural gas- and or hydrogen-based DRI technology add up to 124 Mt (Agora Industry, 2021). Both of these technologies have the potential to achieve near-zero emission production over time if sufficient low-emissions electricity or hydrogen is made available. LeadIT's Green Steel tracker has identified a range of innovative technology developments in more than 60 steel projects around the world, although many of these are at the pilot or demonstration phase and not due to be operational for several years (LeadIT, 2021). While these developments are positive, the first few commercial-scale plants are urgently needed, to facilitate learning by doing with these as-yet untested technologies. There is a clear opportunity for international collaboration if countries and companies work together to increase the number of plants in which these technologies are deployed and tested, and share findings from these experiences, the learning process can be accelerated across multiple regions in parallel.

The steel sector already has a large number of research and innovation forums that have been operating for a number of years, although few with an explicit focus on decarbonisation. Most major steel producing countries have established national research and technology institutes, focused on steel and metallurgy, in close partnership with national companies. Alongside these national efforts, a number of multinational initiatives have been established, including the European Steel Technology Platform (ESTEP), the Hydrogen Iron and Steelmaking Forum (HyIS) and the Global Low Carbon Metallurgical Innovation Alliance. The latter being set-up by Baowu Steel with 60 partners from 15 countries. This Alliance’s aim is to combine R&D resources of major steelmakers, promote technical cooperation and accelerate the formation of a low carbon steel value chain. This initiative could play a valuable role in increasing the pace of technology sharing between different markets.

At the COP26 climate change conference in November 2021, Mission Innovation members stated their intention to launch a new Net Zero Industries Mission in 2022, co-led by Austria and Australia, with the support of China, Germany, the UK and the European Commission (in total representing over 60% of global steel production). This initiative is currently developing a joint roadmap of focus sectors and processes, and considering a focus on (a) improving connections between national and multinational RD&D efforts; (b) facilitating novel technology transfer, particularly in developing countries; and (c) joining forces with existing networks and platforms. These priorities are well aligned with what is needed in the steel sector, in particular for faster sharing of practical technology outcomes from early pilots and demonstration projects with developing countries. To fulfil this potential, it will be vital for member countries to launch the Mission without delay in 2022, and to follow this with a rapid series of well-targeted sector or process-specific technology sharing projects.

International efforts should seek to facilitate faster deployment of commercial-scale plants using the leading near-zero emission steel technologies in a larger number of regions, so that lessons can be learned from the deployment of each of them within the context of different regional circumstances. These include the proximity to, and quality of, iron ore reserves, availability of carbon storage and transport infrastructure, the price and availability of scrap, and the variability of local renewable electricity resources. This would be similar to existing forums, such as Metnet which socialise learning across a network of pilot projects in Europe, but with an explicit focus on near-zero emission technologies.

Recommendation 4

Governments and companies should identify several commercial-scale pilot projects, in all major steel producing regions, where international collaboration can support shared technology learning, business case development and policy support. Collaborative networks should deliver operational projects in these countries by the late 2020s at the latest. Emerging markets and developing countries' participation in key R&D and demonstration initiatives should be increased in support of this aim. *This will help eliminate technology availability issues, providing multiple case studies for a large group of countries and companies to further improve upon.*

Increasing international assistance to catalyse private sector investment in pilot, demonstration and commercial-scale plants

The transition in the steel sector will need strong support from policy, and as in other sectors, international assistance, finance, and the sharing of best practice can help to enable the necessary policy measures.

Half of the world's current top 20 steel-producing countries are emerging economies (WorldSteel, 2022), making deployment of near-zero emission technologies in these regions a priority for the global transition. Emerging markets and developing countries are also projected to account for around three quarters of the growth in global steel demand in the coming decades (IEA, 2022), meaning that their policy choices will have a significant influence on the global market.

At present, there is an extremely low level of financial support being provided to emerging and developing economies to aid the transition from conventional steelmaking technologies to low emission alternatives. Between 2000 and 2021, a total of USD 3.5 billion was provided by international financial institutions, mainly in Europe and Central Asia. This is miniscule in a market worth over USD 1 trillion, with a single plant requiring investment close to USD 2 billion (SEI, 2020). Moreover, most of these projects were focused on business-as-usual upgrades, not the deployment of deep decarbonisation technologies required (LeadIT, 2022b). The total amount of international financial support provided for industry-related climate programmes in 2020 under the OECD's Development Assistance Committee (DAC) was around USD 300 million, or less than 0.5% of total climate finance from the DAC members (OECD, 2022c). These programmes include relevant parts of the World Bank's Energy Sector Management Assistance Program (ESMAP). Again, this is very low; especially when compared to industry's contribution of around a quarter of all global greenhouse gas emissions. More funds are available in various dedicated hydrogen and CCUS programmes under the World Bank and the Asian Development Bank, although these are not specifically focused on the use of those technologies in industry, and are still at the USD 10 million-scale, not the USD multi-billion scale that is required.

There is a clear need for stronger international efforts in this area. Emerging markets and developing economies are expected to deploy 85% of the new production capacity coming online within heavy industry sectors by 2030. This implies that a large portion of the USD 60 billion per year of investment needed to enable the global transition to near-zero emission steel production would take place in those geographies (IEA, 2021b). The majority of this will come from private sources, as is the case for most conventional steel facilities today. However, for the first wave of plants, including large-scale demonstrations and first-of-a-kind facilities, international climate finance will be a vital enabler. Concessional loans and blended finance, typically provided by MDBs, can help accelerate the pace of deployment in a larger number of countries.

The role of public funds here is primarily to de-risk investments, helping to mobilise larger-scale private finance, and is not to cover the entire cost of a new plant. To ensure private sector finance is likewise targeted at near-zero emission steel projects, measurement and disclosure frameworks and climate-aligned standards for bonds and or loans, will be vital in supporting banks, export credit agencies and capital markets as they assess alignment of their portfolios against 1.5ºC-compatible pathways. Existing initiatives are increasing work in this area, with the RMI Centre for Climate Aligned Finance recently launching a set of 'Steel Principles' (RMI, 2022) for investors and the Climate Bonds Initiative is planning to launch a steel standard for bonds and loans.

Donor countries should collectively recognise the importance of steel (and wider industry) decarbonisation within their portfolios, working closely with recipient countries. The provision of funds needs to be accelerated and scaled-up, supported by dialogue to identify specific needs in recipient countries and mitigate risks of anti-competition concerns. To enhance the effectiveness of funds, a model pioneered by the Energy Transition Council (ETC) could be usefully applied to steel (BEIS, 2021). The ETC brings political dialogue together with practical and financial assistance, supported by a 'Rapid Response Facility' to support short-term projects and help build the case for larger investments. One immediate opportunity to increase the scale of funds is presented by the Climate Investment Funds (CIFs) Industry Transition programme, which is the largest new fund to support industrial decarbonisation currently being developed. Several other industry transition funds are likely to be required, building on the respective expertise of different multilateral development banks and other partners.

Recommendation 5

Donor countries and MDBs, led by the priorities of developing countries, should significantly increase funds supporting industry transition to near-zero emission technologies in emerging and developing countries. *This will provide much needed, near-term technology and financial support to unlock additional private sector capital to support the first wave of near-zero emission projects in key steel producing countries, especially for developing countries.*

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Annex

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Long-term vision and action plans	By the early 2020s, governments should have in place a strategy for incorporating near-zero emissions technologies into the next series of capacity additions and replacements for steel plants, including decisions about a combination of hydrogen, CCUS, and direct electrification.	34 roadmaps covering 15 countries/regions on the deep decarbonisation of the steel sector.
Demand creation and management	By the early 2020s, commitments to purchase near-zero emission steel from both public and private sector actors have scaled significantly, covering greater than 5% of total steel production by 2030. These commitments are high quality, supported by adequate legal frameworks or policy support where necessary. This includes advanced market commitments or Carbon Contracts for Difference, to create certainty for leading producers.	SteelZero includes 23 companies FMC for steel includes 18 companies CEM IDDI includes four member countries, covering approximately 2-3% of global steel demand
Infrastructure and supply chains	By the mid-2020s, governments should have in place firm plans for developing and financing infrastructure for hydrogen, CCUS and clean power in support of near-zero emission plants. The construction of the required infrastructure should begin as soon as possible given the long lead-times involved. Governments should also require that any new capacity should incorporate retrofit-ready designs so that unabated capacity added in the next few years has the technical capacity and space requirement to integrate near-zero emissions technologies over the 2020s and early 2030s. Governments and companies should collaborate to agree a decoupling of iron and steel production, where this can be of mutual benefit. This would include establishing new production hubs in those regions with abundant land, low-cost renewables and iron ore reserves, enabling the production of competitively priced near-zero emissions iron. By the mid-2020s, governments should revise product design regulations, adopt incentives to promote longer product and building lifetimes, and improve systems for collecting and sorting scrap for recycling seeking to stimulate a more efficient use along the value chains. They should also reduce impurities such as copper in scrap to enable increased circularity.	Global investment in low carbon fuels and CCUS at USD 16 billion, a 60% increase on the previous three years.
Finance and investment	By the early 2020s, significant new funds are made available via multilateral development banks to support the deployment of pilot and demonstration projects in key developing countries. A particular focus should be made on those countries expecting high rates of steel demand growth in the coming years. By the mid to late 2020s, developing countries have access to adequate low interest and concessional loans and blended finance.	In 2020, climate finance supporting industry transition projects was around USD 300 million from DAC member countries.

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Research and innovation	As soon as possible, governments in advanced economies take decisions to scale-up R&D funding for critical near-zero emissions technologies and for mitigating the investment risks associated with demonstrating them at scale. Learning and knowledge to be shared more effectively across major projects, supported by key initiatives such as Mission Innovation.	TRLs for key technologies Hydrogen direct reduction – TRL 6 Natural gas based direct reduction with CCUS – TRL 9 BF BOF with CCUS (very high rates of capture) – TRL 5 Iron ore electrolysis – TRL 4
Market structures	By the mid-2020s, a long-term emissions reduction policy framework is in place to provide certainty that the next wave of investment in capacity additions will focus on near-zero emissions technologies. Alongside initial demand-side measures such as carbon contracts for difference and procurement, this should also include mass market carbon pricing and/or emissions performance standards that will limit the production of high emission steel.	
Standards and certification	As soon as possible, an agreement is reached by countries and companies on the definition for near-zero emission steel production and on concrete steps to harmonise standards for product labelling and procurement based on such definition. Standards are adopted from the mid-2020s at the latest. By 2030, definitions for near-zero emission steel production are well established across all regions and commonly used by any type of near-zero emission procurement standards and steel-containing product labelling (including adaptation of data collection systems, which make the data public).	51 companies signed up to ResponsibleSteel 0 countries agreed a near-zero emission standard
Trade conditions	A strategic dialogue focused on the trade of near-zero emissions steel is reached by the mid-2020s, so as to support the establishment of a level playing field. Alternatively, countries may need to resort to measures to shield domestic near-zero emissions production from competition from high emission products by the late 2020s. Any such policy would need to be designed to respect the regulatory frameworks governing international trade, such as those of the World Trade Organization.	0% of global trade of steel covered by a near-zero aligned agreement
Knowledge, capability and skills	By the mid-2020s, governments have a strategy in place in collaboration with the private sector for training and retraining programmes in line with their strategies for incorporating near-zero emissions technologies into the next series of capacity additions and replacements for steel plants. This build on existing successful efforts, such as 'steeluniversity' from the World Steel Association.	
Social acceptance	By the mid-2020s, dialogues are held with communities in regions most affected by the transition to new near-zero emission technologies and any changes in supply chains.	

