announced plans to develop two projects for hydrogen production from natural gas with CCUS, for a combined production capacity of 350 kt $H_2$/yr. Plus, the Korea National Oil Corporation and Korea East-West Power have announced the potential incorporation of a 100-MW electrolysis plant into the Donghae 1 offshore wind project, expected to be completed by 2025. On the infrastructure side, Linde and Hyosung partnered in 2021 to build Asia's largest hydrogen liquefaction plant (30 t $H_2$/day) to supply hydrogen for use in transport.

## Latin America

Latin American countries consumed 3.5 Mt $H_2$ in 2020, of which 2.5 Mt $H_2$ was used in industry and the rest in refining. The vast majority of the production (90%) was based on natural gas, with by-product hydrogen from refineries making up the rest.

A combination of factors has spurred increased interest in hydrogen in the region. The major economies (Argentina, Brazil, Chile, Colombia and Mexico) already produce large volumes from unabated fossil fuels for use in oil refineries and in the chemical and iron and steel industries, and Trinidad and Tobago is among the world's largest producers of ammonia and methanol.

Latin America also has one of the world's highest shares of renewables in electricity generation, with Costa Rica, Paraguay and Uruguay producing practically all their electricity from renewables. Plus, the region has significant oil and gas resources, particularly in Venezuela, Brazil and Mexico.

This combination of factors can create complementarities and synergies across the region. Establishing effective co-operation among the countries could therefore help the region meet the challenges of adopting hydrogen as a clean fuel while generating economic growth.

Chile has taken the lead in announcing hydrogen developments. Having enormous renewable energy potential – well exceeding its energy demand – it can produce renewable hydrogen at costs that are among the lowest in the world. The government published its Green Hydrogen Strategy in November 2020 with the ambition of becoming the top destination in Latin America for renewable hydrogen investment by 2025 and one of the world's largest exporters of hydrogen-based fuels by 2030. The strategy also targets 25 GW of electrolysis operational or under development by 2030.

Chile's private sector has responded to the government's call for action by launching some major initiatives. For instance, the Haru Oni project, led by HIF, aims to demonstrate synthetic methanol production using hydrogen produced by wind-powered electrolysis in Magallanes. The first phase is expected to be operational by 2022, and if successfully demonstrated, the project will be expanded in subsequent phases to produce 550 million litres of synthetic fuels annually by 2026 (with 2 GW of installed electrolysis capacity). The objective is to export these hydrogen-based fuels.

Meanwhile, in 2020 ENAEX and Engie announced the HyEx project to deploy up to 780 MW of electrolysis by 2030 to produce ammonia in Antofagasta, starting with a pilot of 50 MW of electrolyser capacity to be implemented by 2024. ENAEX, a company that produces explosives for the mining sector, imports 350 kt of fossil fuel-based ammonia annually, subject to high price volatility. The company therefore aims to secure and internalise its ammonia feedstock supply while also reducing its $CO_2$ emissions.

Chile's national hydrogen strategy also highlights the usefulness of electrolysis in decarbonising existing uses (in the chemical industry and refining), and especially heavy road transport. In a noteworthy activity in the mining sector, a major contributor to the economy, stakeholders are developing as many as 13 different initiatives for using hydrogen in mining, particularly for trucks used at mines.

The release of the Chile's strategy stimulated hydrogen-related policy discussions across the region. In Argentina, an inter-ministerial group was created to develop a hydrogen roadmap and update existing laws to promote hydrogen, and in February 2021, Brazil's Energy Research Office (EPE) released its first technical document laying the foundation for a national hydrogen strategy. Colombia announced the launch of its national strategy at the end of September 2021 and the governments of Panama, Paraguay, Trinidad and Tobago, and Uruguay are also developing hydrogen strategies and roadmaps.

In turn, the private sector is taking action to leverage hydrogen opportunities. For example, in early 2021 Energix announced the Base One project to deploy around 3.4 GW of electrolysis capacity powered by renewable energy (at Ceará, north-eastern Brazil). All hydrogen produced will be exported from the Port of Pecem (a founding member of the Global Ports Hydrogen Coalition).

In 2017, Costa Rica was the first country in the region to deploy a fuel cell bus and four FCEVs. The government, in collaboration with the private sector, presented an institutional plan to facilitate the use of hydrogen in transport in 2018 and is currently developing a national strategy. Meanwhile, Panama's strategic location at the crossroads of major shipping routes makes it a global hub for maritime transport and a centre for regional trade. While current hydrogen production and use are very limited, in 2021 the government presented its vision for Panama to become a logistics and distribution centre for low-carbon hydrogen-based fuels, initially focusing on the maritime shipping industry.

More details about hydrogen's status and opportunities in Latin America can be found in the IEA's August 2021 report Hydrogen in Latin America.

## Middle East

Countries in the Middle East consumed around 11 Mt $H_2$ in 2020, using close to 4 Mt $H_2$ in refining, more than 5 Mt $H_2$ in the chemical industry and 1.5 Mt $H_2$ in steel production. Natural gas accounts for close to 90% of production, with by-product hydrogen from refineries making up the remainder.

The Middle Eastern region has a formidable combination of oil and gas reserves and tremendous renewable energy potential (particularly solar) that can enable low-carbon hydrogen production at significantly lower cost than in most parts of the world. Plus, Middle Eastern countries have considerable experience in exporting LNG. Owing to all these factors, the countries aim to become major international suppliers of low-carbon hydrogen. Oman, Saudi Arabia and the United Arab Emirates have been the most active to date, having several projects under development and participating in various international co-operations.

