International Trade Rules for Hydrogen and its Carriers:
Information and Issues for Consideration

A Discussion Paper for the
IPHE Hydrogen Trade Rules Task Force

FEBRUARY 2022 (Rev 1)

Table of Contents

List of Figures

List of Tables

Disclaimer

The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), formed in 2003, is an international governmental partnership currently consisting of 21 member countries and the European Commission. Its objective is to facilitate and accelerate the transition to clean and efficient energy and mobility systems using hydrogen and fuel cell technologies across applications and sectors. Work of the IPHE is organised around the principles of sharing information, informing future government R&D and policy initiatives, and fostering collaboration.

This publication was developed under the framework of the IPHE but does not necessarily reflect the views of individual IPHE member countries. The IPHE makes no representation or warranty, express or implied, with respect to the publication's contents (including its completeness or accuracy) and shall not be responsible for any use of, or reliance on, the publication.

IPHE is aware that this discussion paper, analysing the current and potential future rules and challenges for hydrogen trade, is being requested by multiple governments. It occurs during a period when policymakers, industry, and various stakeholders are discussing how hydrogen and its derivatives, alongside other clean energy technologies, can help meet their climate goals. Consideration is also being given to the allocation of incentives and funding to accelerate deployments. However, nothing in this discussion paper should be construed as an indication of intentions or policy directions.

Acknowledgements

This discussion paper was written by **E4tech**, principal author Dr Charlotte Kirk, on behalf of the IPHE. E4tech, an ERM Group company, is an international consultancy that helps organizations understand and implement sustainable energy technologies, policies and solutions. Since 1997, E4tech has worked with businesses, governments, and investors to help them understand the global opportunities and challenges of clean energy. E4tech has built a strong track record of providing objective and strategic business and policy advice based on deep technical understanding, insightful analysis and industry knowledge. This expertise underpins detailed modelling and assessment work: techno-economic analyses of energy systems, greenhouse gas and sustainability assessments, and supply chain and primary resource evaluation. E4tech is recognized for its work in the evolving energy transition including the potential role of low carbon hydrogen and its derivatives across the global energy system.

The IPHE would like to acknowledge the **Swiss Federal Office of Energy** (SFOE) for its funding support for the writing of this paper (Contract # SI/502261).

The IPHE would also like to thank all the **stakeholders** that contributed and provided information and their views in making this discussion paper a comprehensive and useful contribution to the understanding of issues in the trade of hydrogen.

Executive Summary

Decarbonization of the global energy system will not be simple. As countries and regions around the world outline ambitious net zero strategies and targets, energy carriers such as hydrogen (and its derivatives) will play an essential role in reducing future carbon emissions. Hydrogen is well suited for use in hard-to-abate sectors where other decarbonization options are limited. For hydrogen to be a practical solution in the energy transition, it must be available in sufficient volumes, at an acceptable cost, and with low or zero carbon emissions associated with its production and distribution. Achieving this will require hydrogen to be transported and traded internationally.

This discussion paper *International Trade Rules for Hydrogen and its Carriers: Information and Issues for Consideration*, was prepared for and in close collaboration with the International Partnership for Hydrogen and Fuel Cells (IPHE). It examines the potential for future international hydrogen trade and identifies potential barriers, hurdles, and considerations to explore now to ensure appropriate future trading conditions. The discussion paper does not seek to make recommendations, set policy, or design trading frameworks. Instead, it identifies areas for further analysis and questioning, outlining potential opportunities to support market transparency and future large-scale international trade in hydrogen.

Hydrogen energy trade will grow, requiring rules

There is already widespread global hydrogen production, distribution, and use as a *chemical feedstock*, with no significant market barriers or impediments to supply-chain growth. However, the global hydrogen *energy* market is nascent. As demand for conventional and low carbon hydrogen energy increases, long-distance and large-scale international transport and trading of hydrogen will be needed to link areas of surplus and deficit.

Competition will intensify with the growth of hydrogen trade, as seen in more mature commodity markets. It is crucial that the global hydrogen market develops in an efficient, inclusive, and transparent manner. Technical, legal and commercial challenges may arise, for which a rules-based approach is logical, governing aspects such as the carbon intensity of hydrogen, customs procedures, market frameworks and many other features.

WTO rules need to be more specific for hydrogen energy

The World Trade Organization (WTO) provides the global trade framework and its rules. How this framework will affect hydrogen energy trade is not yet clear as there is currently no well-established international market.

In considering how current WTO rules apply to hydrogen, it is important to remember that hydrogen energy, unlike fossil fuels, has many different pathways to produce and transport it, with varying carbon intensities. As a result of this and other features it will be challenging to apply the same trade rules and regulations fairly or easily under the current framework. In particular:

- If different hydrogen carriers were subject to **different import tariffs**, impacting the cost per unit of hydrogen energy, this could distort market behaviour.
- There are different trade rules for goods and services. Hydrogen production and distribution **contains elements of both goods** (e.g., a molecule) **and services** (e.g., operating a production facility) potentially leading to confusion into how to apply rules
- It is difficult to encourage and support **environmental policies** and mandates driving low carbon energy solutions within the context of a rigid trade system.
- Existing trade rules do not address **export restrictions** and **investment protection** well.

- More clarity is needed around **access to fixed infrastructure** or fixed energy grids, since the WTO does not regulate the use of infrastructure or provide anti-trust rules.

Overall, although the WTO framework poses no roadblocks to hydrogen trade, it will require greater precision to enable hydrogen energy to be traded efficiently and fairly.

Hydrogen will face other trading challenges

This paper also looks beyond the legal frameworks for international trade to other trading challenges for hydrogen and its derivatives, drawing the following conclusions:

- **Future trade patterns are hard to predict:** developments in technology, manufacturing capacity and experience are needed before widespread deployment is financed**.** These will influence which regions have comparative advantage in production and use, meaning that the areas of greatest surplus and deficit are currently unclear.
- **Infrastructure is a bottleneck**: reliable and accessible infrastructure connecting supply and demand is critical for the widespread use and trade in hydrogen. The current lack of large-scale infrastructure hinders trade and the markets that develop will be influenced by where and when infrastructure becomes available.
- **Policy uncertainty hinders international trade:** hydrogen is a new area of energy policy, with fast-evolving regulations, legislation, and incentive instruments across jurisdictions. The complexity and current uncertainty around these changing regulatory and market frameworks directly impact investment, which in turn affects international trade.
- **Policy support should not conflict with trade rules:** today's low carbon hydrogen market requires supportive policy frameworks and financing mechanisms. Countries and institutions should ensure that these frameworks and mechanisms are managed within the context of trade arrangements, do not violate trade rules, and do not prejudice future investment and roll-out.
- **There is a strong role for global collaboration:** developing a future global market for the trade of low carbon hydrogen will require international dialogue and cooperation, across borders, regions, and the public and private sectors.

The IPHE and member countries can help to address trade issues

Addressing multilateral trade framework issues is beyond the scope of the IPHE. However, many of the most pressing challenges facing the future hydrogen market lie outside the broad trade framework and need to be approached by stakeholders across the wider hydrogen trade community.

Collaboration between IPHE member countries can support the development of appropriate future trading conditions for hydrogen and its derivatives. For example, cross-border collaboration to ensure alignment and consistency in definitions, certification schemes, and import tariffs for hydrogen and its potential carriers will help to address potential hydrogen related trade policy issues.

Naturally, nation states will need to address national and regional issues within their own jurisdictions. However, sharing these approaches with other IPHE members will further support international market development. Non-trade policy issues, such as sharing information on technology and infrastructure development, are already a focus of IPHE work and will continue to be important as the market develops.

Finally, the IPHE and its members can play a significant role by taking this discussion paper to governments, trade experts, and industrial stakeholders such as ports, infrastructure operators, producers, and industrial consumers, to solicit input and perspectives on the challenges raised and potential solutions to address them.

1 Introduction

It is increasingly expected that molecular energy carriers such as hydrogen and its derivatives will play an essential role in reducing future carbon emissions. For hydrogen to be a useful solution in the energy transition it must be available in sufficient volumes, at acceptable cost, and with low or zero carbon emissions associated with production and distribution.

Hydrogen is predominantly produced today from fossil sources and supplied to markets as a chemical feedstock. Its limited use in energy is typically associated with the space industry or cleaning and upgrading refinery output fuels. However, widespread use of low carbon hydrogen is envisaged in an increasing number of ambitious national strategies and in a growing pipeline of announced low-carbon hydrogen projects[1]. In the near term, supply and demand are likely to be geographically close but as volumes grow and production and use locations diverge, increasingly long-distance and large-scale transportation of hydrogen, in pure or other forms, will be required.

A global market for the trade of low carbon hydrogen is therefore expected to develop in the long term, to connect areas of production surplus and deficit. Significant shipment volumes of low carbon hydrogen are envisaged, with production and transportation hubs starting to be considered. Early-stage and small-scale shipments of low carbon hydrogen and its carriers have been demonstrated, with ambitions for larger volumes potentially even as early as 2025.

This leaves a large gap between the current hydrogen sector and where ambitions intend it to be[2]. Neither conventional nor low carbon hydrogen currently have a global market, and future markets will depend on investable business cases. Any shipping of hydrogen[3] will need to respond to market signals (relating to both price and carbon impact) and fit with existing and future trade rules, as well as addressing the practical issues to enable the trade volumes proposed. Ideally, any trading frameworks will support and not hinder the rapid development of low-carbon hydrogen delivery.

1.1 Purpose of this study

Although the deployment of hydrogen energy is at a very early stage, the prospect of large-scale international trade of hydrogen and its derivatives seems likely. This study was commissioned to examine the potential for future international hydrogen trade and identify potential barriers, hurdles, or considerations that should be explored now, to try and ensure appropriate future trading conditions.

To do this, the discussion paper briefly summarises emerging trends and drivers for hydrogen uptake and trade, considers practical issues related to large-volume trade and looks at the current trading rules. The purpose of the study is not to make recommendations, set policy or design trading frameworks, but to identify which areas should be analysed further, what questions remain to be answered, and some of the steps that could be taken to support future trade and market transparency. The study also does not evaluate the feasibility of different components of the supply

[1] In this discussion paper the term 'low carbon' encompasses all production methods and pathways that achieve GHG emissions reductions per unit hydrogen delivered compared to unabated fossil production – See Section 2.2.1

[2] IEA Global Hydrogen Report 2021

[3] Throughout this discussion paper we use the simplified phrases 'hydrogen shipping' or 'hydrogen trade' also to encompass hydrogen derivatives such as ammonia and liquid organic hydrogen carriers (LOHCs).

chains, hydrogen strategies or announced projects, but asks what needs to be in place if the large-scale international trade in hydrogen from production hubs to demand centres does develop.

1.2 Discussion Paper Structure

The discussion paper starts by setting the scene, outlining why hydrogen is being considered, the current state of the market and anticipated growth based on public announcements. Potential supply chains for international trade are sketched out, with rough orders of magnitude indicated. This has implications for the technical approaches taken to enable trade, both the physical means (e.g., pipelines/shipping), and the hydrogen carrier. The current state and anticipated development of these technologies are briefly discussed, alongside the implications of trade on market development. The drivers for trade are examined, and their impact on which supply chains are starting to emerge. Conventional trade conditions, such as product definitions and certification, are highlighted where appropriate to frame the considerations required when thinking about the regulatory structure this nascent market may require.

The potential implications of hydrogen trade are complex, as it has many possible production routes, many carrier forms, and many end uses. It is essential to consider its high interconnectivity to the energy system and other value chains (e.g., chemicals, heavy industry, and transport sectors), especially when some of its carriers are also products in their own right. The discussion paper therefore considers the current trade framework that hydrogen must operate within, identifying the most relevant trade rules at the World Trade Organization (WTO) multilateral level.

Current WTO rules are complex when applied to energy, and not all existing issues have been resolved. This complexity does not reduce when hydrogen is considered as an energy carrier, and these issues are discussed alongside the attempts that have been made to address them, both in and outside the WTO system. Lessons may be learnt in some cases for future hydrogen markets, and these are discussed. Where appropriate, suggestions for further analysis are made.

2 The importance of hydrogen and national aspirations

2.1 Purpose of hydrogen and where to find out more

Hydrogen has attractive properties that enable its use in a variety of different applications. Existing markets build on the fact it is reactive and is a fundamental chemical building block. Global hydrogen **demand** in 2020 was 90Mt[2], predominantly from the refining and chemicals sectors to produce ammonia and methanol (Figure 1). 95% of existing **production** comes from the unabated combustion of fossil fuels, emitting 900 $MtCO_2/yr$[4]. There is pressure to lower the carbon footprint of existing hydrogen use, and its replacement with lower carbon alternatives already represents an existing, 'no regrets' source of demand for low-carbon hydrogen production.

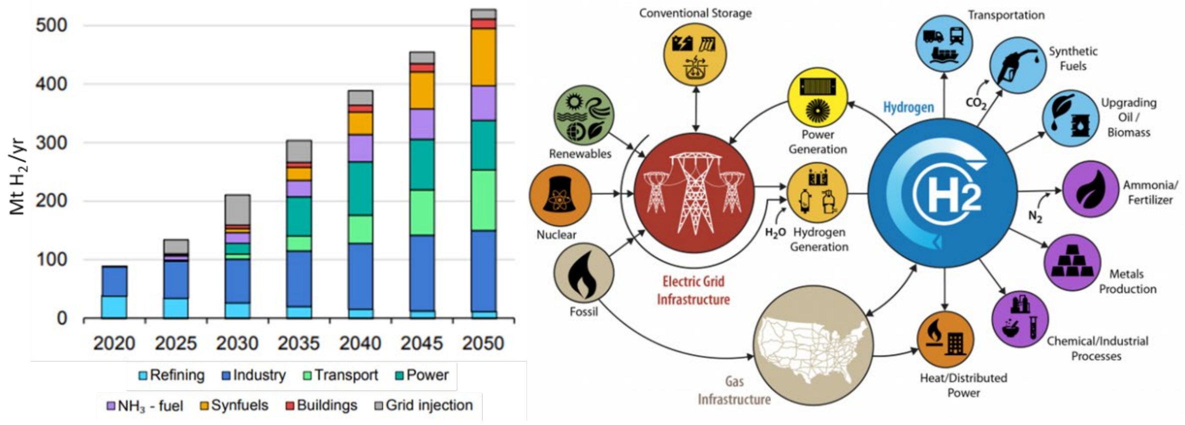


Figure 1: Projected hydrogen use by sector (left)

Source: IEA Global Hydrogen Review 2021 *Source: U.S. Department of Energy*

However, for hydrogen to make a significant contribution to the global energy transition, it also needs to be adopted in a wide range of new applications and value chains.

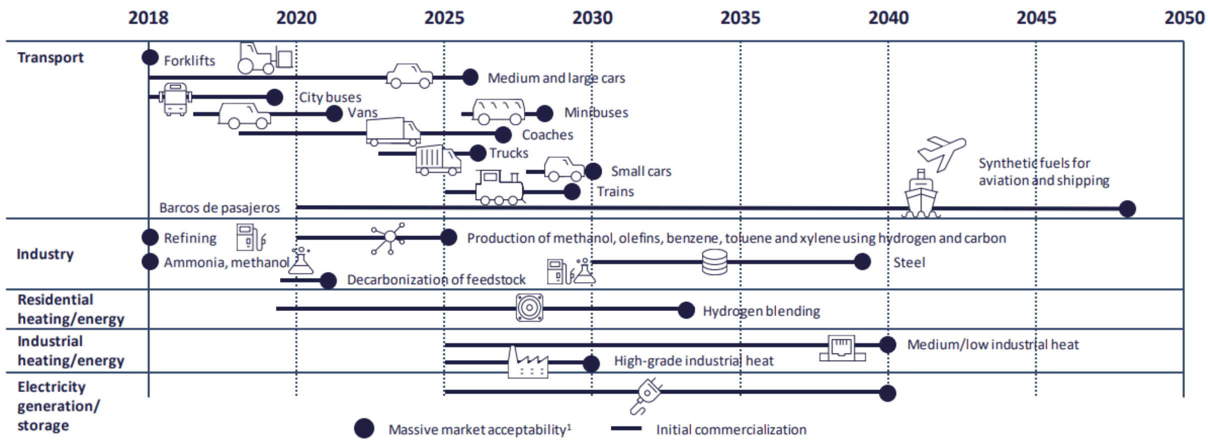


Figure 2: A roadmap of projected hydrogen applications

Source: McKinsey & Co.

[4] IEA Global Hydrogen Review 2021

Low carbon hydrogen is expected to play an important, complementary, and enabling role alongside low carbon electricity in decarbonising the energy system. It is well suited for use in 'hard to abate' sectors where other decarbonisation options are limited. Hydrogen can be used as a thermal fuel (similar to natural gas) and/or for electricity generation using modified gas turbines or fuel cells. Hydrogen can also be converted to a range of derivative fuels and feedstocks, so low carbon hydrogen can be embedded into current export value chains and facilitate a potentially wide range of low carbon commodities such as steel, aluminium and ammonia.

Hydrogen can be used as a fuel for transport applications, either directly (e.g., in fuel cells or internal combustion engines), or through conversion to hydrogen-based fuels, particularly for heavy-duty road transport, shipping and aviation. The use of hydrogen in an alternative method for steelmaking (Direct Reduced Iron - DRI) can significantly reduce emissions through its combined potential as a reductant and heat source in blast furnaces.

Similarly, hydrogen can be used to generate heat for high temperature industrial applications or in the building sector, supplied through the existing gas or dedicated hydrogen grids, and in large scale or long duration energy storage. It produces no Greenhouse Gas (GHG) or air pollutant emissions at the point of use, which also helps address air quality concerns in cities. Hydrogen uptake in different sectors will be adopted on different timescales in different countries, depending on policy drivers and technology progression (Figure 2).

Many reports have been published explaining in more detail the variety of roles that hydrogen can play in global decarbonisation including from the IEA [5], IRENA[6], Hydrogen Council[7] , Hydrogen Europe[8], the Energy Transitions Commission[9,10] , BloombergNEF[11], and the Fuel Cells and Hydrogen Joint Undertaking[12]. The new roles for hydrogen are to support decarbonisation, and so future hydrogen markets and trade rules will have to consider the carbon intensity of hydrogen and any carriers or derivatives.

2.2 Archetypes for hydrogen production

One of the attractions of hydrogen is that it can be produced from many different feedstocks and energy sources using a variety of technologies and processes. Today hydrogen is almost exclusively produced from fossil fuels through unabated combustion processes, producing significant emissions. The most common production technology is steam methane reforming (SMR) (75% of production). Autothermal reforming of natural gas (ATR) is also used, and coal gasification is common in China.

The GHG emissions of hydrogen produced from fossil fuel combustion can be lowered by adding carbon capture, use and storage (CCUS). The capture rates of CO_2 and the treatment of CO_2 (for storage or use) vary greatly depending on the characteristics of the plant. Hydrogen produced via this pathway is sometimes referred to as 'blue hydrogen', though no clear definitions for hydrogen 'colours' exist, and future regulations will likely refer only to greenhouse-gas equivalent emissions values although some jurisdictions may refer to production technologies. Hydrogen can also be produced through electrolysis, where electricity is used to split water into hydrogen and oxygen.