CHAPTER 6. AGRICULTURE

"Climate-resilient, sustainable agriculture is the most attractive and widely adopted option for farmers everywhere by 2030." -- *Agriculture Breakthrough goal*

KEY MESSAGES

- Supply chain disruptions, climate change and the war in Ukraine have contributed to driving the global food crisis to famine levels in some countries. Achieving the Agriculture Breakthrough goal will not only enable an accelerated pathway to reaching lower emission levels, but it will also help deliver a more resilient agriculture sector, which is essential to global food security.
- Agriculture is highly vulnerable to climate change and the sector will need to implement dramatic changes if it is to rapidly decrease emissions and produce nutritious food in ways that are sustainable and climate resilient. The sector uses more land and water than any other human activity and is the leading driver of deforestation and biodiversity loss.
- The agriculture sector is one of the leading sources of greenhouse gas emissions. Agriculture and land use change are currently responsible for 20% of global GHG emissions. Under a Paris-aligned pathway, agricultural emissions need to be reduced 39% by 2050.
- The connections between climate change and agriculture have only recently gained international attention and the transition toward a climate-resilient, sustainable sector is fragmented and in its early stages. At the same time, the agriculture sector must increase production to feed the world's growing population
- Public finance, which represents the vast majority of investment in the sector, needs to shift urgently towards supporting innovations that promote climate resilience and preserving the natural resources on which the sector depends. International collaboration on research and development and strategic dialogues among governments are also needed for knowledge sharing.
- Five areas stand out as priorities for strengthening international collaboration over the next 1-2 years, where we recommend the following actions:
    - Governments and companies should work together to deliver higher levels of investment in agricultural research, development, and demonstration (RD&D), to be maintained over the course of this decade. The scale and diversity of collaborative international RD&D initiatives and programmes should also be increased. Priority should be given to innovations that can reduce food waste, limit emissions from livestock and fertilisers, improve alternative proteins, develop

climate-resilient crops and livestock, and protect soil and water resources. *This will accelerate the development and eventual cost-effective deployment of technologies and solutions that can reduce emissions across multiple regions.*

- The level of international climate finance directed at agriculture should be greatly increased, in line with its importance to global emissions, adaptation and resilience and food security. Governments, MDBs and private sector investors should work together to make finance available to small- to medium-sized enterprises (SMEs) and smallholder farmers in developing countries on a far larger scale than has been achieved so far. Finance should be accompanied by assistance with the adoption of practices that increase productivity and resilience while reducing emissions and protecting natural ecosystems. *This will support economic development, resilience, and food security, as well as reducing emissions.*
- Governments, research institutions, international organisations, and the private sector should commit to a long-term process to test, develop evidence and share learning on approaches to redirecting policies and support for agriculture towards sustainability and climate resilience. This should involve all of the world's largest agricultural producer countries, whose policies heavily influence global markets, as well as countries representing a diverse range of environmental and economic conditions. *This will help countries identify the most effective and feasible ways to incentivise the transition to sustainable agriculture.*
- Governments should begin a strategic dialogue on how to ensure international trade facilitates, and does not obstruct, the transition to sustainable agriculture. International organisations can advise on options to ensure a level playing field so that policy measures essential to drive the transition do not put a country's agricultural sector at a competitive disadvantage in international trade. Early priority should be given to agreeing sustainability standards for the agricultural commodities that contribute disproportionately to deforestation. *A level playing field in international trade will give countries and companies greater confidence and ability to move ahead in the transition.*
- Countries and international organisations should develop internationally agreed standards for monitoring and reporting on the state of natural resources on which agriculture depends, including soil carbon content and health, and pollinator health, as well as on the geographical extent of agriculture. *International measurement standards will help support high-quality knowledge sharing on policy effectiveness and enable international trade to play a positive role in supporting the transition.*

SIGNIFICANCE OF THE SECTOR

The agriculture sector is the source of the world's food, feed and fibre, while generating income and supporting billions of people in rural areas around the world. At the same time, the sector is particularly vulnerable to climate change and is one of the leading sources of greenhouse gas emissions.

Recent food, fuel, and fertiliser prices spikes have been exacerbated further by the war in Ukraine, driving more people into extreme poverty and malnourishment (WFP, 2022). This is on top of the climate-related stresses already reducing crop yields and hindering efforts to meet human needs (IPCC, 2022).

Agriculture and land use change are responsible for 20% of global GHG emissions (FAO, 2022a). After considering emissions across food supply chains and food waste in landfills, total food system emissions account for about one-third of global GHG emissions (Crippa et al., 2021). Agriculture is the leading driver of land use change and biodiversity loss (Benton et al., 2021). Halting agricultural expansion into carbon-rich natural ecosystems is a necessary step to achieve the goals set out in the Glasgow Leaders' Declaration on Forests and Land Use, and to align with IPCC pathways for limiting global warming to 1.5ºC and even 2ºC. Agriculture is also responsible for broader environmental degradation, such as freshwater depletion, soil erosion, and the ecological impacts of fertiliser and manure run-off.

Agriculture, when combined with forestry and other land use, is the only sector that has the potential to be a carbon sink through natural climate solutions (also known as nature-based solutions[1]), although implementing these actions at scale will only be possible if human needs for food, feed, and fibre are sufficiently met while halting and reducing agriculture's large land footprint.

SECTOR GOALS

The agriculture sector is at an early stage of its transition to sustainability. Paris-aligned pathways make clear that agricultural production emissions need to be reduced 39% by 2050 and land use change needs to halt, while at the same time the sector must increase production to provide food for a global population estimated to reach 9.8 billion (Searchinger et al., 2019). Approaches to reduce emissions and improve productivity are being implemented in a number of countries and alternative proteins are being developed that could shift consumption patterns and drastically reduce emissions from the sector.

Notwithstanding the positive efforts and initiatives that are under way, emissions from global agriculture continue to increase, as demand for food and land has grown. The agriculture sector will need to change profoundly if humanity is to produce healthy food sustainably without expanding into natural ecosystems and in ways that are resilient to climate change.

[1] According to IUCN, Nature-based Solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature.

Meeting climate and development goals requires urgent action on many fronts, including scaling up efforts to reshape the agriculture sector to better support farmers, improve the productivity of farms, tackle food insecurity, promote healthy diets, avoid agricultural land expansion, build resilience, and reduce emissions.

There is no one technology or practice that can transform the agriculture sector. The sector produces a diversity of products in heterogeneous agroecological and social environments. Innovations in practices, technologies, policies, and financing will be needed across supply and demand to transform incentives for farmers everywhere so that they adopt climate-resilient and sustainable agriculture. Many solutions to improve crop yields, such as better seed varieties for example, can be delivered today at low costs. However, a scarcity of reliable information, lack of land tenure, and inadequate access to capital prevent their uptake (Kelsey, 2013). With the right policy support, governments can incentivise investment in climate-resilient, sustainable agriculture to make solutions accessible for all.

To put the agriculture sector on a Paris-aligned pathway will require the world to meet the Breakthrough goal which a number of countries have endorsed:

"Climate-resilient, sustainable agriculture is the most attractive and widely adopted option for farmers everywhere by 2030."

Achieving this will require action across four guiding principles of climate-resilient, sustainable agriculture:[2]

- Sustainably increases agricultural productivity and incomes;
- Reduces greenhouse gas emissions;
- Safeguards soil, water resources, and natural ecosystems;
- Adapts and builds resilience to climate change.

It is essential to ensure that efforts to mitigate emissions do not undercut initiatives to adapt and improve resilience. In line with these principles, the primary metrics of the Breakthrough goal is broken down into targets for tracking the progress in the sector to 2030 (see Figure 6.1).

[2] Three of the four principles of climate-resilient, sustainable agriculture are from the United Nations Food and Agriculture Organization's (FAO) definition of climate-smart agriculture. The fourth principle, 'Safeguards soil, water resources, and natural ecosystems' was added to emphasise the importance of protecting natural resources and ecosystems.

Figure 6.1. Metrics covering the agriculture sector

Sustainably increases agricultural productivity and incomes	Reduces greenhouse gas emissions	Safeguards soil, water, and natural ecosystems	Adapts and builds resilience to climate change
Increase crop yields Current (2020): 6.6 tonnes per hectare 2030 Target: 7.7 tonnes per hectare	Halt agricultural expansion Current cropland extent (2019): ~1,200 Mha Current pasture extent (2019): ~3,200 Mha 2030 Target: No increase	Reduce water stress	Develop and deploy crop and livestock varieties resilient to climate extremes and pests
Increase ruminant meat productivity Current (2019): 27.4 kg / ha / year 2030 Target: 33.4 kg / ha / year	Reduce farm-gate greenhouse gas emissions Current (2019): 7.2 Gt CO_2eq 2030 Target: 5.7 Gt CO_2eq	Increase soil carbon content	Integrate local perspectives in research and innovation agendas
Increase food producer income	Reduce GHG intensity of protein production (all sources) Current (2019): 31 grams CO_2-eq per gram of protein 2030 Target: 23 grams CO_2-eq per gram of protein	Improve biodiversity and pollinator health	Improve access and use of financial services and climate-relevant information services

Sources: Data on crop yields, ruminant productivity, farm-gate emissions, and the GHG intensity of protein are from FAOSTAT. Crop yields are a global weighted average over all crop groups in FAOSTAT. The geographical extent of cropland is from Potapov et al., 2022 and pasture extent is from FAOSTAT. Targets were adopted from Searchinger et al., 2019. Seven of our identified metrics either lack regularly updated data or 2030 targets.

SUSTAINABLY INCREASES AGRICULTURAL PRODUCTIVITY AND INCOMES

Productivity improvements (crop, ruminant meat, and milk yields) (Valin et al., 2013), particularly in lower- and middle-income countries (LMICs), are critical to the sustainability of agriculture because they can improve farm worker livelihoods and reduce incentives for agricultural expansion. Average cereal crop yields in Africa are about one-third of cereal yields in Europe and one-quarter of the Americas (Boehm et al., 2021). In sub-Saharan Africa in particular, increasing yields is a key lever to improve livelihoods while reducing poverty and hunger (IFPRI, 2022). By 2030, modelling suggests average yields of all crops must improve from 6.6 tonnes per hectare (t/ha) to 7.7 t/ha of cropland,[3] to allow broader climate mitigation targets to be met. Average yields of meat from ruminants (cattle, sheep, goats, and buffalo) must improve from 27.4 kilogrammes per hectare (kg/ha) to 33.4 kg/ha of pastureland (Boehm et al., 2021).

[3] FAO crop yields are expressed in terms of fresh weight, unless otherwise specified within the database. Yields trends may be distorted by crops with high moisture content.

Farmers increase crop yields in part by using higher quality seeds or through better management practices such as adding more water, using fertilisers or legumes, using agronomic information, or introducing basic machinery. Small additions of inputs to nutrient-starved soils can result in high productivity improvements. For example, shifting nitrogen fertiliser inputs from fields that apply too much to those that apply too little could increase cereal production by about 30% globally, while reducing nitrous oxide emissions (Mueller et al., 2014; Gerber et al., 2016).

However, some practices used to improve yields come with environmental trade-offs. For example, introducing machinery to smallholder farms to boost yields, which can be used to reduce emissions from deforestation and other land use change, increases emissions from on-farm energy use. And raising yields could make farming more economical and spur deforestation and draining of peatlands. There is therefore a need to link incentives to improve yields with government policies to protect forests and other natural resources. In terms of livestock production systems, there is a need to avoid increased use of antimicrobials to protect against the global health risk of antimicrobial resistance (AMR).

In addition to yield improvements, demand-side drivers such as decreasing ruminant meat consumption in high-income countries and reducing food loss and waste in all countries will be key to meeting food demands sustainably.

Policies and finance mechanisms aimed at increasing yields on existing farms and pastures must be tied to social and environmental outcomes, especially the protection of carbon-rich natural ecosystems. Sustainable intensification could free up land for reforestation, restoration of peatlands and mangroves. Land-based carbon mitigation and nature-based solutions have the potential to be a major carbon sink, provided that the world can halt and reduce agriculture's large land footprint, which currently stands at nearly 5 billion hectares (IPCC, 2022; Roe et al., 2021; Griscom et al., 2017).

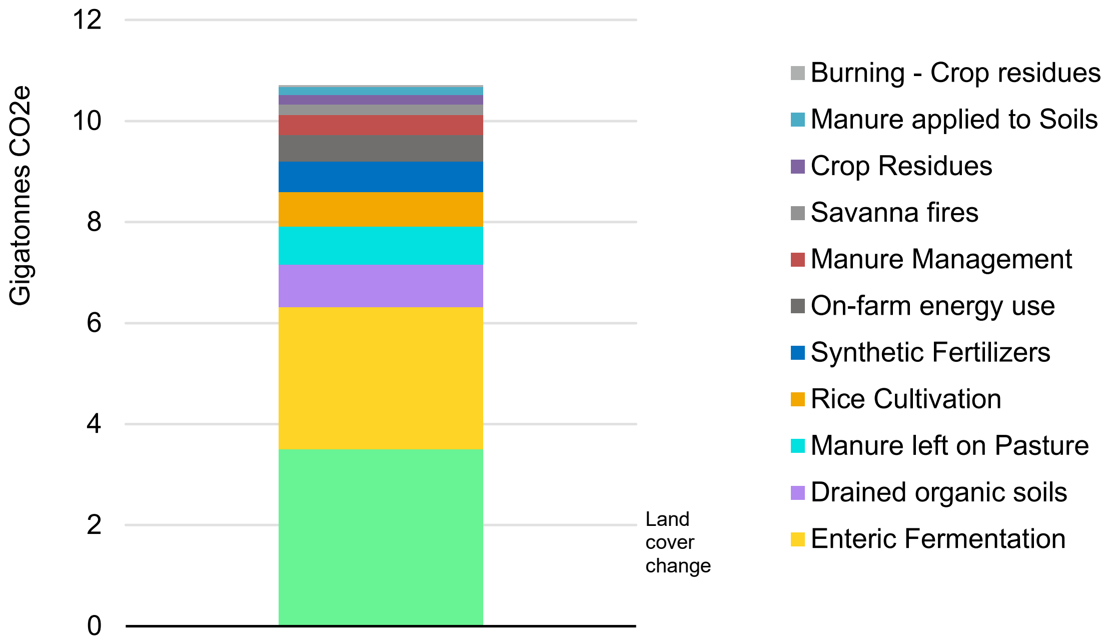
REDUCES GREENHOUSE GAS EMISSIONS

Agriculture and land use change contribute about 10.7 billion tonnes of carbon dioxide equivalent (CO_2e) emissions annually (FAO, 2022a; Tubiello et al., 2021),[4] 20% of all anthropogenic emissions. About 7.2 billion tonnes CO_2e occur on farms and pastures (known as farm-gate emissions) and 3.5 billion tonnes CO_2e are from land use change through deforestation (Figure 6.1).[5] Halting expansion of cropland and pastureland is necessary to end deforestation and associated emissions by 2030.

