WTO OMC

IRENA
International Renewable Energy Agency

International trade and green hydrogen

Supporting the global transition to a low-carbon economy

DISCLAIMER

Contents

ACKNOWLEDGEMENTS

This publication has been prepared under the overall guidance of Aik Hoe Lim of the World Trade Organization (WTO) and Roland Roesch of the International Renewable Energy Agency (IRENA). The core team was composed of Francisco Boshell, Luis Janeiro, Ann Kathrin Lipponer and Jaidev Dhavle of IRENA and Svetlana Chobanova, Mateo Ferrero and Rainer Lanz of the WTO. Valuable comments and inputs were also provided by Zafar Samadov, Emanuele Bianco, Raul Miranda, Paul Komor and Deepti Ashok Siddhanti (IRENA), Monia Snoussi-Mimouni, Ankai Xu, Jose Luis Monteiro, Seref Coskun, Ruosi Zhang, Michael Roberts, Vishva Subramaniam and Philippe Pelletier (WTO), and Chris Agius (IEC).

ABBREVIATIONS

CO_2	carbon dioxide
CTE	Committee on Trade and Environment
GDP	gross domestic product
GH2	green hydrogen
GHG	greenhouse gas
GPA	Agreement on Government Procurement
GW	gigawatt
H_2	dihydrogen (i.e., hydrogen in a stable gaseous form)
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IECRE	IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications
IECEx	International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres
IISD	International Institute for Sustainable Development
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
LDC	least-developed country
LH_2	liquid hydrogen
LOHC	liquid organic hydrogen carrier
Mt/y	million tons per year
Mt CO_2	megatons of carbon dioxide
MtH_2/year	megatons of hydrogen per year
NH_3	ammonia
OECD	Organisation for Economic Co-operation and Development
PJ	petajoule
PV	photovoltaic
QI	quality infrastructure
R&D	research and development
SCM	subsidies and countervailing measures
TBT	technical barriers to trade
UNIDO	United Nations Industrial Development Organization
WEF	World Economic Forum
WTO	World Trade Organization

EXECUTIVE SUMMARY

The role of green hydrogen trade in the transition to a low-carbon economy

Green hydrogen, produced exclusively from renewable energy, is rapidly gaining importance as a potential factor in the transition to a net-zero global economy. It offers a solution to decarbonize energy applications where the direct use of renewable electricity or fuels is not a technically viable or cost-effective solution, such as heavy industry, shipping, aviation and seasonal energy storage.

Green hydrogen could play a key role in achieving the goals of the Paris Agreement[1] by mid-century, i.e., to pursue efforts to limit the increase in the global average temperature to 1.5°C, and to well below 2°C, above pre-industrial levels. Hydrogen production is currently a major net contributor to climate change, rather than to decarbonization, because current methods of producing hydrogen are carbon-intensive. Thus, to arrive at a net-zero world, the landscape of hydrogen production and consumption will need to change dramatically.

To achieve the goals of the Paris Agreement, the current uses served by hydrogen (e.g., to produce fertilizers or other chemicals) will need to be supplied by clean hydrogen. In addition, the supply of hydrogen overall will need to expand more than five-fold by 2050, to more than 500 MT/y, if it is to serve a broader range of uses and decarbonize carbon-intensive sectors. Given that renewable electricity is necessary to produce green hydrogen, delivering on such a scenario will, in parallel, require a massive expansion in renewable power generation.

The International Renewable Energy Agency (IRENA) estimates that the global technical potential to produce green hydrogen is as much as twenty times what the total global primary energy demand will be in 2050. Access to high-quality abundant renewable power generation will be a crucial cost factor, as this will be a key driver of the relative competitiveness of certain regions in producing hydrogen or in producing tradable commodities using hydrogen.

Green hydrogen and derivative commodities, such as green ammonia, make it possible to produce renewable energy in areas with substantial renewable energy potential, and to transport it to regions with significant hydrogen demand but an insufficient or more costly renewable energy supply.

International trade could play a significant role in matching supply and demand for green hydrogen and its derivatives, because the domestic production potential of some economies and regions may not be enough to satisfy their domestic demand, and it may be cheaper for some economies to import green hydrogen from locations with lower production costs. Analysis by IRENA suggests that by 2050 about one quarter of the total global hydrogen demand could be satisfied through international trade.

Currently hydrogen is largely produced using natural gas, with trade flows in the order of US$ 150-200 million per year. The trade of commodities that can be derived from (green) hydrogen, notably ammonia and methanol – is more significant. These were respectively worth US$ 17.5 billion and US$ 14.1 billion in 2022.

The trade dynamics for green hydrogen and derivatives in a net-zero scenario will be very different from those of today's international fossil fuel markets. The geographical distribution of green hydrogen production potential is widespread – as it is linked to solar and wind power supply – and there are few major potential importers. By contrast, in today's oil and gas markets, a handful of players control a large proportion of the global supply, for a much larger number of importers.

The physical characteristics of hydrogen render it technically difficult and economically costly to transport over long distances.

Green hydrogen could play a key role in achieving the goals of the Paris Agreement by mid-century.

For this reason, green hydrogen trade will likely materialize to a great extent as trade in commodities produced through the use of hydrogen, such as ammonia, methanol, synthetic fuels or iron. The prospect of cost-competitive green hydrogen production in regions with abundant, high-quality renewable energy could potentially drive the relocation of some energy-intensive industries and the emergence of new commodity trade flows.

As well as increasing trade of hydrogen and its derivative commodities, scaling up green hydrogen for the purpose of decarbonization will result in a significant increase in trade flows of the technologies and services required for its production, such as electrolysers (which use electricity to split water into hydrogen and oxygen), compressors, pipes and valves.

At present, more than 30 economies around the globe already have national strategies for low-carbon hydrogen. Therefore, it is already critical to begin anticipating the enabling conditions to facilitate this trade, in terms of infrastructure development, market design and regulations, and conducive trade policies.

A number of pathways could help to render trade policies more open, predictable, coherent and inclusive, to advance their role in fostering and shaping the development of green hydrogen supply chains.

This report outlines five actions for consideration by policymakers:

1. **Addressing trade barriers along the green hydrogen supply chain to promote the development of green hydrogen by lowering costs and fostering technology access.**
2. **Developing sound quality infrastructure to guarantee the environmental integrity of green hydrogen production and provide information on the production process and emissions footprint along the value chain.**
3. **Implementing support policies to help sustain market growth, promote cost efficiencies and narrow the cost differential between the production costs of green and of fossil-based hydrogen.**
4. **Using sustainable government procurement to foster a large and stable demand for green hydrogen, its derivatives and related technologies.**
5. **Increasing international cooperation in support of green hydrogen trade to ensure alignment and consistency in definitions and standards for emissions certification schemes and contribute to bringing about social and economic benefits.**

International trade could play a significant role in matching supply and demand for green hydrogen and its derivatives.

Endnotes

[1] See https://www.un.org/en/climatechange/paris-agreement.

FIVE ACTIONS FOR CONSIDERATION BY POLICYMAKERS

A set of five actions for economies to consider in order to scale up and facilitate global trade of green hydrogen.

1. Address trade barriers along the green hydrogen supply chain

- Promote trade in goods and services related to renewable energy production.
- Reduce tariffs and non-tariff barriers on green hydrogen, electrolysers, derivatives and other products along the supply chain.

2. Develop sound quality infrastructure for green hydrogen trade

- Adopt national measures based on international standards and engage in international standardization.
- Foster international dialogue on carbon measurement methodologies, definitions of low-carbon hydrogen and verification procedures.
- Inform customers via labelling requirements based on quality infrastructure.

3. Implement support policies for green hydrogen

- Implement targeted and non-discriminatory environmental subsidies to help sustain growth in electrolyser capacity and green hydrogen production.
- Close the economic gap between fossil fuels and green hydrogen by phasing out fossil fuel subsidies.

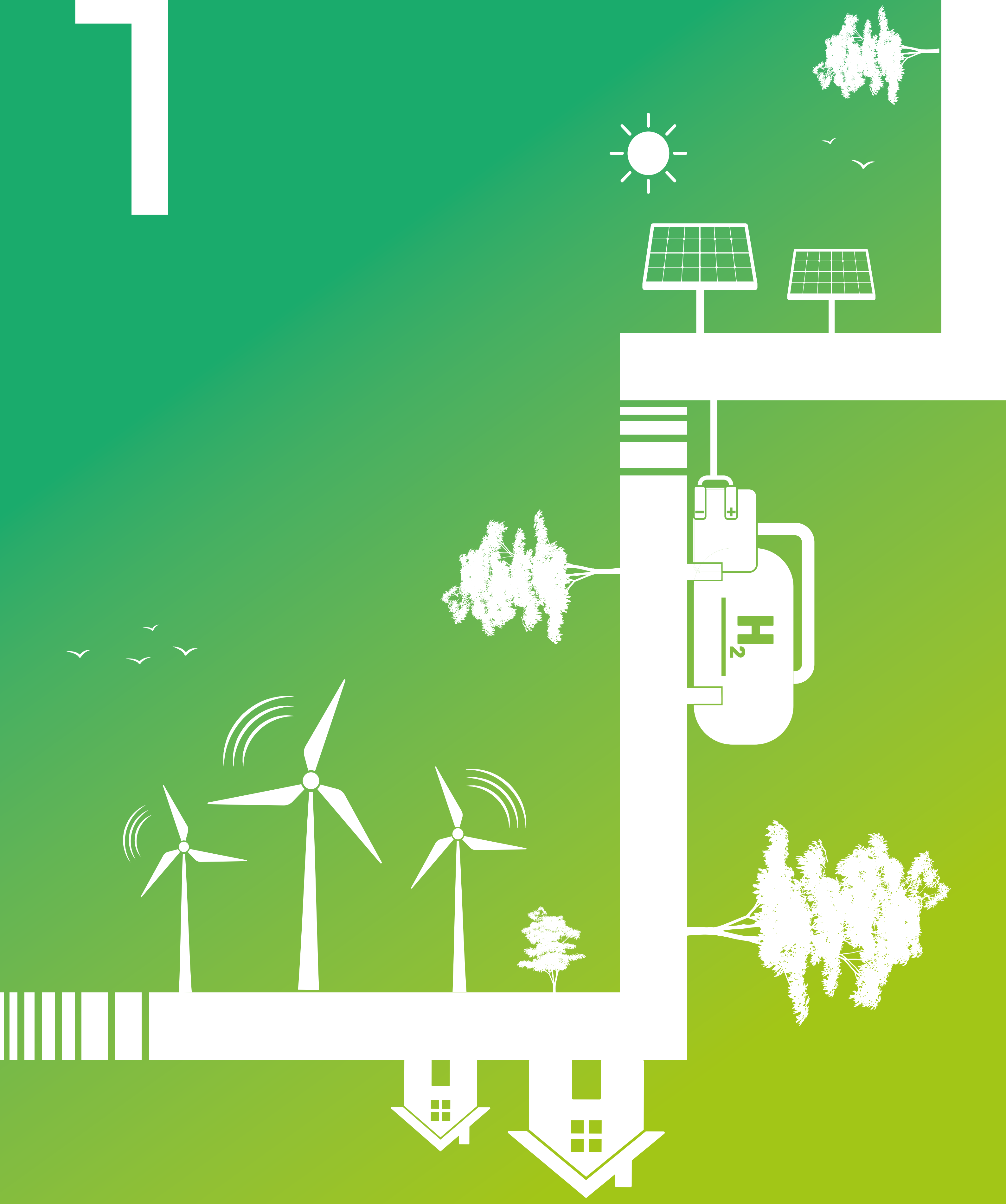
4. Use sustainable government procurement to foster green hydrogen demand

- Implement sustainable government procurement policies by purchasing low-carbon goods and services and stimulating innovative solutions.
- Consider coordinated demand-creating policies and collaboration to achieve economies of scale and accelerate cost reductions.

5. Increase international cooperation on green hydrogen trade

- Encourage technology development and innovation through dialogue.
- Engage in cooperation fora on green hydrogen.
- Increase technical assistance and capacity-building.
- Support the needs of developing economies through Aid for Trade.

1 INTRODUCTION

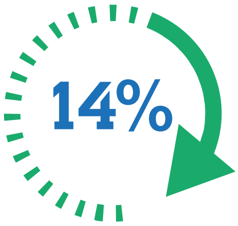


1.1 The role of green hydrogen in a global low-carbon economy

To meet the goals of the Paris Agreement by mid-century, the global energy system will need to be deeply transformed within the next two and a half decades. According to the scenario proposed in the International Renewable Energy Agency's (IRENA) *World Energy Transitions Outlook 2023: 1.5°C Pathway* (IRENA, 2023a), more than two-thirds of the carbon dioxide (CO_2) emission reductions towards a net-zero energy system can be achieved through an increased supply of renewable energy, the electrification of energy services currently supplied with fossil fuels, and the improvement of energy efficiency. In this scenario for a decarbonized world, electricity would become the central energy carrier, accounting for more than half of the worlds' final energy consumption, up from about one fifth today.

However, not all energy uses can be electrified. In some cases, a renewable molecule is needed as part of the process, either as feedstock – such as hydrogen for ammonia production – or as a chemical agent – such as hydrogen for primary steel production. In other cases, electrification is not technically feasible at present due to the energy density requirements of the fuel, such as in the aviation and shipping sectors. Therefore, there is a need for solutions to close the decarbonization gap for applications in which the direct use of renewable electricity or fuels is not a technically viable or cost-effective solution.

Renewable – green – hydrogen can act as the link between renewable electricity generation and hard-to-abate (i.e., for which the transition to net zero is difficult either in terms of technology or cost) sectors



Hydrogen and its derivatives could satisfy 14% of final energy demand in 2050.

or applications (IRENA, 2022a). Renewable electricity can be converted to green hydrogen via electrolysis, broadening the scope of renewable energy utilization. Green hydrogen is a key complement to renewable electrification, offering a solution to decarbonize some applications, for example in heavy industry (including those where fossil hydrogen is used today), shipping and aviation, and seasonal energy storage.

Green hydrogen is a key complement to renewable electrification.

Considering all these applications, IRENA estimates that hydrogen and its derivatives would satisfy a sizeable fraction (14 per cent) of final energy demand in 2050 in a scenario in which rising global temperatures resulting from emissions are limited to not more than 1.5°C (see Figure 1). The bulk of this hydrogen and of its derivatives should be renewable in order to reach climate neutrality in the energy system overall (IRENA, 2023a).

Today, the global production of hydrogen – around 95 megatons of hydrogen per year (MtH_2/year) – is almost exclusively derived from fossil fuels without associated carbon capture and storage. This fossil-based hydrogen is predominantly utilized in industries such as oil refining, fertilizer production, and downstream chemical processes. Current production of hydrogen emits the equivalent of 1,100-1,300 megatons of CO_2 (Mt CO_2) globally (IEA, IRENA and UN Climate Change High-Level Champions, 2023). Thus, at present, hydrogen production is a major net contributor to climate change, rather than a vector for decarbonization.

In a net-zero world, the current landscape of hydrogen production and consumption will need to have changed dramatically. First, existing hydrogen uses need to transition to a clean hydrogen supply. Second, hydrogen supply overall needs to expand to serve a broader range of applications in hard-to-decarbonize sectors. IRENA estimates that total hydrogen production will need to grow more than five-fold from now until 2050 (IRENA, 2023a).

Delivering on this scenario will require a massive expansion in renewable power supply, as the electricity needed for that purpose is comparable to today's total global electricity consumption.[1] It will also require an unprecedented scale-up and deployment of electrolyser capacity, from a negligible installed base today to more than 5,700 gigawatts (GW) by 2050 (see Figure 2).

This expansion of hydrogen production will require the development of new supply chains. This, in turn, will have trade implications, both in terms of the trade of renewable hydrogen itself (or tradable commodities produced with it, such as ammonia, methanol and reduced iron)[2] as well as trade in the required equipment and services to produce the hydrogen, transport it, store it and deliver it to the consumers at the end of the chain.

In a net-zero world, the current landscape of hydrogen production and consumption will need to change.

FIGURE 1

Breakdown of total final energy consumption by energy carrier under IRENA's 1.5°C scenario

Source: IRENA (2023a).

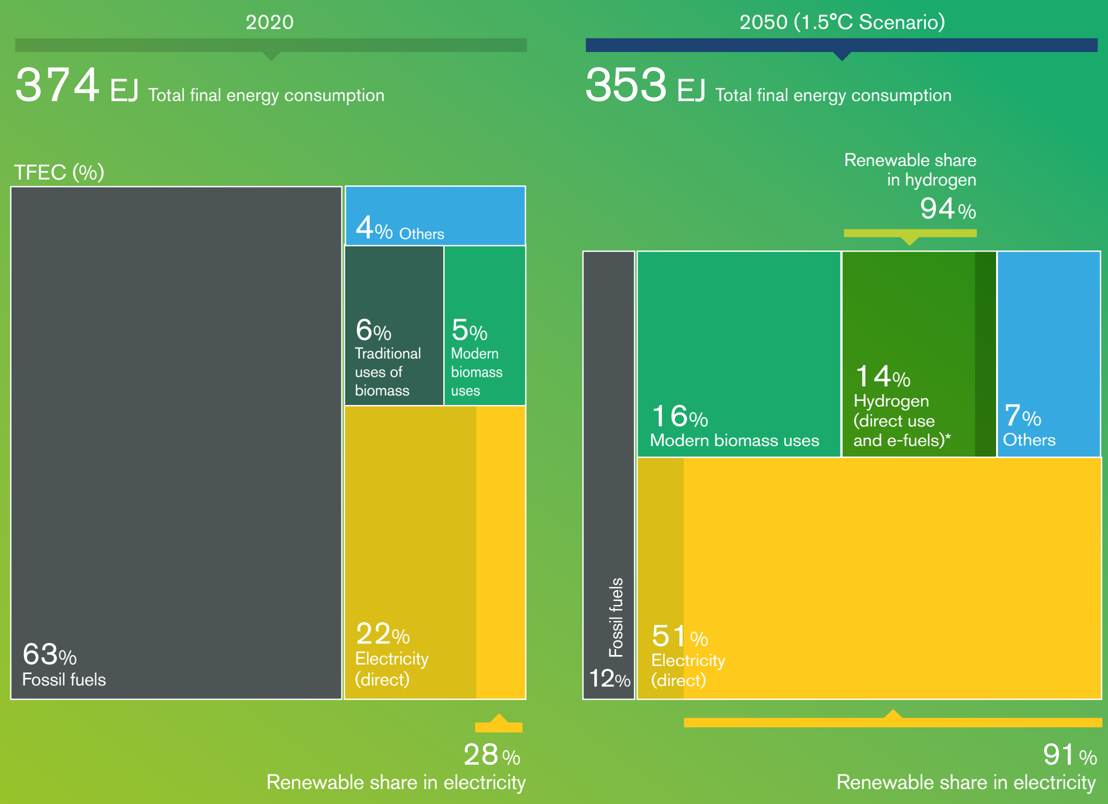
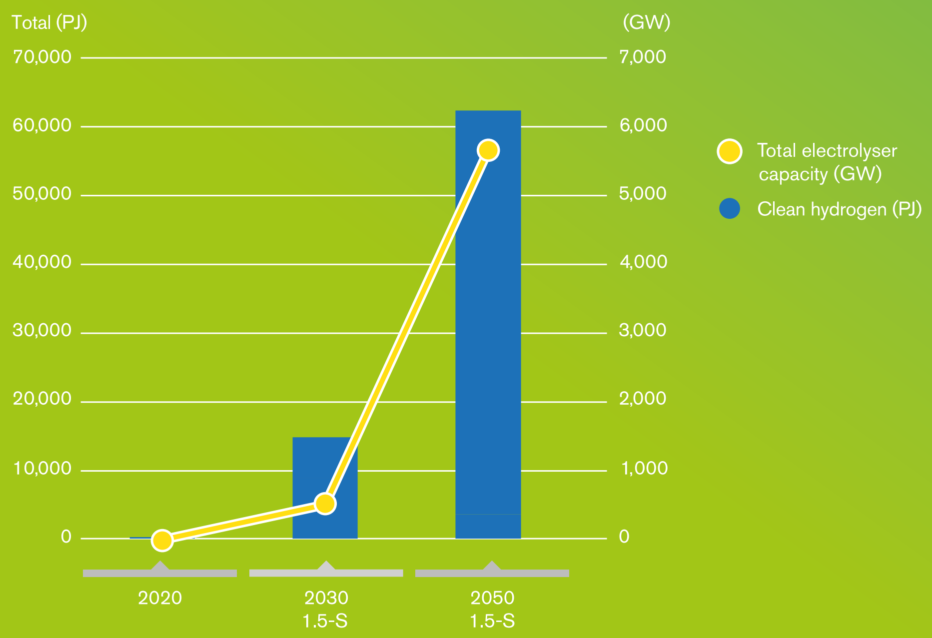


FIGURE 2

Global clean hydrogen supply in 2020, 2030 and 2050 in IRENA's 1.5°C scenario

Source: IRENA (2023a).



