Introduction

Integrating hydrogen as a new vector into energy systems is a complex endeavour: without government intervention, it will not be realised at the pace required to meet climate ambitions. Many governments are therefore already working with diverse stakeholders to address key challenges and identify smart policies that can facilitate this transformation. As needs differ for each country and industry, policies and actions must be based on relevant priorities and constraints, including resource availability and existing infrastructure.

In The Future of Hydrogen, the IEA identified five key areas for governments to define comprehensive policy frameworks to facilitate hydrogen adoption across the entire energy system:

1. Establish targets and/or long-term policy signals.
2. Support demand creation.
3. Mitigate investment risks.
4. Promote R&D, innovation, strategic demonstration projects and knowledge-sharing.
5. Harmonise standards and removing barriers.

The Global Hydrogen Review tracks and reports progress in these areas with the aim of apprising governments and stakeholders of the pace of change in hydrogen policymaking. The Review highlights new policies being adopted around the world, assesses their impacts and identifies potential gaps. Its dual objectives are to help governments adopt or adapt other countries' successful experiences and avoid repeating failures.

1. Establish targets and/or long-term policy signals

In their long-term energy strategies, governments should determine the most efficient way hydrogen can be used to support decarbonisation efforts. They should then set policies that send long-term signals about this role to boost stakeholder confidence in development of a marketplace for hydrogen and related technologies. Integrated actions can guide future expectations, unlock investments and facilitate co-operation among companies and countries.

When The Future of Hydrogen was released in June 2019, only Japan and Korea had published national hydrogen strategies to define the role of hydrogen in their energy systems, and France had announced a hydrogen deployment plan. Since then, 13 countries (Australia, Canada, Chile, the Czech Republic, France, Germany, Hungary, the Netherlands, Norway, Portugal, Russia, Spain and the United Kingdom) have published hydrogen strategies, along with the European Commission. Colombia announced the release of its strategy for the end of September 2021.

Two countries (Italy and Poland) have released their strategies for public consultation and more than 20 others are actively developing them. Several regional governments have also defined hydrogen strategies and roadmaps, including in Australia (Queensland, South Australia, Tasmania, Victoria and West Australia), Canada (British Columbia), China, France, Germany (Baden-Württemberg, Bavaria, North Germany, North Rhine-Westphalia) and Spain (Basque Country).

Some governments have even taken the additional step of defining hydrogen's role in other, overarching policy frameworks. Japan's Green Growth Strategy, for example, describes the country's vision for producing and using hydrogen and for developing international supply chains.

A coherent picture of future-use cases for hydrogen

The strategies published to date show that, with slight differences, almost all countries hold broadly similar views of the role hydrogen should play in their energy systems. Practically all the strategies (15 of 16) highlight its vital importance in decarbonising the transport and industry sectors.

In the case of transport, most governments emphasise medium- and heavy-duty transport, and Japan and Korea envisage an important role for cars. Several governments highlight the potential use of hydrogen and ammonia in shipping, while a smaller number are considering producing synthetic fuels (synfuels) to decarbonise aviation (Germany recently released a power-to-liquids [PtL] roadmap) or using hydrogen in rail transport. Japan has taken the additional step of publishing an Interim Report of the Public-Private Council on Fuel Ammonia Introduction on using ammonia in electricity generation and shipping.

In the industry sector, each country's plans focus on the main industries: some target certain subsectors (chemicals in Chile and Spain; steel in Japan), while others take a more cross-sectoral approach (Canada and Germany). Canada and Chile have highlighted the role of hydrogen in decarbonising mining operations, and all countries with significant refining capacities prioritise this sector as well.

Other potential hydrogen uses that are mentioned in strategies but have received less attention are electricity generation – including energy storage and system balancing (11 of 16) – and heat in buildings (7 of 16). Finally, if international hydrogen trade develops, some countries have a clear plan to become exporters (Australia, Canada, Chile and Portugal) while others have started exploring the possibility of importing hydrogen if national production capacity cannot meet future demand (the European Union, Germany, Japan and the Netherlands).

Different views on how to produce hydrogen

Countries that have adopted hydrogen strategies present quite diverse visions on how it should be produced. Hydrogen production from electricity is common to all strategies, in some cases being the preferred route in the long term. Some prioritise renewable power (Chile, Germany, Portugal and Spain), while others are less specific about the origin of the electricity (France's strategy mentions renewable and low-carbon electricity).

While several governments (9 of 16) have set a significant role for the production of hydrogen from fossil fuels with CCUS, others (including the European Union) consider this option for only the short and medium term to reduce emissions from existing assets while supporting the parallel uptake of renewable hydrogen. Canada has taken a different approach; instead of prioritising any specific production pathway, it is focusing on the carbon intensity of hydrogen production, with targets to drive it to zero over time. Some countries (e.g. Canada and Korea) have flagged the potential use of by-product hydrogen (from the chlor-alkali or petrochemical industries) to meet small shares of demand.

Finally, most strategies refer to the potential for emerging technologies, such as methane pyrolysis or biomass-based routes. As these technologies are still at early stages of development, prospects are considered uncertain.