[4] CO_2 equivalents in FAO (2022a) use IPCC AR5 100-year global warming potentials (e.g. CH_4 = 28, N_2O = 265).

[5] Both on-farm emissions and land use change emissions are from FAOSTAT. Emissions from peatland drainage (or drained organic soils) are included in farm-date emissions. Potapov et al., 2022 estimates higher levels of cropland expansion (and therefore higher land use change emissions) than FAOSTAT.

Figure 6.2. Emissions from agriculture



Source: FAO, 2022a

There are four major components of emissions from agriculture and related land use change, which collectively make up 90% of the sector's emissions: agricultural expansion and drained peatlands (4.3 billion tonnes), livestock enteric fermentation (2.8 billion tonnes), manure and fertilisers (2 billion tonnes), and rice cultivation (0.7 billion tonnes) (FAO, 2022a)[6]

Global farm-gate emissions (which includes livestock enteric fermentation, manure and fertilisers, and rice cultivation) have roughly doubled since 1961 (FAO, 2022a), and under a business-as-usual scenario are projected to grow by another 27% between 2017 and 2050 (Searchinger et al., 2021). Scenarios indicate that farm-gate emissions will constitute a larger share of total anthropogenic emissions in the future, as other sectors are projected to reduce their emissions to a greater extent by 2030 (Wollenberg et al., 2016). However, to limit the global temperature rise to 1.5°C, emissions in 2030 would need to move in the other direction, instead falling by 22% relative to 2017. Current farm-gate emissions therefore must be reduced to 5.7 billion tonnes CO_2e by 2030 (Searchinger et al., 2019).

SAFEGUARDS SOIL, WATER, AND NATURAL ECOSYSTEMS

Agriculture's environmental impacts extend beyond the climate, and innovations to reduce emissions should also safeguard the soil, water, and biodiversity resources on which the sector depends. A portfolio of context-specific soil and water management techniques—including agroforestry, silvopastoralism, water harvesting, alternative wetting and drying of

[6] When looking across the food system as a whole, other important contributors to emissions include energy used in all food system supply chains (4.3 billion tonnes) and food waste disposal (1 billion tonnes) (Tubiello et al., 2021b).

rice paddies, precision application of fertilisers, crop rotations, no-till or minimal tillage, and other agroecological approaches—provide opportunities to reduce the emissions intensity of the food system.

Halting agricultural expansion is necessary to protect the carbon stored in natural ecosystems and is critical to pathways to limit warming to 1.5°C.

In addition, several key environmental indicators will be important to track soil, water, biodiversity, and antimicrobial use. Water stress is measured in the amount of renewable freshwater used as a proportion of what is available. In 2019, 19% of renewable freshwater was used globally. The agriculture sector accounts for about 71% of these freshwater withdrawals (FAOSTAT, 2022b). Many countries use more water than is available from renewable freshwater resources and rely on non-renewable sources that will eventually dry up (UN Water, 2021). More progress will be needed to improve water use efficiency within the agriculture sector to achieve Sustainable Development Goal 6.4, which is: "By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity."

Biodiversity is important to food security and makes agricultural systems and livelihoods more resilient to shocks and stresses, including to the effects of climate change. Yet agricultural expansion is the world's greatest threat to biodiversity and many species that contribute to agriculture, including pollinators, are in decline (Benton et al., 2021; FAO, 2019). Similarly, healthy soils are essential to all food production, but soil erosion and degradation continue to threaten the availability and productivity of land for producing food.

At the time of writing, there are significant gaps in internationally comparable data and 2030 targets for soil health and biodiversity indicators, despite the fact that tracking their progress over time will be important for monitoring the sustainability and climate resilience of the sector.

ADAPTS AND BUILDS RESILIENCE TO CLIMATE CHANGE

Adaptation to the impacts of climate change needs to happen alongside emissions reduction. More than half of the populations in low- and middle-income countries (LMICs) are employed in small-scale agriculture. These smaller food producers are especially vulnerable to climate change and many lack access to finance services. A recent analysis found that smallholder farming households in South and Southeast Asia, sub-Saharan Africa, and Latin America collectively require around USD 240 billion in finance a year, but only about USD 70 billion is currently being provided (ISF Advisors, 2019). Access to this capital would allow smallholders to invest in high-quality agricultural inputs, increased mechanisation, and agroecological and other innovative approaches, which are essential to boosting yields (Committee on World Food Security, 2021).

A necessary component of adaptation and resilience is the integration of local perspectives in research and innovation agendas. To ensure that farmers, ranchers, and farm workers do not have to bear the brunt of climate change, it will be essential that they are able to meaningfully participate in design, implementation, and governance of adaptation strategies, especially smallholders, women, and other vulnerable groups.

Securing land and resource rights for vulnerable groups is an important component of their climate resilience and participation in decision-making. For example, ensuring women have equal rights to seeds, land ownership, and market access is also a key lever to increasing crop yields on small farms (IFPRI, 2022; Searchinger et al., 2019).

As part of adapting and building resilience to climate change, countries should build the capacity for food producers to generate, absorb, and process new information and knowledge. Investment in innovative digital technologies can support food producers' adaptation to climate change in the most at-risk places. One such example is digital climate-informed advisory services (delivered via mobile apps, radio, online platforms), which can integrate climate information into agricultural decision-making and help small-scale farmers better adapt to a more variable climate (Ferdinand et al., 2021). Digital technologies can also inform farmers about technologies and practices that could be used in mitigation and adaptation.

Climate change enhances the importance of continuously improving crop and livestock varieties to withstand variability in temperature and precipitation. Improvements to crop and livestock varieties – which can be achieved through breeding, including new genomic tools such as gene editing – for higher yields or heat- and drought-tolerance will be an important component of climate change adaptation, and should be a key focus area for RD&D.

HOW DO WE GET THERE?

A wide range of policy interventions, investments, and innovations will be needed to accelerate a breakthrough in agriculture—as well as in the food system and land use more broadly—enabling the sector to play its full role in addressing global climate change. Innovations will be needed both in terms of practices, technology development, and scale of and access to finance in particular for smallholder farmers and small- to medium-sized enterprises (SMEs) (FOLU, 2021).

Meeting the Agriculture Breakthrough goal will be necessary to simultaneously achieve broader objectives of food security, protecting and restoring carbon-rich ecosystems, and strengthening rural livelihoods. These interventions map across the entirety of the agriculture sector and encompass issues of supply and demand. Action at both national and international levels is needed.

Early in the 2020s, countries and businesses should set targets to halve the share of food production lost, and halve per capita food waste, in line with Sustainable Development Goal Target 12.3. According to the latest IPCC report, reduced food loss and waste has the technical potential to mitigate 2.1 billion tonnes CO_2e emissions per year (IPCC, 2022). Food waste is doubly harmful to the climate as it wastes all of the inputs from producing the food and it generates methane when it is disposed of. By the mid-2020s, governments and businesses should have in place a process to measure their food loss and waste to identify areas needing action and track progress over time (Boehm et al., 2021).

Governments should redirect subsidies currently being provided to ineffective or harmful products and production systems. Agricultural support policies transfer about USD 620 billion per year to the sector worldwide (IFPRI, 2022). But this support has been moving the sector in the wrong direction and has been harmful to eradicating hunger and transforming the food system. Emission-intensive commodities (e.g. beef, milk and rice) and unhealthy products like sugar receive the most support. And these policies often benefit wealthier farmers at the expense of poorer ones (FAO, UNDP and UNEP, 2021). Agricultural support needs to be redirected as soon as possible to promote technological and financial innovations for climate-resilient, sustainable agriculture. Countries should also link support to food producers with social and environmental outcomes.

Governments and businesses need to use their purchasing power to promote healthy, sustainable diets. They should also identify policies and regulations (within agencies that deal with health, agriculture, water, and environmental policies) that influence diet choices and recommend changes to ensure they are aligned with promoting these diets.

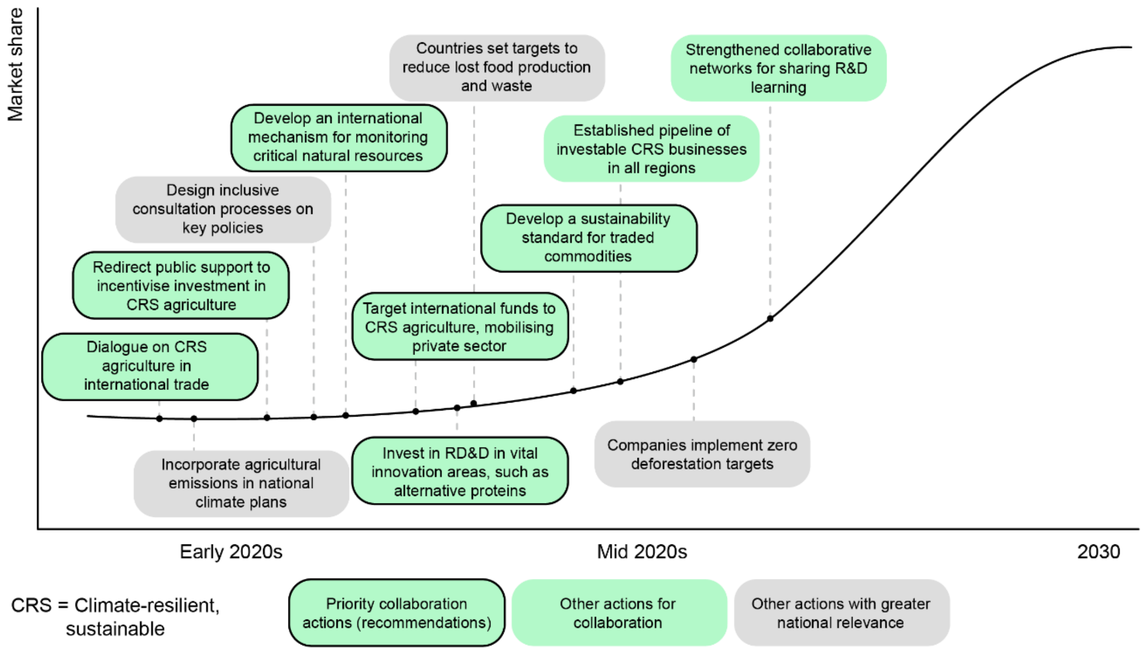
Governments should build inclusive consultation processes with communities affected by the transition toward sustainable livelihoods, while also ensuring that the benefits of the zero-carbon and resilient economy are shared fairly. Countries should also identify regressive subsidies in the sector and redirect them to help vulnerable communities shift to climate-resilient practices. Long-term climate strategies must plan for the social protections required to complement mitigation efforts.

Governments should secure land tenure rights for women and indigenous peoples. Indigenous peoples and local communities are among the most effective groups at protecting and sustainably managing the land and forests that they live in and depend on. Yet less than half of the lands and territories claimed by them are formally recognised by governments (World Bank, 2021). Lack of land tenure rights also impacts farmers' ability to implement practices to improve climate resilience. For example, lack of land tenure in Ghana created bureaucratic and legal hurdles to register trees on cocoa farms impeding farmers' ability to realise the benefits of agroforestry. Land, resource, and property rights should be secured for indigenous peoples, women, and local communities as a path to poverty reduction, sustainable development, and environmental management.

Companies, with support from governments, will need to develop inexpensive, alternatives proteins that mimic the taste and texture of consuming meat, dairy or eggs. This will be key to reducing emissions and land demands for ruminants and other livestock. Many plant-based substitutes are currently more expensive than their animal-based counterparts, but more research and development could help them achieve price parity and consumer acceptance (GFI, 2021). By 2030, ruminant meat consumption in high-consuming regions (Americas, Europe, Oceania) should be reduced from 90 kilocalories per capita per day to 80 kilocalories.

Figure 6.2 shows the critical path to 2030 for the agriculture sector, which includes actions at the national scale and priority areas for international collaboration.

Figure 6.3. Critical path to 2030 for agriculture



By 2030, strengthened international collaboration in these areas will help enable the widespread adoption of sustainable, climate-resilient technologies and practices. Coordinated action on these fronts will bring forward a pipeline of investable businesses that improve yields, reduce emissions, enable smallholder farmers to fully participate in the global marketplace, and improve the climate resilience of the sector.