Note: 1.5-S = 1.5°C scenario; GW = gigawatt; PJ = petajoule.

1.2 Prospects for green hydrogen production

A major barrier to the deployment of green hydrogen to date has been the higher costs of production compared to unabated (i.e., which causes high carbon emissions) fossil-based hydrogen. The prospects for cheaper green hydrogen in the future are driven by two key factors: the cost of renewable electricity and the cost of electrolysers.

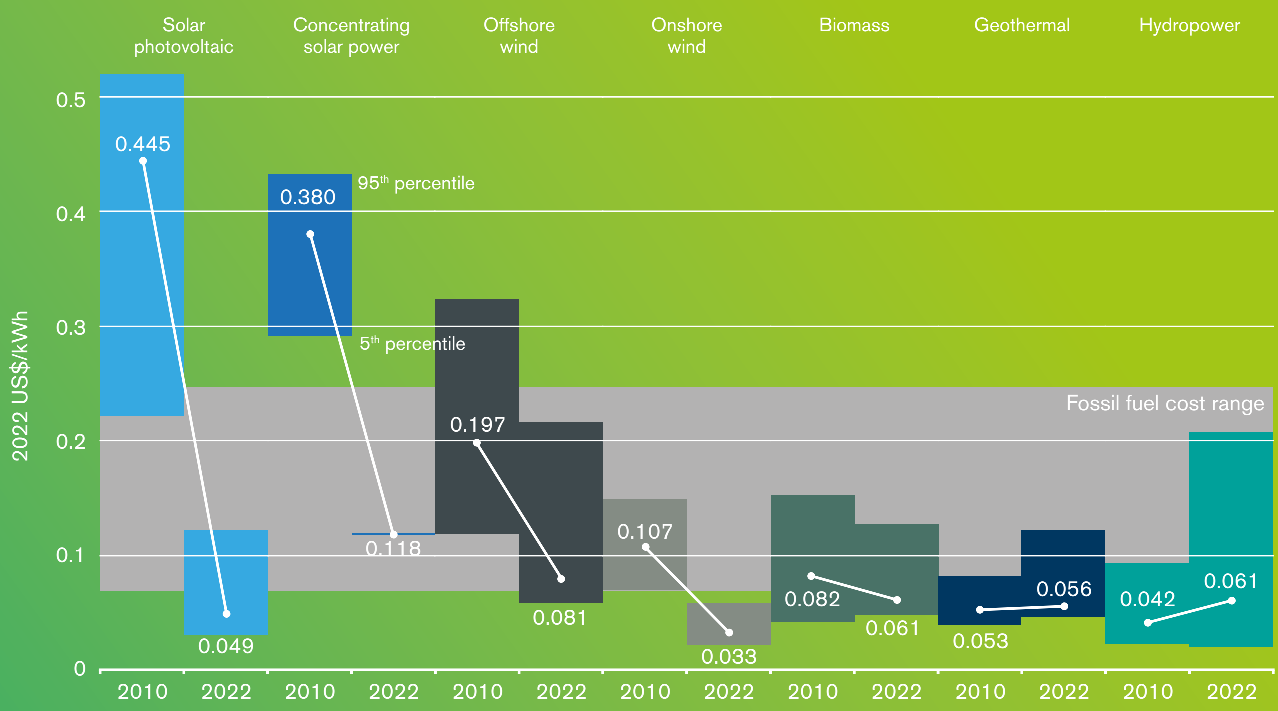
The cost of renewable power generation is falling very quickly (see Figure 3). For instance, over the last 12 years, the cost of solar photovoltaic (PV) power has dropped by almost 90 per cent. The costs of onshore and offshore wind generation have also dropped very substantially, by 69 per cent and 59 per cent respectively (IRENA, 2023b). Today, solar and wind are the cheapest forms of new power generation in many regions of the world, and costs have the potential to continue to decline as the technology continues to improve.

There could potentially be a similar cost reduction phenomenon with electrolysers to produce green hydrogen from renewable electricity. IRENA's analysis suggests that, if technology deployment volumes were to be in line with what is

FIGURE 3

Global levelized cost* of electricity from newly commissioned utility-scale renewable power technologies

Source: IRENA (2023b).

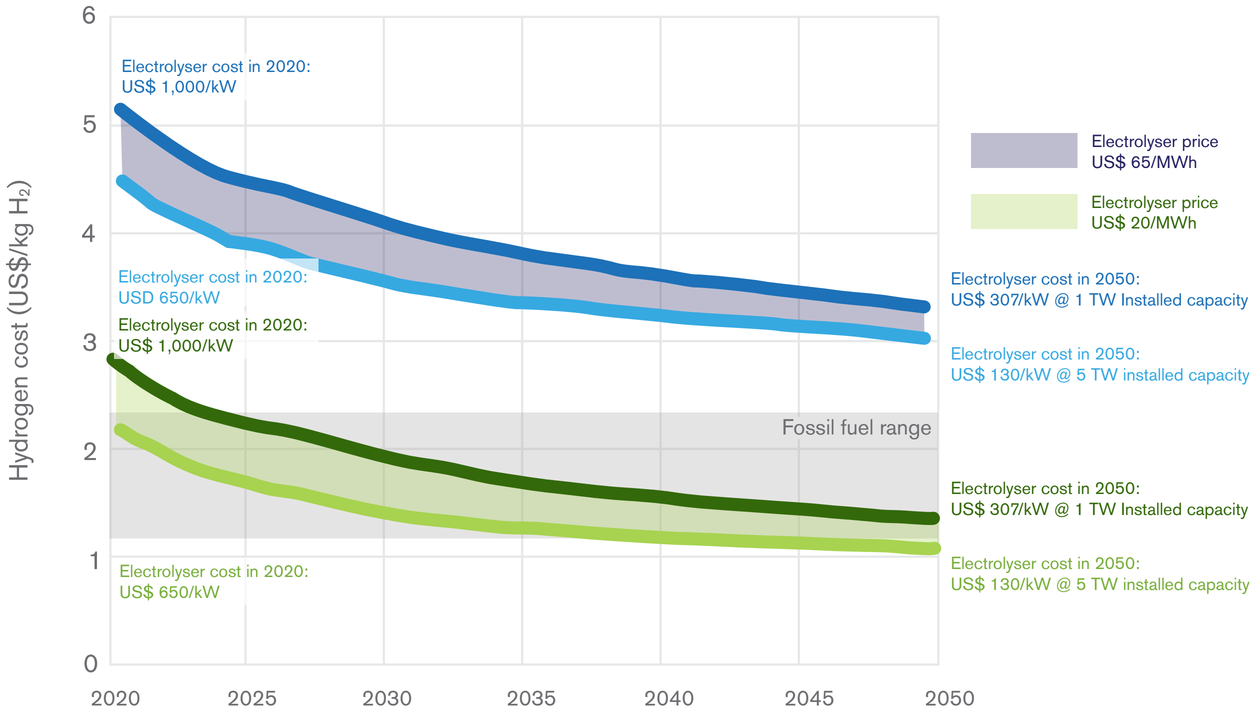


Note: kWh = Kilowatt-hour, i.e., a measure of the quantity of energy delivered by one kilowatt of power for a duration of one hour.

* The levelized cost of electricity is the ratio of lifetime costs to lifetime electricity production of a power generator, both of which are discounted back to a common year using a discount rate that reflects the cost of capital.

FIGURE 4
Green hydrogen cost estimations based on deployment levels, power supply and electrolyser cost

Source: IRENA (2020a).



needed[3] to meet the goals of the Paris Agreement by 2050, the effects of learning by doing and economies of scale would trigger substantial reductions in the cost of electrolysers (IRENA, 2020a). Such reductions in the installed costs of electrolysers, paired with further cost reductions in renewable power generation, could make green hydrogen competitive with fossil-based hydrogen already by the second half of this decade in locations with favourable renewable resource conditions (see Figure 4).

The overall availability of renewable energy will not be a limitation to scaling up hydrogen production in the future. Renewable sources can deliver all the green hydrogen that the world needs for a net-zero energy system: IRENA estimates (IRENA, 2022c) the global green hydrogen technical potential at about twenty times the total global primary energy demand in 2050 (see Figure 5.1).

In contrast to fossil fuels, where a handful of countries control a large fraction of the global resource, in the case of green hydrogen, the potential for green hydrogen is much more geographically distributed in nature, as it relies mostly on solar and wind resources, which are available throughout the world (see Figure 5.2).

This green hydrogen potential, however, will be available at very different costs across different regions. Hydrogen can be produced most cost-efficiently in locations with the best renewable energy resources and low project development costs (IRENA, 2019). Access to high-quality, abundant renewable power generation will be crucial, as this will be a key driver of the relative competitiveness of certain regions compared to others to produce hydrogen or tradable commodities produced with hydrogen. Therefore, the production of green hydrogen is likely to scale up in regions with high potential for renewable energy.

Aside from renewable resource conditions, the cost of capital plays a key role in the overall cost of green hydrogen – as the cost structure is dominated by capital expenditures – and will be another key competitiveness factor. Additional factors to consider include land availability, water access and the infrastructure options necessary for transporting and potentially exporting energy to meet the needs of significant demand centres (IRENA, 2022a).

FIGURE 5.1
Green hydrogen potential versus global primary energy demand in 2050
Source: IRENA (2022c).

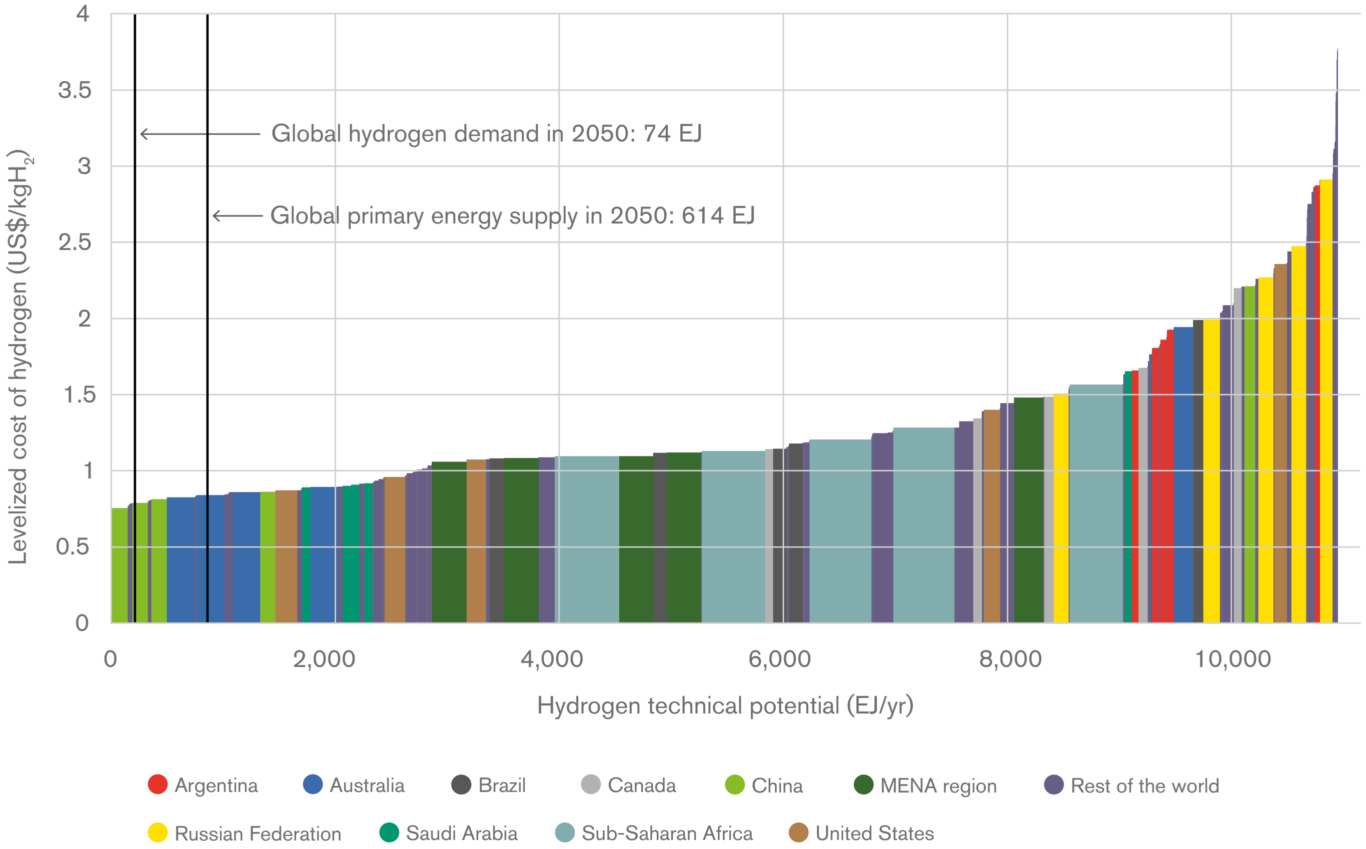
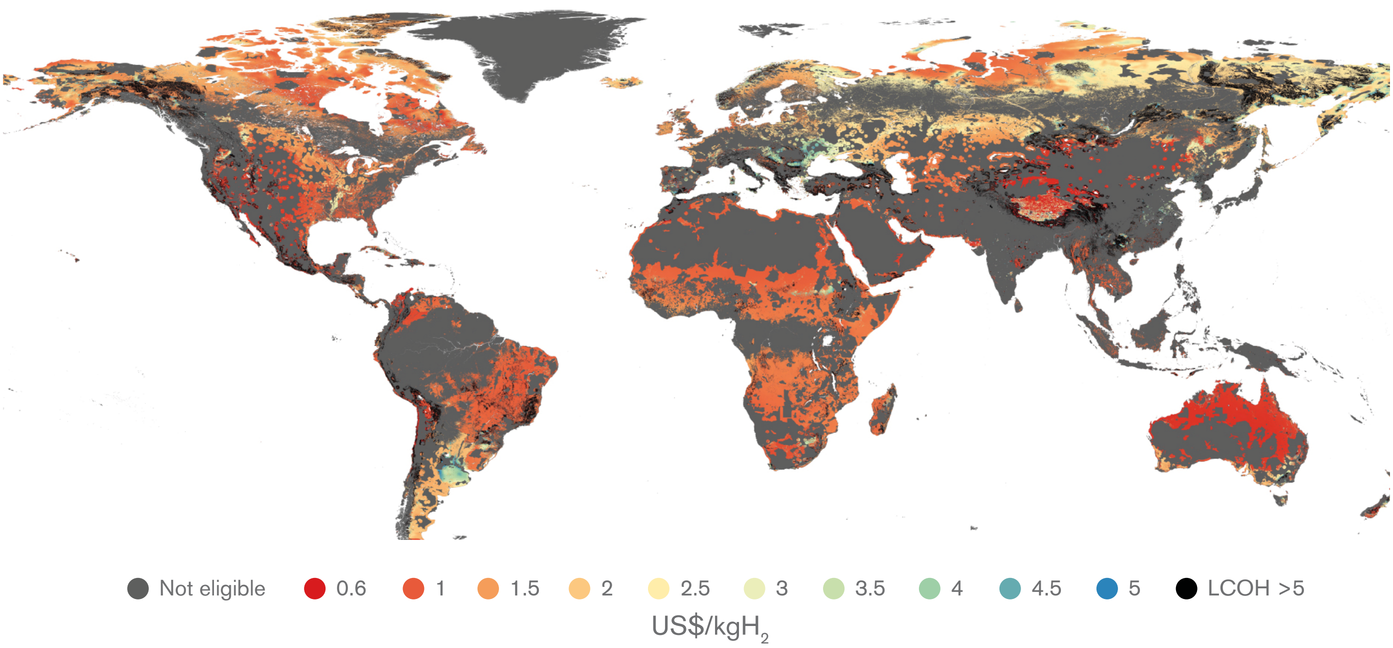


FIGURE 5.2
Levelized cost of hydrogen in 2050
Source: IRENA (2022c).



1.3 How global hydrogen trade could play out in the future

While there is more than enough green hydrogen potential to meet the expected global demand, there are economies or regions in which the domestic production potential might not be enough to satisfy the domestic demand. Furthermore, in some cases, it may be cheaper for certain economies to import from locations with lower production costs. This means that international trade could play a significant role in matching supply and demand.

Green hydrogen and derivative commodities, such as renewable ammonia, offer opportunities for producing, storing and transporting renewable energy from areas with substantial renewable energy potential to regions with significant hydrogen demand but insufficient or more costly renewable energy supply (IRENA, 2022a).

Hydrogen can potentially be traded in multiple forms. It can be transported over long distances as a gas through pipelines, or it can be shipped in liquid form.

Hydrogen can also be further transformed into another commodity, such as ammonia or methanol, and transported in liquid form. This additional processing results in significant energy losses, and therefore an increase in the cost per unit of energy delivered. Table 1 presents a brief overview of hydrogen transport alternatives with key advantages and disadvantages.[4]

To make trade cost-effective, the cost of producing green hydrogen must be sufficiently cheaper in the exporting region compared to the importing region to compensate for the transport cost (IRENA, 2022a).[5]

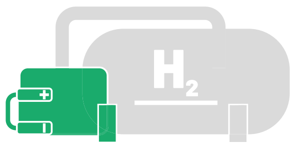
To understand how these global trade flows could potentially play out in a fully decarbonized global energy system, in 2022 IRENA carried out a trade analysis based on a global cost-optimization model. The analysis focuses on two commodities – green hydrogen and green ammonia.

The analysis shows that by 2050, about a quarter of the total global hydrogen demand in IRENA's 1.5°C scenario could be satisfied through international trade. The other three-quarters would be domestically produced and consumed.

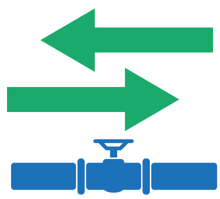
Of the hydrogen that would be internationally traded by 2050 in the 1.5°C scenario, around 55 per cent would be traded via pipelines. The remaining 45 per cent of the internationally traded hydrogen would be shipped, predominantly as ammonia, which would mostly be used without being reconverted to hydrogen, as an input for the fertilizer industry or as synthetic fuel for international shipping (IRENA, 2022a) (see Figure 6).

The results summarized above are based entirely on cost-optimization modelling and do not take into account other investment decision factors, such as energy security, political stability or economic development, which may also substantially impact the future landscape of hydrogen production. However, the results are indicative of potential major trade flows and the predominant transport modes.

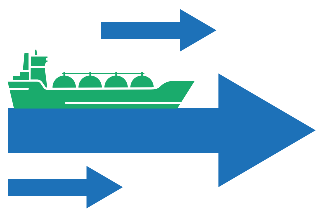
Green hydrogen and its derivatives offer opportunities for producing, storing and transporting renewable energy.