Intermediate milestones to anchor long-term targets

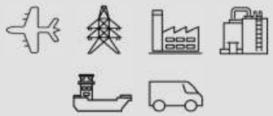
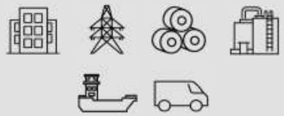
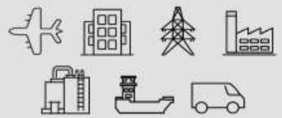
Almost all governments have adopted a phased approach to integrate hydrogen into their energy systems. How they define phases varies, but strategies tend to recognise three stages: scaling up and laying the market foundations (early 2020s); widespread adoption and market maturity (late 2020s to early 2030s); and full implementation of hydrogen as a clean energy vector (post-2030).

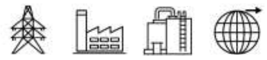
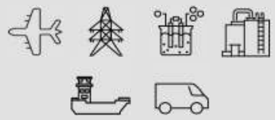
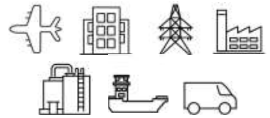
Deployment targets, while not present in all strategies, are a common feature to anchor expected progress within these phases. In some cases, targets have been proposed as a vision or an aspiration (Canada, Japan); in others, they convey a firm commitment with the intent to send strong signals to industry about the future marketplace for hydrogen. To date, practically none of these targets is legally binding.

Governments with adopted national hydrogen strategies; announced targets; priorities for hydrogen and use; and committed funding

Buildings Electricity Exports Industry Industry (chemicals) Industry (steel) Mining Refining Shipping Transport. Aviation

Country	Document, year	Deployment targets (2030)	Production	Uses	Public investment committed
Australia	National Hydrogen Strategy, 2019	None specified	Coal with CCUS Electrolysis (renewable) Natural gas with CCUS		AUD 1.3 bln (~USD 0.9 bln)
Canada	Hydrogen Strategy for Canada, 2020	Total use: 4 Mt H_2/y 6.2% TFEC	Biomass By-product H_2 Electrolysis Natural gas with CCUS Oil with CCUS		CAD 25 mln by 2026[1] (~USD 19 mln)
Chile	National Green Hydrogen Strategy, 2020	25 GW electrolysis[2]	Electrolysis (renewable)		USD 50 mln for 2021
Czech Republic	Hydrogen Strategy, 2021	Low-carbon demand: 97 kt H_2/yr	Electrolysis		n.a.
European Union	EU Hydrogen Strategy, 2020	40 GW electrolysis	Electrolysis (renewable) Transitional role of natural gas with CCUS		EUR 3.77 bln by 2030 (~USD 4.3 bln)
France	Hydrogen Deployment Plan, 2018 National Strategy for Decarbonised Hydrogen Development, 2020	6.5 GW electrolysis 20-40% industrial H_2 decarbonised [3] 20 000-50 000 FC LDVs [3] 800-2 000 FC HDVs [3] 400-1 000 HRSs [3]	Electrolysis		EUR 7.2 bln by 2030 (~USD 8.2 bln)

Country	Document, year	Deployment targets (2030)	Production	Uses	Public investment committed
Germany	National Hydrogen Strategy, 2020	5 GW electrolysis	Electrolysis (renewable)		EUR 9 bln by 2030 (~USD 10.3 bln)
Hungary	National Hydrogen Strategy, 2021	Production: 20 kt/yr of low-carbon H_2 16 kt/yr of carbon-free H_2 240 MW electrolysis Use: 34 kt/yr of low-carbon H_2 4 800 FCEVs 20 HRSs	Electrolysis Fossil fuels with CCUS		n.a.
Japan	Strategic Roadmap for Hydrogen and Fuel Cells, 2019 Green Growth Strategy, 2020, 2021 (revised)	Total use: 3 Mt H_2/yr Supply: 420 kt low-carbon H_2 800 000 FCEVs 1 200 FC buses 10 000 FC forklifts 900 HRSs 3 Mt NH_3 fuel demand(4)	Electrolysis Fossil fuels with CCUS		JPY 699.6 bln by 2030 (~USD 6.5 bln)
Korea	Hydrogen Economy Roadmap, 2019	Total use: 1.94 Mt H_2/yr 2.9 million FC cars (plus 3.3 million exported)(5) 1 200 HRSs(5) 80 000 FC taxis(5) 40 000 FC buses(5) 30 000 FC trucks(5) 8 GW stationary FCs (plus 7 GW exported)(5) 2.1 GW of micro-cogeneration FCs(5)	By-product H_2 Electrolysis Natural gas with CCUS		KRW 2.6 tln in 2020 (~USD 2.2 bln)
Netherlands	National Climate Agreement, 2019 Government Strategy on Hydrogen, 2020	3-4 GW electrolysis 300 000 FC cars 3 000 FC HDVs (6)	Electrolysis (renewables) Natural gas with CCUS		EUR 70 mln/yr (~USD 80 mln/yr)
Norway	Government Hydrogen Strategy, 2020 Hydrogen Roadmap, 2021	n.a.(7)	Electrolysis (renewables) Natural gas with CCUS		NOK 200 mln for 2021 (~USD 21 mln)