RECOMMENDED REPORTS

We recommend the following reports for more detailed illustration of the broader set of interventions required in the global food system.

- Climate Change 2022: Mitigation of Climate Change (IPCC, 2022)
- Actions to Transform Food Systems Under Climate Change (CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), 2020)
- Creating a Sustainable Food Future (World Resources Institute, 2019)
- Global food policy report: Climate change and food systems (International Food Policy Research Institute, 2022)
- Accelerating the 10 Critical Transitions: Positive Tipping Points for Food and Land Use Systems Transformation (Food and Land Use Coalition, 2021)

- State of Climate Action (World Resources Institute, UN High-Level Climate Champions, Climate Action Tracker, ClimateWorks Foundation, Bezos Earth Fund, 2021)

CURRENT STATE OF INTERNATIONAL COLLABORATION

The agriculture sector is diverse and highly interconnected, with traded commodities representing a higher proportion of our food supply every year (IFPRI, 2022). National policies have spillover effects and influence global markets. For these reasons and others, international collaboration will be essential to the sector's transformation.

Much of the world's existing international collaboration on the issue of sustainable agriculture and food systems takes place at the Food and Agriculture Organization of the United Nations (FAO), including its various regional structures and committees, the UN World Food Programme (WFP), and the International Fund for Agricultural Development (IFAD), all of which are based in Rome. Each agency has a unique strength – technical expertise, food aid, and international financial assistance, respectively. These three Rome-based agencies are mostly focused on advancing food security and nutrition: they work together within countries as food security issues arise such as when weather-related disasters impact food production and livelihoods. All three organisations also promote sustainable agriculture and rural transformation, with a particular focus on smallholder farmers.

The FAO also plays an important role in compiling and analysing agricultural data and in brokering and establishing global standards, including the food safety standard for international trade, Codex Alimentarius, which is co-managed with the World Health Organization (WHO).

There is also significant international collaboration on sustainable agriculture research, including through the CGIAR (formerly known as the Consultative Group on International Agricultural Research), the Global Research Alliance on Agricultural Greenhouse Gases (GRA) and the Global Forum for Agricultural Research, as well as regional research of national and regional research institutions.

There is rather less international collaboration focused on the deployment of climate-resilient, sustainable agriculture solutions. In September 2021, the UN held its first-ever Food Systems Summit (UNFSS), with the focus of how national food systems could make the greatest possible contribution to the 2030 Agenda for Sustainable Development. At the summit, several strategies were discussed on financial issues and more than 100 countries signed up to develop national pathways for transforming food systems. In the run-up to COP26, over thirty countries participated in a Policy Dialogue on Accelerating Transition to Sustainable Agriculture, supported by the World Bank. These are valuable efforts; however, they have not yet been institutionalised in a way that supports strong and effective practical collaboration between countries, sustained over the long term.

Agriculture has long been the subject of international trade negotiations. The World Trade Organization (WTO) has a dedicated Committee on Agriculture, in which trade negotiations take place. But sustainability is not the focus of these discussions, and there is currently no international process dedicated to ensuring that trade supports, and does not obstruct, the transition to climate-resilient, sustainable agriculture.

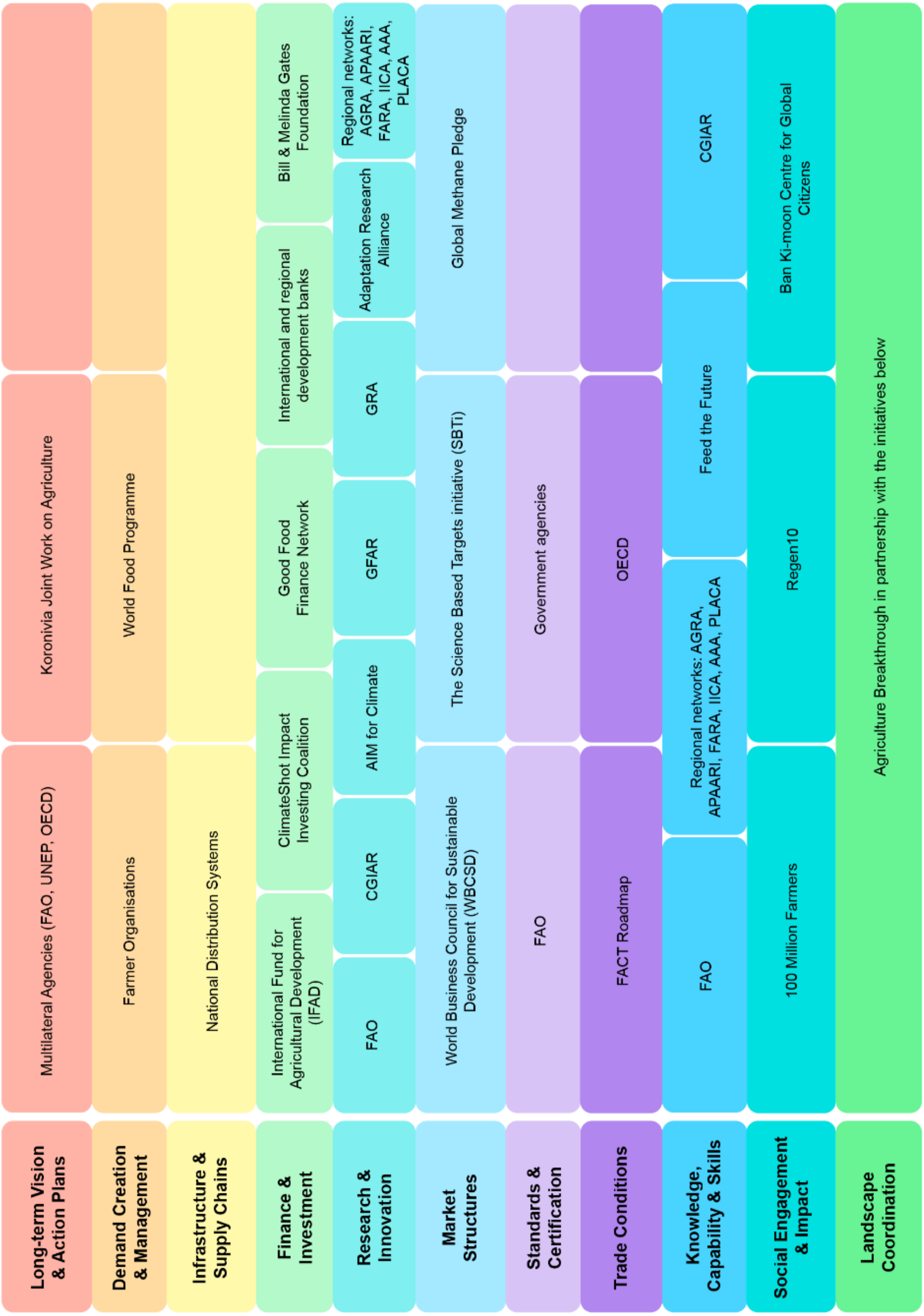
More narrowly, the issue of sustainable production and trade in agricultural commodities that contribute to forest loss is under discussion by 28 countries in the Forest, Agriculture and Commodity Trade (FACT) Dialogue. In addition, at COP26 some of the world's largest agricultural companies and traders jointly committed to develop a roadmap on reducing deforestation within agricultural supply chains in time for COP27.

COP26 also saw more than 100 countries sign each of the Glasgow Leaders' Declaration on Forests and Land Use and the Global Methane Pledge. Agriculture lies at the centre of these important pledges: the sector is the leading cause of deforestation and generates almost half of anthropogenic methane emissions (FAO, 2021a).

International assistance for climate-resilient, sustainable agriculture is scarce and fragmented. The sector receives a small share of international climate finance compared to its importance as a source and a potential sink of emissions.

There is considerable scope for stronger international collaboration to accelerate the transition to sustainable agriculture. The initiatives shown in Figure 6.2, which support collaboration between governments, the private sector and civil society, can make important contributions in this regard.

Figure 6.4. Landscape map of key international agriculture initiatives



Note: The diagram summarises the roles of many public and private sector initiatives in this sector. Initiatives have been included if they have a global scope, with active members from multiple regions of the world, and have at least one significant work programme specifically focused on accelerating emissions reduction in this sector. The list is not exhaustive and will be updated over time.

PRIORITY AREAS FOR INTERNATIONAL COLLABORATION

International collaboration will be essential to addressing the challenges faced in this sector. We identify particular opportunities in five areas: rapidly accelerate collaborative research, development, and deployment of mitigation and adaptation technologies and practices; leverage development aid to increase private investment in the sector; redirect harmful policy support; begin a strategic dialogue on how to ensure international trade facilitates the transition to sustainable agriculture; and monitor natural resources underpinning the agricultural sector.

COORDINATE RESEARCH, DEVELOPMENT AND DEMONSTRATION TO ACCELERATE INNOVATION

Many technologies critical for the transition to climate-resilient, sustainable agriculture are not yet fully developed or commercialised. A 2016 study found that existing emissions reductions strategies (such as better management of livestock and rice paddies) were insufficient to reduce emissions by the amount needed by 2030 (Wollenberg, 2016), meaning that rapid innovation is needed even to meet near-term goals. More far-reaching changes in technologies, practices, and policies will be needed to drastically reduce agricultural emissions by mid-century.

The significant time lag between the discovery of viable and scalable solutions and their widespread deployment means a concerted research and development effort cannot wait. There is a pressing need to accelerate innovation in this sector, both to achieve global food security in the face of climate change, and to reduce emissions in line with the goals of the Paris Agreement. The coordination of international effort can play an important role in accelerating progress to the pace that is required.

Innovation is needed to address each of the main sources of agricultural emissions, as well as to increase crop productivity and yields, improve climate resilience, and minimise agriculture's impacts on the natural resources that sustain it.

The priority areas for innovation and emerging solutions listed below were chosen based on their potential to reduce emissions (according to the IPCC's Sixth Assessment Report) and promote climate resilience. Priorities include:

a) **Reducing methane emissions from livestock**

Other than land use change, methane from ruminant livestock is the largest source of agricultural emissions. Additives to livestock feed that reduce methane emissions are a promising near-term innovation, with potential to achieve emissions reductions of 16-70%, according to a range of studies. Some of these feed additives may be close to commercialisation. However, productivity outcomes for livestock have been mixed, and more research is needed to be confident that any of these feed additives will deliver a co-benefit of increased production (Hegarty et al., 2021; Searchinger et al., 2021). Improving feed quality, by incorporating legumes for example, can improve ruminant weight gain and reduce emissions (Eugène et al., 2021; Project Drawdown, 2022).

In addition, research is underway to identify breeds of ruminants that emit fewer methane emissions (as well as varieties of wheat and maize that inhibit the production of nitrous oxide). In New Zealand, for example, researchers have bred low-methane sheep that emit about 12% percent less methane than their high-emitting counterparts (Rowe et al., 2019). Developing breeds of livestock or crop varieties that produce fewer greenhouse gas emissions has the advantage of not requiring farmers or ranchers to change their behaviour.

The combination of livestock breeding and feed additives has the technical potential to reduce emissions by 0.8 $GtCO_2e$ per year, according to the IPCC (IPCC, 2022). The feasibility of these innovations will depend on the type of production system, localised social acceptance, and making the new breeds and additives available widely. Agricultural extension services in developing countries will need to be supported to help farmers determine solutions that meet their needs.

b) Alternative proteins

Livestock and their feed are responsible for about 57% of all food system emissions and require more land than plant-based foods (Xu et al., 2021; Foley et al., 2011). Alternative proteins – to replace or reduce meat, dairy, and eggs from ruminants and other livestock in the human diet – could be a particularly high leverage way to reduce emissions. These would not only avoid methane emissions from livestock; they could also greatly reduce pressure on land, allowing for the production of more crops while halting or reversing the expansion of agricultural land that is a major driver of deforestation.

Many efforts to develop alternative proteins are under way. Alternative proteins can be sourced from plants, insects, fungi, or through tissue culture, to replace conventional animal-based sources. Plant-based meat, milk, and eggs have been on the market in high-income countries for several years, although their market share is still small. Cultivated meat, which is produced by in vitro cultures of animal cells, is still being developed and several leading companies are transitioning to pilot-scale facilities that will manufacture the first wave of commercialised products following regulatory approval. In a recent review of 75 disruptive agricultural technologies to improve food security and reduce emissions, four of the top ten – ranked in terms of their ability to contribute to achievement of the Sustainable Development Goals – related to alternative proteins, for use either in food or as feed for livestock (Herrero et al., 2020).

Currently, most plant-based proteins are more expensive than their animal-based counterparts. Accelerating research and development of these options so that some reach price parity with meat from animals, as well as equivalence in quality and consumer acceptance, is therefore an important priority (FOLU, 2021).