By 2050, international trade could satisfy about ¼ of the total global hydrogen demand in IRENA's 1.5°C scenario.



55% of this hydrogen would be traded via pipelines.



45% of this hydrogen would be shipped, predominantly as ammonia.

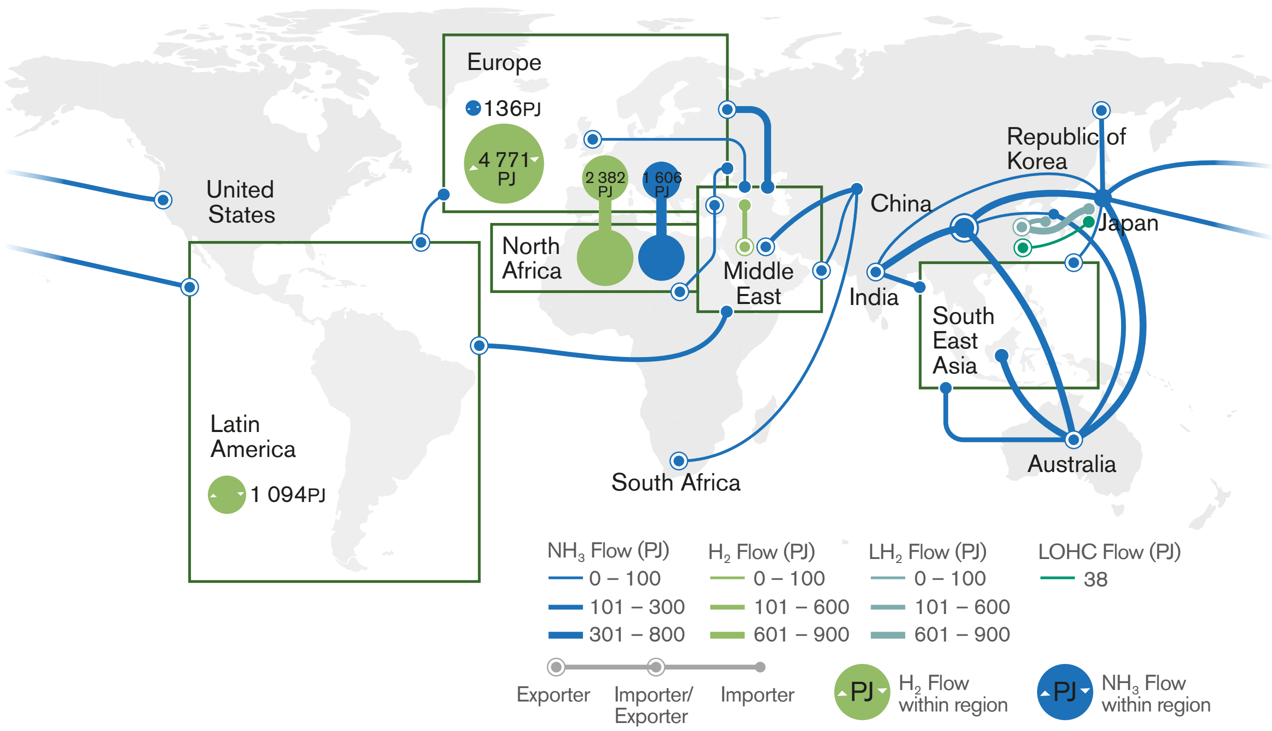
TABLE 1
Overview of advantages and disadvantages of hydrogen transport alternatives
Source: IRENA (2022b).

	Advantages	Disadvantages
Ammonia	▪ Already produced on a large scale. ▪ Already globally traded. ▪ Low transport losses. ▪ High energy density and hydrogen content. ▪ Carbon-free carrier. ▪ Can be used directly in some applications (e.g., fertilizers, maritime fuel). ▪ Can easily be liquefied.	▪ Toxic and corrosive. ▪ High energy consumption for ammonia synthesis. ▪ High energy consumption for reconversion (importing region) with high temperature requirement (up to 900°C but more commonly in the 500-550°C range). ▪ Ship engines using ammonia as fuel need to be demonstrated.
Liquid hydrogen	▪ Limited energy consumption for regasification (most of the energy is consumed in the exporting region, which is expected to have low renewable energy costs). ▪ No need for a purification system at the destination. ▪ Easier transport at the importing terminal. ▪ Low energy consumption to increase pressure of hydrogen delivered. ▪ Liquefaction is already a commercial technology.	▪ Very low volumetric energy density. ▪ High energy losses for liquefaction. ▪ Boil-off losses during shipping and storage. ▪ Cryogenic temperatures lead to high equipment cost.
Liquid organic hydrogen carrier (LOHC)	▪ Can be transported using existing infrastructure, making it suitable for multi-modal transport. ▪ Low capital cost for all steps. ▪ Can be easily stored.	▪ High energy consumption for dehydrogenation (importing region). ▪ Requires further purification of the hydrogen produced. ▪ Only 4-7% of the weight of the carrier is hydrogen. ▪ All the possible carriers currently have a high cost. ▪ Most of the possible carriers require scaling up multiple times from current global production.
Gas (pipelines)	▪ Transport and storage are proven at a commercial scale. ▪ Existing network can potentially be repurposed to hydrogen. ▪ Carbon-free carrier. ▪ Becomes more attractive as the volume increases.	▪ Storage in specific types of reservoirs can lead to losses and contamination. ▪ Not all the pipeline materials are suitable for hydrogen. ▪ Not all regions have an existing gas network. ▪ Cost increases significantly for offshore pipelines. ▪ Energy consumption for transport is higher than for natural gas.

FIGURE 6

Global hydrogen trade flows under optimistic technology assumptions in 2050

Source: IRENA (2022a).



Beyond the trade of hydrogen itself, the prospect of cost-competitive hydrogen production in regions with abundant and high-quality renewable energy could potentially drive the relocation of some key energy-intensive industries and the emergence of new commodity trade flows. Major green hydrogen-consuming industries would include ammonia, methanol or iron production.

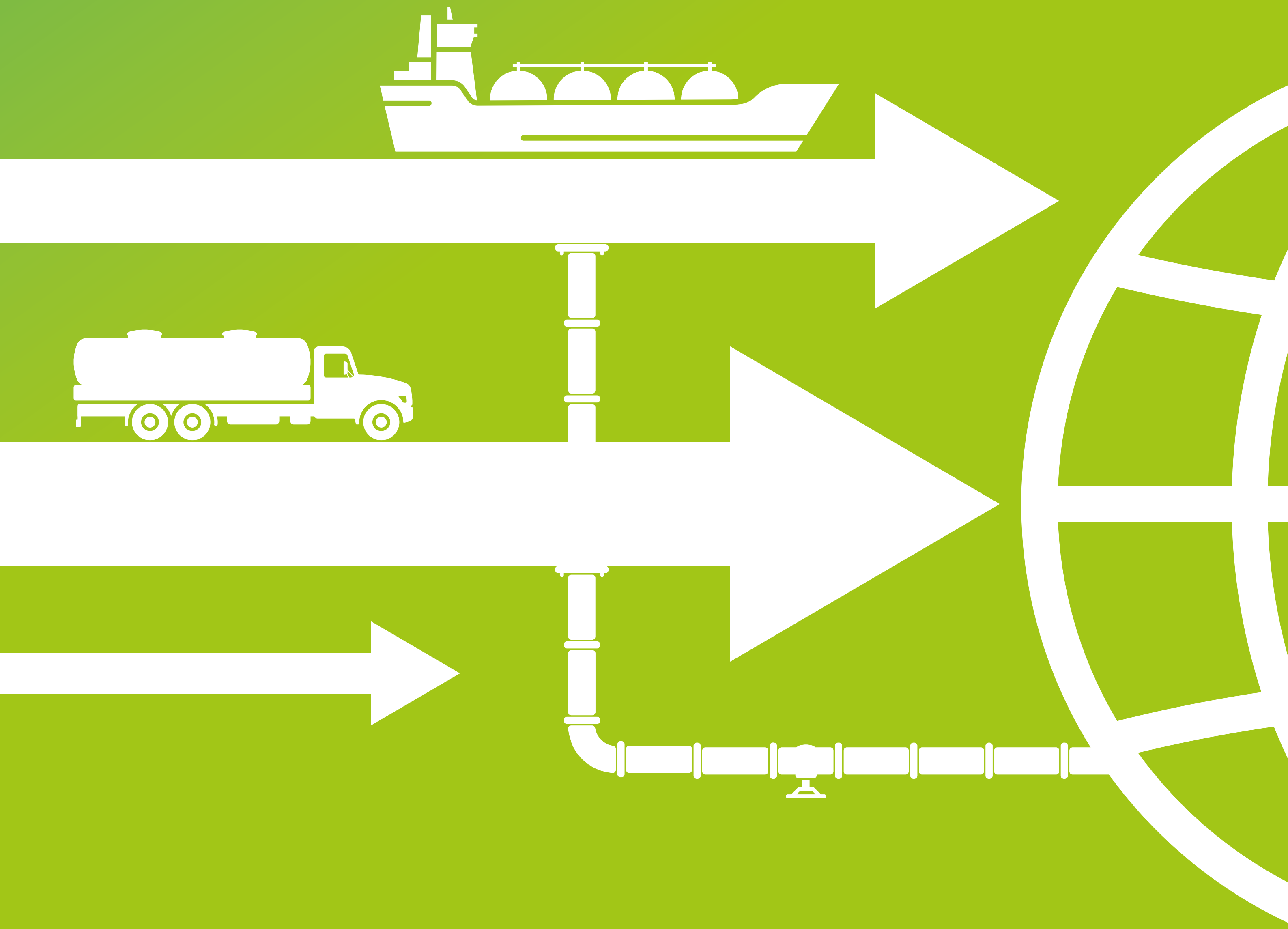
While transporting hydrogen over long distances is technologically complex and costly (both economically and in terms of energy), the transport of these processed commodities represents a small fraction of the overall production cost. Therefore, relatively small differences in the cost of hydrogen production across geographies could potentially make the relocation of industrial facilities economically attractive (IRENA, 2022a). This presents an opportunity for countries with abundant renewables to indirectly export their domestic energy resource in the form of higher value-added industrial products.

Note: NH_3 = ammonia; PJ = petajoule; H_2 = dihydrogen (hydrogen in a stable gaseous form); LH_2 = liquid hydrogen; LOHC = liquid organic hydrogen carrier.
Optimistic capital expenditure assumptions for 2050: photovoltaic (PV): US$ 225-455/kW; onshore wind: US$ 700-1,070/kW; offshore wind: US$ 1,275-1,745/kW; electrolyser: US$ 130/kW. Weighted average cost of capital: per 2020 values without technology risks across regions.
Green hydrogen technical potential is based on assessing land availability for solar PV and wind. Demand is in line with a 1.5°C scenario from IRENA (2023a).
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA or WTO concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Endnotes

[1] IRENA's 1.5°C scenario considers a 94 per cent renewable share in the global production of hydrogen and derivatives in 2050.
[2] Reduced iron is solid iron ore or other iron-bearing materials from which oxygen has been removed without melting it, by means of reducing agents, i.e., carbon monoxide and hydrogen. See, for example, https://www.metallics.org/dri-production.html.
[3] Understood as the annual deployments of electrolyser capacity in line with IRENA (2023a).
[4] For more information about techno-economic considerations for key hydrogen carriers, see IRENA (2022c).
[5] IRENA is working on an extension of this analysis to include trade flows related to methanol and iron produced with green hydrogen.

2 MAPPING SUPPLY CHAIN ISSUES FROM A TRADE PERSPECTIVE



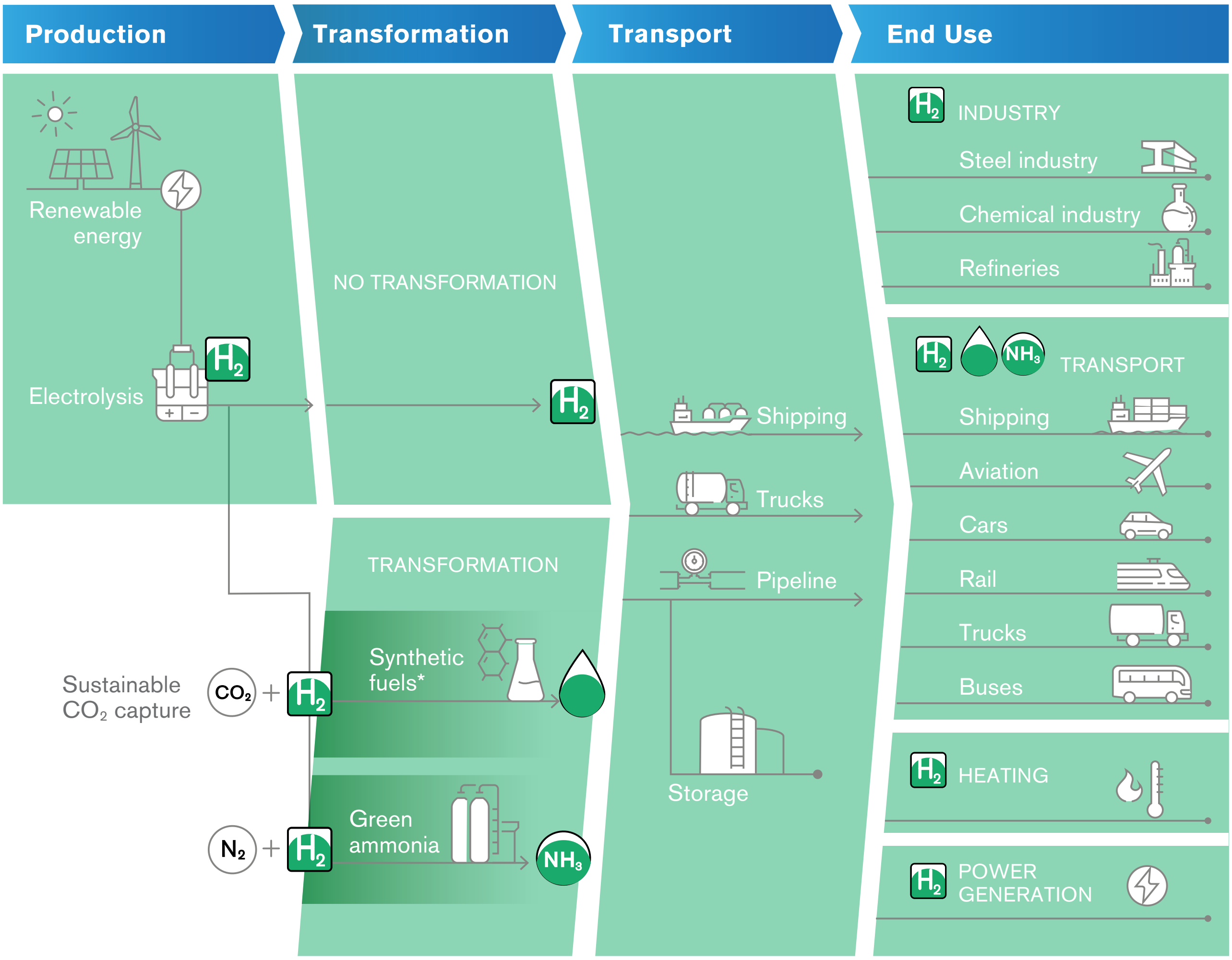
Green hydrogen has a number of uses. It can be used directly as an energy carrier and chemical input in multiple end-use applications. It can also be combined with a sustainable carbon source or with nitrogen, to produce derivative compounds such as methanol or ammonia, which can be used as feedstock for chemical production (e.g., plastics and fertilizers) or as sustainable fuels. Figure 7 shows a simplified illustration of the value chain of green hydrogen, from the production of renewable power, through transformation and transport and to end-use possible applications.

The progressive adoption of green hydrogen as a key building block of the energy transition will have trade implications at different levels. First, green hydrogen can be traded either as a gas (in compressed tanks, or via pipelines) or as a liquid

The adoption of green hydrogen as a building block of the energy transition will have trade implications at different levels.

FIGURE 7
Green hydrogen production, conversion and end uses across the energy system

Source: IRENA (2022b).



Note: The term "synthetic fuels" refers here to a range of hydrogen-based fuels produced through chemical processes with a carbon source (carbon monoxide (CO) and CO_2 captured from emission streams, biogenic sources or directly from the air). They include methanol, jet fuels, methane and other hydrocarbons. The main advantage of these fuels is that they can be used to replace their fossil fuel-based counterparts and can, in many cases, be used as direct replacements – that is, as drop-in fuels. Synthetic fuels produce carbon emissions when combusted, but if their production process consumes the same amount of carbon, in principle this allows them to have net-zero carbon emissions.

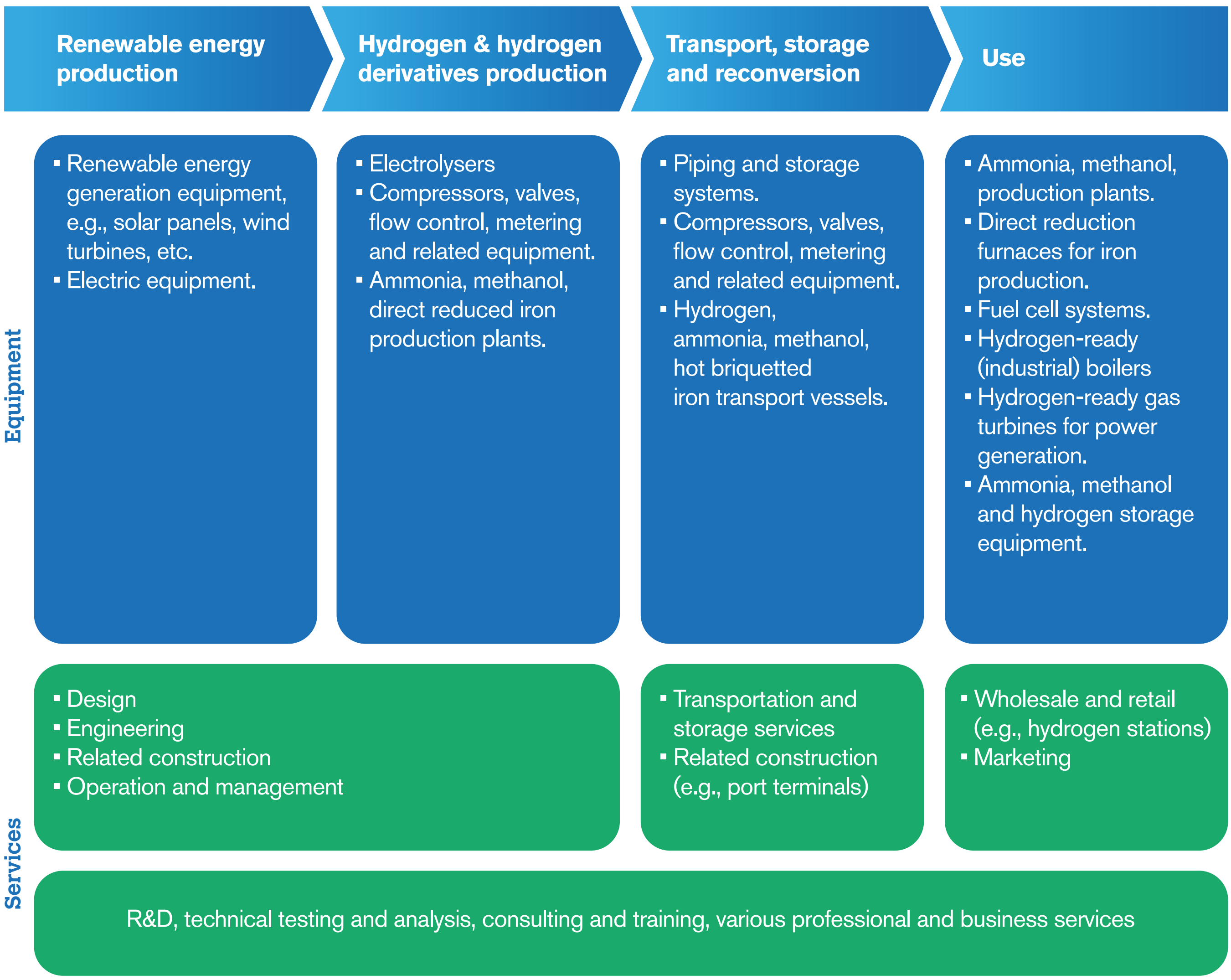
(in ships). Second, green hydrogen can be traded in the form of chemical derivatives, such as methanol, ammonia, methane and jet fuel. Third, green hydrogen can enable the trade of other low-carbon commodities, such as metallic iron, which can be produced using hydrogen as a reductant.