In Saudi Arabia, Air Products, Acwa Power and Neom signed an agreement in 2020 to develop a USD 5-billion project to produce 650 t $H_2$/day using electrolysis powered by 4 GW of solar PV and wind. Part of the hydrogen produced will be transformed into ammonia for export to Air Products clients globally. The project has already reached FID and the design and early work are now under way, with the expectation that it will be operational in 2025. Thyssenkrupp and Haldor Topsoe are involved as technology providers.

Saudi Arabia has been quite active in the international sphere, seeking to develop potential supply chains through which it could become a major exporter, particularly to Europe and Japan. In September 2020, Saudi Aramco, the Institute of Energy Economics, Japan and SABIC successfully carried out the world's first shipment of ammonia produced from fossil fuels with CCUS, shipping 40 t of ammonia from Saudi Arabia to Japan for use in electricity generation while captured $CO_2$ was used in EOR and chemical production in Saudi Arabia. In March 2021, the Saudi government signed a collaboration agreement with Germany to lay the groundwork for developing an international hydrogen (or ammonia) supply chain.

In 2020, DEME announced the first initiative to develop a large-scale electrolysis plant (250-500 MW) in Oman. The number and size of projects announced has since grown significantly. For instance, a USD 2.5-billion collaboration between ACME Solar and the Oman Company for the Development of Special Economic Zone will produce 2 400 t/day of green ammonia. Furthermore, in May 2021 an international consortium of companies announced plans to develop the Green Fuels Mega Project, a 14-GW electrolysis project powered by 25 GW of wind and solar PV, with construction planned to start in 2028 and full operations expected by 2038. As most of these projects aim to produce low-carbon hydrogen or ammonia for export, the Port of Duqm (a founding member of the Global Ports Hydrogen Coalition) is a cornerstone of the initiatives being developed in Oman.

In the United Arab Emirates, Emirates Steel has been operating the Al Reyadah CCUS Project since 2016, capturing 800 kt $CO_2$/yr from DRI-based steel production. In 2021, DEWA and Siemens inaugurated Expo 2020 Dubai (delayed because of the Covid-19 pandemic), the region's first renewable energy-powered electrolysis project.

In addition, by signing an agreement with Japan to collaborate on hydrogen production technologies and create an international supply chain, the Emirates have taken the first steps to becoming hydrogen exporters. ADNOC announced a joint study agreement with two Japanese companies (INPEX, JERA) and a government agency (JOGMEC) to investigate the potential of producing ammonia from fossil fuels with CCUS to supply Japanese utilities. ADNOC is already developing a large-scale low-carbon ammonia production facility (capacity of 1 Mt $NH_3$/yr) at the TA'ZIZ Industrial Chemicals Zone and exploring opportunities to commercialise this product.

Kuwait and Qatar have also taken the first steps in developing their hydrogen strategies, in preparation to capture opportunities to exploit their natural resources to produce hydrogen.

# Policy recommendations

# Attaining climate goals will require ambitious, decisive action in the next decade

The IEA's Net zero by 2050 roadmap shows that achieving net zero targets will require immediate action to make the 2020s the decade of clean energy expansion through massive deployment of available low-carbon technologies and accelerated innovation of those still under development. Hydrogen technologies are a key example, with a considerably higher pace of progress and deployment required from now until 2030. The three overarching goals are to significantly expand hydrogen use while bringing new technologies onto the market; make hydrogen production much cleaner (i.e. shift away from unabated fossil fuel-based routes); and reduce the costs of technologies for hydrogen production and use.

To inform decision-making, this report presents a series of milestones that need to be reached by 2030 to unlock hydrogen's potential to address climate change. These markers cover the entire hydrogen value chain, including its production, infrastructure requirements, transformation into other fuels and end uses. Ultimately, the milestones are a call for action to governments. The implementation of policies to support their achievement can help build confidence among investors, industry, citizens and other countries, in turn prompting collaboration to trigger uptake of hydrogen as a new energy vector.

Key milestones to stay on track with the Net zero Emissions scenarios by 2030

| | 2020 | NZE 2030 | Development status |
|---|---|---|---|
| **Total $H_2$ demand** (Mt $H_2$) | 90 | 212 | - |
| **Electrolysis capacity** (GW) | 0.3 | 850 | Mature |
| **$CO_2$ captured and stored in $H_2$ production** (Mt $CO_2$) | 10 | 410 | Mature |
| **Total road FCEVs** (million vehicles) | 0.035 | 15.3 | Market scale-up |
| **HRSs** (1 000s of stations) | 0.54 | 18 | Market scale-up |
| **$NH_3$ demand in shipping** (Mt $NH_3$) | 0 | 47 | Demonstration |
| **$H_2$ demand in electricity generation** (Mt $H_2$) | 0 | 43 | Demonstration |
| **Low carbon $H_2$ demand in DRI** (Mt $H_2$) | 0.1 | 5.7 | Demonstration |
| **Synfuel demand in aviation** (mb/y) | 0 | 38 | Prototype |
| **Export terminals** (number of terminals) | 0 | 60 | Prototype |

## Near-term policy recommendations to enable the required transformation

To achieve the Net zero Emissions milestones, governments must take a lead role in facilitating the clean energy transition by establishing policy frameworks that stimulate integrated action. In The Future of Hydrogen, the IEA identified a series of recommendations for near-term policy action. Here, this Global Hydrogen Review expands on these policies and explains how they can facilitate attainment of the milestones.