[5] https://www.iea.org/reports/global-hydrogen-review-2021
[6] https://www.irena.org/publications/2019/Sep/Hydrogen-A-renewable-energy-perspective
[7] https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021-Report.pdf
[8] https://www.hydrogeneurope.eu/wp-content/uploads/2021/04/Clean-Hydrogen-Monitor-2020.pdf
[9] https://energy-transitions.org/wp-content/uploads/2021/04/ETC-Global-Hydrogen-Report.pdf
[10] https://www.energy-transitions.org/publications/mission-possible/
[11] https://data.bloomberglp.com/professional//BNEF-Hydrogen-Economy-Key-Messages-30-Mar-2020.pdf
[12] https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

Four main electrolyser technologies exist today, of which alkaline and proton exchange membrane (PEM) are the most mature, solid oxide electrolysis cells (SOECs) and anion exchange membrane cells (AEMs) are emerging. The carbon intensity of the electricity used for electrolysis is defining for the carbon footprint of the resultant hydrogen. Hydrogen produced from this pathway is sometimes referred to as 'green' when renewable electricity is used. Currently less than 1% of hydrogen is produced from fossil sources with CCS and from the electrolysis of water using renewable electricity[13].

Hydrogen is also produced as a by-product of chemical processes (21% of production in 2020[14]) (e.g., from the ethylene industry and chlor-alkali electrolysis) and this can and is used in industrial processes today. This lowers the Scope 1 emissions of the hydrogen user[15].

Other routes to produce hydrogen include using the heat from nuclear power plants[16], biomass as the feedstock (e.g., through gasification), or methane pyrolysis. Methane pyrolysis involves splitting methane (CH_4) at relatively high (>800°C) temperatures into hydrogen gas and solid carbon (e.g., carbon black, graphite) and so does not create direct gaseous CO_2 emissions. Electrification of methane reforming (e-SMR) is another emerging technology.

2.2.1 Hydrogen definitions

The colours sometimes used as shorthand to reference hydrogen produced by different routes are often extended to subsequent hydrogen-based fuels such as ammonia. However, the GHG emissions and environmental impacts vary considerably even within each production route, especially when all components of the whole supply chain are considered. Whilst colour terminology has entered the common vernacular, it is over-simplistic and inexact, and does not provide a sound basis for future markets or trade. Some jurisdictions may also reference production technologies to help meet their policy objectives beyond GHG emission.

'Renewable' hydrogen typical refers to hydrogen produced from the electrolysis of water using only renewable electricity. The definition of what is deemed as renewable electricity can vary by jurisdiction, the life cycle may not be zero carbon, and the principle of additionality can take a role in a definition. The use of renewable electricity to produce 'renewable hydrogen' could still lead to increased carbon emissions in the overall energy system if it leads to increased fossil fuel consumption elsewhere or displaces more effective uses of that renewable electricity.

The purpose of this discussion paper is not to define carbon intensity of hydrogen, but since hydrogen will be traded to facilitate reduced emissions, we will generally use the term 'low carbon'. Currently there is no legal definition or international agreement for the term, and each country may have a different definition as it is at their and users' discretion how to meet GHG objectives (Section 4.3.1). An EU legal definition for 'low carbon hydrogen[17] [18]' is part of the second package under Fit

[13] https://www.hydrogeneurope.eu/wp-content/uploads/2021/04/Clean-Hydrogen-Monitor-2020.pdf
[14] IEA – The Role of low carbon fuels in the clean energy transition of the power sector (2021)
[15] Unless these sources produce low carbon hydrogen, they will not reduce overall emissions, and could even increase emissions if the feedstocks used (such as petcoke from oil refinery waste) were more carbon intensive than reforming of natural gas.
[16] Twelve demonstration projects with combined electrolyser capacity of 250 MW explore using nuclear power for hydrogen production (Canada, China, Russia, the UK and the US).
[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A804%3AFIN&qid=1639665806476
[18] https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_6685

for 55[19] [20]. The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) Hydrogen Production Analysis (H2PA) Task Force published a Working Paper version 1 outlining a methodology for the quantification of GHG emissions via various hydrogen production pathways and continues to develop the framework to include hydrogen carriers and transportation[21].

In this discussion paper the term 'low carbon' encompasses all production methods and pathways that achieve GHG emissions reductions compared to unabated production from fossil fuels[22]. This is predominantly hydrogen produced from electrolysis using renewable energy and production from fossil fuels with CCUS but also includes the other production routes in Section 2.2. Establishing standards and certification and monitoring processes to properly quantify the GHG emissions of the different hydrogen synthesis and delivery methods will be an essential step in future widespread hydrogen adoption (Section 4.3).

2.2.2 Implications of production pathways

Whilst each production method produces indistinguishable hydrogen molecules, their different characteristics have implications on the attractiveness of certain value chains to different customers. These include overall GHG emissions, costs, efficiencies, siting locations, reliance on infrastructure construction, technology readiness and future outlook. The published national strategies demonstrate that countries are already treating the different production methods differently in terms of emerging policy support and legislation as well as in social acceptability. For trade, the impact of these factors on the delivered hydrogen will depend on the full supply chains and are discussed in Section 3.3.

2.3 Synthesis of national aspirations

Over 30 countries have already released hydrogen roadmaps, and 13 countries plus the EU have published National Hydrogen Strategies (NHS)[23]. More are in development, and by 2025, hydrogen strategies are expected to cover countries representing over 80% of global GDP[24]. These Strategies typically focus on integrated energy system transitions rather than isolated sectoral development. They usually signal a country's overall vision and political commitment to hydrogen and provide a roadmap for future developments, setting out how government and industry need to coordinate and deliver activity across the value chain. They vary both in detail and to reflect each country's interests and industrial strengths but viewed together demonstrate a clear and strong global momentum behind hydrogen which will be important for attracting investment and project financing.

The Strategies generally include national goals, demand and supply targets including domestic production and imports, preferred production methods, infrastructure requirements, integrating hydrogen into the current energy system, current support measures and how all these things will evolve over time. Some present legislation to help reach the next steps, but most simply aim to set the framework for future government policy discussions and corporate decision-making. Most lack details on the exact measures to be taken to achieve the ambitious targets and translation of intent into policy is just starting to emerge.

---

[19] https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/package-fit-for-55
[20] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541
[21] https://www.iphe.net/iphe-working-paper-methodology-doc-oct-2021
[22] This is consistent with the terminology used in the IEA Global Hydrogen Review 2021
[23] IEA Global Hydrogen Review 2021 - Page 24
[24] https://www.weltenergierat.de/2020/10/WEC_H2_Strategies_Executive-Summary_final.pdf

Some Strategies refer explicitly to a country's anticipated future role (e.g., a producer and exporter, an importer, or a transit and distribution hub). Some set targets specifically for hydrogen production (Figure 12 in the Appendix), either as Mt H_2 or in terms of GW electrolysis capacity. Not all countries quantify expected national hydrogen demand, but the ones that do are similar with respect to the size of their economy (Figure 13 in the Appendix). Supply and demand data cannot always be directly compared, and different countries use sometimes conflicting terminology to define hydrogen produced by different pathways[25]. However, high-level analysis indicates the extent to which each country envisages producing domestic hydrogen, and where imports will be required. China and the US, for example, may manage to cover demand for low-carbon hydrogen and hydrogen-based fuels domestically, while others (e.g., Japan, Korea and parts of Europe) are very likely to rely on at least some imports.

Scaling the upper hydrogen requirements for 2050 in national strategies to a global level (based on GDP) indicates a *potential* demand of up to 9,000 TWh or around 270 Mt of hydrogen per year[26]. This equates roughly to the annual primary energy currently provided globally by renewables and will require significant growth in the global hydrogen ecosystem. For now, projected forecasts for both production capacity and demand volumes vary widely: some scenarios even show global hydrogen energy demand of as much as 800 Mt by 2050[27] (Figure 14 in the Appendix), and this would be almost 9 times greater than current hydrogen production. In a 2050 decarbonized energy system, hydrogen could meet 18-24% of final energy demand[28], roughly equivalent to the role played by natural gas today.

2.4 Synthesis of industrial project announcements

Alongside ambitious national targets, hydrogen production projects continue to be announced, and many more are expected. Low-carbon hydrogen projects increasingly involve broad consortia including relevant major stakeholders throughout the value chain, to share the financial risk. Consortia of downstream stakeholders are being built to help drive demand, to try to ensure offtake is not the bottleneck, and giving visibility to producers to obtain bankable projects. However, offtake agreements have so far been limited as the cost gap from conventional production is still often large, as is uncertainty regarding possible future regulation (Chapter 4).

Three large-scale production archetypes are emerging:

- Those driven by local, existing demand primarily arising in Europe where the current supply can be decarbonized, complemented by imports to satisfy demand
- Global projects, mostly in new locations, driven by renewable electricity capacity and designed for supplying export markets
- Decarbonisation of existing fossil-based production, targeting export markets particularly between the Middle East and Northeast Asia.

In Europe, large-scale industrial hydrogen users are pooling demand and acting as initial anchor customers for both the replacement of current fossil-based hydrogen with low carbon alternatives,

[25] E.g., The UK 2030 5GW production target includes H_2 from electrolysis and SMR+CCS. 'Sustainable' or 'clean' hydrogen in the Dutch, UK, Japanese, Korean and Canadian NHS covers 'green' and 'blue' H_2. France's electrolyser target is based on renewable and nuclear power which may be 'clean' with respect to CO_2 emissions, but nuclear power is not generally referenced as renewable.
[26] 'International Hydrogen Strategies' (2021). LBST and the World Energy Council Germany
[27] https://www.energy-transitions.org/wp-content/uploads/2021/04/ETC-Global-Hydrogen-Report.pdf
[28] FCHJU (2019), "Hydrogen Roadmap Europe:" Brussels.

and its use in new applications. Hydrogen hubs/valleys are emerging with multiple end-uses for low carbon hydrogen such as HEAVENN in the Netherlands[29]. The European Hydrogen Alliance database of hydrogen production projects across the EU would, if realized, cumulatively provide 9Mt H_2 by 2030[30], equivalent to the total fossil-based hydrogen production in Europe today. 84% of these projects would produce electrolytic hydrogen and over 50% aim to come online by 2025. This compares favourably to the 2030 10Mt renewable hydrogen target set in the EU Hydrogen Strategy.

Mostly outside Europe, some large-scale renewable hydrogen hubs are developing. These are mainly in greenfield locations with dedicated high capacity, low-cost renewable electricity, such as in Australia, South America and the Middle East. These projects primarily focus on production, for the export of renewable energy, and are not necessarily tied to existing hydrogen users.

These projects have the potential for extremely large hydrogen supply given announced electrolyser capacities, the scale of which has increased exponentially. In early 2020, most projects had capacity projections of around 10MW. However, by the end of the year there were many GW scale project announcements (Figure 3) and six of these even have double-digit GW capacity[31], meaning each is greater than the EU's 2030 electrolyser target, and they could cumulatively produce around 17 Mt H_2/yr. Chile is aiming for 25 GW of electrolyser capacity by 2030 and Western Australia alone could produce up to 100 GW renewable energy, of which a proportion could be used for hydrogen production by 2030, and this could increase to 200 GW by 2040[32]. By comparison, in 2020 Australia's entire stationary energy market was 70 GW, demonstrating the potential for exports.

Most of these projects will also be among the largest renewable electricity generating plants globally. If all the announced projects were to be realised in the time frames announced, electrolyser production capacity would have to expand dramatically. Installed global electrolyser capacity has doubled since 2016 to reach approximately 300 MW operating by 2021[33] but to reach targets in the IEA Net Zero Emissions Scenario, installed electrolysis capacity would have to be 850 GW by 2030 and almost 3,600 GW by 2050. Global electrolysis manufacturing capacity was only 3 GW/yr in 2020[25], and while it is ramping rapidly it is currently something of a bottleneck to deployment. A dedicated industrialised supply chain and a corresponding industrial supplier landscape will be essential to meet future capacity demands (Section 5.3.9).

[29] https://www.newenergycoalition.org/en/hydrogen-valley/
[30] 'The role of policy in defining a future for Hydrogen' Keynote Speech, S&P Global Platts, Hydrogen Infrastructure Europe Virtual Conference
[31] Western Green Energy Hub (Australia), Green Energy Oman (InterContinental Energy), Asian Renewable Energy Hub (Australia), Svevind in Kazakhstan, Project Aman (Mauritania), New 50GW project MENA region (InterContinental Energy), Fortescue/Grand Inga hydro dam (DRC),
[32] https://reneweconomy.com.au/western-australia-eyes-100gw -for-green-hydrogen-by-2030/
[33] IEA Global Hydrogen Review 2021 – Page 5 and Page 121

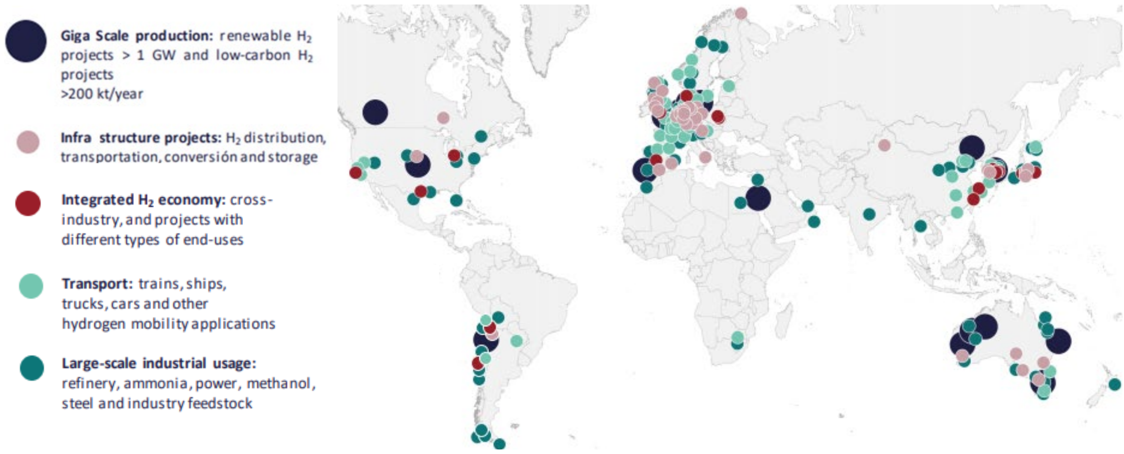


Figure 3: Announced projects involving low carbon hydrogen (June 2021)

Source: Based on Hydrogen Council, McKinsey & Co

IEA figures suggest that targeted global installed electrolyser capacity for 2030 is 54 GW, considering capacity under construction and announced projects, though currently only 7% of these projects (4GW) are under construction or have reached a final investment decision. Another 40 projects accounting for more than 35 GW of capacity are in even early stages of development. 16 projects for producing hydrogen from fossil fuels with CCUS are operational today, producing 0.7 Mt of hydrogen annually, and another 50 projects are under development. These could bring annual hydrogen production from fossil fuels with CCUS to over 9 Mt by 2030. Together the announced plans total 17 Mt of low carbon hydrogen for 2030. However recent IEA estimates[34] suggest 520 Mt H_2/yr will be required by 2050, necessitating a further significant increase in capacity.

Some long-distance hydrogen supply chains could be established before 2030. These could include those between the Middle East (where natural gas is highly abundant, CO_2 can be stored underground, and ammonia (the hydrogen carrier) is already produced) and Northeast Asia, where the focus is on cost reductions, and no mechanism currently exists to reflect the carbon intensity of hydrogen imports. Some of the major future potential exporters do not yet have net zero pledges in place, so importing countries will need to engage with trading partners to encourage and guarantee relevant supply investments if they want their hydrogen imports to be low carbon.

While global hydrogen hubs are under consideration, it is still too early for clarity on specific technologies and business models. These large-scale projects and the necessary technology are yet to be proven at scale, some are targeting the start of operations and the export of large volumes of hydrogen and its derivatives by 2025 including projects in Chile[35], Saudi Arabia[36] and Australia[37].

2.5 Implications for trade

Most countries have sufficient local resources to meet the demands of low carbon pilot projects to demonstrate technology and achieve short-term goals, so most low carbon hydrogen developments have been domestic. Currently most electrolytic hydrogen projects are 1-10MW demonstration projects, but by 2025 these are expected to expand into local clusters (100-500MW) such as ports,

[34] Net Zero by 2050 A Roadmap for the Global Energy Sector
[35] https://www.rechargenews.com/energy-transition/our-green-hydrogen-will-be-cost-competitive-with-fossil-fuels-by-2025-chile-energy-minister/2-1-1096149
[36] https://energy-utilities.com/saudi-arabia-s-5bn-green-hydrogenbased-ammonia-news111872.html
[37] https://research.csiro.au/hyresource/h2-hub-gladstone/

industrial clusters[38] and 'Hydrogen Valleys' [39] where the hydrogen produced is consumed locally. However, future needs will frequently outstrip domestic resources, and analysis is beginning on individual countries' theoretical, technical, economic, and politically feasible potential. Locations of low carbon energy surplus and deficit depend on geography and on regulation (e.g., through ability to access subsidies) and affect both supply capability and the cost competitiveness of domestic supplies relative to potential imports. This will start to drive future trade agreements as supply and demand ramp up. By 2030 projects are expected to be at GW scale, including large-scale export-focused projects, as distinct hydrogen supply centres and demand hubs emerge.

So far Japan, Korea, and Germany explicitly state the need to develop hydrogen import capacity because of the mismatch between domestic production potential and future hydrogen needs. Singapore and The Netherlands see imports as essential to maintain their roles as distribution hubs for Asian and European markets respectively. Initial estimates of possible hydrogen import volumes (rather than just production/demand volumes) are starting to emerge (See Appendix). Potential exporters have also started to state possible supply capacities, transport modes, and timeframes. These include Australia, Chile, The Middle East and North Africa as well as Canada, Russia, Ukraine, Portugal, Spain, and Norway (See Appendix).
Governments and private companies have started to announce international collaborations and projects for hydrogen trade and future supply chains are emerging. Possible trade patterns for low carbon hydrogen and its derivatives will depend on factors beyond volume and cost (Section 3.3). These may include trading distances, existing trade relationships and infrastructure, ease of doing business, price volatility, wider energy geopolitics, and fuel security considerations. Potential trade flows are starting to be mapped, using current pledges and ambitions. For example, Japan and Korea would each import around 60% of their domestic demand for hydrogen and hydrogen-based fuels by 2050 (Figure 4). Wealthy and established economies such as these should enable demand, help reduce costs and stabilize value chains towards 2030, bringing opportunities to expand low carbon hydrogen use in emerging and developing economies.