Country	Document, year	Deployment targets (2030)	Production	Uses	Public investment committed
Portugal	National Hydrogen Strategy, 2020	2-2.5 GW electrolysis 1.5-2% TFEC 1-5% TFEC in road transport 2-5% TFEC in industry 10-15 vol% H_2 in gas grid 3-5% TFEC in maritime transport 50-100 HRS	Electrolysis (renewables)		EUR 900 mln by 2030 (~USD 1.0 bln)
Russia	Hydrogen roadmap 2020	Exports: 2 Mt H_2	Electrolysis Natural gas with CCUS		n.a.
Spain	National Hydrogen Roadmap, 2020	4 GW electrolysis 25% industrial H_2 decarbonised 5 000-7 500 FC LDVs-HDVs 150-200 FC buses 100-150 HRSs	Electrolysis (renewables)		EUR 1.6 bln (~USD 1.8 bln)
United Kingdom	UK Hydrogen Strategy, 2021	5 GW low-carbon production capacity	Natural gas with CCUS Electrolysis		GBP 1 bln (~USD 1.3 bln)

Note: TFEC = total final energy consumption. (1) In addition to CAD 25 mln, Canada has committed over CAD 10 bln to support clean energy technologies, including H_2. (2) This target refers to projects that at least have funding committed, not to capacity installed by 2030. (3) Target for 2028. (4) From the interim Ammonia Roadmap. (5) Target for 2040. (6) Target for 2025 from the National Climate Agreement, 2019 (currently under revision). (7) Norway's strategy defines targets for the competitiveness of hydrogen technologies and project deployment.

2. Support demand creation

Creating demand for low-carbon hydrogen is critical for its widespread adoption. Policy support to "pull" investment across the value chain will be needed to make projects bankable and overcome deployment hurdles. For technologies that use hydrogen and are ready for commercialisation, policy support to close the price gap with incumbents can stimulate faster deployment and accelerate cost reductions that result from scaling up and learning by doing. Progress is under way, but not enough policies have been implemented to support longer-term targets and create demand for low-carbon hydrogen.

A dynamic situation in the transport sector

National hydrogen strategies place great value on using hydrogen in transport. As fuel cell electric vehicles (FCEVs) are commercially available for passenger cars, light-duty vehicles (LDVs) and buses, several countries have policies to support their deployment.

More than 20 countries offer specific purchase subsidies for FCEVs, ranging from EUR 1 500 (~USD 1 700) per vehicle in Finland to more than USD 30 000 in Korea. In fact, purchasers of fuel cell buses in Korea receive KRW 300 million (~USD 250 000). Tax benefits are in place in at least 20 countries, and at least 17 apply specific company tax benefits to support FCEV adoption in professional fleets.

China launched a new FCEV pilot cities programme in 2020 to enlarge FCEV industry supply chains. In contrast with vehicle purchase subsidies, the scheme rewards clusters of cities based on a series of parameters. To be eligible for financial rewards, city clusters must deploy more than 1 000 FCEVs that meet certain technical standards; achieve a delivered hydrogen price at a maximum of CNY 35.00/kg (~USD 5.00/kg); and provide at least 15 operational hydrogen refuelling stations (HRSs). Based on the plan and how well objectives are met, a maximum of CNY 1.5 billion (~USD 220 million) will be transferred to each selected city cluster between 2020 and 2023.

Hydrogen vehicles may also benefit from programmes to support zero emission vehicles (ZEVs) and implementation of CO_2 emissions standards. Recent examples include California's ZEV mandate; the Dutch government's announcement that ZEVs will make up all public transport bus sales by 2025; and the EU CO_2 emissions standards for heavy-duty vehicles (HDVs). In 2018, Switzerland adopted the LSVA road tax, which levies trucks weighing more than 3.5 tonnes but waives the fee for ZEVs. This created an attractive business case for hydrogen trucks, which are expected to reach about 200 by the end of 2021. While not specific to hydrogen vehicles, which have to compete with alternatives such as battery electric vehicles (BEVs), these policies can stimulate FCEV deployment.

Other policies that can support hydrogen uptake in transport are the California Low Carbon Fuel Standard, Canada's Clean Fuel Standard and the UK Renewable Transport Fuel Obligation, which can also spur adoption of low-carbon hydrogen in biofuel production and refining. Meanwhile, in 2020 the Norwegian government announced that the country's largest ferry connection (Bodø-Værøy-Røst-Moskenes) will be fuelled by hydrogen and in March 2021 the Port of Tokyo stated that it will waive the entry fee for ships powered by LNG or hydrogen. These are the first measures implemented to support hydrogen or hydrogen-derived fuels in shipping, but as the technology has not yet reached the commercial level, it will take time to realise the impact of these policies.