Policies should centre on the need to:

- Develop strategies and roadmaps on hydrogen's role in energy systems.
- Create strong incentives for using low-carbon hydrogen to displace fossil fuels.
- Mobilise investment in production assets, infrastructure and factories.
- Provide strong innovation support to ensure critical technologies reach commercialisation quickly.
- Establish appropriate certification, standardisation and regulation regimes.

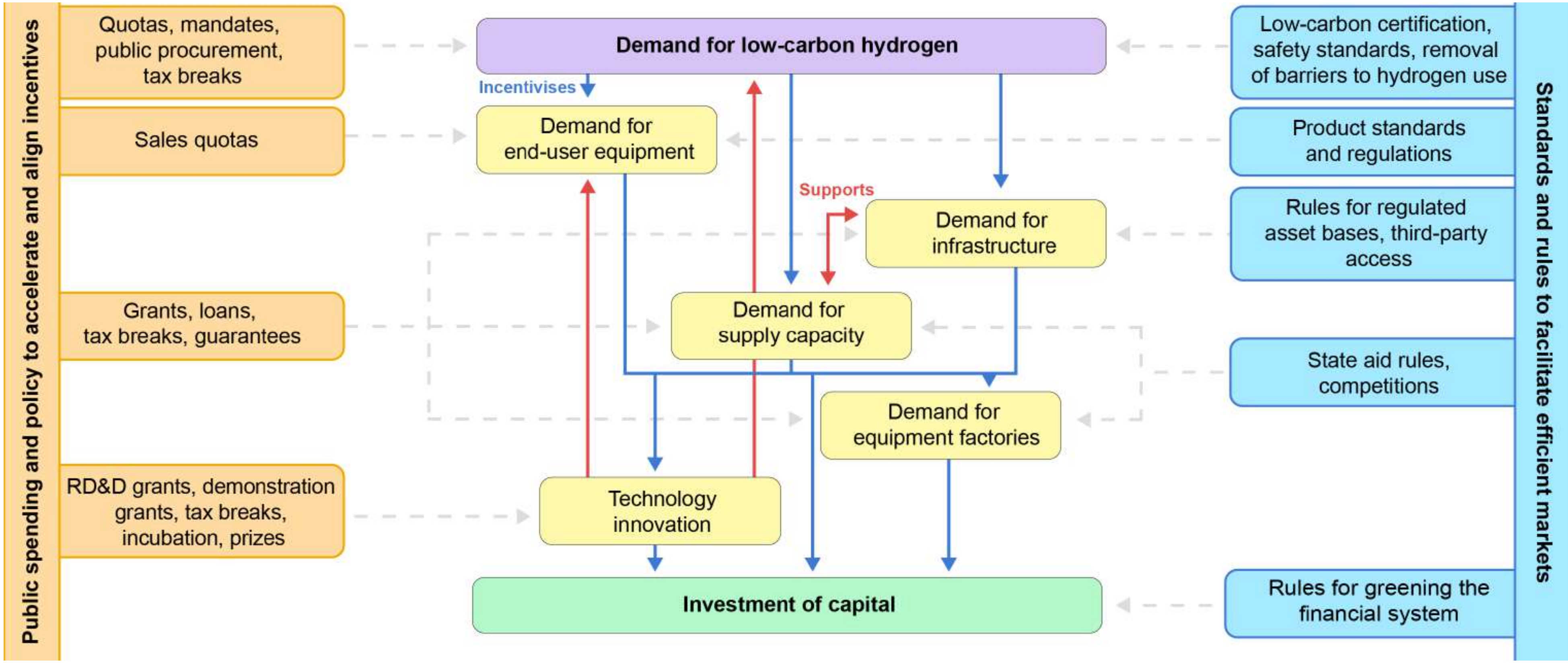
As all these policies are interconnected, implementation of one will impact the potential outcomes of the others. Some are natural first steps, such as defining the role of hydrogen in national energy strategies. However, it is unlikely this role can be realised without sufficient stimulus measures to create demand and mobilise investments for the infrastructure needed to connect hydrogen producers and users in the initial adoption stages. Developing such infrastructure requires planning among diverse stakeholders, with local authorities playing a key role as co-ordinators. Co-ordination of efforts can be facilitated if the roles of the different stakeholders are clearly and properly defined in hydrogen strategies and roadmaps.

In turn, the extent to which demand can be created will depend on increased effort in two main areas: support for innovation to ensure technologies are developed and become competitive; and establishment of standards and certification schemes to ensure the interoperability of these technologies globally and provide certainty to end users about the products they are acquiring on the market. Market development will also depend on adequate regulation to guarantee fair competition.

Ultimately, these features all work together like gears in one system: they all need to be in place and function in a co-ordinated fashion to ensure the effective adoption of hydrogen technologies at the required levels, within the next decade. The success of these policies will also depend on other measures, such as the development of training programmes to create a skilled workforce, ready to deploy and operate novel hydrogen technologies.

In the long term, consumer demand will drive investment in low-carbon hydrogen value chains. In the short term, however, it is up to policymakers to pull various levers to attract capital to the right places to create such demand.

How policy and regulatory interventions can amplify and steer incentives across hydrogen value chains



## Develop strategies and roadmaps on hydrogen's role in energy systems

National hydrogen strategies and roadmaps with concrete milestones for implementation and specific targets for producing and using hydrogen are essential to signal government commitment to expanding hydrogen supply and use. Ideally, they should be part of wider government strategies to achieve climate targets, thereby anchoring hydrogen as part of the expected energy future. Developing strategies and roadmaps is thus critical to build stakeholder confidence in the potential marketplace of low-carbon hydrogen and related technologies.