The move towards alternative proteins can be part of a broader shift to healthy and sustainable diets, which according to a 2019 IPCC assessment has the technical potential to avoid 0.8 to 7.8 billion tonnes of CO_2e emissions per year (IPCC, 2019).[7]

c) Reduce food loss and waste

About one-third of food is lost or wasted between the farm and the fork. Food loss occurs before food gets to market, during harvest or storage; whereas food waste typically occurs at retail markets, restaurants, or in homes. According to the latest IPCC report, reduced food loss and waste could avoid up to about 2 billion tonnes of CO_2e emissions a year (IPCC, 2022a).

Improved harvesting techniques, through mechanisation, can help prevent food loss on fields. Limited refrigeration and food processing in developing countries leads to large storage losses, yet innovative storage systems, such as evaporative coolers or solar-powered cold storage, provide technical options to reduce handling and storage losses. Evaporative coolers can be constructed from locally available materials and do not require elaborate training, but agricultural extension services will be needed to help spread awareness of their potential to preserve food and the availability of water may prevent their uptake. Solar-powered cold storage can also reduce food spoilage in countries with limited electricity and refrigeration. Access to capital for the upfront costs is a key barrier to uptake (Shell Foundation, 2022).

Fruits and vegetables are a common food item wasted in more developed markets. One technology to address this is the emergence of inexpensive methods that slow the ripening of produce. Companies are already investigating a variety of natural compounds to do so. Thin spray-on films that inhibit bacterial growth and retain water in fruit can prevent spoilage.

d) Reducing emissions from fertilisers

The most widely used fertilisers cause carbon dioxide emissions in their production, and of nitrous oxide in their use. There is potential to reduce the CO_2 emissions by replacing natural gas with low-carbon or renewable hydrogen in the production process. As discussed in the hydrogen chapter of this report, the fertiliser sector represents an important early opportunity to expand the use of low-carbon and renewable hydrogen, helping to bring down its costs and enable its use in a broader range of sectors.

Nitrogen and phosphorous can be recovered from human wastewater which does not rely on fossil fuels as a feedstock. In the United States, over one million dry tonnes of biosolids from wastewater treatment was applied to farms in 2019 (EPA, 2022). Manure is also filled with the carbon and nutrients absorbed originally by plants and eaten by animals, and it is already used as fertiliser in many places. However, the right management practices are needed. When manure is stored in lagoons (as is the case for concentrated pig farms), for example, it can emit noxious pollutants into the air. Separating wet and solid manure can help reduce emissions and exporting manure to places that need it can help avoid over-

[7] This large range of emissions-reduction potential includes the mitigation potential for avoided on-farm emissions, avoided land conversion, and additional effects of carbon sequestration from land-sparing.

application. Manure management measures have the technical potential to avoid 0.3 billion tonnes of CO_2e emissions per year, according to IPCC (IPCC, 2022b).

Nitrous oxide emissions can be significantly reduced by avoiding excessive use of fertilisers. At present, fertilisers are used at high levels in many countries, leading to water pollution and high costs, as well as emissions. Innovations to address this include precision application of fertilisers using field productivity data from drones or satellites. Controlled-release fertilisers, which slowly release nutrients over time, have been commercialised but currently only represent a small share of synthetic fertiliser sales. (Uncertainty among farmers about their benefits, and lack of research into scaling them up, may be contributing factors) (Searchinger et al., 2019). According to IPCC, crop nutrient management has the technical potential to avoid 0.3 billion tonnes of CO_2e emissions per year (IPCC, 2022b).

e) Crop and livestock breeding

Crop and livestock breeding has the potential to improve yields and increase resilience to climate change (Acevedo et al., 2020). Crop breeding has driven much of the world's previous yield gains; however, in the past, breeding efforts have focused on certain crops (maize, barley, rice, for example). It will be important for breeding research to expand into crops that are often ignored in breeding efforts (sweet potato, sorghum, millet, potatoes, peas, cassava, and beans), which are key crops in sub-Saharan Africa. Innovations in breeding and biotechnology including gene editing show potential to deliver crop varieties that provide more resilience to climate extremes, as well as higher yields and in some cases (such as rice) lower emissions (IFPRI, 2022).

f) Agroecological approaches

According to the IPCC, agroecological approaches can improve climate resilience and bring multiple co-benefits. These practices include but are not limited to: agroforestry, silvopastoralism, crop and livestock diversification, cover cropping, crop rotations, and improved grazing practices. Well-managed agroforestry systems can enhance crop yields, contribute to climate adaptation and emissions reduction, while reducing soil erosion and improving soil carbon content (IPCC, 2022a). In Niger and Zambia, incorporating the tree species *Faidherbia albida* into row-cropping improved grain yields several years in a row. Trees can also provide shade, nuts, medicines, and fibre—all important for direct human use (Searchinger et al., 2019).

However, as noted in the latest IPCC report, "[agroecology] that incorporates management practices used in organic farming, may result in reduced yields, driving compensatory agricultural production elsewhere" (2022b). A number of studies explore the potential to sequester additional carbon in soils and vegetation in working agricultural lands (e.g., croplands and grasslands) and thereby reduce net agricultural emissions, but more research is needed into approaches that could improve land-based carbon stocks over the long-term, while also maintaining or boosting yields (Bossio et al., 2020). Other innovative approaches that could reduce emissions or improve soil and water management include water harvesting, alternative wetting and drying of rice paddies, and precision application of fertilisers (FAO, 2018).

g) Digital services

In addition to the priorities above, there are a number of innovations in digital services that can help farmers adapt and improve resilience to climate change. Digitalisation is a powerful emerging instrument, whose proper use can support small scale producers (Ferdinand et al., 2021). Improved climate forecasts and pest/disease early warning systems can give farmers and ranchers vital information to support productivity. The number of digital services, such as advisory services, early warning systems, digital finance, and smart farming services, has increased rapidly in lower- and middle-income countries in the past decade, although in some countries their uptake is limited by access to electricity and wireless networks.

As of 2018, 33 million farms in Africa had registered for digital climate-informed advisory services (DCAS) — around 13% of all Sub-Saharan African smallholders (Tsan et al., 2019). An estimated 300 million small-scale agricultural producers globally still lack access. The Global Commission on Adaptation finds that expanding the reach and quality of these digital services will require governments and the private sector to invest approximately USD 7 billion over the next decade. Given that approximately USD 1 billion has been invested in DCAS in the last five years, this means an exponential push in investment from both public and private sector actors is needed (Ferdinand et al., 2021). According to IPCC, “The most effective early warning systems are not simply technical systems of information dissemination, but utilise and develop community capacities, create local ownership of the system, and are based on a shared understanding of needs and purpose” (IPCC, 2019).

THE ROLE OF INTERNATIONAL COLLABORATION

International collaboration can accelerate innovation by developing a wider range of options and testing them in a wider range of contexts. Most agricultural RD&D is funded domestically, so institutions are important for the sharing of learning internationally.

The experience of the CGIAR shows how valuable such collaboration can be. CGIAR was established in 1971 as a global research partnership, focusing on enhancing food and nutrition security, poverty reduction and improving natural resources. Its international research centres work with national agricultural research systems in low- and middle-income countries to conduct joint RD&D programmes and share learning. Studies show this collaborative work has had a large impact. For example, better maize and bean varieties developed through CGIAR partnerships have benefited millions of rural households in sub-Saharan Africa, with the benefit to-cost-ratio of this investment estimated at 10:1 (Adenle et al., 2019; Katungi et al., 2008; Alston et al., 2021a).

Despite the need to accelerate agricultural innovation to meet climate change and food security objectives, the level of funding for agricultural research has actually fallen in recent years, especially from higher income countries. This reduction in funding is weakening collaborative international efforts. For example, spending by CGIAR on agricultural R&D was USD 805 million in 2019, 30% below its inflation-adjusted 2014 level (Alston et al., 2021b). These activities are stretched thinly as a result, in some places lacking the funding or local capacity and personnel to coordinate research (Adenle et al., 2019).

A recent report by the Commission on Sustainable Agriculture Intensification estimated that an investment level of USD 15 billion per year in climate smart agricultural research and development in the Global South is needed to end hunger and reduce emissions by 2030 in line with the Paris Agreement goals (IFPRI, 2021). This compares to the roughly USD 4.1 billion of current annual investment in agricultural research and development in the Global South that has specific environmental aims, from Global South governments, international development assistance, and the private sector (Dalberg Asia, 2021). A scale-up of investment to around four times the current level is needed.

At COP26, the United States and the United Arab Emirates governments launched the Agriculture Innovation Mission for Climate (AIM for Climate), a growing coalition of over 200 government and non-government partners focused on accelerating agricultural innovation in line with climate change goals. It is still too early to evaluate the outcome of AIM for Climate but its members announced USD 4 billion of investment in climate-smart agriculture and food systems innovation at COP26, and in February 2022 announced the goal of doubling this to USD 8 billion by COP27.

These are positive announcements, but they should not be isolated one-off investments. We recommend that countries commit to maintain higher levels of investment in agricultural RD&D over the course of this decade. We also recommend an increase in funding for the institutions that support international collaboration in this area, since this will enable faster innovation and dissemination of solutions.

Recommendation 1

Governments and companies should work together to deliver higher levels of investment in agricultural research, development, and demonstration (RD&D), to be maintained over the course of this decade. The scale and diversity of collaborative international RD&D initiatives and programmes should also be increased. Priority should be given to innovations that can reduce food waste, limit emissions from livestock and fertilisers, improve alternative proteins, develop climate-resilient crops and livestock, and protect soil and water resources. *This will accelerate the development and eventual cost-effective deployment of technologies and solutions that can reduce emissions across multiple regions.*

International assistance to mobilise investment

Across many of the difficult policy problems involved in the transition to sustainable agriculture, international assistance and finance can play a catalytic role. At present, agriculture is under-prioritised in international climate finance, compared to its importance to global emissions. The OECD has found that agriculture received about 9% of climate-related official development aid in 2020. The Climate Policy Initiative's analysis of all climate-related financial flows in 2019/2020 found that agriculture, forestry, and land use received only about 2% (USD 14 billion) of the total, although the sector is responsible for 20% of global greenhouse gas emissions (including almost half of anthropogenic methane emissions) (CPI, 2021). There is a strong case for increasing this share, given the risks posed by climate change to food security, as well as agriculture's contribution to global emissions.

A particular priority for international assistance should be increasing access to finance for smallholder farmers, and for SMEs. Smallholder farmers (cultivating less than two hectares) produce about 30% of global food production on roughly 24% of agricultural land (Ricciardi et al., 2018). Often, smallholder farmers are unable to adopt technologies and practices that would increase productivity and reduce emissions, because they do not have access to finance. (Lack of information or land tenure are other common barriers). Agricultural SMEs — including producer organisations, input providers, storage and transportation facilities, traders, processors, and distribution services — can aggregate the resources of otherwise dispersed smallholder farmers. By providing training, credit, and access to markets, SMEs can play a critical role in supporting the transition to climate-resilient, sustainable agriculture. But in many countries, SMEs themselves face challenges in accessing appropriate financial services (AGRA, 2019).

International finance in the form of grants, concessional lending or innovative blended finance can play an important role by helping to mobilise private investment in the sector. Examples of international initiatives in this space include:

- The Smallholder and Agri-SME Finance and Investment Network (SAFIN), housed within the International Fund for Agricultural Development, which is an inclusive partnership of actors operating in different parts of the ecosystem for agri-food and rural SME investment, with a focus on access to finance and complementary services.
- An initiative by ResponsAbility and CGIAR that aims to provide long-term lending to innovative businesses operating in the food value chain in Asia Pacific, Latin America and Africa, with the goals of reducing emissions, reducing food loss, and promoting the climate change resilience of smallholder farmers.
- The ClimateShot for Impact Investment initiative, which aims to build understanding of opportunities for investment in climate-resilient agriculture among development finance institutes, institutional investors, banks, and other funders.

A significant expansion and strengthening of these efforts is needed. Estimates of the financial resources needed to transform the food system by 2030 to meet food security and climate goals range from an additional USD 15 billion to USD 350 billion a year (IFPRI, 2022). Governments will need to use public funding and policy in a way that creates the right incentives, to mobilise private finance on this scale.

Private sources of funding into sustainable agriculture, from banking systems, capital markets, and corporations have been miniscule in the past. At the same time banks and investors continue to finance activities linked with fossil-fuels and deforestation. Private sector finance into climate-resilient sustainable agriculture should greatly increase, especially in the context of proposed policies to require companies to disclose emissions from their investments and their climate risks (IFPRI, 2022). Less than one in five meat and dairy producers, for example, track even some of their methane emissions (FAIRR, 2021).

We recommend that governments, MDBs and private sector investors work together to put in place the necessary architecture by which to make finance available to agricultural SMEs and smallholder farmers on a far larger scale than has been achieved so far. Concessional finance should be accompanied by technical assistance that supports the adoption of practices that increase productivity and resilience while reducing emissions and protecting natural ecosystems.