Policies to support hydrogen-derived synthetic fuel use in aviation have attracted attention recently. As part of its Fit for 55 package, in July 2021 the European Commission proposed the ReFuel Aviation Initiative to mandate minimum synthetic fuel shares in aviation, rising from 0.7% in 2030 to 28% in 2050. This measure awaits European Council and European Parliament approval. Germany's strategy mentions a minimum quota of 2% synthetic fuels in aviation by 2030, which has now passed the parliamentary process and is legally binding. In addition, Germany's recently released power-to-liquids (PtL) roadmap targets 200 000 tonnes of hydrogen-based sustainable aviation fuel in 2030. The Dutch government has already expressed interest in these types of measures.

Policies for other sectors still under discussion

Little progress has been achieved on policies for low-carbon hydrogen adoption in other sectors. Despite its anticipated importance, few policies have been designed specifically to create demand for low-carbon hydrogen in industry.

Also in its Fit for 55 package, in July 2021 the European Commission proposed a modification of the Renewable Energy Directive to include a 50% renewable hydrogen consumption in industry by 2030. Germany's strategy includes the potential implementation of obligatory quotas for selected clean products (e.g. hydrogen-based steel) and aims to explore how to implement such solutions at the national and European levels.

India has also announced mandatory quotas for using renewable hydrogen in refining (10% of demand from 2023-24, increasing to 25% in the following five years) and fertiliser production (5% of demand from 2023-24, increasing to 20% in the following five years), with potential extension to the steel industry in the near future. This will spur India to replace part of its current capacity for hydrogen produced from natural gas (typically imported) with hydrogen from renewables while also creating new demand for locally produced hydrogen.

Injecting hydrogen into the natural gas grid has also attracted attention as another means of creating new hydrogen demand. While no measures have yet been adopted, some countries are taking steps in this direction. For instance, Portugal's national strategy targets 10-15 vol% H_2 blending by 2030 and Chile is preparing a bill to mandate blending quotas.

Lack of targets and policies for demand creation can stall low-carbon supply expansion

Because most government targets and policies to date have been focused exclusively on enlarging hydrogen supplies, low-carbon hydrogen production has outpaced demand growth. Strategic action is therefore needed to avoid the value chain imbalances that can result in inefficient policy support.

If hydrogen demand is not sufficiently stimulated, producers may not be able to secure off-takers and the development of low-carbon hydrogen supply capacity may held back. This could result in low-carbon hydrogen capacity replacing only certain parts of current production in industrial applications, which would impede scale-up and discourage cost reductions, and ultimately delay adoption of hydrogen as a clean energy vector.

3. Mitigate investment risks

Many projects currently under way face risks related to uncertain demand, lack of experience and value chain complexity. Measures to address risks linked to capital and operational costs can help tip the balance in favour of private investment in these first projects.

European countries are leading the way

European policymakers have been particularly active in implementing measures to mitigate the risks of hydrogen-related project developers. In its Climate Agreement (launched June 2020), the Netherlands proposed including hydrogen in the SDE++ scheme, which offers incentives to develop CO_2 reduction technologies and renewable energy. This scheme recently triggered its intended actions and in May 2021 the Dutch government committed EUR 2 billion for the Porthos project to bridge the gap between current rates for CO_2 emissions allowances and the costs involved in capturing, transporting and storing CO_2 underground. This will facilitate development of projects to produce hydrogen from fossil fuels with CCUS.

In September 2020, the European Commission announced a call for tenders for projects to build electrolysis plants at the 100-MW scale. All proposals have been evaluated and some awarded projects have been announced. Perhaps more importantly, the Commission included hydrogen in the Important Projects of Common European Interest (IPCEI) scheme, which allows projects validated by both member states and the Commission to receive public support beyond the usual boundaries of state aid rules. This is expected to unlock significant project investment across the entire hydrogen value chain, stimulating scale-up in the next decade.

Countries beyond Europe are also taking action. In June 2021, Canada announced a new Clean Fuels Fund to help private investors overcome the barrier of high upfront capital costs to construct new clean fuel production capacity, and will provide support to a minimum of ten hydrogen projects.

Public financial institutions are getting involved

Financial institutions can be critical in mitigating the investment risks of first movers. While the European Investment Bank (EIB) provided significant investments for R&D in hydrogen projects in the last decade, it has now shifted its focus to offer financial support and technical assistance for the development of large-scale projects. The EIB signed related collaboration agreements with France Hydrogène (2020) and the Portuguese government (2021).

In May 2020, the Australian government, through the Clean Energy Finance Corporation, made AUD 300 million available through the Advancing Hydrogen Fund, thereby taking the first steps to facilitate investments in hydrogen projects to scale up production and end uses. In 2021, the government of Chile launched (through CORFO) a USD 50-million call for funding to develop electrolysis projects.

New policy instruments are coming into play

Governments are developing new and innovative policy instruments to support investment in hydrogen projects. In June 2021, the German government announced the H2 Global programme, with the aim of ramping up the international market for hydrogen produced from renewable electricity. The scheme will tender ten-year purchase agreements on hydrogen-based products, providing certainty to investors on project bankability. With a total budget of EUR 900 million, the scheme expects to leverage more than EUR 1.5 billion in private investments.