More and more countries have taken the vital first step of establishing national strategies in the last couple of years, creating momentum for the hydrogen industry and triggering new investments. Nevertheless, IEA analysis of stated targets detects a widening supply-demand gap due to strong policy focus on expanding low-carbon hydrogen supplies and relatively little action designed to increase market demand.

Clearly, emphasising the "push" for low-carbon hydrogen by increasing production capacity without creating sufficient market "pull" for the end product can create imbalances – and even bottlenecks – in the hydrogen value chain. Lack of demand can impede the emergence of supply projects, making it more difficult to achieve government targets for low-carbon hydrogen production.

Scenario analysis in this report suggests a growing need for more ambition to boost demand for low-carbon hydrogen, to both replace current demand for fossil fuel-based hydrogen (in refining and industry) and create demand for new applications such as heavy-duty transport, energy storage, new industrial applications, shipping and aviation.

Specific targets must therefore be adopted for using low-carbon hydrogen in existing applications and for deploying new hydrogen applications within this decade. Endorsing these aims at the national level can facilitate co-ordinated global action to achieve the milestones for 2030 proposed in this report.

Including hydrogen demand and production as well as hydrogen technology deployment in national energy statistics and reporting is also advisable. Tracking demand by sector, production through different routes, and other parameters related to hydrogen technology deployment (e.g. the number of HRSs, installed electrolysis capacity and the number of FCEVs on the roads by vehicle type) is critical to assess progress in meeting strategy and roadmap targets.

The IEA is ready to apply its analytical capabilities to help governments around the world define the role hydrogen can play in meet their climate goals and advance their strategies and roadmapping efforts.

## Create strong incentives for using low-carbon hydrogen to displace fossil fuels

Demand creation is a key lever to stimulate adoption of hydrogen as a clean energy vector. However, using low-carbon hydrogen is more costly than employing incumbent technologies, whether one compares with fossil-based hydrogen in traditional uses or the combustion of fossil fuels in potential new hydrogen applications.

Although an increasing number of countries now impose carbon pricing or taxation, current carbon prices are not high enough to close the cost gap between low-carbon hydrogen and fossil-based alternatives. Carbon prices are expected to rise in some countries and jurisdictions (e.g. Canada, Norway and the European Union), but this can take many years and, while helpful, may not drive transformation at the speed required.

To help industry de-risk investments and improve the bankability of projects, governments should design policy frameworks and financial support schemes that are transparent and predictable. Three key policy instruments already show strong potential for this purpose:

- Carbon contracts for difference. Already proposed by the European Union and Germany, this is a new policy instrument to bridge the gap between current carbon prices and the price needed to trigger fuel switching in target industries (e.g. refining, iron and steel, and chemicals). Using auctions to support the most competitive projects can be an effective way to hasten low-carbon hydrogen adoption (particularly for traditional refining and industrial applications).
- Mandates/quotas. Gradually rising mandatory quotas for low-carbon technologies, both for existing hydrogen uses (e.g. refineries and fertiliser production) and new-use sectors, can be a powerful instrument to stimulate the adoption of low-carbon hydrogen-based fuels in some jurisdictions (e.g. California's Zero-Emission Vehicle [ZEV] mandate). Such demand-pull policies can strengthen the business cases of hydrogen projects without expending significant public funds. For example, demand for low-carbon hydrogen can be stimulated through mandates for ZEVs; blending quotas for low-carbon gases in natural gas grids or low-carbon fuels in power generation; and mandates for synfuel use in aviation. Mandates can also be reinforced by relevant disincentives, such as a ban on the sale of internal combustion engine vehicles; sunset clauses for conventional industrial equipment; and regulations for deploying combustion equipment (e.g. domestic appliances and industrial boilers and turbines) compatible with low-carbon fuels.
- Public procurement. All levels of government and public agencies can help create demand for low-carbon hydrogen by modifying public procurement contracts to require its use for public transport, taxi services, waste collection, trucks, ferries and barges, and by stipulating the use of low-carbon steel and cement in infrastructure projects. For example, the Norwegian government recently decided that the largest ferry connection in the country (Bodø-Værøy-Røst-Moskenes) should be fuelled by hydrogen. In some countries, governments have direct influence on the strategies and investment allocations of state-owned companies.

International engagement will help extend the impact of such policies. Some governments will be first movers, reaping the positive outcomes these policies can deliver while also learning lessons about their inherent challenges. Recognising that the scale of the challenge requires co-ordinated global action and the positive effects of replicating success are multiple. The CEM Hydrogen Initiative has created an unparalleled platform for sharing knowledge and best practices with this purpose.

## Mobilise investment in production assets, infrastructure and factories

A policy framework that effectively stimulates demand can in turn trigger investment in low-carbon production plants, infrastructure deployment and manufacturing capacity. Meeting ambitious climate goals will require additional policy action to accelerate the use of electrolysers and carbon capture in hydrogen production, develop hydrogen-specific infrastructure and ramp up manufacturing capacity for key hydrogen technologies (e.g. fuel cells and electrolysers).

On the production side, the pipeline of sizeable low-carbon hydrogen projects is impressive, with private companies and investors committing considerable investments. These projects are encountering a bottleneck, however, as governments still need to design and implement support schemes and relevant regulations, risking the loss of valuable time.