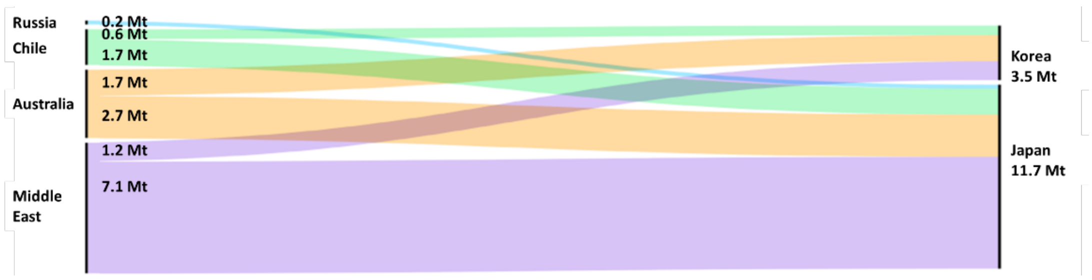


Figure 4: H_2 trade flows to Japan and Korea in 2050 given current announced government pledges

Source: IEA Global Hydrogen Review 2021

Around 60 international hydrogen trade projects have been announced, with a reported total volume of 2.7 Mt H_2/yr and feasibility studies are under way for half of them[36]. Figure 5 displays potential trade routes for hydrogen published by IRENA in 2021. 'Routes in place or under development' include shipments to Japan of natural gas-based ammonia with CCUS from the Middle East[40], or liquid hydrogen[41] from Australia, and a liquid organic hydrogen carrier[42] (LOHC) from Brunei. The latter are operational but as pilot projects. Most low carbon hydrogen projects designed

[38] https://www.iea.org/events/cem-global-ports-hydrogen-coalition
[39] https://www.fch.europa.eu/page/mission-innovation-hydrogen-valleys-platform
[40] https://www.japantimes.co.jp/news/2021/08/19/business/corporate-business/uae-blue-ammonia-japan/
[41] https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20191211_3487
[42] https://www.rechargenews.com/transition/-world-s-first-international-hydrogen-supply-chain-realised-between-brunei-and-japan/2-1-798398

for export markets have yet to announce specific export destinations or the method of hydrogen export (both hydrogen carrier and/or transport mode), and the rapid evolution of hydrogen policies and strategies makes further announcements likely.

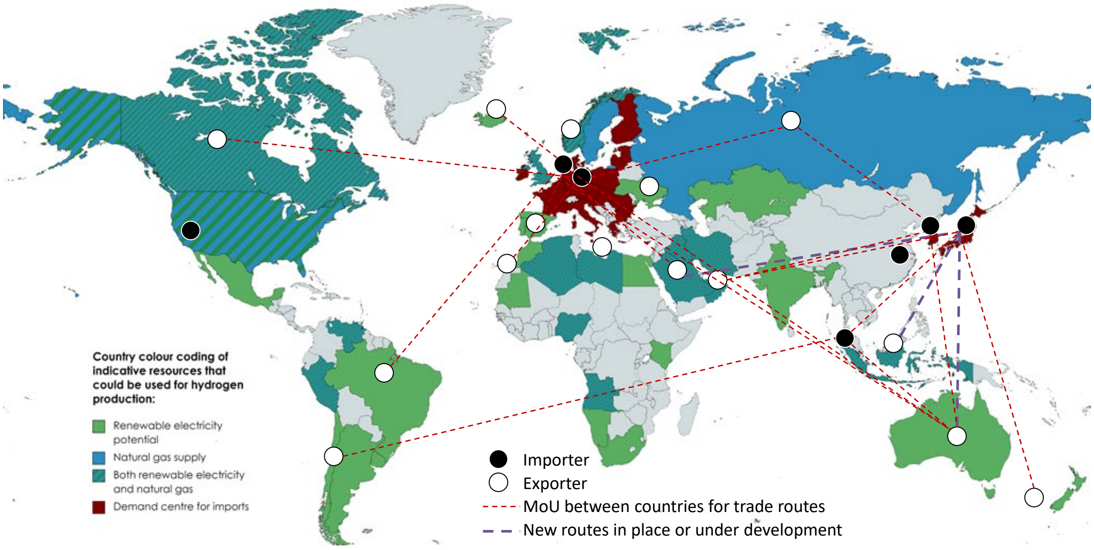


Figure 5: Envisaged trade routes for hydrogen (as of 2021)

Source: Based on IRENA 'Green hydrogen supply: A guide to policy making'

3 Supply chains for hydrogen distribution to enable trade

3.1 Current distribution and trade of hydrogen

Most hydrogen is currently produced close to where it is used. Almost two-thirds of hydrogen production capacity is for internal consumption (e.g., in refineries and for ammonia/methanol production). The EU is currently the only region in the world where hydrogen is regularly transported across international borders, including in cross-border pipelines. This is done on a business-to-business (B2B) basis, and the hydrogen infrastructure is unregulated.

In 2019 EU countries exported 107 ktH_2, mostly to other EU member states. Only 1-2 ktH_2 was exported externally. In 2019, only 8 ktH_2 was imported to the EU, half from Switzerland[43]. Today over 90% of all hydrogen 'trade' between EU countries is between the Netherlands, Belgium and France through a hydrogen pipeline network owned and operated by Air Liquide. Most of the remaining hydrogen exports in 2019 went from the Netherlands and France to Germany, and from Sweden to Denmark. Trade between all the other EU countries is less than 2kt per year.

While some chemicals facilities have low-pressure pipelines, the only other notable network of pressurised hydrogen pipelines is a 965km network between Texas and Louisiana where Air Products links 22 of its hydrogen plants[44].

In terms of trade of possible hydrogen carriers, ammonia is already widely traded globally (Figure 9). The first (pilot) shipment of cryogenic liquid (LH_2) is planned for later in 2021 from Australia to Japan, and in 2020, one (pilot) shipment of LOHC was transported from Brunei to Japan.

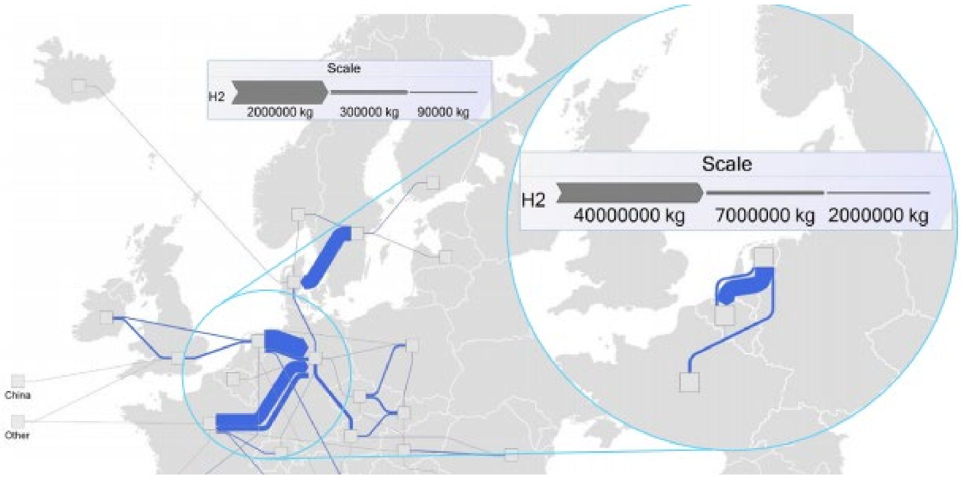


Figure 6: Exports of hydrogen by EU member states in 2019

Source: Hydrogen Europe, based on EUROSTAT international trade database.

3.2 Distribution via future supply chains

Reliable, accessible, and cost-efficient storage and transportation infrastructure is a prerequisite for the widespread use and trade of hydrogen. It will often govern the cost and availability of low-carbon fuels and will precede large-scale hydrogen deployment and a liquid market in hydrogen

[43] Clean Hydrogen Monitor 2020 – Hydrogen Europe
[44] https://www.ifri.org/sites/default/files/atoms/files/philibert_hydrogen_bubble_2021.pdf

trading. Understanding the different components of possible supply chains between production and end-users informs how they may affect the development of large-volume trade.

Hydrogen's high gravimetric energy content (120MJ/kg) is balanced against a low volumetric energy density (Figure 7). This means that it must be conditioned for storage and transportation to enable efficient distribution, especially in large volumes and over long distances, and is the reason why carriers such as ammonia (NH_3) or liquid organic hydrogen carriers (LOHCs) are being considered. Transporting hydrogen in its elemental form as a compressed gas or as a cryogenic liquid (LH_2) is the traditional approach, and is done in relatively small quantities compared to potential future needs.

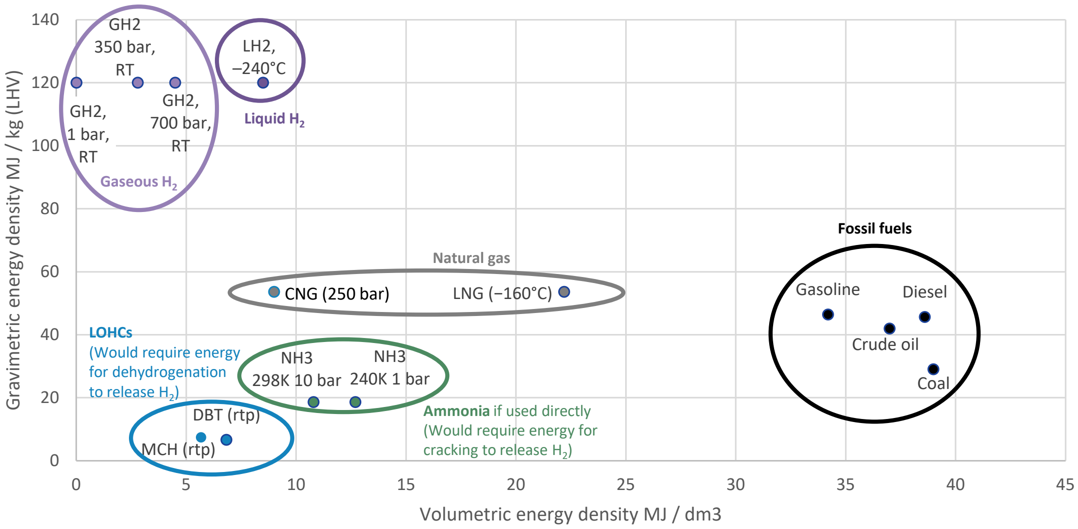


Figure 7: Volumetric and gravimetric energy densities for different hydrogen carriers

Hydrogen supply chains could include multiple hydrogen carriers, various transportation modes and different storage requirements at different locations (Figure 8). The different production and distribution technologies will mature and scale up at different rates, with implications for how trade develops. Technology Readiness Level (TRL), technical requirements, conversion efficiency, operational experience, scale up capacity, infrastructure availability, regulation, safety etc could all act as either hurdles to, or enablers of, large-scale hydrogen trade.

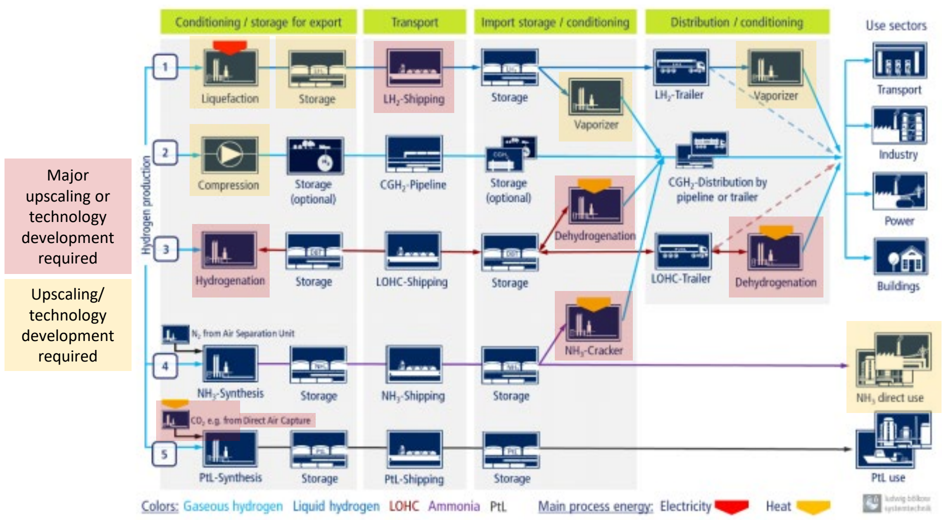


Figure 8: Main elements of large-scale hydrogen export/import supply chains

Source: Adapted from 'International Hydrogen Strategies' by LBST and World Energy Council

3.2.1 Gaseous hydrogen

Hydrogen is produced as a gas, and it can be compressed and distributed in this form. If a network is in place, gas pipelines are often the most cost-effective mode for hydrogen distribution (Figure 10). Currently there are around 5,000 km of hydrogen pipelines globally, with over 50% in the US and almost 40% in Europe, operating in Germany, France, Belgium and the Netherlands. Most are closed systems owned by large merchant hydrogen producers and are concentrated near industrial centres.

In principle, hydrogen can be blended into existing natural gas flows with limited impact on end-users, but this depends on the pipeline material, the types of end-users and local regulations on for example, gas purity. If inter-connected networks transition to hydrogen or hydrogen blends at different speeds, the ability to trade gas between them may be affected, so to avoid interoperability issues, careful coordination will be required between adjacent gas markets.

If pipelines are not an option and inland distribution of gaseous hydrogen is required (networks have inflexible point-to-point connections), it can be compressed to 180-700 bar, (limited by regulation) into long cylindrical tubes/tanks which are stacked onto truck-trailers, trains or barges. Gaseous hydrogen trucking is widely used today, typically for distances up to 300km[45]. Longer distances are unlikely to be economically supplied in this way.

3.2.2 Liquid hydrogen (LH_2)

The volumetric energy density of hydrogen can be increased by cryogenically cooling it below 253°C to produce liquid hydrogen. This is currently distributed in tanks on trucks, railcars and barges (3.5 tLH_2) for distances of 300-4,000 km[46]. Large-scale LH_2 vessels need to be developed and demonstrated but distribution by ship is expected for long distances. This could be combined with onwards inland LH_2 trucking for distributed use.

3.2.3 Hydrogen carriers

There are some technical and economic drawbacks to distributing hydrogen in its native form, primarily the low volumetric energy density of either gaseous or LH_2 (Figure 7), and the lack of existing infrastructure. Safety must be maintained for high-pressure hydrogen gas tanks and energy is required to achieve and maintain the cryogenic temperatures needed for liquefaction.

An alternative to distributing hydrogen in its elemental form is the chemical storage of hydrogen within liquid carrier molecules. Many liquid energy vectors and fuels contain hydrogen, but the majority are intended to be used directly as low carbon hydrocarbons and not as 'hydrogen carriers' (i.e., they are not generally intended to be reconverted to pure hydrogen for end-use). These are often described as Power-to-X (PtX) fuels and include methane[47], methanol[48] and Fischer-Tropsch fuels (synthetic diesel or synthetic kerosene). This leaves two types of potential hydrogen carrier, those such as ammonia where hydrogen can be separated out relatively easily as well as the carrier itself possibly being used directly, and those which are purely hydrogen carriers (e.g., LOHCs).

[45] https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf
[46] https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf
[47] Reforming of synthetic methane to produce hydrogen would be analogous to SMR or ATR of natural gas but is unlikely to be efficient or cost effective from an emissions and life-cycle perspective.
[48] Methanol can be re-converted into hydrogen by reforming + purification, but its use exclusively as a hydrogen transport mechanism is untested at scale, presenting technology uptake risk for the reforming step

Announced projects suggest that ammonia and LOHCs are emerging as the most promising liquid carrier molecules.

Solid carriers such as metal hydrides and metal organic frameworks (MOFs) also store hydrogen through conversion/reconversion cycles. However, these are currently almost all still in the laboratory, and those used commercially are at small scale and high cost for niche applications.

3.2.3.1 Ammonia

Ammonia is widely produced and used globally today. Principal exporting countries and regions are Russia, Trinidad and Tobago and the Middle East, representing 24%, 23% and 15% of global ammonia exports respectively in 2019. Principal importing regions and countries are the EU, India and the US, responsible for 24%, 14% and 13% of global imports respectively[49]. Ammonia is therefore already widely distributed by pipelines, trucks and ships (Figure 9), however additional infrastructure construction would be required to connect new areas of supply and demand. Handling and usage procedures are familiar and there are existing regulations for current applications. The toxicity of ammonia and the public perception of this safety issue may make its distribution, especially in populated areas, a topic for discussion.

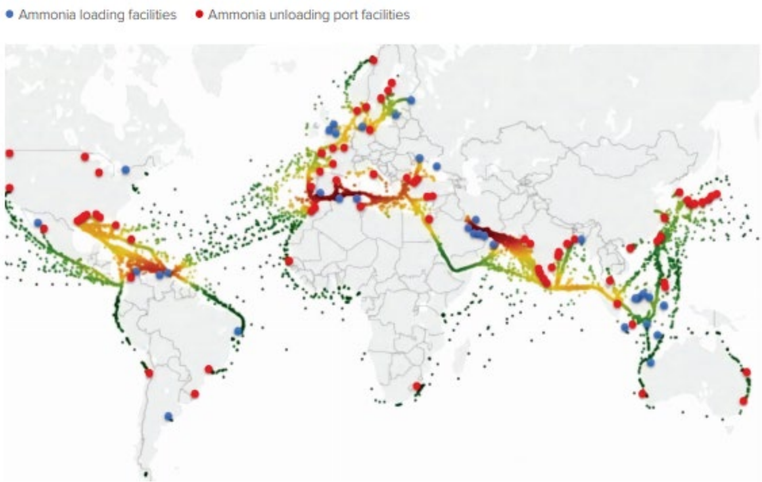


Figure 9: Heat map of liquid ammonia carriers and existing port facilities (2017)

Source: Royal Society 'Green Ammonia Policy Briefing'

Trade of ammonia already occurs via pipelines including in the Tolyatti-Odessa pipeline which pumps ammonia from Russia to fertiliser and chemical plants as far as Ukraine. Existing natural gas and petroleum pipelines can in principle be cost-effectively converted to carry ammonia. Global maritime trade of fossil based anhydrous or aqueous ammonia was estimated at 20 Mt in 2020 (10% of production) and the export economy represents a $6 billion market per year, trading at $250-300/t$NH_3$[50]. 170 ships are currently capable of carrying semi-refrigerated ammonia as cargo including 71 LPG tankers, with capacities from 25-60 ktNH_3, equivalent to 4-10 ktH_2. 120 ports globally are equipped with facilities to import/export ammonia which could help develop a bunkering grid. Ammonia has similar physical properties to LPG meaning existing liquid fuel infrastructure such as bunkering terminal equipment can be retrofitted for ammonia distribution.

[49] IEA_AmmoniaTechnologyRoadmap.pdf 2021
[50] https://www.trademap.org/

Projections as to the size of a future low carbon ammonia market vary, but there is potential for 500 Mt demand from new markets by 2050 on top of, and almost three times larger than, existing demand[51]. Despite already being widely traded, current transport volumes of ammonia are very small in comparison to these predicted future trade volumes. The focus on ammonia and its ability to store and transport low carbon hydrogen and energy across long distances and periods of time is accelerating, with many of the large hydrogen synthesis projects naming it as the carrier of choice for export opportunities. Production capacity for 17 Mt of renewable electricity-based ammonia to be available by 2030 has already been announced[52]. Germany, Norway, Spain, Morocco, Australia, Japan, Korea and the EU Hydrogen Strategies all mention ammonia as a potential carrier for imports/exports, with many of these also suggesting its use as a low carbon feedstock for industry and potential fuel for ships.