In its national hydrogen strategy, Germany's federal government also announced that it will launch a new Carbon Contracts for Difference (CCfD) pilot programme to support the use of hydrogen from renewable energy sources in the steel and chemical industries. This programme will pay the difference between the CO_2 abatement costs of the project and the CO_2 price in the EU Emissions Trading Scheme (EU ETS). If the EU ETS price rises above the project's CO_2 abatement costs, companies will have to repay the difference to the government. If the pilot is completed successfully, the scheme may be expanded to other industry subsectors.

The European Commission announced that it is also considering the carbon contracts for difference (CCfD) concept. Recent price increases in the EU ETS – which nearly doubled in 2021 to more than EUR 60/t CO_2 – are expected to limit the public spending needed to bridge the cost gap in these schemes.

Auctions are also a powerful policy instrument, and they have been critical in ramping up other clean energy technologies, such as solar PV and wind energy. They are now about to be applied to hydrogen, with India's New and Renewable Energy Minister announcing (in June 2021) auctions for the production of hydrogen from renewables. The Netherlands' national strategy also mentions the potential use of combined auctions for offshore wind and hydrogen production.

In Chile, the government is holding regular public and open tenders to develop large-scale projects for producing hydrogen from renewable energy sources on public land. As these projects require large land areas, facilitating access to public land with good renewable resources can reduce investment risks and accelerate deployment.

Along with its Hydrogen Strategy, the United Kingdom launched a public consultation on a business model for low-carbon hydrogen with the aim of defining specific policy instruments to help project developers overcome costs barriers.

4. Promote R&D, innovation, strategic demonstration projects and knowledge-sharing

The future success of hydrogen will hinge on innovation. Today, low-carbon hydrogen is more costly than unabated fossil fuel-based hydrogen, which undermines its uptake. Multiple end-use technologies at early stages of development cannot compete in open markets, in part because they have not yet realised the economies of scale that come with maturity. Governments play a key role in setting the research agenda and adopting policy tools that can incentivise the private sector to innovate and bring technologies to the market.

Selected active hydrogen R&D programmes

Country	Programme	Funding and duration
Australia	ARENA's R&D Programme CSIRO Hydrogen Mission	AUD 22 mln (~USD 15 mln) – 5 yr AUD 68 mln (~USD 47 mln) – 5 yr
European Union	Clean Hydrogen for Europe	EUR 1 bln (~USD 1. bln) – 10 yr
France	PEPR Hydrogène	EUR 80 mln (~USD 91 mln) – 8 yr
Germany	National Innovation Programme for Hydrogen and Fuel Cell Technology	EUR >250 mln (~USD 285 mln) – 10 yr
	Wasserstoff-Leitprojekte	EUR 700 mln (~USD 800 mln) – n.a.
Japan	NEDO innovation programmes	JPY 699 bln (~USD 6.5 bln) – 10 yr
Spain	Misiones CDTI	EUR 105 mln (~USD 120 mln) – 3 yr
United Kingdom	Low Carbon Hydrogen Supply	GBP 93 mln (~USD 119 mln) – n.a.
United States	H2@Scale M²FCT – H2New Consortia DOE Hydrogen Program	USD 104 mln – 2 yr USD 100 mln – 5 yr USD 285 m/yr

Hydrogen innovation requires a boost

Programmes to foster hydrogen innovation are not yet flourishing, although some positive signals are emerging and several governments have launched hydrogen-specific programmes to fund R&D in technologies across the entire hydrogen value chain. However, current public R&D spending on hydrogen is below levels dedicated in the early 2000s during the last wave of support for hydrogen technologies (see Chapter Investments and Innovation). Further, integrated efforts will be required to avoid bottlenecks along the value chain.

Government and industry co-operation is critical to ensure the implementation of robust innovation programmes. With more than EUR 1 billion in funding provided since 2008, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a prime example of a public-private partnership to support R&D and technology demonstration. Building on its success, the European Commission will launch the Clean Hydrogen for Europe Joint Undertaking at the end of 2021, with matching budgets of EUR 1 billion from public funding and private investment until 2027.

The European Commission also initiated the European Clean Hydrogen Alliance in July 2021 to bring together industry, national and local public authorities, civil society and other stakeholders to establish an investment agenda for hydrogen. Similarly, the Chilean Energy Sustainability Agency introduced a Green Hydrogen Incubator in 2021 to co-ordinate stakeholders and provide consulting services to facilitate the development of technology demonstration projects. In Morocco, stakeholders from the private sector, academia and the government established the Green Hydrogen Cluster to support the emerging renewable hydrogen sector. In the United States, the Department of Energy (DOE) launched the First Energy Earthshot dedicated to hydrogen, bringing together stakeholders with the target of slashing the cost of clean hydrogen by 80% (to USD 1.00/kg H_2) by 2030.