Recommendation 2

The level of international climate finance directed at agriculture should be greatly increased, in line with its importance to global emissions, adaptation and resilience and food security. Governments, MDBs and private sector investors should work together to make finance available to agricultural SMEs and smallholder farmers in developing countries on a far larger scale than has been achieved so far. Finance should be accompanied by assistance with the adoption of practices that increase productivity and resilience while reducing emissions and protecting natural ecosystems. *This will support economic development, resilience, and food security, as well as reducing emissions.*

Accelerate the exchange of best practices on redirecting public support to incentivise climate resilient, sustainable agriculture

Governments' agricultural support policies transfer about USD 620 billion per year to the sector worldwide (IFPRI, 2022). But this support has been moving the sector in the wrong direction – away from sustainability – and at the same time has worked against the objectives of eradicating hunger and increasing climate resilience.

Many existing agricultural subsidies and policies encourage farmers to use excessive amounts of fertilisers, one of the main sources of emissions, as well as water. Emission-intensive commodities (such as beef, milk and rice) are among those that receive the most support. As well as being detrimental to the climate, current policies disproportionately support unhealthy products, like sugar, and often benefit wealthier farmers at the expense of poorer farmers (FAO, UNDP and UNEP, 2021). According to analysis by the World Bank, only 5% of direct public support for agriculture explicitly targets conservation, sustainability and other public goods, and only 6% supports research and practical assistance (of which some portion is also relevant to sustainability) (Gautam et al., 2022). The transition to sustainable agriculture cannot proceed without a fundamental redirection of this policy support, so that it promotes the efficient use of land and other natural resources while building resilience and reducing emissions.

The World Bank and the International Food Policy Research Institute (IFPRI) have advised that 'Simply eliminating agricultural support could reduce agricultural output and increase prices. Making agricultural support conditional on environmentally beneficial but lower yielding production methods could also increase poverty and food prices and lead to agricultural expansion. Therefore, the most effective repurposing requires policy incentives and public investment in technologies that both reduce emissions and enhance productivity to meet growing demand for food and ensure food security.' Examples of these technologies 'include feed supplements that reduce livestock emissions while increasing productivity, and rice production systems that use less water and produce less methane, without compromising farmers' incomes and yields' (Gautam et al., 2022).

This represents a significant policy challenge. While the reallocation of resources towards climate-resilient, sustainable agriculture could have major societal gains, for most countries it will be both technically and politically difficult. Consequently, there can be high value in international processes to quickly develop evidence and share knowledge on effective policies in different contexts.

A step in this direction was taken by the 34 countries that participated in the Policy Dialogue on Accelerating the Transition to Sustainable Agriculture, supported by the World Bank in the run-up to COP26. Participating countries shared evidence and experiences on designing and implementing policies and redirecting subsidies to re-shape agricultural practices and investments. It was notable from these discussions that while there are diverse examples of countries taking positive steps forward, there is relatively little collective international understanding of how to achieve the rapid and fundamental reorienting of policy support that is necessary for a transition to sustainable agriculture in line with the Paris Agreement goals.

There is an urgent need to develop a deeper understanding of the policy approaches that will be effective, and to share this widely among countries. We recommend that governments, research institutions, international organisations, and the private sector commit to a long-term process to test, analyse, and share learning on approaches to redirecting policy support for agriculture towards sustainability. This should involve all of the world's largest agricultural producer countries, whose policies disproportionately influence global markets, as well as countries representing a diverse range of environmental and economic conditions.

Recommendation 3

Governments, research institutions, international organisations, and the private sector should commit to a long-term process to test, develop evidence and share learning on approaches to redirecting policies and support for agriculture towards sustainability and climate resilience. This should involve all of the world's largest agricultural producer countries, whose policies heavily influence global markets, as well as countries representing a diverse range of environmental and economic conditions. *This will help countries identify the most effective and feasible ways to incentivise the transition to sustainable agriculture.*

DEVELOP SUSTAINABILITY STANDARDS FOR TRADED AGRICULTURAL COMMODITIES

The global food system is highly interconnected: 27% of all agriculture and related land-use emissions can be attributed to agricultural products consumed in a different country from where they were produced (Hong et al., 2022). Consequently, the standards required by international markets can strongly influence production practices.

Without appropriate international coordination, there is a risk that international trade will hold back the transition to sustainable agriculture. This risk is not as obvious as in, for example, the steel sector. The diversity of products in the agriculture sector, of the agroecological contexts in which they are produced, and of approaches to achieving sustainability, is far greater, meaning that a cost differential between sustainable and unsustainable approaches is extremely difficult to measure. Nevertheless, early research into this issue suggests the risk is real: environmental standards that support climate-resilient, sustainable agriculture could put producers in countries implementing them at a competitive disadvantage compared to those not subject to comparable standards (TULIP and IEEP).

At present, there are no international trade rules in place that are designed to reduce the emissions and other environmental impacts of agricultural commodities. This is a gap that needs urgent attention.

A precedent exists in the form of the Codex Alimentarius created by the FAO in 1961 to establish safety and quality standards for food traded internationally. This provides governments, food producers, consumers, and other stakeholders with a uniform set of principles and practices for the safety and quality of internationally traded food. It is maintained by the Codex Alimentarius Commission, jointly managed by the FAO and the World Health Organisation and composed of 188 countries representing 99% of the world's population. Although the Codex is not a legally binding agreement, it has become the default standard for food safety.

A similar code that sets minimum environmental standards for food traded internationally could be important to creating the right conditions in global markets, so that producers in all countries are able to make the transition to sustainability without being disadvantaged in competition (WWF, 2016). It would be important for the development and implementation of such a code to take into account countries' differing economic circumstances.

An alternative to developing internationally agreed rules is for countries to individually set standards for imports that match those governing domestic production. An example of this is the import provision set in 2017 by the United States, which aims to reduce marine mammal bycatch from fish imports by ensuring they are held to the same standards as US commercial fish operations (NOAA Fisheries, 2021). Such measures could make positive contributions, but may be of insufficient coverage to create the necessary conditions throughout global markets. There are likely to be advantages of both effectiveness and efficiency in a coordinated international approach.

There is little international discussion dedicated to agreeing an approach to trade that supports the transition to sustainable agriculture. Discussions within the World Trade Organisation have so far been broader in scope. The Trade and Environmental Sustainability Structured Discussions (TESSD), launched in November 2020, have begun to address general issues of trade and environment. In December 2021, 71 countries co-sponsored a TESSD Ministerial Statement proposing further work on issues where trade, environmental and climate policies intersect, including on sustainable agriculture.

A move towards more dedicated discussions on sustainable agriculture and trade is likely to be needed, to enable the rapid transition in the sector that has to take place. We recommend that agricultural trading nations should begin a strategic dialogue on how this issue should be addressed. The WTO, FAO and other relevant international organisations could inform such discussions by investigating in detail the risks that policy measures essential to drive a transition to climate-resilient, sustainable agriculture could put a country's agricultural sector temporarily at a competitive disadvantage in international trade, and potential solutions, including the practical options that could be taken to establish a level playing field.

Bilateral, regional or plurilateral trade agreements could be valuable as first steps, and could act as building blocks towards multilateral agreements. These could set environmental standards based on delivery of outcomes related to climate-resilient, sustainable agriculture (considering issues discussed in the opening section of this chapter, such as habitat protection, reduced greenhouse gas emissions, improved soil carbon, or water use efficiency).

Given the breadth of agriculture as a sector, there are also likely to be advantages in coordinating efforts on sustainable production and trade more narrowly around specific commodities. A subset of agricultural commodities that needs urgent attention are those that contribute disproportionately to the loss of tropical forests and peatlands, some of the Earth's most carbon rich ecosystems. Soy, beef, palm oil, and cocoa are particularly important in this respect. Coordination of standards internationally – those governing production, and those governing market access – is likely to be necessary to protect forests while promoting development and trade. To decisively shift global markets towards sustainability, the agreement and implementation of such arrangements will need to involve countries covering a majority of global consumption and production of these commodities. Trade measures will need to be accompanied by financial and technical assistance for smallholder farmers, to support sustainable intensification and ensure they are able to meet sustainability standards.

A collaborative international initiative in this area is the Forest, Agriculture and Commodity Trade (FACT) Dialogue, begun in the lead up to COP26. The 28 countries involved have agreed to work together to promote sustainable development and trade in agricultural commodities while protecting forests and other critical ecosystems. These countries include most of the largest producers and consumers of forest-risk commodities. Their commitment to work together, outlined in a 'Roadmap' released at COP26, is a promising start. Governments should now invest seriously in the detail of implementation. The highest priority should be given to agreeing to the means by which producer country laws and consumer country market access can be aligned with mutually agreed standards of sustainability. This should be accompanied by specific plans to expand access to finance for smallholder farmers to support climate-resilient, sustainable agriculture and protect natural habitats.

Recommendation 4

Governments should begin a strategic dialogue on how to ensure international trade facilitates, and does not obstruct, the transition to sustainable agriculture. International organisations can advise on options to ensure a level playing field so that policy measures essential to drive a transition to climate-resilient, sustainable agriculture do not put a country's agricultural sector at a competitive disadvantage in international trade. Early priority should be given to agreeing sustainability standards for the agricultural commodities that contribute disproportionately to deforestation. *A level playing field in international trade will give countries and companies greater confidence and ability to move ahead in the transition.*

Agree international standards for monitoring and reporting on the state of natural resources on which agriculture depends

There are major data gaps in the international monitoring and reporting of the state of natural resources critical for climate-resilient, sustainable agriculture. Specifically, three of the metrics for tracking natural resource health in the sector in Figure 6.1 (agricultural extent, soil carbon, and biodiversity and pollinator health) lack regularly updated, internationally comparable data.

Countries should monitor the status of carbon-rich ecosystems such as forests, peatlands, and coastal wetlands to ensure that agricultural expansion is not threatening critical carbon sinks. However, differing interpretations of remote sensing data and varying definitions of land use types creates uncertainty around the geographical extent of cropland and pastures (Potapov et al., 2022; Tubiello et al., 2022). International monitoring of agricultural extent is critical to understanding its climate impact and should incorporate findings from both national agricultural research institutions and remote sensing.

Internationally comparable metrics on soil health, soil carbon content, and pollinator health are lacking. Such metrics are essential to support an understanding the extent to which agricultural practices intended to be sustainable actually are. For biodiversity, a 2021 report from the FAO includes national-level Gini-Simpson crop and livestock diversification indices, which can help measure on-farm biodiversity (FAO, 2021b). For pollinator health, a global assessment of pollinators, pollination and food production was published in 2016 by the International Panel on Biodiversity and Ecosystem Services (IPBES) which was the latest major assessment conducted on the topic (FAO, 2019).

On soil health and soil carbon content, the FAO developed a global map of soil carbon in 2018 but this dataset will not be updated regularly. Tracking soil carbon in detail on an annual basis on a global scale may be impractical, but a measurement, monitoring, reporting and verification platform has been proposed by academic experts to track soil organic carbon at benchmark sites over many years to help inform modelling of changes to soil carbon stocks over time (Smith et al., 2019). Combining soil carbon monitoring and verification with the monitoring of agroecological approaches would accelerate research into whether these approaches improve soil health in specific environmental contexts.

Relatedly, antimicrobial use in livestock production contributes to the spread of drug-resistant pathogens in both livestock and humans, posing a significant public health threat. The use of these drugs should be monitored and reduced to preserve their medical effectiveness in humans (Boeckel et al., 2015).

International comparability in these measurements is important to support high quality knowledge sharing on policy effectiveness, and to enable trade to play a positive role in supporting the transition. (This is similar to the need for harmonised standards for the measurement of emissions from steel or hydrogen production, as discussed in other chapters of this report). We recommend that countries work together to develop agreed standards and processes for the monitoring and international reporting of these critical metrics. This could be facilitated by an international organisation such as the UN Food and Agriculture Organisation[8], making use of existing relationships with national agriculture research institutes.

Recommendation 5

Countries and international organisations should develop internationally agreed standards for monitoring and reporting on the state of natural resources on which agriculture depends, including soil carbon content and health, and pollinator health, as well as on the geographical extent of agriculture. *International measurement standards will help support high-quality knowledge sharing on policy effectiveness and enable international trade to play a positive role in supporting the transition.*

[8] This work could build upon FAO's Adaptation, Biodiversity and Carbon Mapping Tool (ABC-Map), which assesses the environmental impact of national policies, plans, and investments in the AFOLU sector: https://abc-map.org/.

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Annex

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Long-term vision & action plans	By the mid-2020s, countries with significant agricultural emissions should have in place climate plans (e.g. nationally determined contributions (NDCs), national adaptation plans (NAPs), long-term strategies) that include commitments and/or targets for climate-resilient, sustainable agriculture.	
Demand creation & management	By 2030, halve the share of food production lost (relative to 2016), and halve per capita food waste (relative to 2019), in line with Sustainable Development Goal Target 12.3. By 2030, reduce ruminant meat consumption in high-consuming regions (Americas, Europe, Oceania) to 80 kilocalories per capita per day. By 2030, increase market share for low-carbon protein alternatives in high-income regions.	14% of food production is lost (before retail), according to FAO's Food Loss Index. 17% of food at the retail level is wasted, according to UNEP's Food Waste Index. Countries and regions representing about half of the world's population have set targets in line with the SDG target 12.3, according to Champions 12.3.