Providing tailor-made support for selected, shovel-ready flagship projects through grants, loans and tax breaks (ensuring due diligence to guarantee fair competition), while establishing the support schemes and regulations that will be needed later, can kick-start low-carbon hydrogen expansion. Tailored support for flagship projects can also unlock significant funding to scale up manufacturing capacity for key hydrogen technologies as well as prompt infrastructure development, from which later projects in the region can benefit. This requires flexible regulations that can help de-risk investment, for example through public-private partnerships designed to fit specific projects.

It can be expected that the hydrogen market will initially develop as integrated supply chains from producer to customer, as in the early days of LNG. Transitioning quickly to a liquid market that supports scale-up and widespread hydrogen adoption will require timely development of hydrogen-specific infrastructure, which implies adequate planning and mobilisation of sufficient investment.

Governments face the challenge of balancing rapid development – to ensure that lack of infrastructure does not impede creation of new demand – with the risk of deploying infrastructure too quickly and having it under-utilised or even stranded if demand does not develop sufficiently, particularly for new applications. To avoid such a scenario, infrastructure development should begin with interconnection of major industrial clusters – a low-regret option, since the hydrogen demand of such hubs is more certain than potential demand from new applications. These hubs are also natural locations for establishing hydrogen valleys, where new demand can be developed.

As these hubs typically have natural gas infrastructure in place, repurposing gas pipelines to serve as dedicated hydrogen pipelines is a low-cost option to initiate hydrogen infrastructure development (in fact, timely gas pipeline can accelerate hydrogen system establishment). Then, beyond these initial deployments to support transmission and distribution, governments should begin planning the development of future hydrogen infrastructure, including storage.

## Provide strong innovation support to ensure critical technologies reach commercialisation quickly

While key hydrogen technologies are ready to start scaling up, continuous innovation is critical to drive down costs and increase competitiveness. Strong efforts are therefore needed in the near term to demonstrate several emerging technologies at scale to ensure that they reach commercialisation early this decade and unlock the full potential of hydrogen demand. Pertinent demonstration projects include using hydrogen in the DRI process for iron- and steelmaking; producing ammonia and methanol using electrolytic hydrogen produced from variable renewable energy; using hydrogen in heavy-duty transport; and using ammonia in shipping.

Governments should also take policy action now to stimulate funding for (and incentivise development of) next-generation technologies, such as use of hydrogen in shipping; transform hydrogen into synfuels; and use hydrogen to provide high-temperature heat in industrial processes (e.g. in cement kilns). Robust R&D and innovation programmes are necessary to ensure these technologies mature enough in the upcoming decade to be ready for deployment at scale in 2030.

In reality, public budgets for R&D and innovation in low-carbon hydrogen technologies do not offer the support needed to ensure the development pace required to meet long-term climate goals. Governments therefore need to take decisive action against these budget shortfalls.

In its Net zero by 2050 roadmap, the IEA estimates that USD 90 billion of public money needs to be mobilised globally as quickly as possible, with around half dedicated to hydrogen-related technologies. This could reduce investment risks for the private sector and help attract private capital for innovation. Furthermore, it is important for government departments managing R&D portfolios to work closely with national hydrogen research labs and other research centres, as well as with industry, to recognise and respond to the needs of the private sector.

International co-operation will be critical in this area. Implementing the agreed doubling of public R&D within the Mission Innovation initiative can be a first step. In parallel, the convening power of the IEA Hydrogen and Advanced Fuel Cells Technology Collaboration Programmes should be leveraged to facilitate international R&D and information exchange.

## Establish appropriate certification, standardisation and regulation regimes

Since adopting hydrogen as a clean fuel is expected to stimulate the development of new markets and value chains, regulatory frameworks, certification schemes and standards will be required to reduce barriers for stakeholders.

In the short term, it is particularly important to develop standards in three domains:

- **International trade**. Standards are required in several areas to develop a global low-carbon hydrogen market. International agreement on a methodology for calculating the carbon footprint of hydrogen production is critical, as it is the basis from which a global certificates market could develop. Importing countries, regions and companies would then be able to decide what carbon footprint threshold they deem acceptable for imported clean hydrogen, although a commonly agreed international standard is vital to avoid future impediments to cross-border trade in hydrogen.
- **Safety**. Safety is a critical topic for low-carbon hydrogen and hydrogen-based fuels. Industry has been able to produce and use hydrogen safely over several decades, but as its use is now expected to expand beyond industry to reach domestic consumers in their vehicles and homes, ensuring safety across all levels is essential. Gaining public acceptance will require the establishment of high safety standards through international co-operation and harmonisation.
- **Technology adoption**. New applications for hydrogen use will result in deployment of new technologies to operate refuelling stations, storage sites and combustion appliances. Internationally harmonised standards for nozzles, valves, burners and storage tanks are therefore necessary to ensure consistent operability around the world.

The IPHE has been leading international efforts in these areas for many years. Governments and industry should thus leverage its progress and collaborate to ensure all required standards are developed quickly enough to prevent the lack of them becoming a barrier to hydrogen adoption. For example, an internationally agreed standard to measure the carbon footprint of hydrogen production on a lifecycle basis will be needed to account for the emissions of the whole hydrogen supply chain, including from electricity generation (where applicable) and fossil fuel production.[38]

Certification is the natural follow-on step after the development of standards. Certification schemes aim to ensure that manufacturers comply with standards adopted internationally to inspire confidence among low-carbon hydrogen users. Furthermore, low-carbon premium markets that rely on product certification can help create demand, mobilise investments and stimulate innovation.