International co-operation is growing rapidly

Multilateral initiatives and projects can promote knowledge-sharing and the development of best practices to connect a wider group of stakeholders. For instance, Mission Innovation (MI), which works to catalyse R&D action and investment, has engaged with the FCH JU through the Hydrogen Valley Platform to facilitate collaboration and knowledge-sharing within more than 30 hydrogen valleys across the globe. With the launch of the Clean Hydrogen Mission in June 2021, MI took another step to boost R&D in hydrogen technologies, with the goal of reducing end-to-end clean hydrogen costs to USD 2.00/kg by 2030. MI also aims to establish at least 100 hydrogen valleys, to be featured on the Hydrogen Valley Platform.

In addition to the several bilateral agreements signed between governments in recent years, international co-operation agreements have been established between governments and the private sector (the MOUs between the Port of Rotterdam and the governments of Chile and South Australia is one example). All have the short- to medium-term objective of co-operating to share knowledge, best practices and technology development to reduce costs. They also share the long-term aim of laying the foundations for future international hydrogen supply chains to ensure the development of trade in hydrogen and hydrogen-derived fuels.

In June 2020, the energy ministers of the Pentalateral Forum (Austria, Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland) signed a joint political declaration affirming their commitment to strengthen co-operation on hydrogen.

Selected bilateral agreements between governments to co-operate on hydrogen development, 2019-2021

Countries	Objective
Germany - Australia	Formulate new initiatives to accelerate development of a hydrogen industry, including a hydrogen supply chain between the two countries. Focus on technology research and identification of barriers.
Germany - Canada	Form a partnership to integrate renewable energy sources, technological innovation and co-operation, with a focus on hydrogen.
Germany - Chile	Strengthen co-operation in renewable hydrogen and identify viable projects.
Germany - Morocco	Develop clean hydrogen production, research projects and investments across the entire supply chain (two projects have already been announced by the Moroccan agencies MASEN and IRESEN).
Germany - Saudi Arabia	Co-operate on the production, processing and transport of hydrogen from renewable energy sources.
Morocco - Portugal	Examine opportunities and actions needed to develop hydrogen from renewable energy sources.
Netherlands - Chile	Establish a structured dialogue on the development of import-export corridors for green hydrogen, aligning investment agendas and facilitating collaboration among private parties.
Netherlands - Portugal	Co-operate to advance the strategic value chain for producing and transporting renewables-based hydrogen, connecting the hydrogen plans of the two countries.
Japan – United Arab Emirates	Co-operate on technology development, regulatory frameworks and standards to create an international hydrogen supply chain.
Japan - Argentina	Strengthen collaboration on the use of clean fuels and promote investments to deploy large-scale hydrogen production from renewable energy sources.
Japan - Australia	Issue a joint statement highlighting the commitment already in place between the two countries and recognising the importance of co-operation on an international hydrogen supply chain.
Singapore - New Zealand	Boost collaboration on establishing supply chains for low-carbon hydrogen and its derivatives, and strengthen joint R&D, networks and partnerships.
Singapore - Chile	Foster co-operation on projects and initiatives to advance hydrogen deployment through information exchange and the establishment of supply chains and partnerships.
Australia - Korea	Develop joint hydrogen co-operation projects with specific action plans.

5. Harmonise standards and removing barriers

Two broad issues have emerged regarding regulations, codes and standards for hydrogen deployment. The first is the need to review national regulations that define the roles of utilities and grid operators. At present, certain aspects of market structure warrant regulatory frameworks that keep these entities separate. If hydrogen deployment is successful, however, it can concurrently become an integral part of the gas network and support electricity grid resilience and reliability of the electricity grid. Hydrogen will thereby facilitate sector coupling between electricity and gas utilities, creating a new role requiring specific regulation.

The second issue is the need to ensure that a standardisation framework based on national or international norms is in place and is appropriately applicable to the use of hydrogen and its carriers. This ongoing process involves numerous international organisations.

Regulations need to be adapted to remove barriers in the near term

The IPHE's Regulations, Codes, Standards and Safety Working Group conducted a Regulatory Gaps Compendium survey among its participating countries to determine regulatory needs in critical areas for hydrogen and fuel cell deployment. Participants provided input on focal areas within two topics: hydrogen infrastructure and hydrogen for mobility/transportation.

Survey results indicated broad regulatory needs, particularly as industry activity increases and expands beyond road transportation. Critical within the infrastructure area is the establishment of a legal framework for injecting hydrogen into natural gas systems (at both the distribution and transmission levels) and requirements for the scale-up and public use of liquid hydrogen in refuelling infrastructure.

Concerning transportation/mobility, the most critical priority is to enable the use of hydrogen in non-road transport modes – i.e. rail, shipping and aviation. The survey also determined that safety (including maintenance requirements, approvals and inspections) is a priority and improvements should be incorporated into efforts to address the other needs identified.

To remove barriers to hydrogen adoption, some countries have taken the first steps to adapt their regulations. For instance, in 2020 the Chinese National Energy Administration released a draft of the new Energy Law in which hydrogen is classified, for the first time, as an energy carrier. This means hydrogen will now be a freely tradable energy asset and its transportation will be subject to less stringent requirements than for hazardous substances (its previous classification).