The adoption of green hydrogen, as well as the trade of hydrogen and its derivatives, will also have implications for the trade of goods and services required along the value chain. Figure 8 provides an illustrative summary of such goods and services.

FIGURE 8

Overview of tradable goods and services along the green hydrogen and derivatives supply chain

Source: IRENA and WTO.



Trade in a wide range of goods related to hydrogen production could be subject to change, including energy generation equipment, electrolysers for hydrogen production, compressors, pipes, gas management systems, transport vessels and storage tanks. This may also be the case with end-use technologies, such as chemical production plants, iron-making facilities, fuel cells and gas turbines.

Beyond the "hardware" of the green hydrogen supply chain, a variety of domestic and traded services will be needed. A number of services are common across the different stages of the supply chain, such as research and development (R&D), technical testing and analysis, consulting, training and various other professional and business services.

At the same time, at each stage of the supply chain, some services may be more important than others. For instance, design, engineering, operation and construction services are particularly relevant for the production stages of renewable energy and hydrogen, while transportation and storage, and wholesale and retail services are among those that are more relevant further downstream in the chain.

2.1 Trade in hydrogen and hydrogen derivatives

The value of global hydrogen imports (of all colours, but mostly those that are fossil-fuel-based) amounted to around US$ 300 million in 2022. While hydrogen trade has seen relatively modest fluctuations over most of the past decade, it saw a sharp increase of 71 per cent in 2022 compared to 2021, mostly reflecting an increase in the value of hydrogen imports by the Netherlands from Belgium (i.e., one of the largest global hydrogen exporters and one of the top markets). It is likely that this increase and, more broadly, the value of hydrogen trade have been driven to a significant extent by fluctuations in the price of natural gas, which is the dominant source in current hydrogen production.

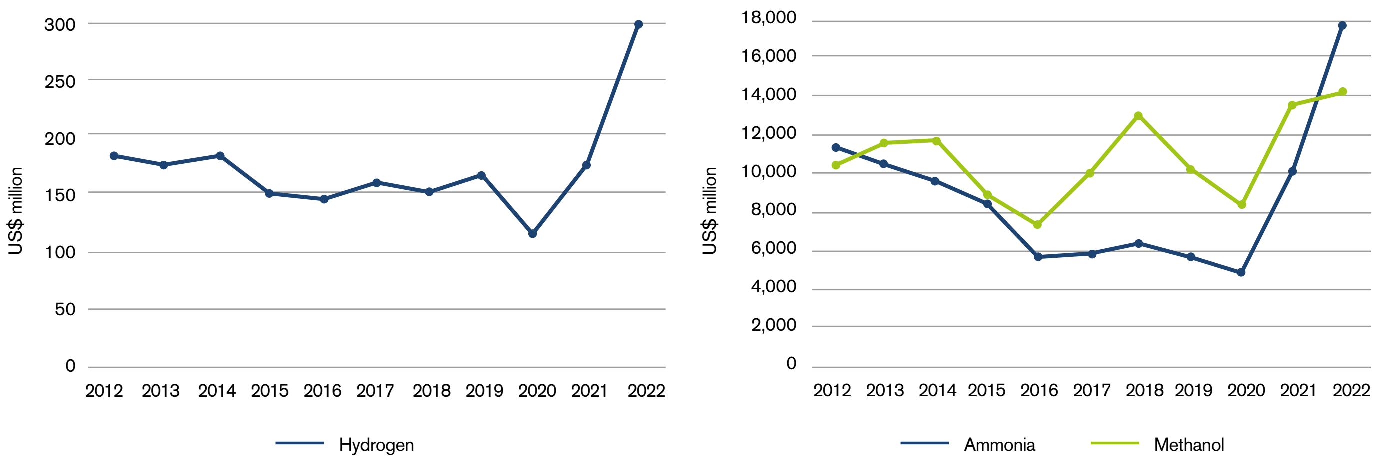
Global trade in hydrogen is very small compared to that in commodities that can be produced as derivatives. For example, global imports of ammonia and methanol have registered strong growth over the past two years, reaching US$ 17.5 billion and US$ 14.1 billion in 2022 (see Figure 9). As described above, the expansion of green hydrogen production is expected to lead to an increase in hydrogen trade from the current low levels.

The leading importers of hydrogen are the United States and the Netherlands and the two largest exporters are Canada and Belgium.

FIGURE 9

Global imports in hydrogen and derivatives (ammonia and methanol)

Source: WTO Secretariat Analytical Database based on data originally sourced from WTO Integrated Database, UN Comtrade and Trade Data Monitor.



Note: Trade data do not allow for the differentiation of hydrogen based on the energy used in production.

Trade in hydrogen is currently concentrated in a few economies. In value terms, the United States and the Netherlands are the leading importers of hydrogen, accounting each for around a third of global hydrogen imports in 2021, while the top 10 import markets represented close to 90 per cent of global hydrogen trade. In particular, imports of hydrogen amounted to US$ 56.8 million (142 million m^3 in volume terms) in the United States, and to US$ 52 million (167 million m^3) in the Netherlands. The two largest exporters of hydrogen are Canada and Belgium, which are the dominant suppliers for the two top markets, the United States and the Netherlands, respectively. Bilateral trade in hydrogen is largely regional (see Table 2).

TABLE 2

Top import markets for hydrogen and top three suppliers, 2021

Source: WTO Secretariat Analytical Database based on data originally sourced from the WTO Integrated Database, UN Comtrade and the Trade Data Monitor.

Importer	US$ million	Suppliers (percentage share in import market)
United States	56.8	Canada (99), France (0), New Zealand (0)
Netherlands	52.3	Belgium (96), Germany (3), Hungary (0)
Singapore	18.2	Chinese Taipei (85), United States (13), Malaysia (1)
Germany	5.9	Netherlands (65), France (19), Belgium (6)
Canada	4.1	United States (96), France (3), Japan (0)
France	4.1	Germany (36), Netherlands (36), Belgium (13)
Mexico	3.6	United States (100)
United Kingdom	3.1	Netherlands (88), France (4), Germany (2)
Austria	2.9	Germany (76), Slovak Republic (20), Switzerland (1)
Malaysia	2.4	United States (53), Chinese Taipei (19), China (17)
Czech Republic	2.4	Poland (86), Slovak Republic (8), Hungary (1)
Ireland	2.3	United Kingdom (56), Netherlands (43), United States (0)
Belgium	2.0	Netherlands (79), Germany (19), France (0)
Switzerland	1.1	European Union (96), Qatar (3), United Kingdom (0)
Poland	1.0	Czech Republic (63), Germany (20), Slovak Republic (4)

Note: The HS subheading code for hydrogen (280410) does not distinguish between gaseous and liquid hydrogen, and trade statistics do not readily shed light on the mode of transport, e.g., pipelines or ships.

Ammonia is produced by combining hydrogen with nitrogen extracted from ambient air. Ammonia is used in nitrogen fertilizer production and other applications such as refrigeration, mining, pharmaceuticals, water treatment, plastics and fibres, and abatement or removal of nitrogen oxides.

Ammonia can also act as an energy carrier for hydrogen, as it has the advantage that it requires less cooling to be liquefied, has a higher volumetric energy density than hydrogen, and can rely to an extent on established transport and storage infrastructures. Ammonia that is produced from green hydrogen is expected to dominate new installed capacity additions for ammonia production after 2025 and could become the main commodity for transporting renewable energy between continents (IRENA and AEA, 2022).

The current trade landscape for ammonia looks more global and less regionalized compared to hydrogen, reflecting its importance as a global commodity. India was the top destination market for ammonia in 2021, followed by the United States and Morocco. The top five suppliers for ammonia in 2021 were Trinidad and Tobago, Russia, Indonesia, the Kingdom of Saudi Arabia and Algeria (Table 3).

TABLE 3

Top import markets for ammonia and top three suppliers, 2021

Source: WTO Secretariat Analytical Database based on data originally sourced from the WTO Integrated Database, UN Comtrade and the Trade Data Monitor.

Importer	US$ million	Suppliers (percentage share in import market)
India	1,577.5	Saudi Arabia, Kingdom of (23), Qatar (22), Ukraine (13)
United States	1,352.2	Canada (48), Trinidad and Tobago (47), Algeria (1)
Morocco	769.6	Russian Federation (50), Trinidad and Tobago (36), Algeria (6)
Korea, Republic of	746.7	Indonesia (40), Saudi Arabia, Kingdom of (19), Trinidad and Tobago (12)
Belgium	521.0	Russian Federation (33), Trinidad and Tobago (24), Algeria (20)
Türkiye	453.1	Russian Federation (60), Libya (8), Algeria (8)
China	416.3	Indonesia (45), Saudi Arabia, Kingdom of (15), Malaysia (13)
Norway	368.6	Russian Federation (66), Trinidad and Tobago (10), United Kingdom (7)
Chinese Taipei	363.3	Indonesia (43), Saudi Arabia, Kingdom of (25), Iran (13)
France	340.5	Trinidad and Tobago (38), Algeria (14), Germany (13)
Thailand	248.4	Malaysia (60), Australia (21), Indonesia (12)
Spain	241.5	Algeria (80), Russian Federation (17), Portugal (1)
Brazil	230.6	Trinidad and Tobago (97), Algeria (1), Colombia (1)
Germany	229.1	Netherlands (45), Russian Federation (19), Belgium (12)
Chile	215.0	Trinidad and Tobago (44), United States of America (26), Brazil (13)

Methanol is a key product in the chemical industry used for producing other chemicals such as formaldehyde, acetic acid and plastics. Renewable methanol can be produced using different routes, including through a catalytic reaction between CO_2 and green hydrogen. Renewable methanol could play a larger role in decarbonizing certain sectors where options are currently limited – particularly as a feedstock, or material input to a production process, in the chemical industry or as a fuel in maritime transport (IRENA, 2021).

China is the top market by some distance for methanol, accounting for a quarter (25 per cent) of global methanol imports. Other major import markets, such as India, the Netherlands, the United States, the Republic of Korea and Japan, are similar in size and accounted for 5-7 per cent of global imports in 2021. The main suppliers of methanol are producers of natural gas, such as Trinidad and Tobago, the Kingdom of Saudi Arabia, Oman, the United Arab Emirates, the United States and Russia (Table 4).

TABLE 4

Top import markets for methanol and top three suppliers, 2021

Source: WTO Secretariat Analytical Database based on data originally sourced from the WTO Integrated Database, UN Comtrade and the Trade Data Monitor.

Importer	US$ million	Suppliers (percentage share in import market)
China	3,367.0	United Arab Emirates (39), Oman (25), Saudi Arabia, Kingdom of (11)
India	996.1	Saudi Arabia, Kingdom of (31), Qatar (19), Oman (15)
Netherlands	929.7	Trinidad and Tobago (20), Equatorial Guinea (19), United States (13)
United States	863.4	Trinidad and Tobago (55), Canada (20), Equatorial Guinea (10)
Korea, Republic of	791.7	United States of America (38), Trinidad and Tobago (25), Oman (16)
Japan	689.0	Saudi Arabia, Kingdom of (50), Trinidad and Tobago (14), United States (14)
Germany	592.3	Netherlands (33), Belgium (18), Norway (10)
Chinese Taipei	590.1	Oman (25), Saudi Arabia, Kingdom of (21), United States (15)
Brazil	558.7	Chile (39), Trinidad and Tobago (38), Venezuela, Bolivarian Republic of (13)
Indonesia	392.1	Malaysia (38), Oman (19), Saudi Arabia, Kingdom of (14)
Belgium	380.3	Trinidad and Tobago (41), Netherlands (30), United States (16)
Thailand	320.7	Saudi Arabia, Kingdom of (42), Malaysia (18), Bahrain, Kingdom of (17)
Poland	262.0	Russian Federation (67), Germany (13), Finland (7)
Singapore	252.0	Saudi Arabia, Kingdom of (47), Malaysia (33), Oman (12)
Türkiye	235.2	Egypt (65), Azerbaijan (24), Saudi Arabia, Kingdom of (4)

2.2 Electrolysers as a key technology for the green hydrogen supply chain

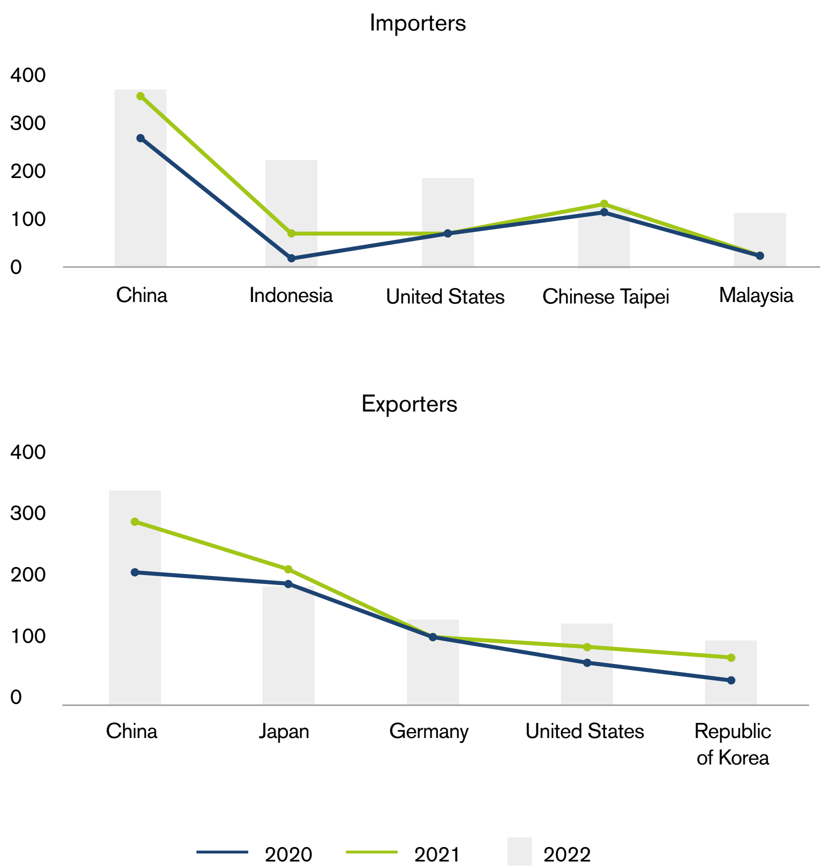
A key technology for the production of green hydrogen is electrolysis, in which an electrolyser uses electricity from renewable energy sources to split water into hydrogen and oxygen. As electrolysers can currently account for 30-40 per cent of the final cost of hydrogen production, creating scale economies in electrolyser manufacturing and enhancing the performance of electrolysers will be essential to achieve cost competitiveness of clean hydrogen (IRENA, 2022).

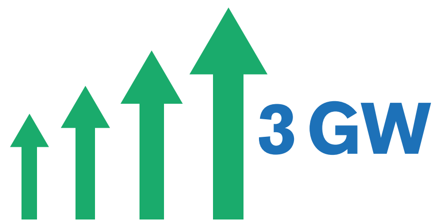
Global electrolyser manufacturing capacity currently stands at around 19 GW per year and is expected to reach 100 GW by 2030 based on announced projects. China currently accounts for around 40 per cent of global manufacturing capacity, and a number of economies, including India, the European Union and the United States, have launched policies aimed at supporting manufacturing capacity for electrolysers (IEA, 2023; Rystad Energy, 2023).

While electrolysers are already widely used in the chlor-alkaline industry, installed electrolyser capacity dedicated to the production of hydrogen could reach almost 3 GW by the end of 2023, a more than four-fold increase compared to 2022 (IEA, 2023). Further strong growth will be required to reach an installed capacity of more than 5,700 GW by 2050 to achieve a scenario limiting global warming to not more than 1.5°C, in which 14 per cent of final energy demand is supplied by hydrogen or its derivatives (IRENA, 2023a).

FIGURE 10:
Top five importers and exporters of electrolysers (US$ million)

Source: WTO Secretariat Analytical Database based on data originally sourced from the WTO Integrated Database, UN Comtrade and the Trade Data Monitor.





Between 2022 and end-2023, installed electrolyser capacity for producing hydrogen could more than quadruple to reach almost 3 GW.

Note: Electrolysers are included under Harmonized System (HS) subheading 854330: Machines and apparatus for electroplating, electrolysis or electrophoresis. It should be noted that the reported values represent trade in electrolysers and other machines for electroplating and electrophoresis.

International trade in electrolysers will play a key role in fostering innovation, scale economies and cost reductions, and in bringing electrolysers from where they are manufactured to where they are installed to produce clean hydrogen.

Global imports of electrolysers, together with certain other machines included under the same HS subheading, amounted to around US$ 1.62 billion in 2022, following two years of strong growth – a rise of 32 per cent in 2021 and of 9 per cent in 2022.

Key drivers of this growth were China, Indonesia, and the United States on the import side, and China, the United States and the Republic of Korea on the export side.

China was both the largest importer and supplier of electrolysers in 2022. The top five importers of electrolysers accounted for 64 per cent of global imports in 2022, while the top five suppliers accounted for more than three-quarters (76 per cent) of global imports in 2022 (see Figure 10 and Table 5).