For instance, a car certified to have been manufactured with low-carbon steel (i.e. steel produced in a factory where low-carbon hydrogen has replaced fossil fuel inputs) may have a small price

[38] See the IEA Methane Tracker for estimates on methane emissions from fossil production."

premium over a standard car, which can make it an attractive option for a significant number of consumers across diverse income levels. The same may apply to other consumer products manufactured with low-carbon commodities, such as fertilisers, cement and solvents. For a low-carbon premium market to function effectively, however, it must be founded on a dedicated and reliable system of certificates and labels to provide certainty to consumers about the low-carbon attributes of products they are acquiring.

In addition, a clear, transparent and supportive regulatory framework is necessary to enable development of a robust hydrogen market. As demand rises and suppliers respond, and entirely new value chains and partnerships emerge, regulatory systems will need to be flexible to adapt to market evolution without jeopardising the solidity of business cases needed to attract investment in production assets and infrastructure.

Clear rules for regulated assets and to ensure third-party access will also be needed to avoid new monopolies and market fragmentation in low-carbon hydrogen. However, given the embryonic stage of hydrogen market development, it is premature to apply rigid regulatory principles that work in other mature markets, since they could create a serious risk of regulatory failure or regulatory disconnect. Rather, a gradual and dynamic regulation approach, carefully calibrated to periodic market monitoring (as suggested by the Council of European Energy Regulators and the Agency for the Cooperation of Energy Regulators) can help minimise the risk of failure.

Governments should also consider ways to align other regulatory aspects and policy domains not directly linked to hydrogen markets but that can affect the business case to ensure that, at the very least, they do not render hydrogen projects unappealing. Some examples are:

- Grid fees and levies, which are often developed independently for electricity and gas and can hamper sector coupling.
- State aid rules, which are of critical importance to ensure fair competition. In some jurisdictions, they may need to be adjusted to facilitate initial deployment of low-carbon hydrogen technologies.
- Spatial planning and licensing, which in some countries can be a long and cumbersome process. Current planning and approval processes do not yet include hydrogen and may need to be revised. Governments and local authorities can help co-ordinate infrastructure planning processes among public agencies, industry and citizens.
- Possible tariff and non-tariff trade barriers, which can hamper hydrogen trade. A strong case exists for striving for uninhibited and smooth global trade in hydrogen, facilitated by early identification of potential barriers and, where necessary, undertaking international efforts to harmonise and tackle them.
- Energy taxation, which ideally should follow the “polluter pays principle” and systematically favour zero-/low-carbon solutions over fossil fuel alternatives.
- Fossil fuel subsidies, which still exist in several countries and can distort the developing hydrogen market. The IEA has long been recommending timely phase out of such subsidies.

Finally, financial market regulations for sustainable financing and initiatives for environmental, social and corporate governance – both national and international – are increasingly helpful to nudge investors towards clean energy, including low-carbon hydrogen. Governments should actively encourage these trends (e.g. by mandating that multilateral banks help fund hydrogen scale-up) to leverage their own public investments.

# Annexes

# Abbreviations and acronyms

| | |
|---|---|
| AEM | anion exchange membrane |
| AFC | alkaline fuel cells |
| AFC TCP | Advanced Fuel Cell Technology Collaboration Programme |
| ALK | alkaline |
| APS | Announced Pledges Scenario |
| ATR | autothermal reforming |
| AUD | Australian dollar |
| BEV | battery electric vehicle |
| BF | blast furnace |
| CAD | Canadian dollar |
| CAPEX | capital expenditure |
| CCfD | carbon contracts for difference |
| CCGT | combined-cycle gas turbine |
| CCS | carbon capture and storage |
| CCU | carbon capture and use |
| CCUS | carbon capture, utilisation and storage |
| CEM H2I | Clean Energy Ministerial Hydrogen Initiative |
| CNY | Chinese yuan |
| $CO_2$ | carbon dioxide |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DAC | direct air capture |
| DRI | direct reduced iron |
| DRI-EAF | direct reduced iron - electric arc furnace |
| EHB | European hydrogen backbone |
| EIB | European Investment Bank |
| EOR | enhanced oil recovery |
| EPC | engineering, procurement and construction |
| ESMR | electrified steam methane reforming |
| EU | European Union |
| EU ETS | EU Emissions Trading Scheme |
| EUR | Euro |
| EV | electric vehicle |
| FC | fuel cell |
| FCEV | fuel cell electric vehicle |
| FCH JU | Fuel Cells and Hydrogen Joint Undertaking |
| FID | final investment decision |
| FT | Fischer-Tropsch |
| GBP | British pound sterling |
| $GH_2$ | gaseous hydrogen |
| GHG | greenhouse gases |
| GHR | gas-heated reformer |