Other countries, including Chile, Colombia, Korea and France, have modified their energy legislation to facilitate the adoption of hydrogen as an energy carrier. As tax regulations can also create significant barriers to hydrogen technology endorsement, several countries are exploring options to reduce this impact. The European Commission recently proposed revision of the Energy Taxation Directive to avoid double taxation of energy products, including hydrogen, and Germany announced that hydrogen produced from renewable electricity will not be subject to the levy used to fund support for clean power.

A low-carbon hydrogen market requires carbon accounting standards

International hydrogen trade could become a cornerstone of the clean energy transition, enabling the export of low-carbon hydrogen from regions with abundant access to renewable energy or low-cost production of hydrogen from fossil fuels with CCUS. To facilitate trade, however, relevant standardisation bodies will need to develop international standards – based on a common definition of low-carbon hydrogen – to remove and/or reduce regulatory barriers.

During the 32nd IPHE Steering Committee, countries recognised that developing internationally agreed accounting standards for different sources of hydrogen along the supply chain will be vital to create a market for low-carbon hydrogen. To this end, a Hydrogen Production Analysis Task Force was established to review and reach consensus on a methodology and analytical framework for determining GHG emissions related to one unit of produced hydrogen.

Such a mutually recognised, international framework will avoid mislabelling or double-counting environmental impacts and should provide consensus on an approach to "certificates of origin". The methodology is based on principles of inclusiveness (methodologies should not exclude any potential primary energy), flexibility (approaches must allow for unique circumstances and hence flexibility), transparency (methodologies must be transparent in approach and assumptions to build confidence), comparability (the approach should be comparable with those used for other energy vectors), and practicality (methodologies must be practical, facilitating uptake by industry and use in the market).

The methodology also describes the requirements and evaluation methods applied from "well to gate" for the most-used hydrogen production pathways: electrolysis, steam methane reforming with CCUS, by-product and coal gasification with CCUS. Over time, the Task Force intends to develop other methods and to potentially apply the approach to different physical states of hydrogen, diverse energy carriers and emissions arising during transport to the end user. In addition to IPHE activities, some countries (e.g. Australia, France and the United Kingdom) have started to develop certification schemes for hydrogen's carbon footprint.

Research to develop evidence-based safety standards

During its recent bi-annual Workshop on Research Priorities for Hydrogen Safety, the International Association for Hydrogen Safety (HySafe) mapped state-of-the-art and recent progress in pre-normative research to support standards development, including identifying and ranking pending research needs. Ultimately, research needs were identified for five key safety areas: liquid hydrogen use; the compatibility of certain materials (metals and plastics) with hydrogen; hydrogen leak detection; hydrogen phenomena modelling; and electrolysis safety for unsteady-state operations. Despite recent progress, a significant lack of understanding regarding the accidental behaviour of liquid hydrogen was identified as an outstanding challenge. At the engineering level, major research gaps exist for the non-road transport subsectors.

Hydrogen demand

Overview and outlook

Hydrogen demand has grown strongly since 2000, particularly in refining and industry

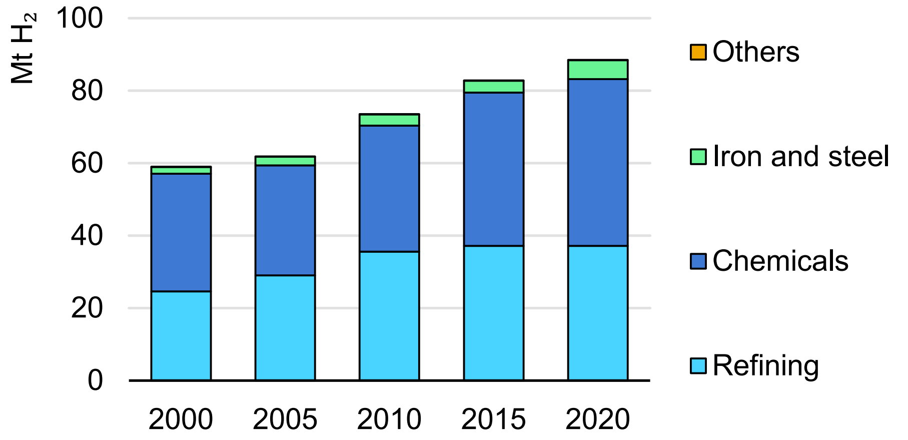
Global hydrogen demand was around 90 Mt H_2[4] in 2020, having grown 50% since the turn of the millennium. Almost all this demand comes from refining and industrial uses. Annually, refineries consume close to 40 Mt H_2 as feedstock and reagents or as a source of energy.

Demand is somewhat higher (more than 50 Mt H_2) in the industry sector, mainly for feedstock. Chemical production accounts for around 45 Mt H_2 of demand, with roughly three-quarters directed to ammonia production and one-quarter to methanol. The remaining 5 Mt H_2 is consumed in the direct reduced iron (DRI) process for steelmaking. This distribution has remained almost unchanged since 2000, apart from a slight increase in demand for DRI production.

The adoption of hydrogen for new applications has been slow, with uptake limited to the last decade, when fuel cell electric vehicle (FCEV) deployment started and pilot projects began to inject hydrogen into gas grids and use it for electricity generation. Positive results from these experiences prompted the development of some hydrogen technologies to the point of commercialisation.