TABLE 5

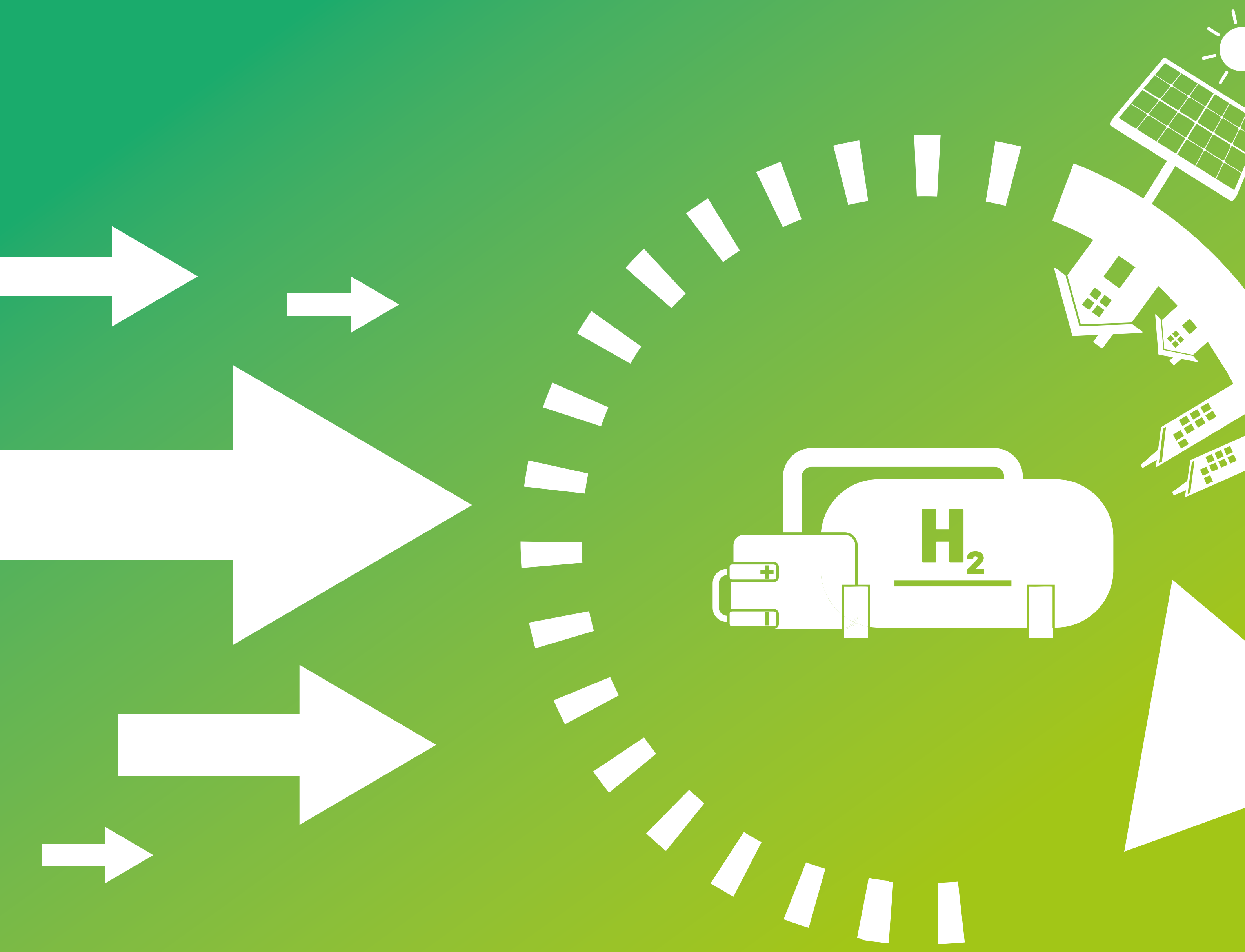
Top import markets for electrolysers and top three suppliers, 2022

Source: WTO Secretariat Analytical Database based on data originally sourced from the WTO Integrated Database, UN Comtrade and the Trade Data Monitor.

Importer	US$ million	Suppliers (percentage share in import market)
China	384.9	Japan (36), Korea, Republic of (20), Chinese Taipei (12)
Indonesia	226.8	China (89), Japan (7), Singapore (1)
United States	191.6	China (47), Japan (17), Germany (9)
Chinese Taipei	121.5	United States (37), Japan (27), China (14)
Malaysia	114.5	Korea, Republic of (52), Japan (26), China (12)
Viet Nam (2021)	52.2	China (37), Japan (25), Korea, Republic of (16)
India	49.6	Japan (36), China (30), Germany (21)
Democratic Republic of the Congo (2021)	45.8	China (97), India (2), United States (0)
Japan	40.6	China (46), Korea, Republic of (31), Malaysia (9)
Korea, Republic of	33.8	Japan (55), Germany (15), China (15)
Hong Kong, China	30.3	China (97), Chinese Taipei (2), United Kingdom (0)
Türkiye	26.4	China (31), Germany (27), Italy (24)
Brazil	24.8	Italy (35), Netherlands (23), Portugal (17)
Canada	22.9	Japan (29), China (25), United States (20)
Australia	22.3	United States (40), China (37), Japan (6)

Note: Electrolysers are included under Harmonized System (HS) subheading 854330: Machines and apparatus for electroplating, electrolysis or electrophoresis. It should be noted that the reported values represent trade in electrolysers and other machines for electroplating and electrophoresis.

3 TRADE-RELATED POLICIES ALONG THE HYDROGEN VALUE CHAIN



The deployment of green hydrogen is still at an early stage. As with other clean energy technologies, progress must be tracked effectively in order to assess whether hydrogen markets are evolving with a pace and in a direction allowing them to play their role in enhancing energy security and facilitating the clean energy transition (IEA, 2022).

Open, predictable and coherent trade policies will play an important role in fostering and shaping the development of green hydrogen supply chains. Tariffs and non-tariff measures – such as technical regulations and conformity assessment procedures, subsidies, antidumping and countervailing duties, trade-related investment measures, government procurement, and policies on services and intellectual property – affect trade along the supply chain.

The WTO provides a rules-based framework for trade-related policies, including on green hydrogen, and a forum for dialogue and experience-sharing. It enhances stability and predictability of policy frameworks through different transparency and monitoring mechanisms such as notification requirements under different WTO agreements and periodic reviews of WTO members' trade policies.

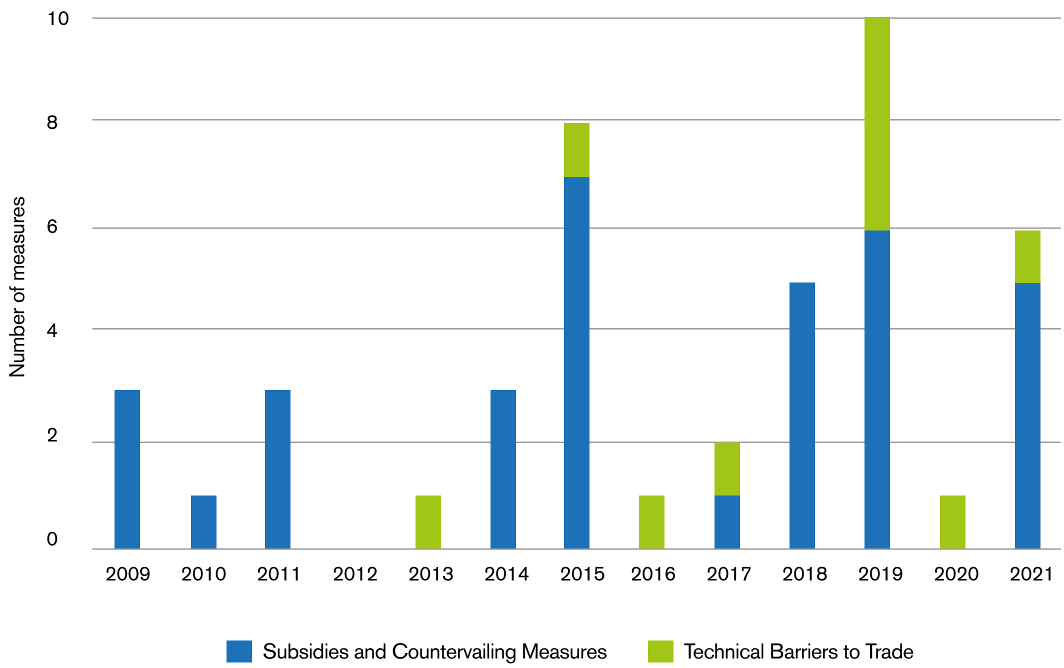
A review of environment-related notifications included in the WTO Environmental Database reveals that WTO members notified 44 hydrogen-related policies between 2009 and 2021. Most hydrogen-related policies take the form of support measures, such as

At present more than 30 countries around the globe have national strategies for low-carbon hydrogen.

FIGURE 11:

Hydrogen-related measures in members' notifications by WTO agreement

Source: WTO Environmental Database.



grants, loans or tax concessions, included in 34 notifications under the Agreement on Subsidies and Countervailing Measures (SCM), while 10 notifications on technical regulations were made under the Agreement on Technical Barriers to Trade (TBT) (see Figure 11).[1]

Recent support measures target the technology and production of renewable energy and hydrogen as well as of hydrogen fuel cells. Examples of support programmes notified under the rules of the SCM Agreement in 2021 include a Renewable Energy and Hydrogen Jobs Fund (Queensland, Australia), a subsidy fund for the hydrogen fuel cell industry (Jiangsu Province, China), support for hydrogen fuel cell vehicle distribution (Republic of Korea) and the Massachusetts Clean Energy Center – Investments in the Advancement of Technology (United States).[2] Examples of policies notified under the TBT Agreement include China's national standard on energy consumption and energy efficiency for hydrogen production through water electrolysis, and technical regulations by the Kingdom of Saudi Arabia and the United Arab Emirates on hydrogen and fuel cell vehicles.[3]

At present more than 30 countries around the globe have national strategies for low-carbon hydrogen.[4] For example, in 2023 the European Union adopted two delegated acts defining renewable hydrogen, and it has implemented funding mechanisms via the "Important Projects of Common European Interest"[5] and the hydrogen auction from the European Hydrogen Bank. The United States has important incentives for low-carbon hydrogen in its Inflation Reduction Act. In 2023, India adopted its National Green Hydrogen Mission to encourage electrolyser manufacturing. Several African countries, including Namibia and South Africa, have established national hydrogen strategies. Japan has an ambitious national strategy to locally produce and import low-carbon hydrogen, and China continues to lead in electrolyser capacity additions.

Between 2009 and 2021, 37 policies and measures aimed at developing hydrogen projects were mentioned in the trade policy reviews of several WTO members, including Argentina's temporary import tariff reduction on a quota of 6,000 hybrid, electric and hydrogen fuel cell motor vehicles, New Zealand's Hydrogen Vision, the United Arab Emirates' Hydrogen Leadership Roadmap, and support programmes of different members.

3.1 Tariffs and other taxes

Trade costs are an important determinant of the viability of supplying green hydrogen across borders for end use, such as in industry and transport. The average applied tariff rate on hydrogen (green and other forms) is around 5.3 per cent in 153 WTO members, higher than for ammonia (4.4 per cent) and methanol (5.0 per cent). Some 39 members apply rates between 5 and 10 per cent on hydrogen imports, while seven members apply rates higher than 10 per cent (see Figure 12).

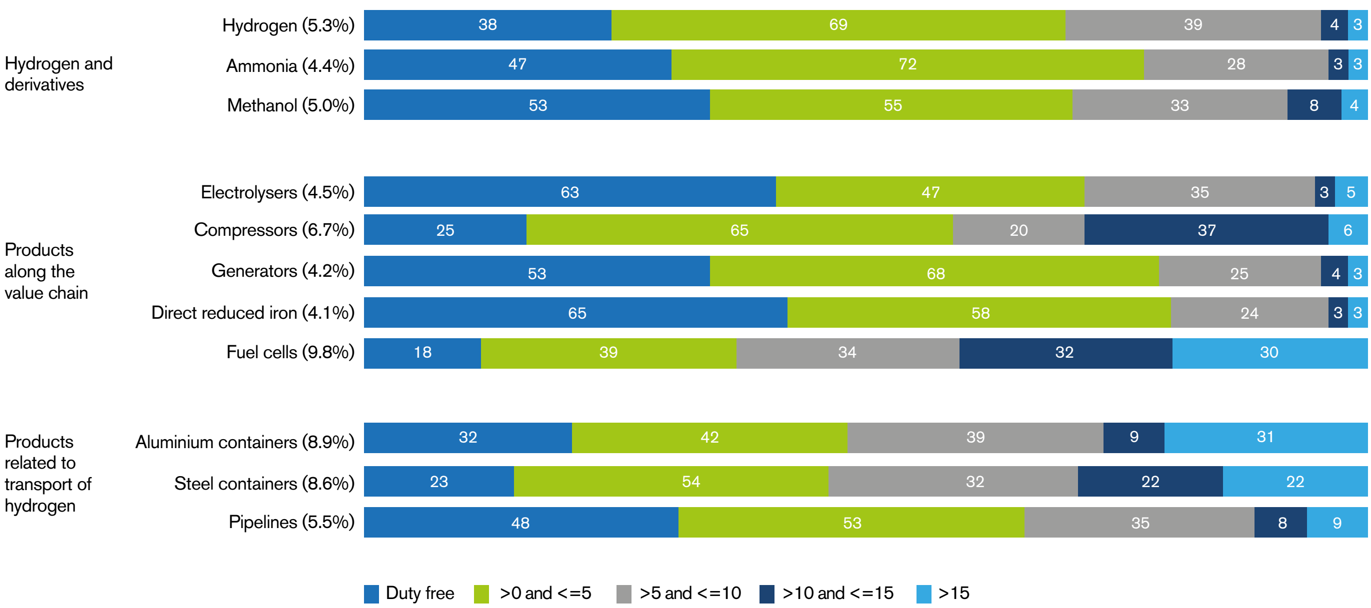
In addition to tariffs, hydrogen and commodities produced with hydrogen, such as ammonia or direct-reduced iron, may be subject to taxes based on their carbon content. For example, under the European Union's Carbon Border Adjustment Mechanism (CBAM), importers of hydrogen, ammonia, steel are required to report the greenhouse gas (GHG) emissions caused in their production, and, starting in 2026, may face an adjustment to align the price of embedded carbon with the carbon price on the EU market. This means that green hydrogen, and ammonia or iron produced with green hydrogen, may face lower costs based on their carbon content.

Open trade in products along the supply chain can foster access to technology, lower costs and promote green hydrogen production. Upstream in the chain, promoting goods and services related to renewable energy production can help to reduce the costs of energy used in the production of green hydrogen. For example, the significant fall in the costs of solar PV energy described above was supported by an open and transparent trade regime which has enabled the emergence of a globally integrated solar PV market (WTO and IRENA, 2021).

FIGURE 12:

Average applied most-favoured-nation tariffs (in parentheses) and number of members by tariff range (bars)

Source: WTO Integrated Database.



Note: Tariffs for 153 reporters, with the most recent year selected between 2020 and 2023. The European Union counts as a single member.

There might be scope to further reduce tariffs on products along the green hydrogen supply chain. Besides renewable energy, electrolysers are another key cost factor for green hydrogen. The average tariff on electrolysers is relatively low, at 4.5 per cent, and more than 60 WTO members provide duty-free access to their markets. However, in 43 members the applied tariff rate is higher than 5 per cent.

For compressors, which are used to compress hydrogen prior or during transport, average tariffs are higher, at 6.7 per cent, and 43 WTO members apply tariffs of more than 10 per cent. Tariffs are highest on other primary cells and batteries, which include hydrogen fuel cells; the average rate is 9.8 per cent, and more than 60 WTO members apply rates higher than 10 per cent.

3.2 Quality infrastructure – standards, certification and beyond

In order to increase global trade in green hydrogen, an effective system will need to be developed to ensure the safety, performance and sustainability attributes of the products and services to be traded. Quality infrastructure (QI) is the national system of organizations, policies, legal frameworks and practices required to assure the quality, safety and sustainability of products and services.

QI comprises metrology (i.e., the scientific study of measurement), standardization, accreditation and conformity assessment, including testing, certification and inspection. Having a robust and internationally harmonized QI system creates the technical basis for the development of the green hydrogen sector, as it helps to reduce the safety, financial and reputational risks in the sector, while supporting the achievement of the intended positive sustainability impacts of investments.

Quality infrastructure to ensure sustainability

Exporters may need to demonstrate the trustworthiness of their own processes and carbon measurements, as well as of the underlying carbon quantification systems. For instance, an accredited third party may be required to verify the carbon content of hydrogen before it is imported to an economy that applies a trade-related climate policy. In this situation, the importing economy applying the policy will need to be able to trust the technical competency of the bodies and systems underpinning the carbon quantification systems in the exporting country (WTO, 2022a).

As indicated in Section 1.1, the global production of hydrogen is currently almost exclusively derived from fossil fuels without associated carbon capture and storage, meaning that it is a major net contributor to climate change, rather than a vector for decarbonization. This fossil-fuel-based hydrogen is predominantly utilized in industry, for example for oil refining, fertilizer production, and downstream chemical processes.

Arriving at a net-zero world will necessitate a transition away from fossil-based hydrogen to a green hydrogen supply, as green hydrogen could offer a solution to decarbonize certain applications – including those in which fossil fuel-based hydrogen is used today – in heavy industry, shipping, aviation and seasonal storage, among others. Green hydrogen could thus act as the link between renewable electricity generation and hard-to-abate sectors or applications (IRENA, 2022a).

At present, there is a wide variety of methods to produce hydrogen, which differ according to their production processes and the GHG emissions released during production. The three most commonly used options are "grey hydrogen" (fossil-fuel-based), "blue hydrogen" (fossil-fuel-based production with carbon capture, utilization and storage) and "green hydrogen" (renewables-based) (IRENA, 2019). Other colours of hydrogen also exist, such as "turquoise hydrogen" (produced through a process called methane pyrolysis) and "pink hydrogen" (produced through electrolysis of water, but with the electrolysis powered by nuclear power instead of renewables).

Since it is not possible to "see" the carbon content or the process used for producing hydrogen, the role of standards, technical regulations and verification procedures will be crucial for the establishment of a well-functioning international green hydrogen market. As the world seeks to transition to the production of predominantly green hydrogen over the next few decades, the development of a robust system of standards, technical regulations and certification along the green hydrogen supply chain, including for derivatives such as ammonia, will be necessary to guarantee the environmental integrity of green hydrogen production and provide information on the production process and emissions footprint along the value chain.[6] Actors involved in the hydrogen market need a stable regulatory framework. However, in this nascent industry, maintaining a dynamic regulatory approach is important to encourage investments (IEA, 2022).

Given the wide variety of production methods that can be used to produce hydrogen, international standards establishing agreed methodologies to evaluate its environmental attributes – markedly its carbon footprint – will play an important role in accelerating the uptake of green hydrogen production facilities and in avoiding obstacles to trade in green hydrogen. Ideally, approaches for measuring the carbon footprint of hydrogen should be based on international standards agreed by consensus.

The International Organization for Standardization (ISO) is developing an international standard, based on previous work from the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), to measure the carbon content of hydrogen with a life cycle approach (IEA, IRENA and UN High Level Champions, 2023). This new standard, ISO 19870,[7] will provide approaches that may be applied to determine the greenhouse gas emissions associated with the production, conditioning and transportation of hydrogen to where it is consumed, in line with ISO 14067 (i.e., "Greenhouse gases; Carbon footprint of products: Requirements and guidelines for quantification").[8]

Quality infrastructure to ensure safety and performance

The key QI services that support the green hydrogen sector are as follows:

Metrology

Standards and methods related to metrology should allow traceable validation and performance evaluation of gas quality, as well as methods for evaluating the uncertainty of the measurements applied along the entire green hydrogen value chain. Economies with advanced metrological systems already have most of the services necessary to cater to the green hydrogen industry. However, they need to develop and provide tailored services, such as measurement of very high pressures and achieving small measurement uncertainties, which are required for tests of equipment durability and for the detection of leaks during the generation, distribution and storage of hydrogen.

Technical standards

There is a need for standards in the areas of the distribution, storage and transfer of hydrogen to the end-user. More QI insights (especially standards) are required with regard to transport of hydrogen through existing gas pipelines. In the context of IRENA's ongoing project on quality infrastructure for green hydrogen, experts noted that there is a serious threat of hydrogen damage, particularly for older gas pipelines with corrosion and other mechanical damages, with long-term blended or 100 per cent hydrogen service. Experts engaged in the project suggest promoting the implementation of standards for the design and construction of hydrogen pipelines (such as the ASME B31.12 Standard on Hydrogen Piping and Pipelines) to guard against hydrogen embrittlement by increasing the wall thickness of

pipelines.[9] There is also a strong call by pipeline experts to accelerate the development and standardization of high-pressure gaseous hydrogen-charging test methods and codes for investigation of the hydrogen embrittlement susceptibility of pipeline steels.

Certification and accreditation

At the international level, the International Electrotechnical Commission (IEC) has established two certification schemes relevant to green hydrogen: the IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications (IECRE), which is concerned with renewable energy technologies; and the International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres (IECEx). Economies with advanced QI systems have internationally recognized accreditation bodies, which must expand their accreditation scope to fulfil the newly developing requirements. Examples include new certification schemes that have been specifically established for the green hydrogen sector. Furthermore, these bodies should invest in enhancing the technical competence of the assessors to adequately assess the compliance of service providers to fulfil these new requirements, such as laboratories performing specific safety tests based on new standards for hydrogen storage infrastructure. A further look into key QI services that support the green hydrogen sector can be found in the Annex.