3.2.3.2 Liquid Organic Hydrogen Carriers

Liquid Organic Hydrogen Carriers (LOHCs) are a family of organic chemicals, rather than a specific molecule, that store and release hydrogen by hydrogenation and dehydrogenation cycles. The hydrogen carrying liquid is transported to the point of use, where the hydrogen is released by supplying high temperatures (250-320°C). Dehydrogenation requires high energy consumption, about 35% of the Lower Heating Value (LHV) of hydrogen. It produces low-pressure hydrogen which may require purification and compression if further distribution is required. The carrier molecule itself is not consumed but returned to the hydrogen source where it can be reloaded and used in further cycles so LOHCs represent a cyclical rather than linear value chain. Over time, LOHC molecules do degrade and need to be replaced. Properties of each LOHC are molecule specific, but generally these are liquid at ambient conditions and similar to other oil products. They can use cheaper storage tanks than those needed for other carriers and there are essentially no energy losses over longer storage periods.

As liquids, LOHCs could be transported by trucks and ships. A ship tanker filled with 75,000t of Dibenzyltoluene (DBT) has a usable hydrogen transport capacity of about 4,000 tH_2. Based on an average storage density of 6.2 wt%, an LOHC trailer could carry around 1.5 tH_2. Dehydrogenation is unlikely to be feasible onboard vessels, so to keep emissions low, ships must also carry a carbon-neutral fuel for propulsion as unlike LH_2 and ammonia the cargo cannot be used as fuel.

Given their relatively new application as a hydrogen carrier, LOHC specific infrastructure does not generally exist, and where there is LOHC hydrogenation and dehydrogenation infrastructure, it is small-scale (5 tpd capacity). Considerable scale-up efforts will be needed to develop and test large-scale hydrogenation and dehydrogenation facilities. Distribution of LOHC could possibly be integrated into existing liquid fuel storage and transportation infrastructure used by the petroleum industry (e.g., leverage pipelines, oil tanker redundancy, or possibly use standard road tankers[53]) reducing the level of development. However, this would be carrier molecule specific. There is also a relative lack of regulation due to the current small volumes of trade today for the use of these carriers in the chemical industry.

Progress in LOHC supply chains is underway. In 2020, Chiyoda Corporation successfully shipped hydrogen using methylcyclohexane (MCH) from Brunei to Japan. The Port of Rotterdam has recently signed a MoU with Mitsubishi and Chiyoda to undertake a feasibility study to develop commercial

[51] SagaPure 1Q2021 presentation – Ammonia Energy Australia Conference 2021
[52] https://www.ammoniaenergy.org/wp-content/AEA-Australia-Rob-Stevens-Saga-Pure-2021-08-25.pdf
[53] Preuster, P., LOHCs: Toward a hydrogen-free hydrogen economy. Acc. Chem. Res. 50, 74–85 (2017)

scale LOHC infrastructure for hydrogen import[54]. German company Hydrogenious is developing the world's largest LOHC storage project (1,800 t/yr using DBT) in Germany as part of a larger plan to develop a renewable hydrogen supply chain with Rotterdam[55].

3.3 Drivers for carrier choice

Cost, risk, availability and other typical factors will affect the success of the different carriers, and trade rules and regulations will play a part. A fundamental driver for the widespread use of traded hydrogen is to reduce carbon emissions, and so demonstration of these credentials will be essential. Any future trade is likely to be strongly connected to greenhouse gas certification mechanisms, either bilateral or multilateral.

The economically optimal distribution method and hydrogen carrier of choice will depend on many factors including the distance between production and consumption (Figure 10), volume to be distributed, intended use at the destination, purity requirements, additional need for long-term storage, existing infrastructure, regulation, terrain and public acceptance. These will also vary depending on whether these processes occur at centralised or distributed facilities.

The relative cost of transporting hydrogen and its carriers is mainly dependent on the distance they need to move. Figure 10 shows hydrogen pipelines (new or repurposed) are likely to be the most cost-effective option for hydrogen imports over distances equivalent to those within Europe and neighbouring regions (<2000km). This is reflected by the push in Europe for a hydrogen pipeline network[56] with conversion facilities for hydrogen carriers arriving from overseas located at ports of first landfall. Low-cost hydrogen transport by pipeline would enable hydrogen imports to the EU from neighbouring regions such as North Africa, Ukraine, Norway, and potentially the Middle East. Some of these areas are labelled as 'priority partners' in the EU Hydrogen Strategy and have already announced pipeline projects.

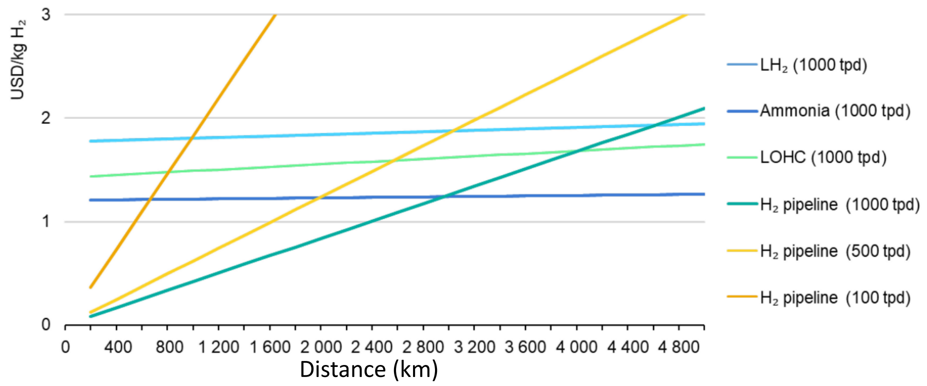


Figure 10: Costs of delivering hydrogen gas by pipeline and LH_2, LOHC and ammonia by ship, 2030[57]

Source: IEA Global Hydrogen Review 2021

[54] https://www.portofrotterdam.com/en/news-and-press-releases/study-for-commercial-scale-hydrogen-imports
[55] https://www.hydrogenious.net/index.php/en/2021/03/03/kick-off-for-construction-and-operation-of-the-worlds-largest-plant-for-storing-green-hydrogen-in-liquid-organic-hydrogen-carrier/ (2021)
[56] https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone
[57] Includes conversion, export terminal, shipping, import terminal and reconversion costs for each carrier system. Storage costs are included in import and export terminal expenses. The pipeline cost assumes construction of a new pipeline.

Shipping hydrogen as ammonia, LOHC, and LH_2 will have to play a role in inter-continental transport over large distances where pipelines are not an option (e.g., over oceans). Figure 10 shows distance does not play a significant role. Shipping and non-networked distribution options such as trucking can also be advantageous for security and flexibility of supply, as pipelines can be difficult to construct across environmentally sensitive or politically unstable regions and shipping routes can be modified in reaction to market dynamics.

Development of hydrogen carriers and distribution infrastructure is likely to come in phases as the timeline for different technology improvements will vary. Given current announced pledges from governments, by 2050 trade in hydrogen and hydrogen-based fuels would account for 20% of global demand. Only 8% of demand is predicted to be traded as hydrogen, with 50% traded as ammonia and 40% as liquid synthetic fuels due to their comparatively lower transport costs.

Early implementation:

- **Ammonia distribution** technology already exists at scale and there are already well-developed export routes globally, so this is a feasible and potentially financially viable distribution method today. Japan has imported 40t of 'low carbon ammonia' produced in Saudi Arabia from natural gas with CCUS for direct use as fuel for electricity generation[58]. However, currently there are limited off-takers willing to pay for low carbon, more costly ammonia and some regulation gaps exist (i.e., certification). Cracking technology requires development so initial use cases will likely use the imported ammonia directly (e.g., for power generation or marine fuel).

Future implementation:

- For **distribution of hydrogen gas by pipeline**, the Netherlands is pioneering regional hydrogen networks from 2025 and a national hydrogen backbone to be ready by 2030 including interconnections to Germany and Belgium. By 2035 it is envisaged the network will be part of a pan-European hydrogen network, with 40,000km of pipelines across 21 countries by 2040[59]. The EU views the development of a pan-European hydrogen pipeline network as an important facilitator for hydrogen distribution and trade within the block. An import route from Ukraine to the EU could emerge as well as potential pipelines between Spain/Italy and North Africa. There are also plans for a pipeline to export hydrogen from Danish offshore wind to Germany by 2025 which could satisfy 10-25% of future German hydrogen demand[60].
- **Distribution of LH_2**, whilst still at very early stage of technology development, could be a longer-term solution given the potential for cost reductions and favourable import characteristics. Kawasaki aims to build 2 commercial-scale ships to import more than 225 kt LH_2/year into Japan by 2030, which could increase to more than 80 ships and 9 Mt LH_2/year imports by 2050[61].
- **LOHCs** also present a longer-term implementation opportunity for hydrogen export given the greater number of scale-up steps and high costs required, especially for the cyclical infrastructure, as well as the challenge of sourcing sustainable LOHC compounds.

[58] https://eneken.ieej.or.jp/data/9135.pdf
[59] https://gasforclimate2050.eu/ehb/
[60] https://cleanenergynews.ihsmarkit.com/research-analysis/-danish-companies-hydrogen-pipelines-to-cut-across-northern-eu.html
[61] https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/021_04_00.pdf

3.4 Customs and tax implications of carrier choice on hydrogen trade

3.4.1 Customs practicalities

Depending on the specific bilateral relationship, many internationally traded goods are subject to customs duties and/or checks before they can enter the customs territory of the importing country. This might apply also to the cross-border trade of hydrogen and its carriers. For global hydrogen trade to develop, it will be important to ensure that the respective approaches to both customs and technical requirements do not adversely impact international trade. Considerations include:

- Minimising delays caused by the need to hold and check goods, as these could affect carriers such as LH2 which need to be held at very low temperatures for effective storage.
- Ensuring clarity and appropriate application of customs clearance and tax points. When goods are brought to a country, it is only after customs clearance that they become 'free for circulation' within that customs territory, and hence can be sold to final customers. This in principle can be done wherever the customer is located, not necessarily at the border. Applying the relevant customs rules to a hydrogen carrier, rather than to the hydrogen molecule after it is liberated, would result in different costs and measurement requirements.

3.4.2 Customs duty and tax implications on carrier choice for imports

In general, the importer must pay the applicable customs duties before goods are free for circulation within that customs territory, unless using special procedures. There are also different taxes and possible other charges that are applied to a good that will vary depending on the importing and exporting country.

Import customs duties are a type of tax on goods imported across borders. They are paid by the importer and are collected by customs as a government revenue to protect local industries. Customs duties are set by the individual countries or customs territories (e.g., the EU) in conformity with their commitments to the WTO and potentially other bilateral or regional Trade Agreements. Customs duties are mostly in the form of import duties, but goods may also be subject to export tariffs, antidumping, countervailing or safeguards measures in the form of import tariffs and local excise duties. More details are given in the Appendix in Section 8.4.5

Taxes are government fees that individual countries place on goods commercialized within the country and are applied uniformly to imported goods and goods produced locally. They are usually paid by the importer and collected by customs when goods enter a country. Taxes vary between countries and goods but can include sales taxes and consumer taxes (e.g., Value Added Tax (VAT) and Goods and Services Tax (GST)).

Other charges that may be incurred by a shipment along the supply chain include: carrier fees, broker fees if using a customs broker to clear goods through customs, surcharges and ancillary fees which are additional carrier costs for goods outside standard shipping and handling (e.g., dangerous goods and temporary imports), insurance, and toll rates paid to the port based on through flow.

The Harmonized Commodity Description and Coding System generally referred to as "Harmonized System" or simply "HS" is a multipurpose international product nomenclature developed by the World Customs Organization. The value of customs duties and taxes required for a shipment are determined by the Harmonised System (HS) commodity code, which is used to classify and define the product being traded, as well as the product value which is listed on the commercial invoice (and includes freight and insurance fees). The HS system is a standardized numerical method of classifying traded products and is used by customs authorities around the world to identify products when assessing duties and taxes, and for gathering statistics.

From a trade perspective, the mode of an import (truck, pipe, ship etc.) and the production and process methods (PPM) that have enabled the good to get to that point are irrelevant (Section 5.3.1). However, some customs developments, such as establishing specific HS codes may be necessary to facilitate trade of some LOHCs, which are not currently commonly traded internationally.

Duty and tax implications for hydrogen and its carriers may affect the relative cost at delivery and therefore attractiveness of various supply chains. As duties and taxes are mostly based on the monetary value of the cargo, not volume[62], mass or energy content, there would be a different impact on a $/kWh of energy basis for different hydrogen delivery modes. This could affect carrier choice or be a consideration for the end consumer depending on its significance to the overall supply chains (Section 4.4). For example, imports of hydrogen itself may have different third country tariffs to some of its carriers, giving rise to tariff implications related to the different quantity of hydrogen contained within the different carriers. Liquid and gaseous hydrogen have the same HS code and hence tariff rates at present, despite having different energy densities.

Disparities could also affect volumes available to other countries looking to import. Provided that WTO and bilateral FTA rules are complied with, countries can modify applicable customs duties to promote trade. For example, South Korea has announced it is charging no tariffs on imports of materials to make hydrogen vehicles, secondary batteries and renewable energy sources, to bolster competitiveness of renewable Korean products[63]. Countries could in principle also raise customs duties, provided they do not go above their respective tariff schedule in the WTO context, with possible benefits for domestic production. This could have adverse impacts on prices and possibly market liquidity. Since infrastructure development is needed, the first hydrogen import contracts could be very important to accelerate the transition in one country relative to others, so the approach to customs duties could have an impact.

3.5 Supply chain implications for hydrogen trade

The economic basis of international trade based on competitive supply is that if hydrogen production in a certain location is sufficiently low cost and has sufficiently good environmental characteristics, then the additional costs of carrier conversion, distribution and import may be preferential over domestic production, if this produces a net economic and environmental benefit. In any case, the trade of hydrogen and its carriers will be required in countries unable to meet absolute demand requirements if local options are insufficient.

It is therefore likely that once regional and global markets are mature, both international trade and domestic supply will contribute to a future hydrogen market. A holistic assessment and a full lifecycle analysis for each supply chain will help determine the techno-economic and environmentally appropriate roles of trade and domestic supply, the preferred carrier and physical distribution mode.

Ultimately, the feasibility of hydrogen exports will be dictated by the economics of the various steps within the supply chain. These depend on current and expected future technology costs, energy costs and utilisation rates, but also on policies such as carbon taxes and subsidies. Ideally, the full

[62] E.g., tariff for 28041000 in Switzerland: 2.30 Fr. per 100 kg gross (based on volume).
[63] https://pulsenews.co.kr/view.php?year=2021&no=6775

costs – and benefits – of supplying hydrogen to an end user must include a common benchmark of emissions, likely on a greenhouse gas equivalent basis. This will require bilateral or international standards for benchmarking, measuring and certifying these emissions, and mechanisms for valuing or pricing them.

Both renewably-produced hydrogen (typically through electrolysis using renewable electricity) and hydrogen from fossil fuels with CCUS will need to be covered by certification, in addition to any other means of production (e.g., nuclear). Some form of Guarantee of Origin (GO) or certification system is likely to enable markets to allow customers to make informed choices based on their own requirements such as GHG footprint and related cost. This would mean that strategies and policies to incentive low-carbon fuels can be kept open for different technology options if sustainability criteria are met. This is likely to increase competition and accelerate cost reductions, while increasing diversification and security of supply.

3.6 Infrastructure development requirements for hydrogen trade

The level of hydrogen imports required by a country, and therefore infrastructure investment decisions, will depend on factors including the local cost and availability of electricity and hydrogen, required energy profiles, interconnection costs, and regional underground storage availability.

Market growth in hydrogen use and trading will depend on infrastructure developments, as trade is premised on the ability to produce and distribute large volumes of hydrogen internationally. Having infrastructure to enable trade to occur is an important part of developing a safe, reliant and competitive supply. As most of the large scale renewable electricity-based hydrogen production facilities reported in Section 2.4 will be sited in greenfield locations, international trade of renewable hydrogen will be heavily dependent on the construction of new infrastructure. This may be slightly less true for hydrogen derived from natural gas with CCUS in the near term, as supply chains seem to be based on ammonia shipping, which is already occurring between the early-adopter locations. Of course, expanding this to areas which do not already either produce or ship ammonia will require new infrastructure, including the building of the CCUS facilities. In the early cases it may just be the end-use of the ammonia (e.g. co-firing or in gas turbines) that differentiates these shipments as 'hydrogen trade' as opposed to existing trade for fertiliser/chemical applications.

These developments will require large financial investments, for example in production capacity, conversion facilities and logistics infrastructure, so initial developments are likely to build on bilateral agreements between producers and users, de-risking capital deployed along the whole supply chain. Infrastructure companies are keen to be involved in the energy transition and to enable international trade. For example, Transmission System Operators' (TSO) and Distribution System Operators' (DSO) fundamental business is to offer transmission and distribution services through gas pipelines and are therefore well placed to maintain commercial viability and sustainability during the energy transition with low carbon and renewable gases. Similarly, many ports that handle energy goods are looking to new ways to maintain revenue as fossil imports decrease. For example, the Transhydrogen Alliance is setting up a dedicated ammonia import terminal at the Port of Rotterdam by 2025, targeting the import of 2.5 Mt of ammonia per year[64].

[64] https://www.portofrotterdam.com/en/news-and-press-releases/alliance-green-hydrogen-production-and-import

4 What is needed for international trade?

4.1 Market development

An additional need for the development of a low carbon hydrogen economy and trade is favourable markets to sell into. The low carbon hydrogen industry is currently pre-commercial and there must be sufficient demand at a competitive price and at scale before trade and a liquid global market can develop. Low carbon hydrogen does not yet have a competitive business case without a degree of market creation around it. A supportive policy framework will be required, and there is a growing influence from factors beyond policy, as Corporate Social Responsibility (CSR) targets and consumer preferences affect strategic business decisions (Section 8.5.1).

4.1.1 Role of policy

Implementing policies to support a low carbon hydrogen market can help build confidence among investors, industry, end-users and other countries, prompting collaboration to drive uptake of hydrogen. Without policy support, the levelized cost of delivered low carbon hydrogen is in most cases currently not cost competitive with either fossil-based hydrogen in traditional uses, or the direct use of fossil fuels in potentially new hydrogen applications[65].

Industry bodies expect low carbon hydrogen to become commercially viable at scale in the next decade across many applications[66], but supportive frameworks and finance mechanisms will be required to bridge this gap between the current cost and a competitive market price. However, care must be taken that these frameworks and mechanisms can be managed within appropriate near- and long-term trade arrangements. A balance will ideally be struck between enabling favourable business cases to drive international trade, and the risk of locking in practices that are unsustainable – either financially or environmentally. For example, subsidising the production of hydrogen and its carriers might have tariff implications when it comes to importing that hydrogen at the distribution end (Section 5.3.2).