| | |
|---|---|
| $H_2$ | hydrogen |
| HDV | heavy-duty vehicle |
| HEM | Hydrogen Energy Ministerial |
| HEV | hybrid electric vehicle |
| HRS | hydrogen refuelling station |
| HT | high throughput |
| IAE | Institute of Applied Energy |
| ICE | internal combustion engine |
| IEA | International Energy Agency |
| IEA GHG | IEA Greenhouse Gas R&D Programme |
| IFA | International Fertilizer Industry Association |
| IMO | International Maritime Organization |
| IPCEI | Important Projects of Common European Interest |
| IPHE | International Partnership for Hydrogen and Fuel Cells in the Economy |
| IRENA | International Renewable Energy Agency |
| IPCEI | Important Projects of Common European Interest |
| JHyM | Japan Hydrogen Mobility |
| JPY | Japanese yen |
| KRW | Korean won |
| LCV | light commercial vehicle |
| LDV | light-duty vehicle |
| $LH_2$ | liquid hydrogen |
| LHV | lower heating value |
| LNG | liquefied natural gas |
| LOHC | liquid organic hydrogen carrier |
| LPG | liquefied petroleum gas |
| LNG | liquefied natural gas |
| M&A | mergers and acquisitions |
| MCFC | molten carbonate fuel cell |
| MeOH | methanol |
| MI | Mission Innovation |
| MOC | memorandum of collaboration |
| MOU | memorandum of understanding |
| MTO | methanol to olefin |
| $NH_3$ | ammonia |
| NOK | Norwegian krone |
| $NO_x$ | nitrogen oxides |
| NREL | National Renewable Energy Laboratory |
| NZE | Net zero Emission Scenario |
| OEM | original equipment manufacturer |
| OPEX | operating expenditure |
| PAFC | phosphoric acid fuel cell |
| PE | private equity |
| PEM | proton exchange membrane |
| PEMFC | proton exchange membrane fuel cell |
| PIPE | private investment in public equity |
| PLDV | passenger light-duty vehicle |

| | |
|---|---|
| POx | partial oxidation |
| PtG | power-to-gas |
| PtL | power-to-liquids |
| PV | photovoltaic |
| R&D | research and development |
| RD&D | research, development and demonstration |
| SCR | selective catalytic reduction |
| SMR | steam methane reforming |
| SOEC | solid oxide electrolysis cell |
| SOFC | solid oxide fuel cell |
| SUV | sport utility vehicle |
| TCO | total cost of ownership |
| TCP | Technology Collaboration Programme |
| TRL | technology readiness level |
| TSO | transmission system operator |
| UK | United Kingdom |
| UN | United Nations |
| US | United States |
| USD | United States dollar |
| VC | venture capital |
| VRE | variable renewable energy |
| WEF | World Economic Forum |
| ZEV | zero emissions vehicle |

# Units of measure

| | |
|---|---|
| °C | degree Celsius |
| bbl | barrel |
| bcm | billion cubic metres |
| EJ | exajoule |
| Gt | gigatonnes |
| Gt $CO_2$ | gigatonnes of carbon dioxide |
| GW | gigawatt |
| GWh | gigawatt-hour |
| kg | kilogramme |
| kg $H_2$ | kilogramme of hydrogen |
| kg $CO_2$eq | kilogrammes of carbon-dioxide equivalent |
| kt | kilotonnes |
| kt $H_2$ | kilotonnes of hydrogen |
| kW | kilowatt |
| kWh | kilowatt-hour |
| mcm | million cubic metres |
| MBtu | million British thermal units |
| MJ | megajoule |

# Acknowledgements

The *Global Hydrogen Review* was prepared by the Energy Technology Policy (ETP) Division of the Directorate of Sustainability, Technology and Outlooks (STO) of the International Energy Agency (IEA). The study was designed and directed by Timur Gül, Head of the Energy Technology Policy Division. Uwe Remme (Head of the Hydrogen and Alternative Fuels Unit) and Jose Miguel Bermudez Menendez co-ordinated the analysis and production of the report.

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Noé van Hulst, chair of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) and Hydrogen Advisor at the IEA, provided valuable, strategic guidance during the report's development process.

The development of this report benefitted from contributions provided by the following IEA colleagues: Adam Baylin-Stern, Mariano Berkenwald, Paolo Frankl, Javier Jorquera Copier, Tae-Yoon Kim, Samantha McCulloch and Rachael Moore. Reka Koczka, Diana Louis and Per-Anders Widell provided essential support.

Thanks also to the IEA's Communications and Digital Office for their help in producing the report, particularly to Astrid Dumond, Jethro Mullen, Isabelle Nonain-Semelin, Gregory Viscusi and Therese Walsh. Marilyn Smith and Kristine Douaud edited the manuscript.

The work could not have been achieved without the financial support provided by the Governments of Germany (Federal Ministry for Economic Affairs and Energy), Japan (Ministry of Foreign Affairs as well as Ministry of Economy, Trade and

Industry) and the United States (Department of Energy). The following governments have also contributed to the report through their voluntary contribution to the CEM Hydrogen Initiative: Australia, Austria, Canada, the European Commission, the Netherlands, and Norway.

Special thanks go to the following organisations for their valuable contributions: Advanced Fuel Cells TCP, Hydrogen Council, Hydrogen TCP, International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE).