Principles to develop a quality infrastructure aligned with trade policies

As governments around the world start regulating hydrogen production and consumption, WTO disciplines can provide useful guidance for this nascent industry. First, under the TBT Agreement, technical regulations shall not create unnecessary obstacles to international trade.

Moreover, the WTO TBT Agreement strongly encourages the use of relevant international standards when enacting technical regulations. Technical regulations[10] in accordance with relevant international standards are, a priori, considered not to create unnecessary obstacles to international trade under the TBT Agreement. In and of itself, this presumption of conformity can be a strong incentive to use international standards when regulating green hydrogen production.[11]
The way international standards for green hydrogen production are set will have a decisive impact on the extent to which those standards are actually used.
In this regard, the WTO TBT Committee has developed six "Principles for the Development of International Standards, Guides and Recommendations".[12] The guidance provided through these "Six Principles" could play a significant role in the development of relevant international standards relating to green hydrogen production. For instance, observing these principles would ensure, among others, that relevant information could be made available to all interested parties, that sufficient opportunities for written comments could be provided, that conflicting international standards would not be adopted, and, importantly, that constraints facing developing economies could be considered.[13]

A recent report by IRENA and RMI analysed existing voluntary and mandatory schemes to measure and/or certify the carbon intensity of hydrogen (IRENA and RMI, 2023). The analysis concluded that the current landscape of schemes is still inadequate to enable international trade, as existing approaches vary substantially in terms of emissions thresholds, boundaries of analysis and acceptable production pathways and energy sources, among others.

But what is to be done in the absence of convergence around an international standard? Such situations may arise, among other reasons, because countries have different levels of development and national capabilities to implement standards, or because a relevant international standard does not exist for an emerging technology, like green hydrogen.

In such situations, dialogue and cooperation to avoid unnecessary negative trade impacts will be particularly important. Regulatory cooperation between WTO members may be an effective means of building trust between regulators, as it allows them to learn about each other's systems. Sharing experiences in regional and multilateral settings can help to bring approaches closer, and eventually enable them to converge through the development of international guidance (WTO, 2022a).

Given the wide variety of verification procedures that members may adopt to ensure compliance with trade-related climate change measures, convergence around methodologies is crucial to reduce trade barriers. WTO disciplines promote harmonization based on relevant guides or recommendations issued by international standardizing bodies as a means of avoiding unnecessary obstacles to trade. This is important because harmonized procedures minimize differences in terms of the verifiers' competences and verification approaches, which increases the overall quality of verification.

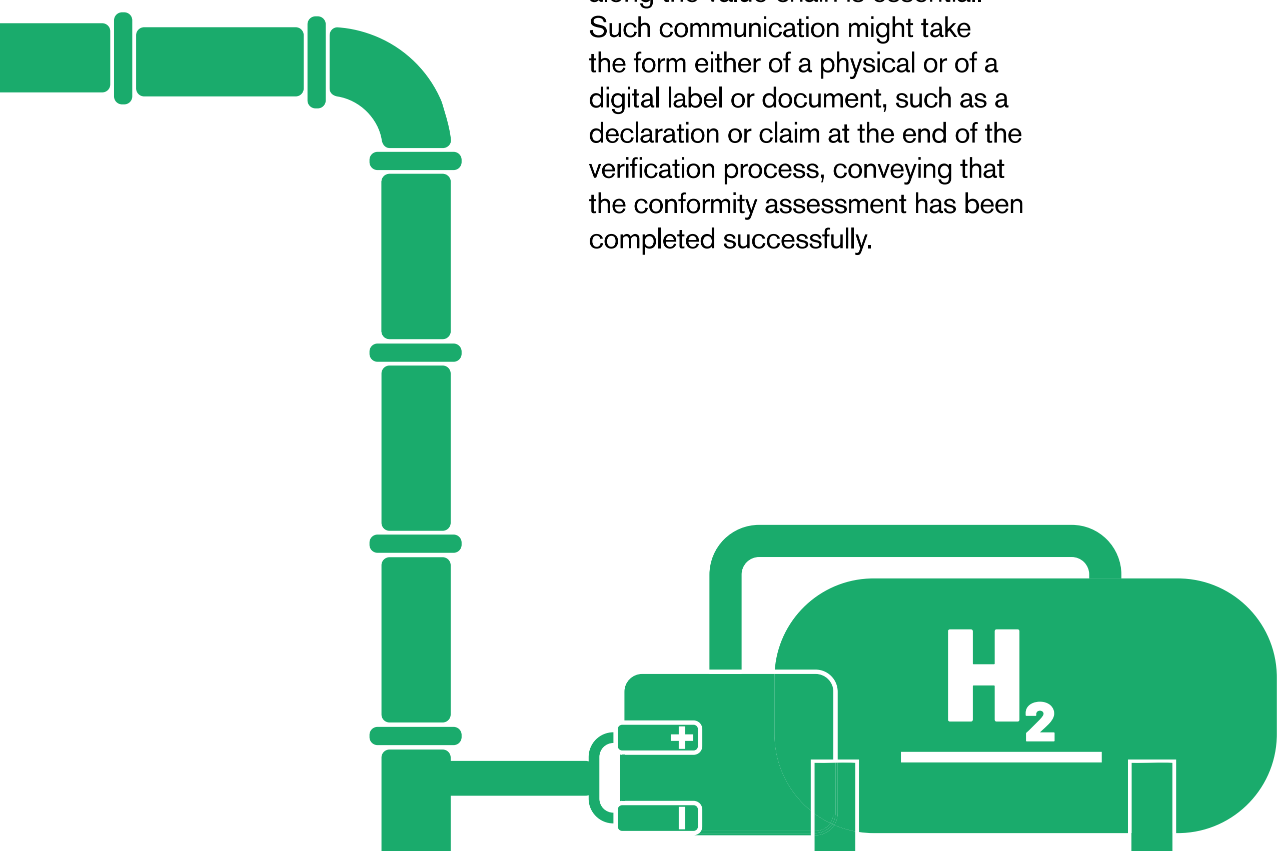
Moreover, the TBT Agreement promotes dialogue by encouraging members to accept, whenever possible, the results of conformity assessment procedures performed by other members, even when those procedures differ from their own.[14] The TBT Committee has provided guidance in this area by developing an "Indicative List of Approaches to Facilitate the Acceptance of the Results of Conformity Assessment"[15] covering a range of approaches that governments might choose to facilitate recognition.[16] WTO disciplines also govern the type of conformity assessment procedure that members may choose to ensure compliance with technical regulations or standards. For example, the selected conformity assessment procedure should not be stricter, or be applied more strictly, than is necessary to give the importing member adequate confidence that products conform with the applicable technical regulations or standards.[17]

As it is generally not possible to determine how hydrogen is produced merely by looking at the product, communication of this information to authorities and along the value chain is essential. Such communication might take the form either of a physical or of a digital label or document, such as a declaration or claim at the end of the verification process, conveying that the conformity assessment has been completed successfully.

One key challenge is ensuring that labelling requirements are clear and credible and achieve the desired policy objectives without creating unnecessary obstacles to international trade. The information conveyed to consumers through labels should not create consumer confusion. The design of the labels should ensure that any claims they make are trustworthy.

Labelling measures are covered by the definitions of both "standards" and "technical regulations" in the TBT Agreement.[18] As such, labelling measures should be based on international guidance where it exists. They should not be discriminatory, should not create unnecessary barriers to trade, and may need to be notified to the WTO. Ultimately, well-designed labelling measures could also facilitate flows of green hydrogen and its derivatives.

> As governments around the world start regulating hydrogen production and consumption, WTO disciplines can provide useful guidance.



3.3 Subsidies

Currently, green hydrogen is more costly to produce than fossil-based hydrogen without carbon capture and storage. IRENA estimates that to achieve a net-zero pathway by 2050 with associated midstream and end-use investments, average total annual investments of US$ 136 billion will be necessary across the hydrogen value chain between 2023 and 2050. Therefore, although investment of US$ 160 billion in projects has been announced, a significant investment gap of US$ 790 billion, which should be filled by 2030, remains across the hydrogen value chain (IRENA, 2023a).

Phasing out fossil fuel subsidies and redirecting funding towards renewable energy and green hydrogen production has a strong potential to stimulate this transition.

Phasing out fossil fuel subsidies

Underpricing fossil fuels undermines domestic and global environmental objectives. In addition, it is a highly inefficient policy for helping low-income households, and has a sizeable fiscal cost for governments.

Government support for fossil fuels almost doubled to US$ 697.2 billion in 2021, up from US$ 362.4 billion in 2020 (OECD and IEA, 2022). The energy crisis only strengthened this trend in 2022.

Increased fossil fuel use contributes not only to climate change but also exacerbates air, water and plastic pollution, worsens land degradation, and locks economies into high-carbon production cycles. Fossil fuel subsidies generate inefficiencies in the production and use of energy economy-wide, and skew long-term capital investment towards fossil fuel producers or fossil-fuel-intensive industries, thus enhancing the risk of locking economies into using high-carbon infrastructure and assets (OECD and IEA, 2021).

The International Institute for Sustainable Development (IISD) estimates that if a set of 32 major developed, emerging, and developing economies reformed fossil fuel subsidies by 2025, this would reduce CO_2 emissions by an average of 6 per cent by 2030, and in the case of some economies, by up to 35 per cent. The reinvestment of just a third of the savings coming from such reform into energy efficiency and renewable energy (a “subsidy swap”) would reduce CO_2 emissions by an additional 3 per cent by 2030 (IISD, 2022). By phasing out fossil fuel subsidies, policymakers can specifically help to close the economic gap with green hydrogen, while unveiling the real price of fossil fuels (IRENA, 2020b).

The phasing-out of fossil fuel subsidies also affects the carbon price (i.e., the cost applied to carbon emissions to incentivize reduction). Because fossil fuel subsidies essentially function as a negative carbon price, removing these subsidies results in an increase in the price of carbon-based fuels. Potential reform of fossil fuel subsidies therefore enables the incorporation of costs of environmental externalities that are not reflected under the subsidized prices, and thereby incentivizes a decreased use of fossil fuels (WTO, 2022b). This, in turn, could increase the competitiveness of green alternatives, such as green hydrogen and its derivative green commodities.

Boosting support for green hydrogen and its derivatives

Achieving the scale-up and associated improvement in cost competitiveness of green hydrogen and its derivatives requires significant investment. Funding of the economic gap is required until a break-even point is reached, i.e., an investment to offset the initially higher costs of hydrogen and of hydrogen equipment compared to alternatives (Hydrogen Council, 2020).

A growing number of economies use subsidies either to encourage producers to invent, adopt and deploy low-carbon technologies, or to encourage consumers to purchase environmentally sustainable products and services. If they are well-targeted and non-discriminatory, environmental subsidies can play a positive role in scaling up new technologies and making climate-friendly products more affordable (WTO, 2022b). In other words, subsidies should aim to boost innovation where support is most needed, e.g., for cleantech startups, and should not place imported products at a competitive disadvantage vis-à-vis similar products from another origin in the absence of a legitimate reason for the differentiation.

Domestic support schemes used for solar photovoltaic and wind power have ensured cost competitiveness with fossil fuel alternatives. For example, R&D subsidies can lower costs and improve the performance of low-carbon technologies, as well as foster innovation in environmental technologies. Subsidies can also be given to producers of renewable energy. Feed-in tariffs and contracts for differences, for instance, allow renewable energy producers to receive a guaranteed price for each unit of electricity generated, guaranteed grid access and long-term contracts with electric grid utilities. Finally, subsidies can be provided to consumers to encourage the adoption of low-carbon products and technologies, for example LED lighting or electric vehicles (WTO, 2022b).

Similarly, governmental support policies can help sustain growth in electrolyser capacity and green hydrogen production by promoting cost efficiencies and narrowing the cost differential between the costs of producing green and fossil-based hydrogen (IRENA, 2020b), such as in the following ways:

- Setting targets for electrolyser capacity, similar to those for renewable energy, can signal economies' commitments to the private sector, thereby attracting more investment.
- Utilizing financial instruments, such as government loans, equity investment, risk mitigation tools, credit guarantees, etc., can strengthen the business case for the installation of electrolysers.
- Modulating the tax structure, especially on electricity consumed by electrolysers, can make green hydrogen production more cost-effective. In addition, revising corporate, business and sales taxes related to green hydrogen can improve revenues and the rate of return on projects.
- Setting ambitious targets for renewable energy capacity can ensure a steady supply of renewable electricity, catering to both the direct electrification needs and hydrogen production as the market for green hydrogen expands.
- Increasing support for R&D can lead to improvements in electrolyser efficiency and the development of standardized, cost-effective designs for large-scale electrolysers.
- Mitigating country-related investment risks can contribute to reducing the cost of production of green hydrogen by reducing the cost of capital.

Similar support measures can be tailored to address challenges related to transport and storage of green hydrogen (e.g., by financing infrastructure development), to use green hydrogen in industrial processes (e.g., by making available loans and specialized funds to render investment in green pathways financially more attractive), or to use green hydrogen to produce synthetic jet fuels and for maritime shipping (e.g., by providing financial mechanisms or fiscal adjustments to minimize the cost gap between fossil fuels and environmentally-friendly alternatives) (IRENA, 2020b).

These trends are already visible. Support for low-carbon hydrogen has quadrupled over the last two years to more than US$ 280 billion. The United States leads the list, with support of US$ 137 billion expected to flow to selected projects over the next 10 years, making clean hydrogen cheaper for the whole world (Bhashyam, 2023).

Importance of transparency, dialogue and cooperation

Some types of support measures can create trade tensions, such as those that attribute exclusive rights to the use of research output by domestic firms or that are provided to shield domestic producers from foreign competition, or strategically for industrial policy purposes. For instance, subsidies with local content requirements can spur investment in homegrown climate-friendly infrastructure and technology, but at the same time be trade-restricting (WTO, 2022b).

Subsidy reforms must therefore be designed with both economic and social considerations in mind and must prioritize a just and equitable transition. Greater transparency and a deeper understanding of the flows of subsidies are prerequisites to ensuring effective and accountable reform. This will pave the way for a careful assessment of the most environmentally harmful subsidies.

In addition, enhanced multilateral cooperation and dialogue could play a positive role in preventing an inefficient race to subsidize environmentally positive, or "green", technology, which could cause avoidable trade tensions, distort international competition and disproportionately harm smaller, fiscally constrained developing economies (see Box 1).

Furthermore, transparency and the need for improved rules to address certain types of subsidies have long been on the agenda of various WTO bodies, such as the General Council, the Committee on Subsidies and Countervailing Measures (SCM Committee), and the Committee on Agriculture (CoA). The WTO organizes technical assistance activities at both the national and regional levels, often with a specific focus on notification obligations. In collaboration with requesting members, individualized technical assistance that also addresses subsidy analysis and design can be provided by international organizations to meet needs of developing members with capacity constraints (IMF, OECD, World Bank and WTO, 2022).

Enhanced multilateral cooperation and dialogue could play a positive role in preventing an inefficient race to subsidize "green" technology

Box 1: WTO environmental initiatives

Two new environmental initiatives at the WTO specifically address the environmental effects and potential reform of subsidies. In the working group on subsidies of the Trade and Environmental Sustainability Structured Discussions (TESSD), participating WTO members have been discussing the environmental and trade effects of subsidies, as well as how to enhance transparency.

Participating members have put a focus on sharing their experiences and considerations regarding the design of subsidies related to the transition to a low-carbon economy, including support measures to foster investment in clean energy and hydrogen.

The Fossil Fuel Subsidy Reform (FFSR) initiative builds upon the comprehensive benefits – spanning trade, economy, society and environment – of addressing fossil fuel subsidies and reallocating government funds towards green, climate-resilient projects. Discussions have highlighted the need to enhance the transparency of fossil fuel subsidies and to consider the developmental and social issues involved in their reform.

3.4 Sustainable government procurement

Government (public) procurement is of great economic importance, accounting for 10-15 per cent of national GDP, on average, and about 13 per cent of world GDP (around US$ 13 trillion per year). Government procurement is estimated to be directly or indirectly responsible for 15 per cent of global GHG emissions.[19] According to the World Economic Forum (WEF), abating emissions from government procurement would lead to a US$ 4 trillion boost to the green economy and create around 3 million new jobs (WEF, 2022).

High coal and gas prices in 2021 and 2022 have affected the competitiveness of fossil fuels temporarily. The recovery from the COVID-19 crisis and the response to the global energy crisis have also provided a significant boost to clean energy investment (IEA, 2023). At the same time, investment decisions are still impeded by a general uncertainty surrounding the long-term development of energy prices as well as the overall energy policy targets and supporting policies. Policies to create demand for low-emission hydrogen, including requirements in government procurement, are therefore important to boost market demand (IEA, 2022).

Through sustainable government procurement policies, governments can influence private-sector producers by purchasing low-carbon goods and services and can create markets for new entrants and stimulate innovative solutions to climate change problems by awarding public R&D contracts. Given the sheer volume of demand for goods and services that government procurement can represent, sustainable government procurement can create a large and stable demand for new low-carbon solutions before a commercial market is viable (WTO, 2022b). Government procurement can be aligned with GHG emissions targets by introducing requirements or preferential treatments for low-carbon emissions for products and services (Australian Industry ETI, 2023).

While most of the technologies needed for the global energy transition are available, some of them are at earlier stages of development and need support to accelerate their rapid commercialization. Such technologies could be particularly important for developing additional green hydrogen capacity. Sustainable government procurement can accelerate the deployment of green hydrogen, of its derivatives and of related climate-friendly technologies by creating a stable demand for those products at lower costs and reducing hydrogen uptake uncertainty (IRENA and WEF, 2022). To do this, government procurement policies and practices must focus on giving a strong preference to renewable energy and green hydrogen and on spurring the use of green hydrogen in the sectors that are hardest to electrify (Green Hydrogen Organisation, 2022).

Sustainable government procurement strategies

Key actions could include introducing minimum requirements for green products in public authorities' procurement processes, introducing green material requirements in policies, such as in auctions for renewable energy, and ensuring the presence of a verification and labelling system to guarantee the sustainability of the products (IRENA and WEF, 2022). In doing so, governments should give a strong preference to the procurement of green hydrogen for those sectors where direct electrification with renewables is not a viable decarbonization option.

Government procurement targets could focus on the industrial use of hydrogen to provide an indicative level of future green hydrogen consumption and, therefore, of future procurement needs. For example, in Spain's hydrogen strategy, the government included a 25 per cent minimum contribution of green hydrogen to total hydrogen consumption in 2030 by all industries, both as a feedstock and as an energy carrier (IRENA, 2022d).

Another solution that governments can provide is a centralized auction scheme to promote hydrogen purchase and consumption, with the cost differential paid for by a public body. A public body would act as central auctioneer and would sign long-term purchase agreements for electrolysers and sale agreements with industrial players. If auctions are successful in reducing the cost of green hydrogen, as has been done for solar PV and wind energy, this would significantly improve green hydrogen's business case in various industries. This kind of scheme is currently being designed in Germany under the H2Global Stiftung – a foundation that promotes the national and international production and use of climate-neutral energy carriers, such as green hydrogen (IRENA, 2022d).

Extending sustainable government procurement beyond green hydrogen and its derivatives to other green goods in the hydrogen supply chains can also have beneficial effects on driving demand. For instance, governments could institutionalize preferential purchasing of steel or other products made sustainably through the use of green hydrogen, or that require the inclusion of a higher share of those products in the overall material mix (IRENA, 2020b). Since steel and chemical industries are very capital-intensive, economies of scale and low raw material and energy prices are crucial to profitability. Furthermore, given the need to experiment with different production technologies, any such investment could be too great for a single firm in the absence of clear demand for green materials or goods (IRENA, 2022d).