4.1.2 Policies and actions to establish markets and enable trade

Several countries and organizations have set out visions and proposals of the policies and actions that might be needed to attract investment, deploy hydrogen at scale and so enable trade (See Appendix). A portfolio of policies will likely be required to compensate for cost gaps and foster uses that maximise system value. Many of these are in place in different countries or have been signalled for implementation in National Hydrogen Strategies, and these all need to be considered in the context of trading requirements, and any costs, benefits or complexity that may result. This policy portfolio includes:

- Quantitative **supply and demand targets**, possibly including binding mandates;
- Effective **carbon pricing** to create incentives for end-use decarbonization;
- **Demand-side support**, which could include introducing mandates for hydrogen blending, zero emissions vehicles, or for equipment to be hydrogen ready;

[65] Depending on what the low carbon hydrogen is being used for and therefore replacing will dictate what its price should be compared against to ascertain competitiveness.
[66] https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

- **Supply-side support** for hydrogen technologies and infrastructure, including setting targets and public funding;
- **R&D, innovation and deployment support** for new technologies, e.g., through targeted procurement, dedicated industry loans and competitions;
- **International cooperation –** Multilateral initiatives and projects can promote knowledge-sharing, develop technology and best practices to reduce costs and connect a wider group of stakeholders and many aim to develop future international hydrogen supply chains;
- Support **public acceptance** and participation of local stakeholders;
- **Support low carbon hydrogen hubs** through coordinated private-sector action supported by national/local government, co-locating various end uses and consumers with producers and exporters; and,
- **Coordination and harmonization of international regulations, codes and standards** on safety, purity and lifecycle GHG emissions along the value chain, particularly regarding imports and cross-border infrastructure.

In some cases, **new legislation and regulation** will be required to enable deployment, in addition to existing legislation and regulation being **modified and expanded** to include hydrogen. Examples include:

- To facilitate trade, countries are recognising that relevant standardisation bodies will need to develop internationally agreed accounting standards for different sources of hydrogen based on common definitions and methodologies along the supply chain to remove and/or reduce regulatory barriers and create a market for low-carbon hydrogen (Section 4.3).
- Hydrogen as an energy vector would be an integral part of both the gas network and electricity sector. Currently these entities are kept separate in regulation, but the potential for sector coupling means a distinct legal framework for the regulation of hydrogen networks and infrastructure may become necessary given its new role. National regulations may need reviewing to define the roles of utilities and grid operators especially once hydrogen is a widely traded commodity to avoid non-regulated monopolistic behaviour that hampers the entry of new players and competitive market outcomes[67]. Outside general competition law, there are currently no sector-specific market rules for hydrogen and its distribution (Section 5.3.6).
- In many countries, systems are currently designed to only allow natural gas to be distributed in pipelines[68]. Existing pipelines are often owned by network operators that may not be allowed to own, operate, and finance hydrogen pipelines.
- Regulation from the IMO and Classification Societies will be required to enable both the certified safe shipping of hydrogen and its carriers as well as the use of LH_2 and ammonia as marine fuel. Technical provisions, standards and regulation will be required for both marine and inland vessels, and these are governed by different regulatory bodies. The use of LH_2 and ammonia as marine fuel will be key to driving demand and scale as it is a large potential market. A key driver of demand for low carbon hydrogen derived marine fuels would be the IMO changing emissions regulations from a Tank-to-Wake to a Well-to-Wake approach, which would make these alternatives much more favourable compared to fossil bunker fuel.

[67] Combined Evaluation Roadmap/Inception Impact Assessment in February 2021 as part of the Gas Networks—Revision of EU Rules on Market Access consultation process

[68] E.g., the transport of pure hydrogen in gas networks is not covered in the EU by Gas Directive 2009/73/EC 6 but the EU will revise its Gas Directives in 2021 and is expected to include hydrogen in any new legislation

- Safety protocols need to be updated and/or developed and safety permit mechanisms devised for hydrogen export. Skills and handling training will be required for engineers, operators and technicians to enable safe distribution and use of hydrogen and maintenance of infrastructure[69].

4.2 What is needed to establish trading contracts

The fundamentals of trade are getting paid for what you deliver and getting delivered what you pay for, so the trust and confidence in both of those occurring is important. To be considered bankable, initial low carbon hydrogen projects will likely require long-term, fixed price offtake contracts like those that helped the LNG industry to develop. These will underpin the revenues of the project by reducing cash-flow variability and investor risk.

The different types of risk (e.g., currency, credit, counterparty, regulatory, damage to goods in transit, delivery etc.) need to be captured and defined in contracts to try and mitigate against them should the risk become a reality. Given the state of flux in the market, this is complex and could prove to be a hurdle precluding trade. For hydrogen, the most important risks affecting trade seem to be regulatory/product definition risk (Section 4.3) and delivery risk/uncertainty (Section 4.4).

4.3 Regulatory risk/product definition risk

4.3.1 Current product definitions

A product to be delivered must be accurately characterized in a contract, because if what is delivered does not match, it could lead to a trade dispute. There are currently different ways to categorise products. For example:

- Within the WTO framework for international trade between nations, products are categorized by HS codes. The preceding process or production methods (PPM) and the subsequent use case are not normally captured (Section 5.3.1).
- ISO develops voluntary, consensus-based, market relevant International Standards that comply with WTO principles (Section 5.2.3). They could be about making a product, managing a process, delivering a service, or supplying materials but ISO does not provide certification or conformity assessment.

In the case of traded hydrogen, both the physical characteristics and the GHG equivalent emissions of the hydrogen are expected to need definition, and in some jurisdictions potentially the production technology. Consumers will want guaranteed supply to keep processes running, as well as to be protected against the risk of not reaching carbon reduction targets and to minimise the impact of rising carbon prices which would reduce their margins.

Emissions avoidance is therefore central to many business cases and important for market creation. Although fuels such as hydrogen and ammonia are carbon free at the point of use, significant and hugely varying GHG emissions may occur during their production, transport and final distribution depending on the feedstocks, processing route and supply chain. Using hydrogen produced from unabated fossil routes can increase emissions rather than reducing them. Therefore, how a GHG footprint is measured, reported and certified will be important to create end-user confidence in the product, and will need to include the full scope of emissions, to ensure the overall aim of emissions reduction is achieved[70].

---

[69] https://www.orkney.gov.uk/OIC-News/Orkney-Leading-the-Way-with-Hydrogen-Seafarer-Training.htm

[70] Energy Science and Engineering, 12 August 2021, DOI: (10.1002/ese3.956)

It will be necessary to characterise and include the PPM history and attached GHG footprint of the delivered hydrogen in addition to the physical specification of the product. In terms of trade, there is a dissonance between the WTO customs duties at borders, which are based on the HS code of the good and do not capture PPMs, and the market and regulatory systems developing for low carbon hydrogen behind borders, where the GHG footprint (i.e., PPM) is emerging as an important feature.

Today, there is no internationally agreed terminology, methodology, regulation or carbon-intensity threshold for the categorization of different hydrogen production methods although the IPHE H2PA Task Force continues to develop a mutually agreed to quantification methodology framework[71]. Different jurisdictions have independently started to calculate the emissions of various hydrogen synthesis methods and assign different thresholds to determine whether they meet the standards developed within their markets. These all differ in their aims, application, and GHG methodology. They include voluntary standards developed specifically for hydrogen (e.g., CertifHy (EU), TÜV SÜD (Germany) and Clean Hydrogen Energy Portfolio Standards (Korea)), and renewable/low carbon transport fuel mandates for which hydrogen can be eligible (e.g., the UK's Renewable Transport Fuel Obligation (RTFO), California's Low-carbon Fuel standard (LCFS) and Canada's Clean Fuel Standard).

Currently there is little agreement between these schemes regarding the necessary threshold of GHG emissions required by hydrogen for eligibility. Europe is currently the most conservative market based on proposed GHG criteria required[72] for energy from Renewable Fuels of Non- Biological Origins (RFNBOS) to be eligible to count towards the targets proposed in Renewable Energy Directive (RED) III[73]. The US also has a new threshold[74] (based on the Infrastructure Bill[75]) that identifies an even lower GHG footprint.

The current thresholds for low carbon hydrogen are liable to change. This gives uncertainty to both producers and consumers when designing projects and agreeing to long term contracts. If developers rely on thresholds that become more, or less strict, they run the risk of over or underbuilding the project. Most large-scale renewable energy-based hydrogen/ammonia plants will require power from multiple sources to ensure plant utilisation can satisfy Internal Rates of Return (IRR) hurdle rates, which will affect both costs and the GHG footprint of the final product. Whilst the additionality principle (Section 2.2.1) for the electricity used in hydrogen production projects is considered important to avoid resource shifting and to promote the increase of renewable energy, it could inflict a first mover disadvantage on some projects. For example, questions have been raised about the practicality of the EU additionality principle for hydrogen production, as utilisation of renewables varies by time, geography and market and so defining what is additional can be complex. In any case, an important discussion point within a contractual agreement is understanding who takes on the risk of changing thresholds of the required carbon content.

To enable trade, there will have to be some alignment on how emissions are defined and managed between jurisdictions. If a country's low carbon standard only applies to certain fuels, dispensed and used domestically, production of those may increase due to increased financial support. This may affect the type and volumes of low carbon fuels available for international trade as markets develop.

---

[71] https://www.iphe.net/iphe-working-paper-methodology-doc-oct-2021
[72] https://eur-lex.europa.eu/resource.html?uri=cellar:d84ec73c-c773-11eb-a925-01aa75ed71a1.0021.02/DOC_2&format=PDF
[73] https://ec.europa.eu/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf
[74] https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf Section 40315, Public Law 117–58 117th Congress
[75] https://www.rechargenews.com/energy-transition/heres-what-you-need-to-know-about-the-hydrogen-section-of-the-1trn-us-infrastructure-bill-passed-by-the-house-and-senate/2-1-1047793

Isolated developments within specific markets and the lack of a liquid global market could lead to a complex system emerging and could lead to market fragmentation. Regulatory competition (e.g., from a range of certification schemes), could confuse consumers and increase the cost and regulatory burden for producers who may therefore only export to specific markets if they all have different criteria. Future trading hubs have been envisaged in which hydrogen or ammonia with different GHG footprints can come in from different supply sources and go out to a variety of customers. However, without certification to track and enable this, the future trading model may end up being direct purchase agreements for a given carbon content.

Market fragmentation could lead to a greater risk of market manipulation and distortion. If large, market dominant producers distort hydrogen markets, which could also distort other value chains such as ammonia, countries may put up barriers to mitigate that impact (Section 5.3). This could result in less trade.

An agreed set of common standards and methodologies to determine associated carbon emissions should allow support for low carbon hydrogen across the energy system, enabling:

- Certification schemes to be supported, which means the product can be defined and traded
- Compliance with market-based policy mechanisms, or to ensure compliance with hydrogen support schemes (e.g., to qualify for a subsidy), to participate in the German H2Global CfD Program, or to comply with various versions of Emission Trading Schemes (ETSs) and Carbon Border Adjustment Mechanisms (CBAMs)
- Non-trade benefits, such as verifying eligibility for a capital grant

4.3.2 Future product definitions – Certification

If hydrogen is to be an internationally traded commodity, agreeing on consistent and accurate approaches to define, measure and track the GHG footprint of hydrogen produced by various technologies, and with different temporal and geographical origins will be important. Establishing widely accepted Guarantee of Origin (GO), or certification schemes would give consumers confidence the product meets their expectations and claimed specifications and allow them to actively choose the GHG footprint and related cost of the hydrogen they purchase, sending market signals about relative demand. Several future hydrogen-importing and exporting regions reference the establishment of a hydrogen GO, or certification scheme as a priority in their national hydrogen strategies (e.g., Australia, the EU, Germany, the Netherlands, France and the UK).

The development of standards, discussions on certification and how to qualify different properties of hydrogen leads to a series of questions largely looked at in other studies[69,76,]. For example:

- How is the carbon intensity calculated (i.e., the process which leads to the certificate)?
- Who sets up, manages, and verifies the system?
- What is measured (e.g., broader aspects of sustainability may need to be considered in addition to GHG footprint, such as water, biodiversity and social impacts)?
- What is the system boundary?

As noted previously, the IPHE H2PA Task Force is aiming to develop a mutually agreed methodology framework[77] to determine the greenhouse gas emissions associated with hydrogen produced from different pathways. It is envisaged the methodology developed will form the inputs to a future

[76] https://www.gov.uk/government/publications/options-for-a-uk-low-carbon-hydrogen-standard-report
[77] https://www.iphe.net/iphe-working-paper-methodology-doc-oct-2021

international standard applicable to a broad range of countries and hydrogen production processes, helping to facilitate market valuation and international trade in low carbon H_2.

In Australia, work is underway on an initial hydrogen GO scheme consistent with the work so far through the IPHE[78], including production technology, production location and Scope 1 & 2 well to-gate emissions. The Australian Government expects to launch trials of a hydrogen GO scheme in the second half of 2021. The focus is on the carbon accounting elements of the scheme, not certificate creation and surrender, as these components would need legislation.

CertifHy[79] has developed a hydrogen certification scheme across Europe, CertifHy® Guarantees of Origin (GOs), to support the growth of the hydrogen market as a reliable tool for consumers to track the hydrogen's origin and environmental attributes. It aims at facilitating the creation of an EU-wide system of GOs. CertifHy was initiated at the request of the European Commission and is financed by the Clean Hydrogen Partnership.

4.3.3 Implications for trade

A GO or certification system could be established 'bottom-up' (e.g., on a bi-, tri-, pluri-lateral level) with potential multilateral links emerging later. Alternatively, there could be consolidation at a higher level early on, to establish a more global system from the outset. In this case, a set of common principles and key concepts that are mutually accepted and respected by different jurisdictions would need to be agreed internationally. These could then be used when more detailed national rules are developed to determine the carbon emissions associated with hydrogen.

However, in the past, globally collaborative systems have proven difficult to establish and can take a long time to coordinate. As international trade and supply chains are already emerging from different countries and sectors moving independently and on different time frames, frameworks may emerge between first mover nations which in time have scope to either expand and include more countries and supply chains, and/or converge.

Types of certifications range from GO systems, principally concerned with how the hydrogen is produced, to full lifecycle analyses (LCAs) which are administratively more burdensome. A modular approach to boundaries and emissions accounting (e.g., separate modules for production, conditioning, and transportation as per the IPHE hydrogen production analysis methodology framework) could balance environmental needs against lowering regulatory barriers, so that accounting systems do not become an implicit barrier to trade or lead to trade distortions[80]. Such modular approaches could start from GOs and be built up and expanded over time to cover more areas and increase accuracy.

However, from a trade perspective, the specific nature of the standard is less important than its existence. Enabling the most relevant characteristics of a product to be defined means contracts can be drawn up for trade, helping to unlock the supply chain by giving both producers and end users comfort that they are talking about the same product.

As with all current trade, the burden of greenhouse gas emissions will fall differently for different combinations of hydrogen production and use. Mechanisms to acknowledge and price both embedded and cross-border emissions will affect hydrogen trade as they will other commodities.

---

[78] https://consult.industry.gov.au/climate-change/hydrogen-guarantee-of-origin-scheme-discussion/
[79] https://www.certifhy.eu/
[80] https://www.sciencedirect.com/science/article/abs/pii/S0360544220322465

This will also affect products further downstream. If for example 'renewable hydrogen' was used to produce 'renewable steel' and that was to be exported, any certification scheme would ideally be linked to and interoperable with hydrogen certification.

This suggests that schemes for other routes and products should ideally be considered in parallel. For example, the Ammonia Energy Association (AEA) supports the adoption of a globally harmonized framework for the accounting, reporting, and verification of emission reductions associated with low-carbon ammonia initiatives[81]. Low carbon ammonia certification and tracking is also being looked at by the Midwest Renewable Energy Tracking System (M-RETS) in the US[82]. In Australia, the industry led, GO-style 'Zero Carbon Certification Scheme' from The Smart Energy Council will assess the embedded carbon in renewable electricity-based hydrogen, ammonia and metals produced in Australia to promote the uptake and distribution of renewable products domestically and abroad.

However, as the WTO only regulates state mandates, certification schemes established by separate industry associations sit outside the scope of WTO trade law. This is the case for analogous sustainable products (e.g., biogas and sustainable wood). The relationship between certification and the WTO is discussed further in Section 5.3.1.

4.4 Delivery risks and considerations for trade

In addition to the need to define the product, how the delivery takes place is currently one of the largest areas of uncertainty and therefore risk. How the hydrogen will be carried (i.e., as gaseous or liquid hydrogen, ammonia, LOHC), and how the product will be delivered (i.e., pipeline, ship, truck) have implications for what conversion and unloading facilities are needed by the consumer. Ultimately, someone has responsibility for the delivery of the right amount of hydrogen, with the right quality, at the right time and careful definition of this responsibility is required as the hydrogen passes through different delivery mechanisms.

4.5 Future for trade

Figure 11 shows a potential path to maturity for hydrogen, in the sense that it shows how a future traded hydrogen market might develop and what the prerequisites would be for a wholesale market[83]. The steps listed are not necessarily sequential and it has been adapted from a similar path for natural gas, with the added essential pre-conditions of demand and physical infrastructure at the bottom. Unlike the development of the natural gas market in the 1950s, however, hydrogen distribution infrastructure today is virtually non-existent, and there is essentially no underlying market for hydrogen as an energy commodity.

[81] https://www.ammoniaenergy.org/certification/
[82] https://mn.gov/pdf_files/Hydrogen20Reese20-20Green20Ammonia%20-%20MN%20PUC%201-24-21.pdf
[83] Source: Heather, P. (2021), How a traded hydrogen market might develop - OIES, ISSUE 127

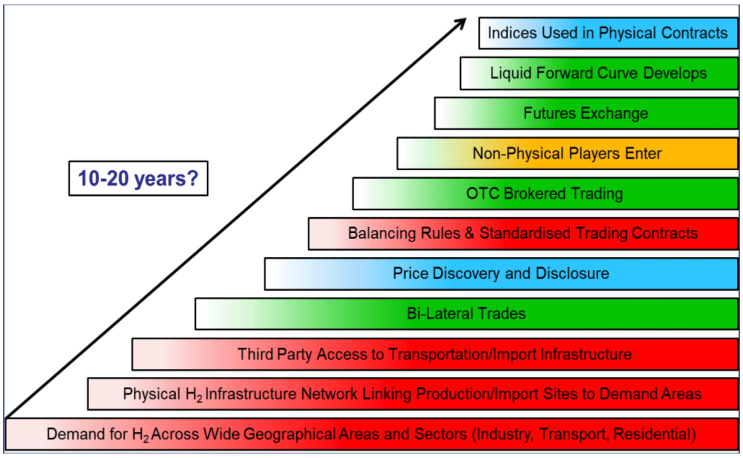


Figure 11: Path to maturity for the hydrogen market

Source: Oxford Institute of Energy Studies[84]

The demand for hydrogen needs to increase substantially for a traded market to develop and become established and will require physical infrastructure. For a competitive market, many suppliers and buyers are needed, and the process will require third party access to infrastructure (Section 5.3.6). In some jurisdictions this may require legislative changes to allow/encourage incumbents to release infrastructure capacity to incentivise independents to enter the market. A growing physical market will need structured trading rules and regulations governing the physical side of the business, and standardized contracts for the commercial aspects. The first contracts and trades may be intra-firm, between different branches of large industrial companies that both make hydrogen and use it (e.g., to make synthetic fuels), to remove trade uncertainty and counterparty risk. Large industrial partnerships will form, with initial relationships for export/import expected to build on bilateral agreements.