In parallel, concerns about climate change have increased and governments and industry are making strong commitments to reduce emissions. Although this has accelerated the adoption of hydrogen for new applications, demand in this area remains minuscule. In transport, for example, annual hydrogen demand is less than 20 kt H_2 – just 0.02% of total hydrogen demand. As shown in the IEA's Net zero by 2050 roadmap, achieving government decarbonisation goals will require a step change in the pace of rolling out hydrogen technologies across many parts of the energy sector.

Hydrogen demand by sector, 2000-2020

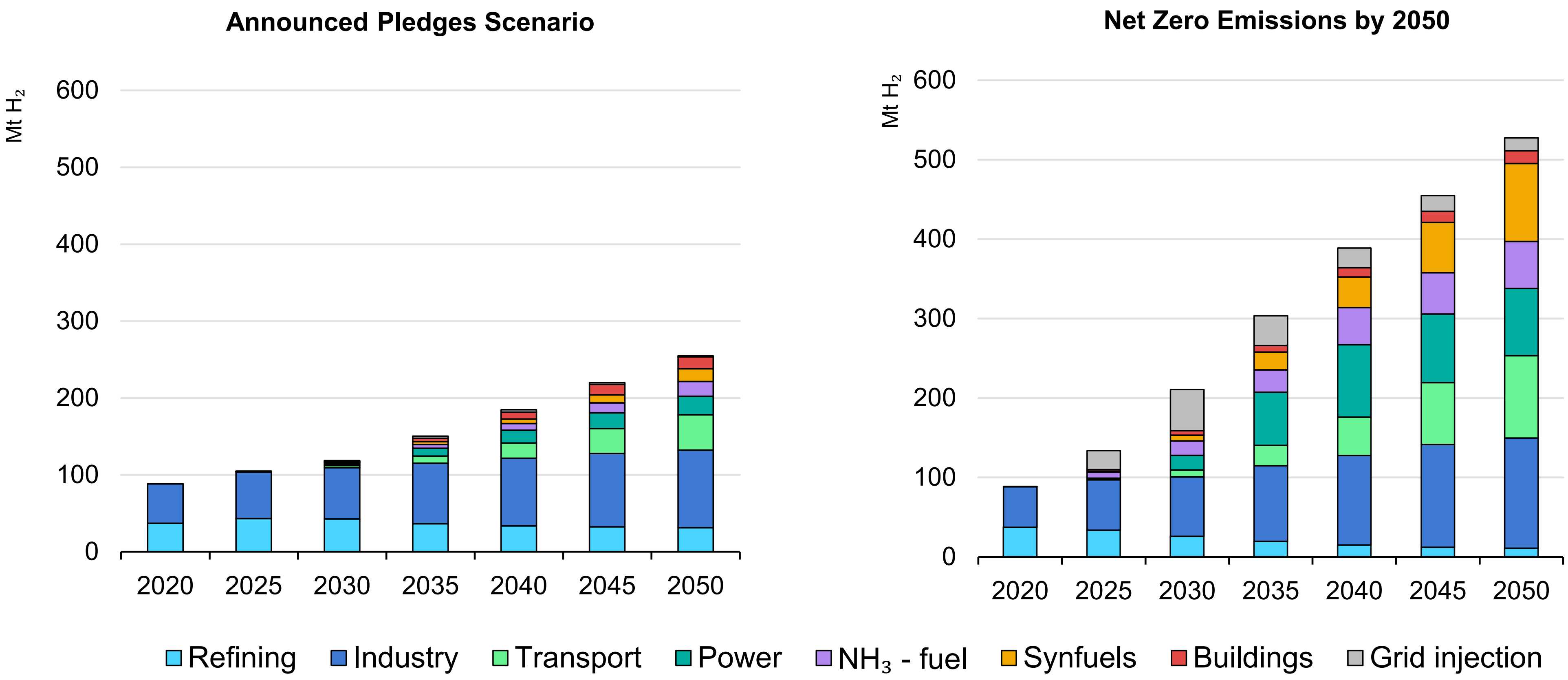


Note: "Others" refers to small volumes of demand in industrial applications, transport, grid injection and electricity generation.

[4] This includes more than 70 Mt H_2 used as pure hydrogen and less than 20 Mt H_2 mixed with carbon-containing gases in methanol production and steel manufacturing. It excludes around 30 Mt H_2 present in residual gases from industrial processes used for heat and electricity generation: as this use is linked to the inherent presence of hydrogen in these residual streams – rather than to any hydrogen requirement – these gases are not considered here as a hydrogen demand.

Government pledges suggest greater hydrogen use, but not nearly enough to the level needed to achieve net zero energy system emissions by 2050

Hydrogen demand by sector in the Announced Pledges and Net zero Emissions scenarios, 2020-2050



Notes: “NH_3 - fuel” refers to the use of hydrogen to produce ammonia for its use as a fuel. The use of hydrogen to produce ammonia as a feedstock in the chemical subsector is included within industry demand.