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
		Ruminant meat consumption in high-income countries in 2019 averaged 91 calories per person per day, according to FAOSTAT. Alternative proteins represented roughly 1% of the total protein market in 2020, according to FAIRR.
Infrastructure & supply chains	Increase the market share for sustainably produced commodities, through enhanced trading possibilities and improved access of small-holder producers to international markets. By the mid-2020s, 150 companies have Science Based Targets initiative, Food, Land, and Agriculture sector (SBTi FLAG), zero-deforestation targets. By 2030, these companies should be on track to hit targets.	99 companies have established deforestation commitments for all their commodities exposed to forest risks. (Forest 500: Burley & Thomson, 2021).
Finance & investment	By the mid-2020s, double quantum of investment and action (public and private) in agricultural research, development, and demonstration (RD&D) focused on climate-resilient and sustainable agricultural technologies and practices. Areas of focus could include crop breeding, green fertilisers, agroforestry, methane and nitrogen management, food loss and waste, and alternative proteins. By 2030, develop methods and metrics to measure the performance of climate-resilient and sustainable agricultural technologies and practices.	7% of agricultural research and innovation investments (roughly USD 4 billion) in developing countries were focused on developing or improving climate-resilient and sustainable agricultural technologies and practices (average between 2010-2019, according to Dalberg Asia, 2021).
Research & innovation	By 2030, increase share % of US$600 billion per year in agricultural subsidies to align with climate-oriented support, with the guiding principles of increasing the efficient use of land and other natural resources while building resilience and reducing emissions. By the end of 2023, double investment in all forms of finance for sustainable agriculture, and create pipeline of investable projects, with a particular focus on smallholders. By 2030, increase number of countries linking farmer access to credit with conservation or environmental performance. Develop weather-based insurance programs for crop and livestock systems.	~5% of financial support went to conservation-related measures in 2016, Gautam et al., 2022. According to the Climate Policy Initiative's analysis of all climate-related financial flows in 2019/2020, agriculture, forestry, and land use received only about 2% (USD 14 billion) of total climate finance.

Enabling condition	Pathway to 2030	Tracking (as of July 2022)
Market structures	By 2030, increase number of farmers globally with access to high-quality storage facilities, markets, affordable energy, and infrastructure that enables trade. Improve coordination and capacity of all actors in the supply chain around sustainable, climate-resilient agriculture, with particular attention to power relations within value chains to ensure fairness, equity and transparency.	
Standards & certification	By the mid-2020s, agree on production and sustainability standards within the Forest, Agriculture and Commodity Trade (FACT) Dialogue, and begin process of socialising these within the Committee on Agriculture at the WTO. By the mid-2020s, increase number of the world's financial institutions with strong anti-deforestation policies (aligned with established standards and includes measurable targets for achieving net zero deforestation) by 25% (2020 baseline). By 2030, increase number of the world's largest banks that publicly disclose procurement standards and supply chain footprints on deforestation.	33 financial institutions representing about USD 8.7 trillion in assets committed to create plans, milestones and incentives to fulfil the proposed timeline for commitments on deforestation-free forest-risk agricultural commodity portfolios, aligned with a Paris Agreement-compliant 1.5°C pathway, UN High-Level Champions, 2021.
Trade conditions	Develop widely accepted international standards around sustainable climate-resilient agriculture, matched with metrics and measurement. Secure land and resource rights for indigenous and local communities. Reform laws that discourage farmers from investing in protecting or regenerating trees.	Strong, secure, and clear land management rights, as measured through the Physical Property Rights component of the International Property Rights Index was 6.5 in 2021, a 10% improvement from 2016.
Knowledge, capability & skills	By 2030, increase percent of farmers with access to communication technologies. By 2030, establish early warning systems and advisory networks in countries to monitor weather, pests, animal health, and global markets. By 2030, develop infrastructure to create and share to knowledge about sustainable climate-resilient agriculture, which is interdisciplinary, involving multiple stakeholders, integrating different forms of knowledge in close collaboration with local communities, including among marginalised groups, so it is suited for end-users.	33 million farms registered for agricultural climate services — around 13% of all Sub-Saharan African smallholders in 2018 (The Technical Centre for Agricultural and Rural Cooperation, (CTA), Tsan et al., 2019).
Social acceptance	Design inclusive consultation processes on policies and strategies designed to shift investment to sustainable agriculture, to ensure an equitable and just transition.	

Chapter 7. Putting the world on track to meet the Paris goals

Meeting the goals of the Paris Agreement – in particular, limiting the increase in global temperatures to 1.5°C – requires much faster progress in decarbonisation throughout the global economy. The Breakthrough Agenda agreed at COP26 provides a framework for countries to collaborate internationally to accelerate transitions in each of the emitting sectors. It will also be important to take advantage of cross-cutting opportunities to support progress simultaneously in all sectors.

Collaboration across all of the major emitting sectors is essential

The Breakthrough Agenda will need to address all major emitting sectors to put the world on track to meet the Paris Agreement goals

The five sectors included in this report cover over 50% of global GHG emissions. To reach net zero global emissions by around mid-century, countries will need to implement their commitments in the Breakthrough Agenda to collaborate internationally throughout the course of this decade in each major emitting sector of the global economy (COP26, 2021). Decisions on which additional sectors would benefit from prioritisation within the framework of the Agenda should be informed by their impact on emissions, the political commitment to lead activity in this area from countries, businesses and international initiatives, and the sector's dependence on international collaboration to advance in its transition.

Four sectors stand out for consideration: shipping, aviation, cement and buildings. Combined these would encompass an additional 20% of emissions, bringing total coverage to over 70%.

1) Shipping

Shipping accounts for around 2% of global energy-related CO_2 emissions (IEA, 2021a), roughly the same as the entire nation of Germany. On its current growth trajectory, shipping emissions could potentially increase by half by 2050 (IMO, 2020). The sector's transition to net zero has barely begun: while governments and industry are taking important steps forward, at present there are no long-distance zero-emission ships in operation. Since ships typically have a lifespan of over 25 years, turnover in the global fleet is slow. Investments in zero-emission ships and their supporting infrastructure need to be made now to enable the path to a low-carbon fleet in later years.

Higher capital and operating costs of zero-emission shipping, compared to fossil-fuelled shipping, and the globally interconnected nature of the sector, make international collaboration essential to the transition.

International collaboration on the shipping sector has expanded in recent years, however there remains much to be done. Many pilot projects for zero-emission shipping are being taken forward, but countries could do more to share knowledge learned from these efforts. The International Maritime Organisation (IMO), Mission Innovation, the First Movers Coalition, the Green Shipping Challenge, the OECD Council Working Party on Shipbuilding and the Getting to Zero Coalition all offer platforms to facilitate the exchange of knowledge.

At COP26, 14 countries signed the Declaration on Zero Emission Shipping by 2050, pledging to work for the adoption by the IMO of a goal of full decarbonisation of international shipping by 2050.

Additionally, at COP26 a group of 24 countries committed in the Clydebank Declaration to bring at least three deep-sea green shipping corridors into operation, supported by an equivalent number of regional or near-shore corridors, by the middle of this decade. To date, industry consortia have also announced plans to create eight green shipping corridors, ranging across Atlantic, European, Southeast Asian and Pacific routes.

Industry coalitions are also forming to create clear demand signals for zero-emission shipping, notably the Cargo Owners for Zero Emission Vessels (coZEV) initiative, which is a cargo owner-led platform that enables maritime customers to work together to accelerate shipping decarbonisation. The group has committed to using only zero-carbon ocean freight from 2040 onwards.

2) Aviation

Aviation is responsible for around 2.5% of global energy-related CO_2 emissions (IEA, 2021b). With its emissions growing at around 2.2% per year from 1990 to 2019, and with passenger air travel projected to triple by mid-century (ICAO, 2019), aviation's share of emissions is expected to increase over the coming decade. Strong action needs to be taken now to put the sector on course for a transition aligned with international climate change goals.

Similar to the shipping sector, international collaboration is important in aviation because of its interconnected nature, the early stage of development of its clean fuels and technologies, and the need to establish a level playing field to prevent competition being a barrier to the transition.

International collaboration in the aviation sector has most prominently taken place within the International Civil Aviation Organisation (ICAO), and has resulted in the agreement of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), in which over 100 countries have agreed to participate. While this is a positive step forward, its aim of offsetting the growth in aviation emissions after 2020 is not yet consistent with targets to achieve net zero global emissions by around mid-century. Moreover, stronger and more direct policy measures that focus on in-sector emissions reductions are needed to enable the deployment of low-carbon aviation fuels and technologies.

Industry coalitions such as the Clean Skies for Tomorrow Coalition and the First Movers Coalition are pointing the way forward, with plans to aggregate demand for zero-emission aviation, and to coordinate investment. In 2021, IATA (International Air Transport Association) member airlines, covering 290 airlines and 82% of global air traffic, made a commitment to achieve net zero CO_2 emissions from aviation by 2050. Stronger intergovernmental collaboration could help to make this a reality, by ensuring routes exist where zero-emission aviation is not at a competitive disadvantage.

3) Cement

Cement, the key binding ingredient in concrete production, is one of the largest contributors to industrial emissions, accounting for 7% of global CO_2 (IEA, 2021c). Concrete is the most used man-made material in the world, and is expected to remain central to meeting the world's construction needs for the foreseeable future. An estimated three quarters of the infrastructure that the world will need by 2050 (including buildings, transport, water systems, and other infrastructure), has yet to be built. Consequently, a transition to the production of near-zero emissions cement is essential for the achievement of international climate change goals.

Opportunities for international collaboration to accelerate the transition in the cement sector are likely to include knowledge-sharing on decarbonisation technologies and processes, aggregated demand creation, and measures to establish a level playing field in international markets.

Industry-led coalitions have recently begun taking collaborative action on cement decarbonisation. For example, the Global Cement and Concrete Association (GCCA), an industry group (representing 80% of global cement production outside China, as well as some of the largest Chinese manufacturers), and the Mission Possible Partnership (a civil society initiative working with industry leaders), have launched the 'Concrete Action for Climate' initiative, bringing actors across the supply chain together to collaborate on issues including standard-setting and demand creation. The GCCA is also supporting the development of national cement decarbonisation roadmaps in some countries.

Governments of five countries, plus the European Commission, have agreed to collaborate on research and development in Mission Innovation's Net Zero Industries Mission, and discussions on the pathway to cement decarbonisation have been held by the 18-member countries of the Leadership Group for Industry Transition. In the Clean Energy Ministerial's Industrial Deep Decarbonisation Initiative (IDDI), four countries have agreed to work together to use public procurement to create an initial market for low-carbon cement, as well as steel.

4) Buildings

Buildings are the largest emitting sector not currently addressed by the Breakthrough Agenda. While the emissions that occur directly from activity in buildings such as heating, cooling, and cooking account for around 9% of global energy-related CO_2 emissions, those that occur indirectly – from the steel, cement, and other materials used in buildings' construction, and from the generation of the electricity they use – account for an additional 28% of global energy-related CO_2 emissions (IEA, 2021d). More than half of the buildings expected to exist by 2050 have not yet been built, meaning that choices made now will have substantial and long-lasting effects on material use and emissions.

There are likely to be significant opportunities for international collaboration in this sector, despite the widely varied needs and opportunities for resilient zero-emission buildings in different regions of the world. These may include collaboration on research and development of zero-emission heating and cooling technologies; sharing learning in the design and construction of high-energy performance buildings with low embodied emissions; and coordination on building codes, standards, and the measurement of life-cycle emissions.