Peer reviewers provided essential feedback to improve the quality of the report. They include: Evrim Akar (Ministry of Infrastructure and Water Management, the Netherlands), Adbdullah Alabri (EJAAD), Laurent Antoni (CEA), Alessandro Arrigoni (European Commission, Joint Research Centre), Florian Ausfelder (DECHEMA), RB Balaji (World Bank), Claudia Bassano (ENEA), Amar A. Bhardwaj (Columbia University), Bart Biebuyck (Fuel Cells and Hydrogen Joint Undertaking), Herib Blanco (IRENA), Joß Bracker (Federal Ministry for Economic Affairs and Energy, Germany), Paula Brunetto (Enel), Tyler Bryant (Fortis BC), Cosmas Chiteme (National Department of Science and Innovation, South Africa), Bjørn Christian Enger (Sintef), Tudor Constantinescu (European Commission), Cameron Davies (Department for Business, Energy and Industrial Strategy, United Kingdom), Jonathan Davies (European Commission, Joint Research Centre), Carl de Maré (ArcelorMittal), Fernando Sisternes (World Bank), Guillaume De Smedt (Air Liquide), Denis Deryushkin (Russian Energy Agency), Martine Espeland Sørlie (Ministry of Petroleum and Energy, Norway), Beatriz Fidalgo (BP), Alan Finkel (Special Adviser to the Australian Government), Gniewomir Flis (Agora Energiewende), Alexandru Floristean (Hydrogen Europe), Sam French (Johnson Matthey), Marius Fuglerud (Ministry of Petroleum and Energy, Norway), Ryosuke Fujioka (METI), Hiroyuki Fukui (Toyota), Marta Gandiglio (Politecnico di Torino), Diego García (Tecnalia), Bastian Gillesen (Jülich Research Centre), Stefan Gossens (Schaeffler), Konstantin Grebennik (Russian Energy Agency), Thomas Grube (Jülich Research Centre), Augustijn Haasteren (European Commission), David Hart (E4tech), Masao Hayakawa (METI), Heidi Heinrichs (Jülich Research Centre), Thorsten Herbert (Nel Hydrogen), Yukari Hino (METI), Yuta Hirakawa (METI), Marina Holgado (Hydrogen Technology Collaboration Programme), Aaron Hoskin (Natural Resources Canada), Uyigue Idahosa (World Bank), Andreas Indinger (Austrian Energy Agency), Shunsuke Kageyama (METI), François Kalaydijan (IFPEN), Tim Karlsson (IPHE), Miklos Kaspar (European Commission), Ruud Kempener (European Commission), Mikio Kizaki (Toyota), Ralph Kleinschmidt (Thyssenkrupp), Agnes Koh (Energy Market Authority, Singapore), Volker Kraayvanger (Uniper), Gijs Kreeft (Ministry of Infrastructure and Water Management, the Netherlands), Martin Lambert (Oxford Institute for Energy

Studies), Angel Landa Ugarte (Iberdrola), Pharoah Le Feuvre (Enagás), Eric Lecomte (European Commission), Jabbe Leeuwen (Ekinetix), Franz Lehner (NOW GmbH), Andy Lewis (Cadent), Jochen Linßen (Jülich Research Centre), Eirik Velle Wegner Lonning (European Commission), Asuka Maeda (METI), Benjamin Maluenda Philippi (Ministry of Energy, Chile), Paulo Martins (Directorate-General of Energy and Geology, Portugal), Akiteru Maruta (Technova), Rebecca Maserumule (National Department of Science and Innovation, South Africa), David Mason (Department for Business, Energy and Industrial Strategy, United Kingdom), Cyriac Massué (Federal Ministry for Economic Affairs and Energy, Germany), Mikako Miki (METI), Jongsoo Mok (Hyundai), Steffen Moller-Holst (Sintef), Pietro Moretto (European Commission, Joint Research Centre), Matus Muron (Hydrogen Europe), Atsuhito Nara (METI), Petter Nekså (Sintef), Motohiko Nishimura (Kawasaki Heavy Industry), Christoph Noeres (Thyssenkrupp), Koichi Numata (Toyota), Misa Okano (METI), Paulo Partidário (Directorate-General of Energy and Geology, Portugal), Grzegorz Pawelec (Hydrogen Europe), Cédric Philibert (IFRI (retired)), Rodrigo Pinto Scholtbach (Ministry of Economic Affairs and Climate Policy, the Netherlands), Joris Proost (UCLouvain), Ireneusz Pyc (Siemens), Gunhild Reigstad (Sintef), Carla Robledo (Ministry of Economic Affairs and Climate Policy, the Netherlands), Roland Roesch (IRENA), Justin Rosing (European Commission), Mark Ruth (NREL), Kostis Sakellaris (Fuel Cells and Hydrogen Joint Undertaking), Juan Sánchez-Peñuela (Permanent Representation of Spain to the European Commission), Sunita Satyapal (US Department of Energy), Laura Savoldi (Politecnico di Torino), Dirk Schaap (Ministry of Infrastructure and Water Management, the Netherlands), Manfred Schuckert (Daimler), Yoshiaki Shibata (The Institute of Energy Economics, Japan), Ryota Shiromizu (METI), Matthijs Soede (European Commission), Markus Steinhäusler (Voestalpine), Zsuzsanna Szeles (European Commission), Emanuele Taibi (IRENA), Kai Tateda (METI), Michael Turley (Shell), Naoya Uehara (METI), Ari Ugayama (METI), Nico van den Berg (Ministry of Infrastructure and Water Management, the Netherlands), Wilco van der Lans (Port of Rotterdam Authority), Augustijn van Haasteren (European Commission), Ad van Wijk (Delft University of Technology), Julius von der Ohe (NOW GmbH), Kota Watanabe (METI), Masashi Watanabe (METI), Eveline Weidner (European Commission, Joint Research Centre), Derek Wissmiller (Gas Technology Institute), Hergen Thore Wolf (Sunfire), Makoto Yasui (Chiyoda Corporation), Rudolf Zauner (Verbund), Robert Zeller (Occidental Petroleum).

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Typeset in France by IEA – October 2021

Cover design: IEA


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