Different off-take models will develop over time (Table 1). Market participants are likely to start trading bilaterally and over the counter, often aided by brokers. Reporting trades will allow a transparent market to emerge. Price disclosure and discovery will attract more players and encourage financial players and exchanges to start offering hydrogen spot and futures contracts based on the underlying physical contracts, offering greater access to the market. Although this is some way off, in The Netherlands research has already been carried out into the practicalities of setting up a hydrogen exchange[85].

Table 1: Offtake Models: A Potential Roadmap

	Current state of the market (2020s)	Future state of the market (2030s)
Nature of offtake	Higher-risk but higher-reward	Commodity-style risk profile
Downstream market profile	Downstream market risky/speculative. Small pool of large-scale consumers. Regulatory uncertainty	Established demand centres. Clear destination markets and consumers. Some markets require a lower carbon footprint than others
Trading of product	Limited spot market/trading. Small pool of export projects. No established supply chains. No agreed standards on specification. Limited/no arbitrage.	Merchant market. Portfolios of export projects. Established supply chains. Opportunities for sophisticated marketing/trading operations

[84] Adapted from Heather, P. (2015) Oxford Institute for Energy Studies, NG104, Figure 1.
[85] https://fuelcellsworks.com/news/creation-hyxchange-hydrogen-exchange-a-step-closer/

Nature of offtake arrangements	Long-term take or pay offtakes. Debt will struggle to take market risk	LNG-style offtake strategies. Debt may take some market risk
Off taker involvement in equity	Typical – To manage risk for off takers and other sponsors	Less typical
Features of pricing	Price needs to cover project costs, repay debt and provide acceptable IRR	Market pricing track record. Financial tools available to manage volatility
Tenor of offtake	Longer to cover tenor of debt	Short-term. Mix of term and spot
Bargaining power	Suppliers	Buyers

Source: Adapted from Shearman & Sterling conference presentation[86]

Standard trading contracts, which form the backbone of the brokered market for natural gas trading today, took 20-30 years to develop. In Europe, the European Federation of Energy Traders (EFET) drafts Master Agreements for the trade of different products such as gas, electricity, and LNG. These are umbrella agreements which comprises of General Terms and Conditions on all possible details including supply modalities, payment modalities, settlement risks, risks of failure, netting compensation, and the term. They apply to each underlying transaction and based on that 'mother contract' a bilateral agreement is made between counterparties. Despite the standardisation of these contracts and their popularity, these are still bilateral contracts and so carry counterparty credit and performance risk. Exchanges are regulated markets and take over the counter-party risk as traders are secure in the knowledge that they are governed by the relevant financial regulator in each country and that the clearing house also financially guarantees all the trades executed.

Eventually, as increasing numbers of varied participants come to trade, a global, Asian, European and/or Latin American hydrogen benchmark may emerge, and a hydrogen Title Transfer Facility (TTF) equivalent could be possible. There is currently no hydrogen price index, but S&P Platts has launched a precursor in the form of a "hydrogen price assessment" with the price of hydrogen constructed based on different production methods.

[86] https://www.ammoniaenergy.org/wp-content/uploads/2021/09/AEA-PresentationAugust-2021Feldman.pdf

5 Trade rules for hydrogen

5.1 Introduction

As the traded volume of hydrogen and its carriers increases, they must operate within the existing global trade framework. International trade is the exchange of goods and services across borders, and market openness has resulted in substantial benefits and created new opportunities for participants, contributing to an increase in world GDP. Trade is a powerful driver of structural change, and a key tenet of undistorted trade and investment is helping to reallocate resources to the sectors and areas where they can be used most efficiently. In that sense, goods such as hydrogen are produced where it is best to do so globally, rather than necessarily domestically. However, the competitive pressure exerted by imports can lead governments to implement policies and measures including tariffs, quotas, and subsidies to protect domestic industry. Given the significance of low carbon hydrogen for climate change mitigation, a common rules-based market is important to balance the interests of all countries in the value chain.

Three bodies governing existing international trade rules related to the regulation of energy traded across borders are therefore relevant to hydrogen and its carriers as energy vectors. The most prominent is the World Trade Organization (WTO) but the Energy Charter Treaty, and energy relevant disciplines in Preferential Trade Agreements will also be discussed (Section 5.4.2).

5.2 The WTO and the multilateral trade framework

The post-WWII General Agreement on Tariffs and Trade (GATT) evolved into the World Trade Organization (WTO) in 1995 as a governing structure for global trade.

The WTO is the international body that upholds global trade rules in 164 countries, accounting for 98% of global trade, and provides an inclusive forum for governments to negotiate trade matters. The WTO is underpinned by a Trade Policy Review Mechanism and a Dispute Settlement System (DSS) to ensure members adhere to the rules and their commitments.

WTO Agreements provide the legal framework for international commerce and are contracts binding states to keep their policies that affect trade within agreed limits. States must be aware of trade rules to ensure that policies (e.g., to enable the hydrogen industry ramp up) are compliant with them and actions do not violate them. If a WTO member were negatively affected by the hydrogen policies of another member which infringed the rules of the WTO law, they could be challenged by raising a dispute. This is not uncommon: states will not always be able to predict the implications of a new policy on third parties. For WTO disputes to be raised, there must be concrete problems or issues with how the law is being treated, so hydrogen disputes may take a while to emerge once policies have come into force and implications are actually felt. The goal of the WTO is to help producers of goods and services conduct their business and trade, while allowing governments to meet objectives (e.g., socially and environmentally). The WTO only regulates state-mandated measures. However, as states regulate industry, their behaviour is relevant by proxy and companies can lobby governments to start disputes.

The WTO's rules-based trading system is based on several principles: non-discrimination, freer and predictable trade through bindings and transparency, fair competition, and encouraging development. A contentious policy or measures may be counter to multiple Articles in the different Agreements due to the interconnectedness of the system, so when a dispute is raised it will often cite multiple different violations. The WTO's basic rules (explained in more detail in Section 8.5.4) are:

- Non-discrimination
- Protection only through tariffs
- Obligation not to raise tariffs
- Regulation of subsidies

The three broad areas of trade that the WTO covers are:

- Goods - represented by the General Agreement on Tariffs and Trade (GATT)
- Services - represented by the General Agreement on Trade in Services (GATS)
- Trade Related Aspects of Intellectual Property Rights (TRIPS)

These 3 Agreements start with broad principles, with each sector subsequently covered in depth through extra Agreements and annexes, including access to markets. For the GATT, these take the form of binding commitments on customs duties for general goods. GATS commitments cover access of foreign service providers. These Agreements are not static but are periodically renegotiated (Section 5.4.1). However, in practice it is not a flexible system, so hydrogen trade will most likely have to fit within the existing WTO framework (Section 5.3). The fundamental WTO Agreements are often called the WTO trade rules (Table 2).

Table 2: Basic structure of the WTO agreements. How the 6 main areas fit together (The umbrella WTO agreement, goods, services, intellectual property, disputes and trade policy reviews)

Umbrella:	**Agreement establishing the WTO**		
	Goods	Services	Intellectual Property
Basic principles:	**GATT**	**GATS**	**TRIPS**
Additional details:	Other Agreements and annexes incl.: • Technical Barriers to Trade (TBT) • Trade-Related Investment Measures (TRIMS) • Subsidies and Countervailing Measures (ASCM) • Anti-dumping Agreement (ADA)	Services annexes	
Market access commitments:	Countries' schedules of commitments	Countries' schedules of commitments	
Dispute:	**Dispute settlement**		
Transparency:	**Trade policy reviews**		

The WTO framework does not include rules specific to energy. The basic rules of the WTO apply to all goods and scheduled services traded across international borders. Many will be relevant to the trade of energy and therefore hydrogen and its carriers, but since hydrogen is connected to many other components of the energy system, through feedstocks or downstream energy vectors, it cannot be considered in isolation. Existing trade rules affect the integrated energy system as a whole, with implications for hydrogen trade. Nevertheless, while energy is covered by the WTO Agreements, this does not mean that the legal framework is optimal for dealing with energy, and therefore hydrogen.

Unresolved issues in current WTO rules already exist in the trade of energy (Section 5.3). Additionally, the requirement to decarbonise, and the increasing trade of alternative forms of energy including hydrogen, pose challenges under existing international trade law. Attempts exist to address these issues at multilateral level (Section 5.4.1), but their shortcomings have also led to commitments beyond the WTO (Section 5.4.2) including the Energy Charter Treaty and a growing number of Preferential Trade Agreements. The future of energy governance remains unclear (Section 5.4.3), but members of the WTO are trying to ensure it can make a valuable contribution to decarbonizing the energy sector and supporting the sustainable development goals.

5.2.1 WTO and the environment

While the WTO has an economic focus as the traditional objective of the GATT was to promote free trade though strictly economic values, its mission has developed to 'allow for the optimal use of the world's resources in accordance with the objective of sustainable development, seeking both to protect and preserve the environment'[87]. These issues are inseparably linked to energy, and hydrogen.

The WTO has no specific agreement dealing with the environment and states it does not want to intervene in national or international environmental policies or to set environmental standards[88]. In environmental issues its only task is to study questions that arise when environmental policies have a significant impact on trade. A Trade and Environment Committee[89] has been established and considers for example the relationship between trade rules and government requirements for products to protect the environment (e.g., eco-labelling, standards and technical regulations, packaging, and recycling requirements). WTO members have autonomy to determine their own environmental policies[90] and have the right to adopt trade-related measures to protect the environment and human health if such measures comply with GATT rules or fall under the general exceptions to these rules in GATT Article XX (Section 5.2.2). However, a balance is required between market access obligations, and the right to invoke environmental justifications, so that one objective is not compromised by the other.

5.2.2 The General Agreement on Tariffs and Trade (GATT) for goods

The GATT regulates the international trade in goods and so applies to the trade of energy, hydrogen and its carriers insofar as goods (i.e., products and molecules) are involved. Note that cross border electricity trade is considered a good not a service. The GATTs basic principles are governed by Articles and Agreements (Section 5.2.3), which together include disciplines on transit, subsidies, customs matters, state trading enterprises actions and standards. Articles relevant to the trade of energy and hydrogen are highlighted here, and their broader implication expanded in Section 5.3.

- **Article II** is the Schedules of Concessions and the Schedules annexed to the GATT Agreements contains the customs duties set by each member. *These are relevant to hydrogen trade as different carriers may have varying tariffs* which also differ by country, affecting the cost of delivered hydrogen for different supply chains (Section 5.3.7).
- **Articles I and III** on non-discrimination mean that 'like' products cannot be discriminated against on the basis of their origin or destination and imported energy products cannot be treated differently from 'like' domestic products through taxes or other regulations. *The definition of 'likeness' is important for hydrogen trade* (Section 5.3.1), given both the different potential carriers, and the different GHG footprints associated with the traded molecules.

[87] https://www.wto.org/english/docs_e/legal_e/56-dtenv_e.htm
[88] https://www.wto.org/english/thewto_e/whatis_e/tif_e/bey2_e.htm
[89] https://www.wto.org/english/tratop_e/envir_e/cte00_e.htm
[90] WTO case Nos 2 and 4 1996. US/Venezuela - Standards for Reformulated and Conventional Gasoline

- **Article V** is on freedom of transit and is relevant to discussions surrounding gas pipelines and electricity grids, so will be *important for the distribution of hydrogen* (Section 5.3.5).
- **Article XI** generally prohibits import and export restrictions. It does not explicitly cover many restrictive practices which have had distortive effects in fossil fuel energy markets (Section 5.3.6). *These practices could affect hydrogen trade*, and their continued use in natural gas markets could affect the cost competitiveness of low carbon hydrogen and its derived fuels.
- **Article XVII** requires state-owned trading enterprises (STEs) to adhere to higher standards, act consistently in a non-discriminatory manner, and carry out sales and purchases solely in accordance with commercial considerations. *This is relevant to hydrogen*, given some major energy exporting states operate through vertically-integrated energy companies, some already active in low carbon ammonia trading[91]. STEs have been active in dual-pricing practices in fossil fuel markets, so these enterprises could also apply these to markets for hydrogen and its derivatives.
- **Article XX** on General Exceptions can sometimes be used to deviate from obligations under the GATT to pursue legitimate policy objectives. The most relevant for energy trade are measures in paragraphs (b) 'necessary to protect human, animal, plant life or health' and (g) 'relating to the conservation of exhaustible natural resources.' Their broad interpretation gives WTO members leeway to justify measures to further environmental policy objectives that may be inconsistent with GATT, if compliant with certain requirements. *These are relevant to hydrogen* as 'clean air' was confirmed as an exhaustible natural resource by the Appellate Body in the case *US – Gasoline,* meaning measures that promote clean air and curb CO_2 emissions, such as the use of low carbon hydrogen, may be justified.
- **Article XXI** is on Security Exceptions. It has been used in the past by certain members to try and justify trade restrictive measures and defend conduct inconsistent with the GATT[92], but has been widely resisted by most members. Energy and security policies are often linked (i.e., energy security) so it is conceivable it could be invoked in future trade disputes concerning energy.

5.2.3 Agreements within the GATT

5.2.3.1 The Technical Barriers to Trade (TBT) Agreement

The TBT Agreement aims to ensure that technical regulations (mandatory), standards (voluntary), testing and certification procedures (conformity assessment), which vary between countries, do not create unnecessary obstacles to trade. Also, this Agreement allow for flexibility on approaches to standards subject to disciplines that encourage non-protectionist approaches.

Technical standards are important and prevalent in the energy sector as they can encourage energy efficiency and sustainability. In the absence of international disciplines, there is a risk that national technical regulations and standards could be adopted and applied to protect domestic industries (i.e., become hidden restrictions to trade). For example, a hypothetical technical regulation that said hydrogen had to be produced from wind built in shallow waters could favour the European offshore grid.

It is important to harmonize regulations, codes, and standards, where possible, at all steps along the value chain to allow for a reliable operating environment and a level playing field. For example, it is important to harmonize refuelling station protocols and regulation worldwide so hydrogen fuel cell vehicles can be sold into all markets and will be able to refuel and access the infrastructure.

---

[91] https://www.aramco.com/en/news-media/news/2020/first-blue-ammonia-shipment
[92] Such as the US embargoes on Nicaragua and Cuba, among others

The TBT Agreement encourages members to use existing international standards where they exist for their national regulations. The International Standardization Organization (ISO) committee ISO/TC 197[93] has published 18 ISO standards on systems and devices for the production, storage, transport, measurement and use of hydrogen. The equivalence provision allows members to accept other countries' differing technical regulations as long as they agree they fulfil the same policy objectives.

Labelling environmentally friendly products is an important environmental policy instrument and could apply to the certification of hydrogen produced by different methods (discussed in Section 4.3). The Trade and Environment Committee has highlighted[94] the need for further discussions on how to handle labelling used to describe whether the way a product is produced, as distinct from the product itself, is 'environmentally friendly'.

5.2.3.2 The Trade-Related Investment Measures (TRIMS) Agreement

Recognizing that certain investment measures can have trade-restrictive and distorting effects, the TRIMS Agreement states that no member shall apply discriminatory investment measure (e.g., against foreign products). These could include local content requirements (Article III) or measures that lead to quantitative restrictions (Article XI), both of which violate basic WTO principles. This Agreement applies to the trade in goods only and does not apply to services.

For the energy sector, the TRIMs Agreement is relevant where cross-border energy investments or energy generation are concerned. The first WTO dispute on renewable energy involved the domestic content requirement of Ontario's feed-in tariff, which was challenged as a discriminatory investment related measure and as a prohibited import substitution subsidy violating the TRIMS and the GATT[95].

5.2.3.3 The Agreement on Subsidies and Countervailing Measures (ASCM)

The ASCM sets out rules concerning the use of subsidies and aims to protect members' national industries from the negative cross-border effects of state subsidization of the same industries in other WTO member countries. Only 'specific' subsidies of four types are subject to the ASCM[96], if a government targets:

- A particular company or companies for subsidization – *Enterprise-specificity*
- A particular sector or sectors for subsidization – *Industry-specificity*
- Producers in specified regions of its territory for subsidization – *Regional specificity*
- Export goods or goods using domestic inputs for subsidization – *Prohibited subsidies*

The ASCM regulates two separate but closely related topics, how subsidies can be provided, and how governments can respond using countervailing measures to offset harmful subsidies. The ASCM establishes two categories of subsidies:

- **Prohibited subsidies** include export subsidies (e.g., tax rebates on exported goods), or local content subsidies encouraging the use of domestic over imported goods. These are prohibited because they are designed to directly affect trade.
- **Actionable subsidies**: Most subsidies such as on production are in this category. They are not prohibited but can be challenged, either through the dispute system or through countervailing

[93] https://www.iso.org/committee/54560.html
[94] https://www.wto.org/english/thewto_e/whatis_e/tif_e/bey2_e.htm
[95] https://www.cambridge.org/core/journals/world-trade-review/article/canadarenewable-energy-implications-for-wto-law-on-green-and-notsogreen-subsidies/33D8401BFCD8F07649074145B0DF2EB4
[96] https://www.wto.org/english/tratop_e/scm_e/subs_e.htm

action if they cause adverse effects to another member. For example, subsidizing domestic production for own use is allowed, but it may encourage over-production which could outcompete imports or lead to low-priced dumping on global markets which would get challenged. 'Injury to a domestic industry in the territory of the complaining member caused by subsidized imports' is the only allowed reason for countervailing action.

- **Non-actionable subsidies** are not a category of subsidy specified by the WTO[97], but are generally accepted and include non-specific subsidies, specific subsidies involving assistance to industrial research and pre-competitive development, support for small and medium-sized enterprises, assistance to disadvantaged regions, assistance for adapting existing facilities to new environmental requirements imposed by law or regulations.

Energy is one of the most heavily subsidized sectors globally (for renewable or fossil fuels) and there is a clear link between energy subsidies, the use of energy and climate change. Energy subsidies can be broadly divided into producer subsidies (e.g., feed-in tariffs (FITs)) to stimulate the scale-up of renewables, and consumer subsidies (e.g., to create cheaper inputs for energy intensive industries or lower energy bills for household consumers). The provisions of the ASCM are strict, particularly with respect to renewable energy sources and the implications of the ASCM on future hydrogen trade are discussed in Section 5.3.2.

5.2.3.4 The Anti-dumping Agreement (ADA)

This aims to protect WTO members domestic producers from the harmful effects of dumped imports by providing detailed rules on the use of anti-dumping measures and providing for countervailing duties. The increase in trade of alternative energy goods and those for renewable energy generation has led to disputes over anti-dumping duties, particularly on solar panels and biofuels[98].