Sustainable government procurement could have a particularly large impact on the creation of a green steel market, given that steel is used to construct buildings, bridges, railways and transport fleets. A recent example is the Buy Clean California Act, which imposes a maximum acceptable global warming potential limit on selected construction materials. It targets, among other materials, carbon emissions associated with the production of structural steel and concrete reinforcing steel (IRENA, 2022d).

Importance of international cooperation

International cooperation is vital to create demand for green and low-carbon hydrogen use, particularly in priority sectors like heavy industry, maritime shipping and aviation, where competition could hinder decarbonization efforts. Coordinated demand-creating policies can send a stronger signal to mobilize investment in low-carbon and green hydrogen production, while collaboration allows actors to share experiences of establishing more secure, diversified demand for hydrogen over time. Both are crucial to achieving economies of scale and accelerating cost reductions on the supply side.

Various initiatives are in place to facilitate coordination between countries and private sector stakeholders. For instance, the Mission Innovation Hydrogen Valley Platform 2.0, which showcases hydrogen valley projects (i.e., a geographical area combining several hydrogen applications into an integrated ecosystem)[20] around the world, was relaunched in May 2023. Based on extensive collection of primary data, the platform provides insights into the most ambitious hydrogen valleys around the globe. If all of the 83 valleys showcased on the platform are realised, they will unlock significant demand for renewable and low-carbon hydrogen (IEA, IRENA and UN Climate Change High-Level Champions, 2023).

The plurilateral WTO Agreement on Government Procurement (GPA 2012), together with other WTO rules, can play an important role in ensuring that open government procurement markets are leveraged to support green hydrogen markets. The GPA helps governments to overcome a home bias in government procurement by ensuring that sustainable government procurement practices are non-discriminatory, based on open markets, and in line with good governance practices. By opening domestic procurement markets to foreign competition, the GPA 2012 can also help governments to obtain better value for money for climate-friendly goods and services, including of hydrogen, its derivatives and related technologies. It can do so by increasing the number of bidders, including foreign bidders, and by facilitating access to climate-friendly technologies that may not otherwise be available in the domestic market. In particular, the Agreement allows parties to apply technical specifications aimed at promoting natural resource conservation or protecting the environment, as well as to use the environmental characteristics of a good or service as an award criterion in evaluating tenders (WTO, 2022b). The GPA parties, mindful of the importance of government procurement as a strategic tool to promote environmental sustainability, among other things, initiated a Work Programme on Sustainable Procurement in 2014.

The WTO can help by providing examples of what members are already doing in terms of government procurement, including by providing dedicated fora for policy learning and exchange, such as the Committee on Trade and Environment or the Committee on Government Procurement, and by providing technical assistance to those seeking to explore this option further. The WTO Secretariat's technical assistance and related programmes concerning government procurement policy and the GPA can also serve as a valuable tool to facilitate informal discussions on related issues among interested officials from economies around the globe.

Endnotes

[1] The SCM Agreement requires that WTO members submit a new and full notification of all specific subsidies every three years, with updated notifications due in the intervening years. The notification obligation extends to all specific subsidies related to goods, in any sector, and provided by any level of government (i.e., national, regional, state/provincial or local). Under the TBT Agreement, WTO members are obliged to notify draft technical regulations and conformity assessment procedures that are not in accordance with relevant international standards or recommendations issued by international standardizing bodies (or such standards and recommendations do not exist) and to indicate whether the technical regulation or conformity assessment procedure may have a significant impact on trade.

[2] The WTO official document numbers for these respective notifications are G/SCM/N/372/AUS, G/SCM/N/372/USA, G/SCM/N/372/CHN and G/SCM/N/372/KOR. Official documents can be viewed at https://docs.wto.org/.

[3] The WTO official document numbers for these respective notifications are G/TBT/N/SAU/1225, G/TBT/N/ARE/461, G/TBT/N/CHN/1131. Official documents can be viewed at https://docs.wto.org/.

[4] See Policies for green hydrogen (irena.org).

[5] See https://commission.europa.eu/projects/hydrogen-projects-within-framework-ipceis_en.

[6] For a discussion on the role of standards and verification methods in the area of climate-related policies, see WTO (2022a).

[7] See https://www.iso.org/standard/65628.html.

[8] See https://www.iso.org/standard/71206.html.

[9] See https://www.asme.org/codes-standards/find-codes-standards/b31-12-hydrogen-piping-pipelines/2019/drm-enabled-pdf.

[10] TBT Agreement, Article 2.4 ("Preparation, Adoption and Application of Technical Regulations by Central Government Bodies"). See https://www.wto.org/english/docs_e/legal_e/17-tbt_e.htm.

[11] TBT Agreement, Article 2.5 ("Preparation, Adoption and Application of Technical Regulations by Central Government Bodies"). See https://www.wto.org/english/docs_e/legal_e/17-tbt_e.htm.

[12] See https://www.wto.org/english/tratop_e/tbt_e/principles_standards_tbt_e.htm.

[13] Essentially, the "Six Principles" are intended to help international standards better facilitate global trade and to provide guidance in the areas of "transparency", "openness", "impartiality and consensus", "effectiveness and relevance", "coherence" and "development dimension".

[14] TBT Agreement, Article 6.1 ("Recognition of Conformity Assessment by Central Government Bodies"). See https://www.wto.org/english/docs_e/legal_e/17-tbt_e.htm#articleVI.

[15] See WTO official document number G/TBT/1/Rev.15, pp. 66-67. Official documents can be viewed at https://docs.wto.org/.

[16] The approaches that governments might choose to facilitate recognition include the following options: (i) mutual recognition agreements for conformity assessment to specific regulations; (ii) cooperative (voluntary) arrangements between domestic and foreign conformity assessment bodies; (iii) the use of accreditation to qualify (or recognize) conformity assessment bodies; and (iv) the designation by governments of specific conformity assessment bodies, including bodies located outside their territories, to undertake conformity assessment.

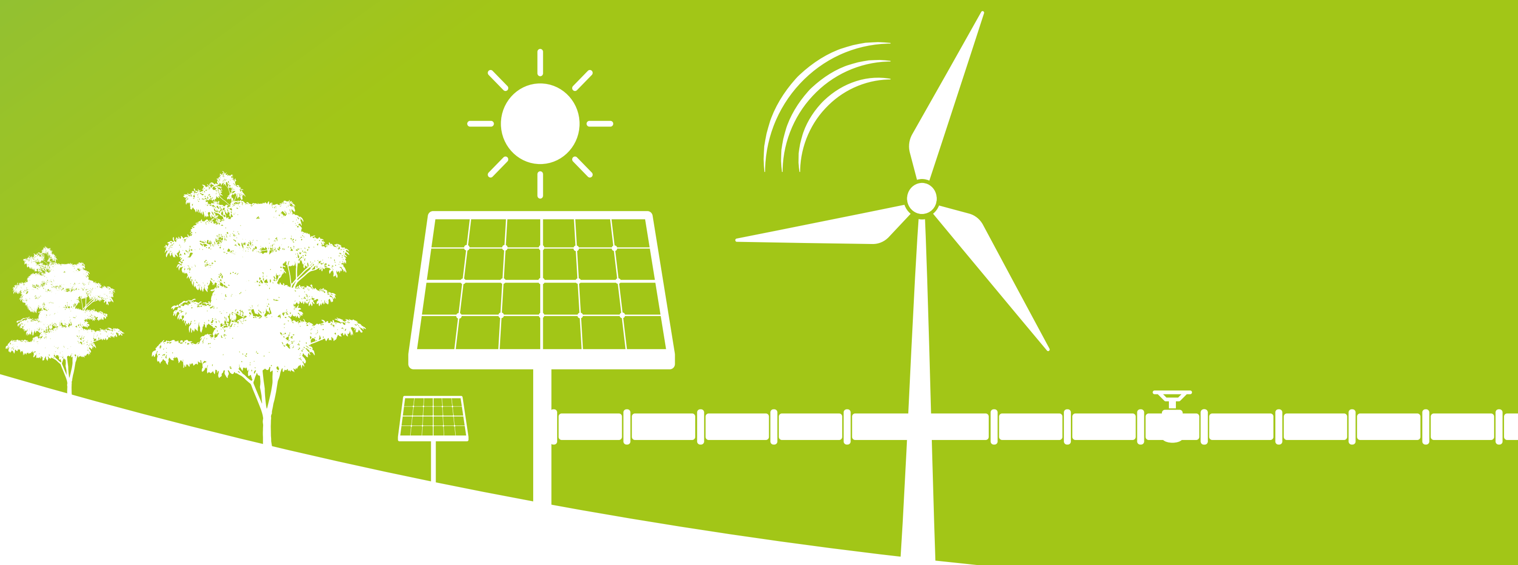
[17] TBT Agreement, Article 5.1.2 ("Procedures for Assessment of Conformity by Central Government Bodies"). See https://www.wto.org/english/docs_e/legal_e/17-tbt_e.htm#articleV.

[18] TBT Agreement, Annex 1, Paragraphs 1 and 2 ("Terms and their Definitions for the Purpose of this Agreement"). See https://www.wto.org/english/docs_e/legal_e/17-tbt_e.htm#annexI.

[19] This footprint is explained by the mix of goods and services that governments purchase, which notably comprises goods or services of the construction, transport, defence, utilities, waste management and other industries.

[20] See https://www.clean-hydrogen.europa.eu/get-involved/mission-innovation-hydrogen-valleys-platform_en.

4 CONSIDERATIONS FOR DEVELOPMENT



Recent projects show the important role that green hydrogen production can play in accelerating developing economies' transition to net zero and their inclusion in green value chains. For instance, Kenya's 2023 Hydrogen Roadmap lays out initial plans for reaching 100 MW of installed electrolyser capacity by 2027 and supporting production of 100,000 tons per year of nitrogen fertilizers, which would replace around 20 per cent of the country's fertilizer imports. In a second stage, by 2032, Kenya would target between 150-250 MW of installed electrolyser capacity, increasing domestic fertilizer production to up to 400,000 tons per year in the hope of exploring opportunities for exporting green fertilizers within the region.[1] In its Hydrogen Roadmap, also launched in 2023, Malaysia shares its intent to increase the share of clean energy in the country's energy mix by promoting the use of hydrogen in energy storage and as a fuel. Malaysia further intends to invest in hydrogen technologies in order to address domestic consumption, energy security, sustainability of international energy trading and decarbonization.[2]

Factors fostering green hydrogen production in developing countries

In an emerging market such as the green hydrogen market, access to low-cost and stable renewable electricity, such as that from solar PV- or wind-powered electricity, together with water availability, is an important prerequisite for investors selecting large-scale project locations. Another criterion is the existence of land and infrastructure, while the availability of power transmission lines, inbound and outbound logistics infrastructures and deep-sea harbours, especially for exports of ammonia, steel or synthetic fuels, prove decisive for some projects (Cordonnier and Saygin, 2022).

Existing and mature hydrogen markets can increase an economy's potential for green

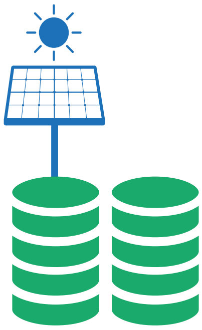
hydrogen production because sectoral knowledge and skills, enabling infrastructure, as well as networks and practices that offer a competitive advantage have already been established (Eicke and De Blasio, 2022). Finally, an enabling environment in a given economy, defined by economic stability, ease of doing business and regulatory transparency, is essential (Cordonnier and Saygin, 2022).

Many developing countries are endowed with abundant low-cost renewable energy resources, thus making them major potential producers of green hydrogen. At the same time, financial support is necessary for the successful uptake of green hydrogen markets. Another crucial element is the developing of solid policy and legal frameworks based on international standards.[3]

The development of green hydrogen production can bring about important social and economic benefits for developing economies, including improved energy security and affordable clean energy access for remote regions. In larger grids, green hydrogen could support the integration of renewables, limit power supply interruptions and provide long-term energy storage (Cordonnier and Saygin, 2022).

Green hydrogen could also help to usher in a domestic clean energy

Many developing countries are endowed with abundant low-cost renewable energy resources, thus making them major potential producers of green hydrogen.



In 2020, 51% of all Aid for Trade commitments included climate-related objectives.

transition by providing cleaner alternatives to hard-to-abate sectors. Developing a hydrogen sector could also help to improve export diversification potential, as hydrogen (or hydrogen-derived commodities) created through domestically available renewable sources could then be internationally traded.

Economies such as China, Indonesia, the Philippines and South Africa have started to take advantage of these opportunities and are gaining experience in using ammonia-based and methanol-based fuel cell systems for their telecommunications sectors. Large hydrogen or fuel cell projects for stationary power solutions are being built in Argentina, Mali, Martinique and Uganda. Leveraging the full potential of green hydrogen, however, requires building local capacity and increasing access to expertise that, at the global level, remains limited (ESMAP, 2020).

Importance of technical assistance and financing

Technical assistance can help developing economies to take advantage of their comparative advantages in the context of renewable energy production in order to create an enabling environment for large-scale green hydrogen production. This could support and build capacities in developing countries by putting in place robust certification and verification frameworks in line with existing international standards, thereby creating opportunities to integrate effectively into green global value chains. Financial assistance can further mobilize both public and private support, which are essential to propel innovation in the production, transport and use of green hydrogen, and which support the green transition, job creation and improved resilience. For instance, through its Global Gateway initiative,[4] the European Union has built partnerships with a number of economies, including Brazil, Chile, Kenya, Morocco, Namibia, South Africa and Tunisia, establishing joint research and investment projects, leveraging public and private investments, and building capacity.

In 2020, more than half (51 per cent) of all Aid for Trade commitments included climate-related objectives with a large majority (69 per cent) focusing on climate change mitigation. There is also an emerging trend to allocate more and more support to renewable energies (OECD, 2022). Enhancing and better tailoring Aid for Trade to the needs of developing economies and least-developed countries (LDCs)

can support their participation in hydrogen value chains by fostering the sustainable extraction of the minerals and metals necessary to produce electrolysers and expand supply-side manufacturing capacity.

Aid for Trade can also facilitate technology transfer partnerships that can help to expand domestic manufacturing capacity in developing economies. For example, in 2021, together with partner economies, UNIDO launched its Global Programme for Hydrogen in Industry.[5] The initiative stimulates the accelerated uptake and deployment of green hydrogen in industry in developing economies and aims to build cooperation and partnerships for knowledge and technology transfer (UNIDO, 2022).
Aid for Trade can also help to enhance market access and create adequate regulatory conditions for a cross-border hydrogen trade. This is part of the rationale behind the creation by the World Bank Group and its partners of the Hydrogen for Development Partnership (H4D), which has supported economies such as Brazil, Mauritania, Morocco, Tunisia and Uzbekistan in developing policies to boost their green hydrogen offer and demand.

Investments in green hydrogen can in turn spur industrial development in developing economies. To begin with, demand for green hydrogen would further increase demand for renewable energy and attract additional investments in solar and wind farms, geothermal and hydropower projects. It will also attract investments in other conversion technologies since hydrogen needs to be converted into higher energy density products, such as methanol or ammonia, for easier storage and transportation.

Furthermore, economies producing renewable energy and green hydrogen plus derivatives at competitive costs will become more attractive also for energy-intensive industries such as the steel and chemical industries. They, in turn, provide inputs to many downstream industries, from automotive to pharmaceutical and fertilizer industries. Therefore, as decarbonization efforts intensify, the availability of renewables and green hydrogen may become a key consideration for the relocation of industries. Finally, there is a growing market for hydrogen-based technology exports that can be tapped into including markets for fuel cell technology, hydrogen-based steelmaking technologies and synthetic fuels[6] (UNIDO IAP, 2022).

Investments in green hydrogen can spur industrial development in developing economies.

Endnotes

[1] See https://www.argusmedia.com/en/news/2486143-kenya-eyes-green-hydrogen-production-for-food-security.
[2] See: https://www.skrine.com/insights/alerts/october-2023/malaysia-launches-hydrogen-economy-technology-road.
[3] See https://iap.unido.org/articles/green-hydrogen-energy-opportunity-decarbonization-and-developing-countries.
[4] See https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/stronger-europe-world/global-gateway_en.
[5] See https://www.unido.org/hydrogen.
[6] See https://iap.unido.org/articles/green-hydrogen-fuelling-industrial-development-clean-and-sustainable-future.

5 THE ROLE OF INTERNATIONAL COOPERATION

International trade cooperation is important to ensure sustainable market growth and encourage technology development and innovation.

The previous chapters have demonstrated the importance of trade policies for the rapid and efficient scaling-up of green hydrogen markets. The development of an international market for low-emission hydrogen will strongly depend on effective international cooperation (IEA, 2022). In contrast, the proliferation of divergent trade policies, such as tariffs, regulations and support programmes, coupled with various private standards, can raise costs for firms, create unnecessary barriers and red tape, and ultimately stall progress.

Cross-border coordination and collaboration to ensure alignment and consistency in definitions, standards for the emissions intensity of green hydrogen production and transport, certification schemes to ensure interoperability, and import tariffs for hydrogen and its potential carriers, will help to address potential hydrogen-related trade policy issues (IPHE, 2022).

The Breakthrough Agenda Report, produced by IEA, IRENA and the UN Climate Change High-Level Champions, measures international collaboration in several key areas of importance for the scaling-up of the production and use of low-carbon and green hydrogen. These include standards and certification, demand creation, technology demonstration and finance. However, the 2023 Report (IEA, IRENA and UN Climate Change High-Level Champions, 2023) finds that progress is still modest to minimal (see Table 6).

International trade cooperation is important not only to ensure sustainable market growth, but also to encourage technology development and innovation. Regulatory cooperation among WTO members and with other stakeholders on a sector-by-sector basis could be an effective means of building trust between regulators, and could serve as an incubator for discussions at the multilateral level on emerging regulations.

Several WTO bodies can serve as forums for transparency and dialogue on members' green hydrogen policies. The WTO Committee on Trade and Environment (CTE) is a central forum for members to exchange best practices, and to present and comment on recent regulatory proposals relating to the climate change mitigation, including renewable energy policies and sustainable supply chains. In recent discussions, members have shared experiences of decarbonization policies applied to transport and industry, with some expressing strong commitment to the production and export of green hydrogen, and have highlighted the importance of international cooperation.[1] International organizations, such as the International Solar Alliance, have also shared green-hydrogen-related initiatives. Briefings at the CTE have specifically highlighted the importance of green hydrogen technology transfer for developing economies.[2]

The work of the TBT Committee in discussing specific trade concerns helps to provide clarification on proposed measures and to enhance alignment with international standards. The Committee also serves as an interface between member governments and standard-setting organizations (which have a status of observers to the Committee) to identify needs and gaps in standards development from a trade and regulatory point of view.

The TBT Committee's work with standard-setting organizations has helped to address potential trade frictions and implementation challenges for members at different levels of development, and provides

TABLE 6:
The state of international collaboration on green hydrogen

Source: Adapted from IEA, IRENA and UN Climate Change High-Level Champions (2023).