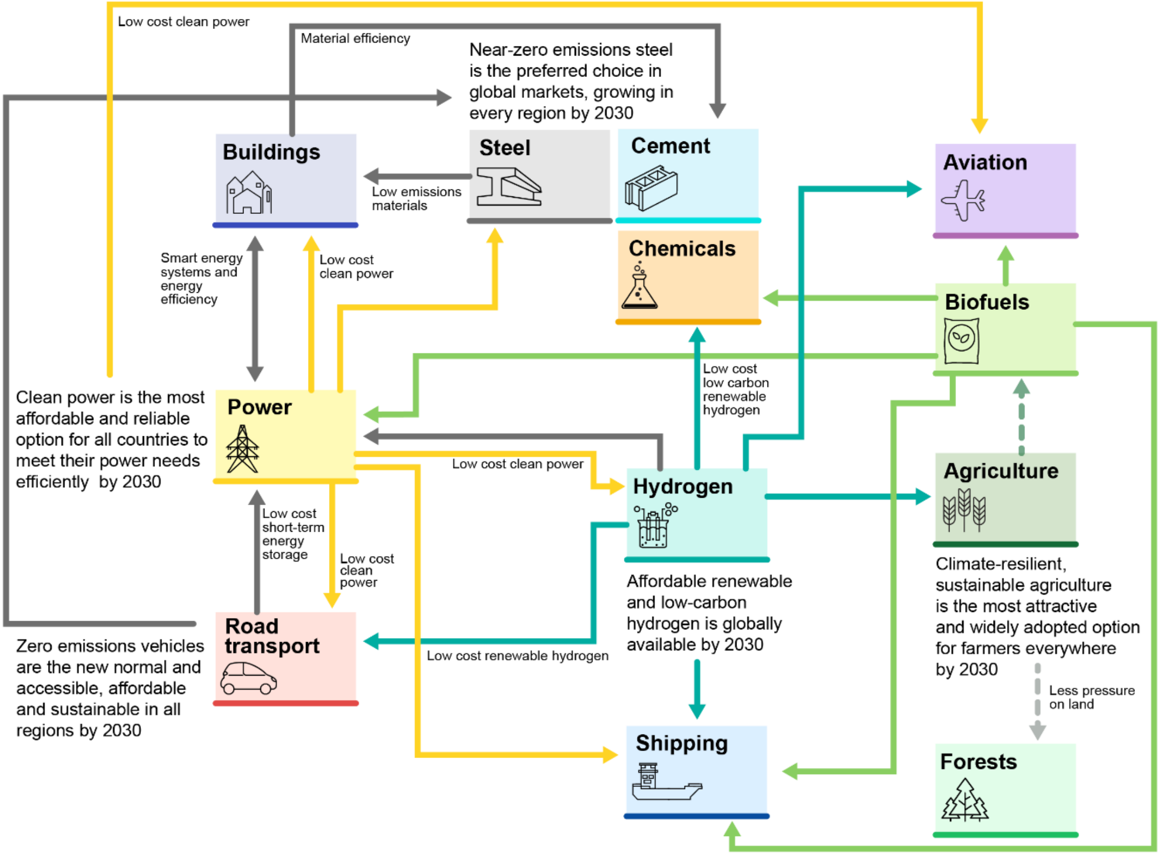
Important collaborative initiatives in the sector include the Global Alliance for Buildings and Construction, which shares knowledge and policy best practice among its 36-member countries, and the World Green Building Council, which brings business and civil society actors together in a large number of countries. Relevant research and development initiatives include work on affordable heating and cooling of buildings within Mission Innovation, the IEA's Technology Collaboration Programme (TCP), and innovation competitions such as the Global Cooling Prize and the Million Cool Roofs Challenge.

THE ADDITIONAL GAINS FROM ADVANCING ON ALL SECTORS AT ONCE

While most of this report focuses on the collaboration opportunities in individual sectors, it is clear that action in each sector can support progress in others. For example, scaling up the deployment of batteries in road transport can help to bring down the costs of energy storage in the power sector, supporting the integration of larger shares of renewable power. Enabling a more rapid build-out of low-cost renewable electricity generation will in turn facilitate faster deployment of low-carbon and renewable hydrogen, which could lead to a more rapid shift in the steel industry to the use of hydrogen in direct reduction furnaces.

Similarly, demand for hydrogen from agricultural fertilisers can drive up the pace and scale at which key clean hydrogen-producing technologies are deployed (such as electrolysers), resulting in faster cost reductions, to the benefit of steel producers, and other sectors (such as road transport, chemicals, aviation and shipping), which may also use hydrogen. In this way, the crossing of a tipping point in one sector – where clean technologies or sustainable solutions become the most affordable, accessible and attractive option – can increase the chances of crossing similar tipping points in other sectors. Figure 7.1 illustrates some of these interconnections between sectors.

Figure 7.1. How actions in each sector can contribute to progress in others



To fully realise this potential for accelerated global progress, countries and industries should:

- Establish strong international collaboration to accelerate progress in each of the emitting sectors, taking these forward simultaneously.
- Identify and act on specific opportunities for action in one sector that can also enable faster progress in others. Several such opportunities are identified in the sector-specific chapters of this report. For example, collaboration on strengthening electricity grids in the power sector can support the road transport transition by enabling wider deployment of electric vehicle charging infrastructure. It is important to recognise, establish and strengthen these cross-sectoral linkages and feedback loops through initiatives and actors that work across technology families and sectors, as well as within them.
- Take advantage of cross-cutting opportunities to accelerate progress in all sectors, using the full range of levers available in international development, trade, diplomacy and governance.
- Ensure that progress is indeed global, with the necessary support and access to technology and finance for developing countries.

Leveraging cross-cutting opportunities

There are a number of cross-cutting opportunities, which are common across the current and potential Breakthrough Agenda sectors. International action in these areas can help to support progress in all sectors simultaneously.

Establish a clear structure for international collaboration within each sector

Each sector stands to benefit from having at least one forum in which actors with strong influence and interests in the sector collaborate to accelerate the global transition. Having such a clearly identified, well-resourced body can enable all actors to engage effectively with areas where they have most to contribute. The activities to be prioritised are those through which international collaboration can most effectively accelerate the transition, such as financial and technical assistance, trade conditions, definitions and standards, and procurement commitments.

The complexity of low-carbon transitions means that a diverse range of international efforts in each sector will be helpful. Rigid centralising of activities should not be the aim. At the same time, it can be useful to have an agreed focal point for collaboration for specific priority areas of collaboration. This can benefit all by making the best use of limited resources, limiting duplication of efforts and reducing barriers to engagement for new participants. This is important for sectors with relatively well-established international collaboration, such as power, where the proliferation of initiatives has made it challenging for stakeholders to engage effectively, as well as for those with a rapidly expanding landscape of initiatives, such as steel, where it will be vital to get ahead of potential overlaps.

In this report we have focused our recommendations on the international collaboration efforts that could have the greatest impact on low-carbon transitions, without taking a view on the channels through which it should be taken forward. Nevertheless, it is clear from our assessment that in each sector there are opportunities to strengthen the underpinnings for collaboration. Countries can strengthen international initiatives by participating in them, by investing in them politically and financially, by requesting them to focus on issues critical to the global transition, and by ensuring the collaborative initiatives they support are sustained long enough to achieve their objectives.

Beyond international fora to support collaboration within individual sectors, institutions with a cross-sectoral remit are also needed to help maintain a consistent quality and focus of collaboration across all sectors. The Breakthrough Agenda can serve some of this function by systematically and regularly taking stock of the state of collaboration in each of its focus sectors. Countries must also work together through established international fora such as UN organisations, the G7 and G20, the Clean Energy Ministerial, Mission Innovation, IEA, IRENA, and regional international organisations to agree activities to strengthen international collaboration in each sector.

Recommendation 1

Countries should work to agree the international fora and institutions through which they will take forward each of the recommendations for collaborative action contained in this report, and should then invest in those fora both politically and financially. Existing institutional frameworks should be used wherever these are appropriate to the task. *This can help to establish the institutional underpinnings needed for strong and sustained international collaboration over the course of this decade.*

Strengthen the provision of technical assistance and finance, to ensure it is sufficient, coherent, accessible and effective across all sectors

The level of finance and technical assistance being provided by donor countries and associated organisations has increased significantly over the past decade, particularly in the power sector. However, a step change in the scale and delivery of funds and technical assistance will be required to accelerate the transition across all sectors. Funding should be made accessible and responsive, so that assistance can be rapidly mobilised to meet countries' needs.

To improve the effectiveness of implementation, governments, philanthropies, financial institutions and delivery partners should better coordinate programmes, driven by the needs, priorities and leadership of developing countries. In each sector, strategic international dialogues about the priorities for accelerating the transition globally can also help to inform choices regarding the most effective use of technical and financial assistance.

Recommendation 2

Governments, philanthropies, financial institutions and delivery partners, should together review the state of international assistance in each major emitting sector, identify the gaps in assistance that are most important to address, and coordinate efforts to provide responsive and accessible support in these areas, led by the needs of developing countries. *This will ensure that assistance is appropriately targeted and available to support countries in relation to each of the major low carbon transitions.*

AGREE NET ZERO-ALIGNED TRADING ARRANGEMENTS THAT CAN ENABLE A FASTER TRANSITION ACROSS SECTORS AND REGIONS

Several sectors, particularly heavy industries, are highly trade exposed and operate with relatively narrow profit margins. This makes manufacturing products with a low-emission premium challenging unless policy measures (such as regulations or carbon pricing) are put in place to support first movers and increase the speed of the transition in the wider market. While there are measures that countries can put in place individually to help domestic industries to decarbonise while limiting the risks from international competition, there is a risk that unilateral approaches may cause trade disputes, while at the same time being insufficient to bring about a global transition at the pace required. Similar issues are likely to affect some agricultural commodities, as discussed in Chapter 6.

A range of measures can support the development of a level playing field for near-zero or low-emissions materials, commodities, products and fuels in international markets. These include a common approach to data monitoring, reporting and verification (MRV), definitions for low-emission materials, products, fuels, and energy and agricultural commodities, public and private procurement guidelines, and financial and technical assistance. Collaboration on these issues could help to build the confidence and trust that will be needed for strategic dialogue and eventual agreement on coordination around standards or carbon pricing.

In each sector, the success of these efforts will depend on the inclusion of not only the countries willing to take a leading role in the transition, but also those with a large contribution to global production or consumption, and others whose interests are most strongly affected. It will also depend critically on ensuring that the international measures support, and do not obstruct, the economic development objectives of developing countries and marginalised communities.

Such an approach can support first movers, while also encouraging all countries to participate in the transition. Ultimately, most trade-related measures are likely to be temporary, and should be able to be phased out as the "differentiated" market grows in scale within the overall market, and technology costs for near-zero or low-emission commodities decrease.

RECOMMENDATION 3

Governments, companies and relevant international organisations should establish high-level, strategic dialogues in each sector that is highly exposed internationally and where competition risks being a barrier to the transition, to develop a common approach to reaching a level playing field. This should include, where relevant, actions on data, standards, procurement, technology collaboration and technical and financial assistance, as well as trade. *This will help to focus dialogue on areas where collaboration is most urgent, and ensure that competition accelerates transitions, and does not hold them back.*

URGENTLY SCALE UP DEMONSTRATION PROJECTS FOR CLEAN TECHNOLOGIES IN AREAS OF GREATEST NEED

The world needs to rapidly increase the number of demonstration projects of clean energy technologies and sustainable agriculture solutions, across multiple regions and sectors in parallel. International collaboration will be important in determining the priority gaps to address, and in ensuring deep, systematic and widespread sharing of learning between countries. International fora can also provide a 'matchmaking' function: enabling financiers, policy makers and consumers to understand the supply chain implications and business case for deploying new technologies, and to launch new demonstration projects. This will need to be supported by large-scale public investment, such as the USD 90 billion proposed at the Major Economies Forum (MEF) in June 2022 (The White House, 2022), including investment in institutions to support ongoing sharing of learning – particularly with countries that have limited resources for research, development and demonstration projects of their own.

RECOMMENDATION 4

Governments and companies should greatly increase spending on clean technology demonstration projects, working together to bring new technologies to commercial-scale deployment as soon as possible. Early deployment projects should be supported by matchmaking forums and ensuing commitments and processes in all regions. *This will help ensure deep and sustained sharing of experiences gathered with these projects between countries, including those with limited resources.*

ACCELERATE THE BUILD-OUT OF INTERNATIONAL ENABLING INFRASTRUCTURE TO SUPPORT THE TRANSITION IN MULTIPLE SECTORS

Early experience from multiple major new energy projects points to a lack of enabling infrastructure – such as electricity, hydrogen and CO_2 networks – acting as a brake on the pace of deployment. It is clear that transitions in many sectors would benefit from strengthened international collaboration to share best practices in infrastructure planning, regulation, market design and investment, as well as in the technology solutions that can make best use of existing infrastructure and resources. Furthermore, in several sectors, a coordinated international approach to infrastructure deployment will be important for the pace of the transition. Cross-border infrastructure, such as interconnectors and pipelines, can enable the international trade of clean power, and low-carbon and renewable hydrogen, respectively. Harmonised standards for vehicle charging or refuelling can facilitate zero-emission international road freight. Coordinated investment in zero-emission refuelling infrastructure will be essential for the decarbonisation of long-distance aviation and shipping.

Collaboration in this area should include the development of platforms and mechanisms to help crowd-in public support and private investment, helping to ensure wider lessons learned are rapidly shared globally.

Recommendation 5

Wherever not already agreed, governments in each region of the world should agree the top priority common infrastructure projects that can support near-term growth in the deployment of clean solutions, such as interconnectors and hydrogen pipelines. In each of the land, sea and air transport sectors, countries and companies should identify specific international routes to be prioritised for the coordinated first deployment of zero emission charging or refuelling infrastructure. *This will support earlier deployment of infrastructure that unlocks accelerated deployment of clean technologies and solutions in multiple countries and regions.*

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