Hydrogen trade could benefit from lessons learnt from the trade of other energy products. In 2008, a policy loophole allowed U.S. refiners to import biodiesel from abroad, get a subsidy by adding a tiny amount of conventional diesel and then ship the resulting B99 biodiesel back to Europe ('splash and dash'). This subsidized biofuel represented 90% of the volume entering Europe so the practice was subject to anti-dumping complaints as contrary to WTO rules. This could be analogous to the mixing of different streams of hydrogen or ammonia with varying GHG footprints.

5.2.4 The General Agreement on Trade in Services (GATS)

The GATS contains rules for and regulates all measures connected to the international trade in services[99], within twelve service sectors[100]. Currently no service sector is devoted to energy, but several sub-sectors are directly or indirectly relevant to energy trade (e.g., generation, construction and distribution services). Some members have made specific commitments on services relating to the energy sector in their schedules, opening up the sector to services from abroad and aiding *inter alia* fuels production, pipeline construction and energy distribution. In addition to a market for hydrogen expressed in volumes, other elements might be traded, including storage capacity, futures, and other grid services.

---

[97] https://www.wto.org/english/thewto_e/whatis_e/tif_e/agrm8_e.htm#subsidies

[98] US – Countervailing Measures, EU – Biodiesel (Argentina) and EU – Biodiesel (Indonesia)

[99] There are two exceptions - "services supplied in the exercise of governmental authority" and measures affecting air traffic rights and services (https://www.wto.org/english/tratop_e/serv_e/gatsqa_e.htm)

[100] Business; Communication; Construction and Engineering; Distribution; Education; Environment; Financial; Health; Tourism and Travel; Recreation, Cultural and Sporting; Transport; and "Other" – In MTN.GNS/W/120

The MFN principle is most important for energy-related services. The GATS defines 4 modes of supply, or ways to trade services, largely on the basis of where and how the service supplier and consumer are situated during the transaction. The GATS treats separately trade that is:

- Cross-border (supplier and consumer in different jurisdictions),
- Consumption abroad (consumer in supplier's jurisdiction),
- Commercial presence (supplying company in consumer's jurisdiction)
- Presence of natural persons (supplying individual in consumer's jurisdiction).

Viewed in this light, the GATT generally covers only a single mode, equivalent to cross-border trade.

The GATS encourages the progressive liberalization of all sectors but does not impose the obligation to accept foreign services and service suppliers in its market, contingent on specific countries' services schedules. However, it does contain rules on what restrictions a country can put in place for third party operators in its domestic market (e.g., if they can discriminate and require a degree of equity to be supplied by a domestic operator, therefore requiring a joint venture to be established). Obligations of the GATS such as Article XIX on progressive liberalization aims to gradually eliminate restrictions on the kind of legal entity or joint venture through which a service is provided, or any foreign capital limitations on the maximum levels of foreign participation.

However, it is domestic regulations, not border measures, that most significantly influence the trade of services and the provisions of the GATS require these to be applied in a reasonable, objective, and impartial manner. GATS also contains rules on other disciplines such as monopolies and exclusive service suppliers. This applies to energy companies that are monopolies, which is not uncommon given the prevalence of Vertically Integrated Utilities in the fossil fuel sector, many of which are now starting to investigate the production and trade of hydrogen and its carriers.

5.2.5 Agreement on Trade-Related Intellectual Property Rights (TRIPS)

Recognising that what makes trade valuable has evolved beyond just shipping goods across borders, the TRIPS Agreement acknowledges the significance of links between intellectual property and trade. It is intended to facilitate the trade in knowledge, innovation and creativity across borders, covering intellectual property rights and how to protect them (e.g., industrial designs and patents). It aims to foster technological innovation and the transfer and dissemination of technology. The TRIPS Agreement requires developed countries to provide incentives for their companies to promote the transfer of technology to Least Developed Countries (LDCs) to enable them to create a sound and viable technological base. This is relevant to hydrogen production and trade as a large proportion of world class renewable resources are located in LDCs (Figure 5).

The development of and access to new technologies (e.g., electrolysers), are important for the energy transition and reducing the sector's environmental impact. Various countries have already stated in their hydrogen strategies intentions to export equipment, technology, education, training and innovation which would therefore be subject to the TRIPS.

5.3 Implications and shortcomings of WTO trade rules for hydrogen

The general principles of the WTO framework should benefit the trade of hydrogen and its carriers. However, although energy trade is and always has been covered by GATT/WTO disciplines, it has not traditionally been a priority of the trading system, as features unique to energy have set this sector apart. There is ongoing debate over the applicability and potential implications of some existing WTO rules, not particularly geared to the sector, towards energy trade.

Energy is currently the largest and most significant commodity traded internationally in both value and volume due to the uneven global distribution of fossil fuel reserves, and accounts for nearly a third of world sea borne trade[101]. However, the energy sector developed in a vertically integrated manner, often by completely state-owned companies operating as a natural monopoly, with limited cross-border energy trade. This was mostly dealt with outside the global trading system in *ad hoc* contractual arrangements. The treatment of energy is also *politically sensitive* as energy is a strategic commodity, *uncertain* as it is a highly volatile sector and often *disputed* because of its close ties to national security and industrial policy. Only after the global oil crises did energy issues begin to be discussed in the GATT forum. The result is a set of rules and obligations that are not specifically tailored to the needs of the energy sector.

Since the establishment of the GATT, the world, the global energy market, and the trading landscape has changed significantly due to liberalisation, the growing emphasis on climate change mitigation, technological developments, and an increased focus on energy security from increasingly globalized geopolitics. More countries engaged in energy trade have acceded to the WTO and the expansion of cross-border energy trade beyond fossil fuels has contributed to the energy sector playing an increasingly prominent role in the multilateral trading system. Trade in alternative forms of energy and related technologies, such as solar panels, wind turbines, and biofuels is common, and that of other low carbon energy vectors such as hydrogen will doubtless increase in the future.

The energy transition has also been accompanied by increasing regulation of low carbon energy technologies in domestic law, which in turn affects cross-border energy regulation. This has led to a growth in the number of energy disputes relating to both renewable and non-renewable energy being settled in the WTO. The needs of an energy sector orientated to the trilemma of decentralization, decarbonization and energy security are highlighting tensions with current WTO rules. (Section 5.4.1).

Since a liquid global hydrogen market does not exist today, lessons may be learnt from trade issues and market distortions seen for other mature commodities, so that misaligned incentives and unexpected or unintended consequences are minimised within a hydrogen market. Issues include:

- It is unclear how some current WTO rules apply to energy trade, specifically hydrogen;
- The changing energy market and need to decarbonise challenges the existing WTO framework

5.3.1 'Like' Energy Goods and non-discrimination

Discrimination is only illegal under WTO rules if the two products are considered 'like'. In WTO case law, four criteria determine if products are 'like'[102]:

- The physical properties of the products
- The extent to which the products are capable of serving the same or similar end-uses
- The extent to which consumers perceive and treat the products as alternative means of performing particular functions to satisfy a particular want or demand
- The international tariff classification of the products

There are two important aspects of 'likeness' when considering hydrogen trade:

- The physical characteristics of the hydrogen being traded (i.e., its physical form)
- The non-physical characteristics (e.g., varying GHG footprint embodied in the hydrogen)

[101] Marhold, Anna-Alexandra. Energy in International Trade Law (Cambridge Int. Trade and Economic Law)
[102] https://www.wto.org/english/tratop_e/envir_e/envt_rules_gatt_e.htm

Previous disputes can inform possible future ones: in the case *EU-Energy Package*, the EU successfully argued that natural gas and LNG were not physically 'like' because they were in different forms (gas vs. liquid) and were classified under different HS subheadings. Russia was unsuccessful in arguing they were 'like' because once gasified they were capable of performing the same end use[103]. Analogies could be drawn with gaseous and liquid hydrogen although currently they have the same HS code. Therefore, hydrogen gas could be classified as not 'like' any of its carriers (LH_2, NH_3, LOHC). As hydrogen is produced as a gas and is likely to only be converted to a carrier for long distance international trade, this could mean gaseous hydrogen, produced domestically (or close enough to be imported via pipeline), could be treated differently to imports from further afield which require a carrier. In the *EU-Energy Package* example, the implications were significant: not being 'like' meant that while natural gas TSOs (pipeline operators) were legally required to unbundle sales and distribution activities under the EU's Third Energy Package, LNG system operators were not required to do so.

Considering the 'product' versus 'process' issue, the trade of goods and rules in trade agreements are based on the nature of a good defined by Harmonised System (HS) commodity descriptions and codes. This HS code mostly depends on the physical characteristics of the good *at the point of trade*, and therefore an associated GHG footprint linked to processes and production methods (PPM) may not be captured. Within the WTO system, all molecular hydrogen (H_2) is considered 'like', with the same HS codes for hydrogen produced by different methods (e.g., natural gas compared to electrolysis). These hydrogen molecules only have different non-physical characteristics (i.e., GHG footprint), which may have value (Section 4.3) but is not accounted for within the trading system.

The WTO regulates state policies, so any standards or certification to quantify this GHG footprint set by industry associations, private standard-setting bodies or companies, or NGOs, fall outside the realm of the WTO, unless directly linked to state activity. These would be allowed under WTO principles to differentiate products determined 'like' by the WTO. Industry associations can play a role in promoting and aiding emission reductions among their members, for example by providing comparative metrics and facilitating knowledge exchange. For example, Fertilizers Europe has developed a Carbon Footprint Calculator, which enables fertiliser producers to measure and benchmark their CO_2 emissions and report verified results via a certification scheme developed in partnership with the Carbon Trust[104].

Only if a state imposed certain sustainability standards on hydrogen would this be regulated by the WTO and such a country would have to be careful to act in a non-discriminatory way. The EU RED mandate contains sustainability criteria required for hydrogen to be eligible to count towards the targets for renewable energy in the transport sector. As a state directive, its provisions apply equally to all WTO members and so it allows for and does not discriminate against imports. Hydrogen meeting the required sustainability criteria and imported to the EU would be eligible for subsidies under the RED, as would be the case for any domestically produced hydrogen. However, as the directive is regulated by WTO law, it can be the subject of disputes (e.g., *EU – Palm Oil (Indonesia)*[105]).

Questions include:

- To what extent should PPMs or criteria that do not leave a trace in the final product be considered when analysing tradable goods for 'likeness' within the meaning of the GATT?

[103] However, this case is currently in limbo due to the impasse affecting the Appellate Body, so the panel's conclusions have not been adopted by the DSB and there is no legal ruling yet.
[104] IEA Ammonia Technology Roadmap 2021
[105] Indonesia maintains RED II unfairly discriminates against palm oil for use in biofuels

- Should products be treated differently within the trading system for environmental reasons because of how they have been produced, even if they are identical in their final form?
- Should WTO rules treat hydrogen with varying GHG footprints differently?

No WTO Agreement currently looks explicitly at PPMs, and anything that does exists outside of trade law. However, there are starting to be provisions outside of HS codes in FTAs (but not in the multilateral WTO framework) such as requirements for environmental impact assessments to promote environmentally sound production of raw materials.

It is hard to draw conclusions from WTO case law on the 'likeness' of energy goods and so a case-by-case analysis remains essential. In the case *Canada – Renewable Energy*, the Appellate Body took the view that the market for electricity generated from renewable sources was not the same as the market for all electricity, implying that it was possible to differentiate between the two. This bodes well for differentiating between low carbon and polluting energy products in the future, which could benefit trade in low carbon hydrogen. However, no conclusive answers have been given.

A further implication of 'likeness' is that Article II GATT allows members to apply 'a charge equivalent to an internal tax' to imported products, imposed consistently with the National Treatment principle in respect of the 'like' domestic product. This is crucial to discussions on carbon border taxes and means polluting imported products can be taxed or charged with duties equivalent to polluting national products, and potentially higher than those imposed on non-polluting equivalents.

The Carbon Border Adjustment Mechanism (CBAM) is a climate measure proposed by the EU, but the US[106], Japan, and Canada[107] are considering similar schemes. It is a tax on imported goods based on their carbon content, aiming to reduce the risk of carbon leakage from the EU due to differing global climate mitigation ambitions. For WTO legality reasons the EU wants to align rules for imported products with rules for producers under the EU ETS, by ensuring equivalent carbon pricing for imports and domestic products. To be compliant with WTO rules, any carbon border tax would need a mechanism through which producers can prove and declare the total embedded emissions of their imports, which reinforces the need for a reliable international guarantee of origin or certification scheme for hydrogen and its derivatives. The implementation of the proposed CBAM will add complexity to developing supply chains that include hydrogen, as it only covers a limited number of carbon-intensive products which may use hydrogen as an input: cement, iron and steel, aluminium, fertilisers (from ammonia) and electricity, but it does not include hydrogen itself as this is not currently traded internationally. A coalition of European electricity groups including EDF, Enel, Iberdrola, and Ørsted and the industry grouping Hydrogen Europe have called on the European Commission to include hydrogen in the proposed CBAM and impose a carbon tariff on hydrogen imports to the EU[108][109].

5.3.2 Subsidies and countervailing measures

Energy is one of the most heavily subsidized sectors globally[110]. Subsidies are a recognised way to encourage both production and consumption to kick-start an industry. A huge scale up of the low carbon hydrogen sector is required to meet decarbonisation objectives, and this will require a

[106] https://ustr.gov/sites/default/files/files/reports/2021/2021%20Trade%20Agenda
[107] https://budget.gc.ca/fes-eea/2020/report-rapport/FES-EEA-eng.pdf
[108] https://www.euractiv.com/section/energy/news/electricity-giants-call-for-carbon-tariff-on-eu-hydrogen-
[109] https://fuelcellsworks.com/news/hydrogen-europe-reforming-carbon-markets-to-enable-a-liquid-sustainable-and-affordable-hydrogen-market/
[110] https://academic.oup.com/jiel/article-abstract/18/2/261/799666?redirectedFrom=fulltext

significant amount of capital and stimulation. It is likely that the subsidisation of hydrogen and its derivatives will be an important enabler. Consequently, consideration must be given to how and to what extent the hydrogen ramp up can be subsidised without leading to disputes, as there are strict rules on subsidising renewable energy under the ASCM and in state aid rules.

Subsidies allowed under WTO law can be used to help market creation (e.g., to develop technology) or bring the first scaled plants to bear (pilots) etc. (Section 5.2.3), corresponding to the current state of the hydrogen sector. After this development phase, subsidies are more strictly regulated and the market should function more organically (e.g., driven by effective CO_2 prices and CSR targets). For example, operational subsides and export subsidies are prohibited as they are designed to directly affect trade. As the hydrogen market develops and imports and exports increase as trade ramps up, government subsidies may be classed as 'actionable', and so could be challenged or countered by third parties. For example, heavily subsidized and subsequently exported hydrogen may have a countervailing duty imposed as a trade defence measure. States might also put in countervailing measures on imports of downstream products which have benefited from subsided inputs. However, if a particular country has a natural competitive advantage for producing renewable energy, this will extend to all downstream manufactured goods so is not an issue in WTO law in the absence of restrictive practices or other contentious behaviour.

Least developed countries are exempt from the ban on 'export subsidies' and treated more favourably with respect to 'actionable subsidies' and imposed countervailing measures. This could benefit hydrogen production projects in such countries. Another consideration is that WTO rules on agricultural subsidies may affect some biofuels (Section 5.3.7) and may currently allow for subsidies on such agricultural products also used as fuels, potentially affecting hydrogen trade.

A particular shortcoming of the existing WTO rules on subsidies is the difference in treatment of fossil fuels and renewable energy. Fossil fuel subsidies (FFS) are often available as consumer subsidies across the entire economy, which makes it hard to qualify them as 'specific' (Section 5.2.3) and so are outside the current scope of the ASCM and not regulated by WTO trade law. By contrast, subsidies for renewable energy are more easily defined as 'specific', as they often target particularly industries or regions. These are subject to the ASCM, so subsidizing renewable energies – and potentially low carbon hydrogen – could be problematic. Many renewable energy cases have been referred to the dispute settlement in the past decade[111], although none have been initiated against the much larger and environmentally harmful fossil fuel subsidies.

Despite this implication of the current rules, existing disciplines in the ASCM do not themselves inherently distinguish between subsidies for renewable and non-renewable energy sources, (or any other types of sectoral subsidies), raising questions over the balance to be struck between promoting environmental policies and the current WTO framework. The legitimacy of 'green subsidies' under the ASCM has been debated in policy forums for years[112]. For example, should the WTO consider the challenges of the climate transition and allow for additional subsidisation for low carbon technologies such as hydrogen, which could trigger the necessary investments for rapid scale-up?

5.3.3 Export restrictions

Existing trade rules do not address export restrictions and investment protection well, providing room for distortions to trade and investment. GATT Article XI prohibits export restrictions, with

[111] https://www.wto.org/english/tratop_e/dispu_e/dispu_status_e.htm
[112] https://openknowledge.worldbank.org/bitstream/handle/10986/20500/WPS7060.pdf?sequence=1&is

exceptions, and does not explicitly cover or regulate practices such as export taxes (duties and tariffs), export licenses, export monopolies and production quotas. This is a shortcoming of the existing trade framework and has arisen due to the GATT's traditional focus on limiting import barriers for manufactured goods in unlimited supply. However, for goods in limited supply export restrictions are a concern, as the needs of consumers to access unevenly distributed supplies is generally greater than that of producers for export markets, shifting the power balance towards exporters. For strategic finite commodities, export restrictions can be used to exercise market power, maximise revenue, and manipulate and distort global trade, so have the capability to shape international trade policy. This is an issue for fossil fuel energy trading as well as markets for rare earth metals, crucial components of many hydrogen production and end-use technologies.

Companies will invest in hydrogen production outside their national borders. Import and export policies can constitute an investment risk. If rules are not consistent thereby putting the basis for the business case at risk, they may not invest. A clear framework internationally, could help support diversifying supply chains and build more efficient global markets for hydrogen.

Export licensing through environmental regulations is not regulated under the WTO. It has been used in other industries, such as natural gas, as an indirect way to block trade (e.g., by not allowing construction of the infrastructure needed to enable the exports). Planning approval and environmental-related permitting regimes will be required for lots of infrastructure necessary to enable hydrogen trade (e.g., licenses to authorize construction and operation of pipelines, liquefaction or conversion facilities[113]). Additionally, it is important to build relationships and obtain approval from indigenous groups who may be custodians of the land on which infrastructure may be built although this is a domestic issue and so not regulated by the WTO.

Export restrictions could artificially depress the price of a good in a domestic market by increasing supply, indirectly subsidizing and lowering production costs, benefiting domestic industries. This may affect the competitiveness of other industries such as those creating value added products using low carbon hydrogen (e.g., supply chains for ammonia or steel). Export restrictions are therefore connected to dual-pricing practices which have been very distortive for fossil fuel energy markets, which hydrogen may be produced from, or compete with (Section 5.3.4).

If export restrictions are not regulated, it is likely other countries cannot put in place trade restrictions on subsequent exports in reply, but it could lead to a tendency to increase import tariffs or, if ASCM rules are breached, to trade defence measures being used. However, countries are gradually shifting away from non-transparent pricing policies. Acceding members are increasingly binding their export duties and several have bound export duties specifically on energy goods.