Area	Progress made	Recommendations for governments and companies	2023
Standards and certification	▪ The IPHE is leading major efforts on methodologies for measuring hydrogen emissions, in partnership with ISO, with the aim of developing common global standards and associated certification schemes. ▪ The IEA's Hydrogen Technology Collaboration Programme (TCP) has set a group of experts to work on technical matters of harmonization of certification. ▪ IRENA and RMI, the European Clean Hydrogen Alliance and the Hydrogen Council are currently engaging in other assessments and relevant work.	▪ Prepare a well-articulated plan that defines financial and human resource needs for the development of a comprehensive portfolio of national and international standards. ▪ Provide appropriate resources necessary to undertake the relevant work on standards development. ▪ Work towards the adoption of a common methodology to calculate the carbon footprint of the hydrogen value chain to facilitate mutual recognition and interoperability of certification systems. ▪ Work through existing forums to ensure that the methodologies used to define regulatory frameworks are interoperable. ▪ Anticipate building technical capacity of national systems to verify compliance with international hydrogen standards.	Modest
Demand creation	▪ There have been notable government-led demand-creating initiatives, but also a lack of international coordination on near-term commitments and policies. ▪ The IRENA Collaborative Framework on green hydrogen has established a workstream on understanding how to coordinate demand and supply globally.	▪ Increase the strength of the demand signal by moving from commitments and pledges for the use of low-carbon and renewable hydrogen to contracts and policies. ▪ Improve the coordination of efforts between economies and companies to increase commitments in sectors where hydrogen is already used to collectively send a strong demand signal and mobilize investment in production. ▪ Share learning to accelerate early deployment in new priority application sectors, in a manner that ensures a level playing field in international trade.	Minimal
Research and innovation	▪ The Mission Innovation Clean Hydrogen Mission (CHM) has committed to establishing a conceptual framework to exchange best practices, identify gaps and access support, including for R&D, by COP 28. ▪ The Hydrogen Valley Platform had identified 83 projects from 33 countries by July 2023.	▪ Increase the number and geographical distribution of hydrogen demonstration projects and ensure that these appropriately cover each of hydrogen's high-value end-use sectors, including maritime shipping, heavy industry and long-duration energy storage. ▪ Increase efforts to establish proactive knowledge-sharing platforms and processes between lead projects.	Minimal
Finance and investment	▪ UNIDO, World Bank and IRENA are mapping existing financial and technical assistance support towards hydrogen projects in developing economies, with a view to supporting an improved offer. ▪ The Hydrogen for Development Partnership was launched by the World Bank to help catalyse funding for projects in developing economies by providing improved in-country support.	▪ Work with international financial institutions to identify projects that are being delayed by high costs of capital and other obstacles to investment, then identify best practices to support targeted and tailored technical assistance for policy design. ▪ This should be supported by appropriate technical assistance programmes to assist governments with policy design for the further scale-up of projects.	Modest

feedback which strengthens standards review and development. This makes the TBT Committee a valuable forum for technical discussions at the multilateral level on trade-related aspects of carbon measurement methodologies and verification procedures, as well as on ways to support developing countries in this area.

Other ongoing initiatives at the WTO could further support trade-related solutions in support of green hydrogen. In 2020, the participants in the Trade and Environmental Sustainability Structured Discussions (TESSD) launched work towards concrete actions to expand opportunities for sustainable trade. Discussions have covered experience-sharing on the design of subsidies related to a low-carbon transition, including on clean energy and hydrogen, as well as on identifying and compiling principles and member practices in the development of trade-related climate measures. A further important part of TESSD's work includes identifying opportunities and approaches to promote and facilitate trade in environmental goods and services in support of renewable energy development, including green hydrogen. In this regard, one specific suggestion has been made that collaboration among members to formulate trade rules ensuring the interoperability of guarantee-of-origin certifications could facilitate the development of renewable and low-carbon energy markets, such as a global low-carbon hydrogen trading market.

Further avenues for international cooperation on green hydrogen policies could be built at the WTO among its members, standards-setting bodies and other relevant stakeholders. Multilateral initiatives and projects can promote knowledge-sharing, develop technology and best practices to reduce costs, and connect a wider group of stakeholders. In this way, they can help to develop future international hydrogen supply chains (IPHE, 2022).

IRENA's Collaborative Framework on Green Hydrogen serves as an effective vehicle for dialogue, cooperation and coordinated action to accelerate the development and deployment of green hydrogen and its derivatives for a global renewable energy transformation. The Collaborative Framework leverages IRENA's work on green hydrogen, the wealth of knowledge and expertise that exists within IRENA's membership, and the benefits that may be reaped through wider global cooperation with other entities. Participation in the Collaborative Framework is open to the private sector and other international organizations.

IRENA also supports the global Alliance for Industry Decarbonization (AFID) which is a multi-stakeholder platform of more than 60 members and ecosystem knowledge partners to foster action for decarbonization of industrial value chains, promote understanding of renewables-based solutions and their adoption by industry with a view to contributing to country-specific net-zero goals. In 2023 among joint initiatives the AFID addressed techno-economic challenges and solutions on safety standards for generation, transport and storage, and regulatory aspects to fast-track green hydrogen projects.

Endnotes

1 See WTO official document number WT/CTE/M/78. Official documents can be viewed at https://docs.wto.org/.

2 See WTO official document numbers WT/CTE/M/78, WT/CTE/M/77, WT/CTE/M/76, WT/CTE/M/75 and WT/CTE/M/74. Official documents can be viewed at https://docs.wto.org/.

FIVE ACTIONS FOR CONSIDERATION BY POLICYMAKERS

From the above analysis, the WTO and IRENA propose a set of five concrete actions for economies to consider in order to scale up and facilitate global trade of green hydrogen.

1. Address trade barriers along the green hydrogen supply chain

Open trade along the supply chain can promote the development of green hydrogen by lowering costs and fostering technology access and development. Promoting trade in goods and services related to renewable energy production could help reduce the costs of energy used in the production of green hydrogen, while lowering trade costs on electrolysers could further support the scale-up and efficiency of manufacturing capacity.

Trade in goods and services along the green hydrogen supply chain is affected by various barriers to trade, including tariffs and non-tariff measures. For example, there is scope to further reduce tariffs as a number of WTO members have set tariffs higher than 5 per cent for hydrogen as a commodity (46 members), for derivatives such as ammonia (34) and methanol (45) and for products along the supply chain, such as electrolysers (43), compressors (63), generators (32) and fuel cells (96).

2. Develop a sound quality infrastructure for green hydrogen trade

Quality infrastructure (QI) is the system that ensures that products and services are sustainable, safe and durable, and that they meet the expectations of all stakeholders. QI includes standards, testing, certification, metrology, inspection and accreditation. Since it is not possible to "see" the carbon content or the process used for producing hydrogen, sound QI will be crucial to guarantee the environmental integrity of green hydrogen production and provide information on the production process and emissions footprint along the value chain.

a. Engage in international standardization for green hydrogen

Standards are a key element of a QI. Adopted national standards should be based on international standards developed in line with the six "Principles for the Development of International Standards, Guides and Recommendations" (i.e., transparency, openness, impartiality and consensus, effectiveness and relevance, coherence, and development dimension), agreed upon by the WTO Committee on Technical Barriers to Trade (TBT) in 2000.[1] Economies should actively engage in the technical committees in international bodies like the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) to ensure that their national context is properly reflected in international standards.

b. Foster international dialogue on carbon measurement methodologies, definitions of low-carbon hydrogen and verification procedures

Where there is no convergence around international standards, procedures or guides concerning carbon measurement methodologies, definitions of low-carbon hydrogen or verification, dialogue is crucial. Regulatory cooperation can prevent unnecessary negative trade impacts and could be an effective means of building trust among regulators. The WTO TBT Committee has provided guidance in the area of verification procedures by developing an "Indicative List of Approaches to Facilitate the Acceptance of the Results of Conformity Assessment" [2]

c. Inform customers via labelling requirements based on quality infrastructure

Communication of information about how hydrogen is produced – both to responsible authorities and along the value chain – is essential. Labels in particular should convey information to customers about green hydrogen production processes in a clear, credible manner, with a view to achieving the desired policy objectives without creating unnecessary obstacles to international trade.

3. Implement support policies for green hydrogen

Midstream and end-use investments will be required in order to achieve a global net-zero emissions pathway by 2050, with average total annual investments in the hydrogen value chain of US$ 136 billion needed between 2023 and 2050. Phasing out fossil fuel subsidies and redirecting funding towards renewable energy and green hydrogen production has strong potential to stimulate this transition.

a. Implement targeted and non-discriminatory environmental subsidies

Governmental support policies can help to sustain growth in electrolyser capacity and green hydrogen production, promoting cost efficiencies and narrowing the cost differential between the production costs of green and of fossil-based hydrogen. Policies should be targeted to boost innovation in cleantech startups, and should not place imported products at a competitive disadvantage vis-à-vis domestic ones unjustifiably.

b. Close the economic gap between fossil fuels and green hydrogen

Phasing out and redirecting fossil fuel subsidies would make it possible to incorporate costs of environmental externalities not reflected under subsidized prices, which would render green hydrogen more competitive. Subsidy reforms must be mindful of the various economic and social forces at work, as well as the imperative for a just and equitable transition.

4. Use sustainable government procurement to foster green hydrogen demand

Government procurement is of great economic importance, accounting for between 10 and 15 per cent of national GDP, on average, and about 13 per cent of world GDP. Through sustainable government procurement policies, governments can influence private-sector producers by purchasing low-carbon goods and services, creating markets for new entrants and stimulating innovative solutions.

a. Implement sustainable government procurement policies

Governments can leverage sustainable procurement policies to create a large and stable demand for green hydrogen and derivative commodities, contributing to lowering costs and reducing hydrogen uptake uncertainty. This could include actions such as introducing minimum requirements for green products (e.g., green steel) in public authorities' procurement processes, introducing green material requirements in policies, and ensuring the presence of a verification and labelling system to guarantee the sustainability of green products. In doing so, governments should give a strong preference to the procurement of green hydrogen for those sectors where direct electrification with renewables is not a viable decarbonization option.

b. Consider international collaboration

Coordinated demand-creating policies can send a strong signal to mobilize investment, while collaboration can support the establishment of more secure and diversified demand over time. Both are crucial to achieving economies of scale and accelerating supply-side cost reductions.

5. Increase international cooperation on green hydrogen trade

Cross-border coordination and collaboration to ensure, for example, alignment and consistency in definitions and standards for emissions certification schemes, would help to address potential hydrogen-related trade policy issues. Supporting developing economies would contribute to bringing about important social and economic benefits, including improved energy security and affordable clean energy access.

a. Encourage technology development and innovation through dialogue

Regulatory cooperation between WTO members and other stakeholders on a sector-by-sector basis could be an effective means of building trust between regulators, and could serve as an incubator for discussions on emerging regulations. Through its bodies, including the Committee on Trade and Environment (CTE) and the TBT Committee, as well as ongoing environmental initiatives, the WTO can act as a focal point for transparency and dialogue on members' green hydrogen policies.

b. Engage in cooperation fora on green hydrogen

For instance, IRENA's Collaborative Framework on Green Hydrogen[3] serves as an effective vehicle for dialogue, cooperation and coordinated action to accelerate the development and deployment of green hydrogen and its derivatives for the global renewable energy transformation. IRENA also supports the Alliance for Industry Decarbonization that aims to use green hydrogen and other solutions to decarbonize industrial value chains and accelerate net-zero ambitions in accordance with the Paris Agreement.

c. Increase technical assistance and capacity-building

Advanced economies could provide technical assistance and capacity-building to developing economies with comparative advantages in renewable energy production, to help them create an enabling environment for green hydrogen production at scale. For instance, IRENA with its global membership and network of partner organisations, supports building capacities in developing countries to put in place robust certification and verification frameworks, in line with existing international standards.

d. Support the needs of developing economies through Aid for Trade

The WTO-led Aid for Trade initiative helps developing economies, and particularly least-developed countries (LDCs), to trade. It can facilitate technology transfer partnerships that can help to expand domestic manufacturing capacity, as well as help enhance market access and create adequate regulatory conditions for a cross-border hydrogen trade.

Endnotes

1 See https://www.wto.org/english/tratop_e/tbt_e/principles_standards_tbt_e.htm.

2 The Indicative List of Approaches to Facilitate the Acceptance of the Results of Conformity Assessment can be found in Annex 1 of WTO official document number G/TBT/1/Rev.13 (page 52) (https://docs.wto.org/dol2fe/Pages/SS/directdoc.aspx?filename=q:/G/TBT/1R13.pdf&Open=True).

3 See https://www.irena.org/How-we-work/Collaborative-frameworks/Green-Hydrogen.

ANNEX

This annex provides a comprehensive, but non-exhaustive, list of quality infrastructure elements for green hydrogen (GH_2) that should be implemented, according to an Expert Survey for IRENA's ongoing project "Quality Infrastructure for Green Hydrogen: technical standards and quality control for the production and trade of renewable hydrogen".

Standards:
The following standards provide overall guidance across the hydrogen value chain:

Design:

- ISO 22734-1 Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications – Part 1: General requirements, test protocols and safety requirements.
- ISO TR 22734-2 Hydrogen generators using water electrolysis – Part 2: Testing guidance for performing electricity grid service.
- ISO 17268 Gaseous hydrogen land vehicle refuelling connection devices ISO 19884 Gaseous hydrogen – Cylinders and tubes for stationary storage.
- ISO 16111 Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride.
- ISO 19880-1 Gaseous hydrogen – Fuelling stations – Part 1: General requirements
- ISO 19880-3 Gaseous hydrogen – Fuelling stations – Part 3: Valves
- ISO 19880-5 Gaseous hydrogen – Fuelling stations – Part 5: Dispenser hoses and hose assemblies ISO 19880-6 Gaseous hydrogen – Fuelling stations – Part 6: Fittings
- ISO 19880-7 Gaseous hydrogen – Fuelling stations – Part 7: O-rings
- ISO 19880-8:2019 Gaseous hydrogen – Fuelling stations – Part 8: Fuel quality control
- ISO/CD 19880-9 Gaseous hydrogen – Fuelling stations – Part 9: Sampling for fuel quality analysis
- IEC 60079-10 series on Area Classification
- IEC 60079-14 Installation
- IEC 60079-17 Inspection
- IEC 60079-19 Repair and Overhaul of Equipment
- ISO/TR 15916, Basic Safety considerations for safety of hydrogen systems.
- ISO 16110 series Hydrogen generators
- ISO 17268 - Gaseous hydrogen land vehicle refuelling connection devices.
- ISO 19880 series- Gaseous hydrogen – Fuelling stations
- ISO 19882 Gaseous hydrogen – Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers
- ISO 26142 Hydrogen detection apparatus – Stationary applications
- IECEx Certification System via IECEx OD 290 Standardised approach to Testing and Certification of Hydrogen dispensing Equipment and Systems

Installation and infrastructure:

- ISO 19880-x series – Gaseous hydrogen – Fuelling stations
- IEC 60079-x series – General requirements for construction, testing and marking of Ex Equipment and Ex Components intended for use in explosive atmospheres.
- ISO 22734-1 Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications – Part 1: General requirements, test protocols and safety requirements.
- ISO TR 22734-2 Hydrogen generators using water electrolysis – Part 2: Testing guidance for performing electricity grid service.
- ISO 19884 Gaseous hydrogen – Cylinders and tubes for stationary storage
- ISO 16111 Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride ISO.
- CEN Standard EN16325
- ISO/TR 15916, Basic Safety considerations for safety of hydrogen systems.
- ISO 16110 series Hydrogen generators
- ISO 17268 - Gaseous hydrogen land vehicle refuelling connection devices.
- ISO 26142 Hydrogen detection apparatus – Stationary applications
- IEC 80069

Operation and maintenance:

- ISO 19881 Gaseous hydrogen – Land vehicle fuel containers
- ISO 19882 Gaseous hydrogen – Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers
- ISO 19885-1 Gaseous hydrogen – Fuelling protocols for hydrogen-fuelled vehicles – Part 1: Design and development process for fuelling protocols
- ISO 19885-2 Gaseous hydrogen – Fuelling protocols for hydrogen-fuelled vehicles – Part 2: Definition of communications between the vehicle and dispenser control systems
- ISO 19885-3 Gaseous hydrogen – Fuelling protocols for hydrogen-fuelled vehicles – Part 3: High flow hydrogen fuelling protocols for heavy duty road vehicles.
- ISO 19887 Gaseous Hydrogen – Fuel system components for hydrogen fuelled vehicles.
- ISO 21087:2019 - Gas analysis – Analytical methods for hydrogen fuel – Proton exchange membrane (PEM) fuel cell applications for road vehicles
- IEC 60079-10 series – Area classification (needs to form part of routine inspection plan)
- IEC 60079-17 – Inspection
- IEC 60079-19 Repair and Overhaul
- IEC 62990 series – Gas detectors
- IEC 60079-29-2 Gas detectors – Selection, installation, use and maintenance of detectors for flammable gases and oxygen.
- IEC 60079-29-3 Gas detectors – Guidance on functional safety of fixed gas detection systems
- IEC/IEEE 60079-30-1 Electrical resistance trace heating – Application guide for design, installation, and maintenance
- IEC 60079-32-1 Electrostatic hazards, guidance
- IEC 60079-43 Equipment in adverse service conditions
- ISO 26142 Hydrogen detection apparatus – Stationary applications
- IEC 62282 series, Fuel cell technologies (currently 29 standards in the series) via IEC TC 105

Safety:

- ISO/TR 19516
- ISO 26142
- IEC 60079-29 series
- ISO 16110-1 Hydrogen generators using fuel processing technologies – Part 1: Safety
- ISO/TR 15916 – Basic considerations for the safety of hydrogen systems
- ISO/IEC 80079

Metrology:

The following metrological standards provide overall guidance to the green hydrogen sector:

- OIML R137 – Gas Meters
- OIML R139 – Compressed Gaseous Fuel Measuring Systems for Vehicles
- OIML R140 – Measuring Systems for Gaseous Fuels
- Standards issued by ISO/TC193 and ISO/TC193/SC1
- ISO 14687 – Hydrogen fuel quality
- ISO 21087 – Analytical methods for hydrogen fuel

Certification:

The International Electrotechnical Commission (IEC) Conformity Assessment Systems allows multiple international conformity assessment bodies to participate in these systems based on a rigorous peer assessment qualification process. Ideally green hydrogen is produced from energy generated by renewable energy sources and verified by harmonized conformity assessment processes. Countries with advanced quality infrastructure systems have internationally recognized conformity assessment bodies, already actively participating in these International IEC Systems and Schemes with those not already involved being encouraged to expand their accreditation scope to participate in these IEC International Schemes. While noting the already existing International Schemes of the IEC covering:

- Certification of Components, equipment and systems
- Certification of Services
- Certification of Personal Competence
- Project Certification
- Carbon Footprint verification

Any new certification schemes that are specifically focused towards the green hydrogen sector should be proposed to the IEC and the International Organization of Legal Metrology (OIML).

Testing:
There is a lack of testing protocols or large-scale high pressure and cryogenic components. Furthermore, it is necessary to develop services to train workers to handle new safety considerations, and calibration services and traceability to the International System of Units (SI) is needed. Within testing protocols, there is an increasing focus on developing associated procedures for pressure ranges up to 100 bars. However, there is still a lack of test infrastructure for wide ranges (quantity measurement H_2). Testing for some specific applications addressed, such as H_2 dispensers (refer to https://www.iecex.com/publications/operational-od/) or domestic meters are becoming available in certain economies.

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Report designed by Touchline.
Printed by the World Trade Organization.

Print ISBN 978-92-870-7564-2
Web ISBN 978-92-870-7563-5
Published by the World Trade Organization and
International Renewable Energy Agency.

Hydrogen produced exclusively from renewable power – known as green hydrogen – is widely recognised as a key pillar in replacing fossil fuels and decarbonizing sectors that cannot easily be electrified, such as some industrial processes, shipping and aviation. This publication – jointly produced by the International Renewable Energy Agency (IRENA) and the World Trade Organization (WTO) – explores how trade policies can support the development of green hydrogen markets.

The publication highlights in particular how lowering tariffs on key products, building reliable infrastructure, realigning domestic support programmes and developing green government procurement can foster the development of green hydrogen supply chains and the transition to a low-carbon economy. International trade could also play a significant role in matching supply and demand for green hydrogen, as the potential for domestic production in some economies might not be enough to satisfy domestic demand.

The publication also addresses the challenges and opportunities for developing economies offered by green hydrogen and its derivatives, such as green methanol and green ammonia. It underscores the importance of international cooperation and the need to align regulatory frameworks to encourage technology development, enhanced transparency and market growth.

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