5.3.4 Dual pricing

Dual pricing has significantly affected the global trade in fossil fuels. Resource-rich countries (e.g., through monopolistic STEs) sell their energy resources on the domestic market at significantly lower prices than on the export market, to provide domestic downstream energy intensive industries and the economy at large with cheap inputs, giving them an advantage over competitors. However, this typically leads to negative environmental impacts from wasteful consumption and preventing diversification to lower carbon energy sources by maintaining artificially low fossil fuel prices.

[113] https://renewablesnow.com/news/australia-rejects-massive-26-gw-wind-solar-hub-for-h2-ammonia-export-745040/

This amounts to an indirect, inverted subsidy, so dual-pricing practices are considered within the broader category of environmentally harmful fossil fuel subsidies (FFS). Dual pricing can violate multiple WTO rules, including GATT Article XI on Quantitative Restrictions, Article XVII on STEs, the ASCM and the Anti-Dumping Agreement. Such policies have been applied by Russia, Ukraine and OPEC countries, notably Saudi Arabia, who are all likely to be hydrogen exporters in the future (see Appendix). Dual pricing has been a recurring issue in GATT/WTO negotiations for decades but remains unresolved. Although current WTO rules could in theory curb dual-pricing policies and significantly contribute to FFS reform, this is not occurring, although efforts are being made outside the WTO to reform fossil fuel subsidies.

As no other energy market is regulated internationally when it comes to dual pricing, although it should ideally be avoided for hydrogen, this may not be realistic. However, dual-pricing is likely less applicable to the hydrogen sector than the fossil fuel sector, as in principle hydrogen can be produced in every country, unlike geographically distinct and finite petroleum reserves. Although it will be cheaper to produce in certain locations, hydrogen is unlikely to be a scare resource, so there is less scope for countries to exercise market power. If producers do start to distort markets, importers will have some power to react. Perhaps a greater concern would be the continued use of dual-pricing to artificially depress fossil fuel prices, reducing the relative cost-competitiveness and therefore relative trade opportunities of low carbon hydrogen and its derivatives.

5.3.5 Transit of energy using third party infrastructure

Activities related to the transit of energy through a territory are regulated by both the GATT (i.e., specifically Article V on freedom of transit) and the GATS. However, it is unclear if this includes third party access to fixed infrastructure such as gas pipelines or fixed energy grids such as cross border electricity transmission networks. Currently transit is mainly regulated through cross-border agreements, both bi- and multilateral, including formalities of customs transit procedures and operations.

Transit issues (e.g., third-party access to pipelines) are receiving increased attention in accession negotiations. However, there is no consistency in commitments between countries, reflecting the lack of clarity in Article V GATT. For example, Ukraine and Kazakhstan are required to give third parties access to their gas transport networks, whereas Russia made no commitments on access to pipelines and pipeline transport services. It is unclear if the State Trading Enterprise (STE) provision means that energy companies that own distribution networks must respect the rules of non-discrimination when it comes to third party access to pipelines (e.g., for the transit of hydrogen). Article XVII on STEs applies to any enterprise that has been granted exclusive or special privileges, even if such a company is not owned by the state. Control over national energy infrastructures could be considered a special privilege, implying the energy company would have to comply with Article XVII's non-discrimination.

5.3.6 Domestic regulation on the use of infrastructure and competition principles

The energy sector is highly regulated and infrastructure-bound. Competition principles between market players, and domestic regulation provisions on access to infrastructure, are important to help ensure a level playing field. However, WTO does not regulate the use of infrastructure, so there is no guarantee that a third country active in a domestic market has equal right of access, influencing industry wanting to set up production capacity within third countries as well as traders. In principle countries could limit access to infrastructure for third party operators to prevent them from being active in a certain sphere.

Competition and antitrust rules exist at national and regional levels but not in WTO law. Any abusive practices by global public monopolies, not uncommon in the energy sector, are outside the scope of national anti-trust laws and there are no provisions in international trade law. For example, the Organization of Petroleum Exporting States (OPEC) has significantly influenced global crude oil prices since it came into existence, though the distributed nature of hydrogen makes an analogous future case unlikely. Grid and network operators have natural monopolies as single systems are typically more effective. If they can prevent enterprises from other WTO members competing for sales or purchases on an equal footing, this would be contrary to Article XVII (on STEs), though it is not yet clear how networks will develop and how third-party access can be ensured in the absence of WTO law. In the EU, the European Commission will revise Gas Directives in 2021 and is expected to include hydrogen in any new legislation which should address unbundling, third party access, monitoring, oversight by National Regulatory Authorities (NRAs), tariffs and cost mutualisation[114].

5.3.7 Import tariffs

Import tariffs for different products depend on their place in the HS convention. Hydrogen's production and use in many different value chains when considered as part of an integrated energy system, means it may link products and sectors that have traditionally been very distinct. The remit of energy goods has also now broadened from fossil fuels as the sector seeks to decarbonise, and so relevant import tariffs may be classified in different Agreements. Some biofuels such as ethanol are treated as agricultural products in the Agreement on Agriculture instead of as conventional goods and are generally subject to higher import tariffs, especially compared to traditional energy products. Hydrogen can both be used to synthesise ethanol and be produced from ethanol reforming. This exemplifies that if import tariffs between hydrogen and its up-stream components (e.g., feedstocks), and down-stream derivatives (e.g., carriers or fuels) were empirically significantly different, alignment would be important to ensure trade distortions do not occur.

As highlighted in Section 3.4.2, different hydrogen carriers will contain different relative amounts of hydrogen, as well as being subject to different third country tariffs. Therefore, the MFN tariffs would have a different impact on the delivered energy on a $/kWh basis depending on the hydrogen carrier chosen.

5.3.8 Goods vs. services divide

An important concept for analysing future hydrogen trade is understanding how it is being traded across borders, whether it is as a good or a service. These are categorized differently within the traditional WTO framework and are governed by the GATT and the GATS respectively. Much of the energy traded globally possesses elements of both goods and services and does not always fall neatly within these parameters. The manufacture of an energy good such as hydrogen is sometimes hard to separate from the service or activity connected to its production, transit, or distribution. To be compliant with the international trade rules, it must be determined which legal treaty is applicable for the aspect in question, to determine the obligations that must be adhered to, and there could possibly be an overlap.

Agreements within the GATT only apply to goods and not to services, and so whether a certain energy-related economic activity is considered as a good or a service could have significant consequences in terms of which trade rules and WTO Agreements apply. Members can be more restrictive on services and can protect their national service sectors more compared to goods, so

[114] https://fsr.eui.eu/guarantees-of-origin-support-schemes-and-network-regulation/

depending on the service commitments a particular country has undertaken, this divide could be important.

5.3.9 Protectionism and local content requirements

The trade and offtake of hydrogen and its derivates will be affected by the concurrent trade of related services and manufactured products, such as fuel cells and electrolysers. The trade of these products (in limited supply), face different challenges to the trade of *energy* products, such as hydrogen, in theoretically unlimited supply. Predominant issues are protectionism and the substantial increase in recent years of local content requirements (LCRs) of key components to qualify for subsidies, forcing the localization of whole supply and value chains, including hydrogen technologies.

Governments adopt LCRs to try and achieve technological development goals such as building up a domestic equipment manufacturing base. However, protectionist and restrictive localization rules place a significant burden on industrial manufacturers (e.g., of fuel cells and electrolyser) seeking to expand in these markets and can increase the overall cost of producing manufactured goods and reduce supply chain flexibility. This may affect trading in hydrogen, which needs to reduce costs of both hydrogen and its necessary technologies.

Local content requirements for products purchased or used by companies may violate provisions in WTO Agreements including GATT Article III (National Treatment), GATS, TRIMS, ASCM, and for relevant members, the plurilateral Agreement on Government Procurement (GPA). Despite their widespread adoption and enormous impact, the WTO legality of local content requirements has not been comprehensively analysed and they have rarely been addressed by the WTO[115]. Their continued use, despite possible violation of these rules exemplifies the need for a functioning DSS.

5.4 Attempts to address rules on the energy sector

5.4.1 Within the WTO

Changes to and within the WTO, including more detailed rulemaking in energy, have been considered and in some cases tested (see Section 8.5.5), but complexity and the need to get agreement across such a wide range of stakeholders and interests mean it has not succeeded. It is unlikely that reform specifically targeted at hydrogen would have any more success.

5.4.2 Beyond the WTO

The difficulty of addressing energy within the WTO has led to efforts outside it. Treaties are the form of international law most important for the regulation of international energy relations and guaranteeing energy security. These include the establishment of the plurilateral Energy Charter Treaty, Euratom (nuclear energy in Europe), the Statute of the OPEC, and the decision to establish the International Energy Agency (IEA). Many countries or regions have also been active pursuing their own ‘Preferential Trade Agreements’ (PTAs) outside the WTO’s multilateral framework.

[115] The Legality of Local Content Measures under WTO Law June 2014, Journal of World Trade 48(3):553-591

5.4.2.1 The Energy Charter Treaty (ECT)

The plurilateral Energy Charter Treaty (ECT) came into force in 1998 as an alternative to concluding an energy-specific agreement within the multilateral WTO framework, and addresses many of the challenges in Section 5.3. It is the only energy specific international agreement that establishes a framework for cross-border cooperation and aims to create open, non-discriminatory, and competitive energy markets throughout its members. It has been acceded to by 53 states and the EU[116], but does not include major oil producers such as the US, Russia, Saudi Arabia, Oman and China.

The treaty is designed to promote energy security and covers all aspects of commercial energy activities including free trade, protecting foreign investments and promoting energy efficiency. While it contains definitions of energy materials, products, equipment and related services, currently its scope is mostly limited to fossil fuels. Renewable forms of energy or biofuels are not expressly covered, and it does not differentiate between electrical energy generated with different GHG footprints (i.e., PPMs are not considered). Hydrogen is not currently captured by the Treaty, but this could change. The EU has proposed definitions for low-carbon hydrogen and renewable hydrogen for inclusion (but not HS codes)[117].

5.4.2.2 Preferential Trade Agreements (PTAs)

Given the lack of consensus at the multilateral level from both the WTO and ECT, many countries are independently pushing progress on enhanced energy regulation in Preferential Trade Agreements (PTAs). These include customs unions, common markets, and bilateral, regional, or multilateral Free Trade Agreements (FTAs) as well as sector-specific initiatives. PTAs tend to be more modern and progressive than older multilateral agreements or WTO accession protocols. Smaller groups of countries can be more innovative and rigorous developing rules which are harder to achieve, and go beyond what is possible, at the multilateral level. Further reaching commitments being made in PTAs reflect a demand for deeper market integration and aim to increase trade and boost economic growth.

There is a growing tendency to include dedicated and specialized energy-specific chapters and provisions in PTAs, particularly FTAs concluded recently by the EU[118] [119]. These attempt to address the specific needs of the energy sector whilst accounting for the situations and interests of the parties involved. Nothing yet exists on hydrogen, though this approach could be taken in future.

5.4.3 Future energy trade

Given the current trajectory, it is most likely solutions for energy trade will get developed first through informal agreements or discussions involving smaller groups of countries, possibly drawing from relevant international organizations such as the United Nations Framework Convention on Climate Change (UNFCCC). Later, these could be aligned at a more international level or crystallised into something more solid within the WTO.

---

[116] https://www.energycharter.org/process/energy-charter-treaty-1994/energy-charter-treaty/

[117] https://trade.ec.europa.eu/doclib/docs/2021/february/tradoc_159436.pdf

[118] https://trade.ec.europa.eu/doclib/docs/2018/april/tradoc_156800.pdf Modernisation of the Trade part of the EU-Mexico Global Agreement

[119] https://ec.europa.eu/info/strategy/relations-non-eu-countries/relations-united-kingdom/eu-uk-trade-and-cooperation-agreement_en EU-UK Trade and Cooperation Agreement

5.5 Conclusion – Treatment of hydrogen in trade rules

The main principles of the WTO's rules-based trading system of non-discrimination, freer and predictable trade should in theory apply to – and benefit – the development of hydrogen trade. All WTO Agreements are relevant, but the WTO framework was established to deal with the trade of manufactured products so is not tailored to energy, including hydrogen. In addition, the structure and legitimacy of the WTO is currently under scrutiny[120].

Particularly relevant to hydrogen trade, issues for consideration within the current framework include:

- The applicability of the concept of 'likeness' to hydrogen trade, particularly the 'product' versus 'process' issue given the varying GHG footprint embodied in low carbon hydrogen and its derivatives is important to consumers;
- The treatment of subsidies for renewable compared to non-renewable energy sources;
- The insufficiency of current rules to address export restrictions and investment protection;
- A lack of clarity on whether under current trade rules third parties have access to fixed infrastructure installation such as pipelines;
- The WTO does not regulate the use of infrastructure or have competition and antitrust rules; and,
- The rise of protectionism and increasing local content requirements is distorting the trade and cost of hydrogen technology.

It is not yet clear how hydrogen will be affected by such issues, as currently there is no global market. Where possible, lessons should be learnt from analogies in existing industries to try and avoid similar or predictable issues occurring for hydrogen. As the market develops, competition becomes fiercer and stakeholders become less cooperative, challenges and trade issues seen for more mature commodities could arise.

With increasing interdependence between net exporters and importers of energy, in many cases multilateral rules can provide a more balanced and efficient framework for international cooperation than is offered by bilateral agreements alone or by non-legislative instruments. Nevertheless, more clarity in existing trade rules applied to energy is required, known trade issues should be actively tackled and gaps in the law should be identified and the necessary solutions developed.

However, work on a more efficient system of energy regulation may well go beyond the confines of the WTO. Given the rise in bilateral and plurilateral Agreements tackling challenges in energy trade, it may be likely that a consensus on hydrogen trade issues is established first in smaller forums, which could later be crystallised into something more solid, possibly within the WTO. Increased coordination and/or possible or partial integration with the ECT may be an option to explore, as well as cooperation with other relevant energy related international organizations. Ideally, the results would be a more coherent and comprehensive framework for energy governance that also takes environmental, social and other requirements into account, and thus be beneficial for sustainable development, though this will be extremely complex to achieve in practice.

[120] https://www.g20-insights.org/policy_briefs/the-need-for-wto-reform-where-to-start-in-governing-world-trade/

6 Conclusions

As countries aim to decarbonize in line with the Paris Agreement, low carbon fuels such as hydrogen can play a significant role in the clean energy transition, particularly in regions where the potential to integrate more renewable energy directly is low. Trade of hydrogen and its derivatives will play an important role in meeting the challenge posed by the global trilemma of energy security, economic development and environmental protection. To help, there needs to be a sense of shared purpose between the climate and trade communities.

Hydrogen production, distribution and use already take place with no significant barriers, and in principle, there is nothing fundamentally inhibiting hydrogen supply chains at scale. Although R&D will drive innovation, and future technologies will differ to those in use today, the individual components have already been demonstrated in isolation. Some technicalities must be overcome, which differ by carrier and by component, and regulatory obstacles remain to be aligned, but the practicalities of supply chain construction are promising.

However, whilst trade in hydrogen and its carriers does exist today, volumes are far below the scale necessary to meet envisaged demand or decarbonisation targets. New drivers, production locations, technologies, and increased scale for all components of the value chain will take time to develop and will start to generate further trade. Hydrogen policy, legislation, and incentive instruments based on the three pillars of sustainable development are still evolving, and the complexity of regulatory and market frameworks alongside infrastructure roll-out will affect how trade develops.

This means investment decisions for future infrastructure developments are made in the context of the current market framework, policy and regulatory uncertainties. Markets are only now starting to evolve, and how to best facilitate them will require international dialogue and cooperation potentially involving fora such as the IPHE.

6.1 Issues for Consideration

1. Trade Structure

Understanding the role of the WTO and other aspects of the existing trade framework is important, so that the trade of low carbon hydrogen and its derivatives develops in an efficient, inclusive, and transparent way. International trade law from the WTO regulates some aspects of the cross-border trade in energy but it is a complicated sector to regulate, especially considering the interlinked challenges of decentralisation and decarbonization of the energy market, and the need for energy security. The existing trade framework does not preclude trade, but at the multilateral level there is a need for clarification and more appropriate rules that address the realities of cross-border energy trade and tackle the necessary regulation in a proper and proactive manner (Section 5.5).

Hydrogen and its carriers do not seem to warrant special treatment, but more detailed analysis of specific pathways, detailed by production method, carrier, intermediate transformation and final use may shed light on areas not covered in this high-level study.

2. Market equilibrium and favourable business cases

There is a need for **supply and demand coordination** from **volume and offtake agreements** to close the cost gap and create **favourable markets** in which to sell. Support schemes at both ends are needed to develop new production facilities and use cases in tandem to balance supply and demand.

Both must increase in scale before a traded market can develop. Markets for low carbon hydrogen are still small, with few buyers willing to pay the price premium. However, demand is rising in Europe because of binding targets for industry in the Fit for 55 proposal, legal implementation of RED II in France, Germany and the Netherlands, the German government's plans for a Contract-for-Difference (CfD) scheme and H2Global. Japan has already imported 'low carbon' hydrogen carriers and has many projects in power generation, heavy industry, and transport applications that show hopeful signs of clear demand being created. Customer adoption of low carbon hydrogen and willingness to pay is important. It will be driven either at country level through policy or at the customer level by passing the cost on to those that want and expect products to have a certain footprint or environmental impact. Drivers are increasingly coming from external players; investors, insurers, financiers and trading partners who expect products to meet a certain standard.

The development of an internationally, and ideally globally accepted standard for measuring, certifying, and tracking emissions for all hydrogen chains will strongly support the development of transparent markets.

3. Policy and regulatory uncertainty, role of certification

Providing **clear regulatory frameworks** will be important to enable rapid hydrogen scale-up**.** Hydrogen is a nascent area of energy policy and industry is looking to government to provide capital and revenue support, regulatory levers and incentives, systems for assurance on quality and safety, direction on supply chains, and decisions on broader strategic direction for the sector. Both producers and consumers need confidence in low carbon hydrogen products having value in the marketplace. Establishing a common certification or GO scheme is fundamental to de-risk projects and investments, unlock the supply chain and enable the industry to grow. There is a need for common standards and consistent methodologies (such as those being developed by the IPHE) to quantify emissions associated with hydrogen production and distribution to underpin certification to enable cross-border trade. Ideally this will include collaboration with major trading partners, so that the relevant criteria, requirements, and the various aspects of the certification scheme can be met.

Clear policy and other rules for implementing the standard outlined above will be needed to allow trade to develop.

4. Overcome the cost gap

The cost of low carbon hydrogen is currently challenging relative to existing high carbon fuels, but costs are likely to reduce significantly and rapidly as innovation and deployment accelerate. Government regulations and incentives are important for favourable business cases. 'Market pull' policies, such as **effective carbon pricing** will close the cost gap between the price of low carbon products and their value for reducing emissions. Each potential market will have a different baseline in which low carbon hydrogen must compete (i.e., existing fossil fuels, alternative technology, or higher carbon analogues) and the use cases with the lowest entry hurdles can be used initially to build scale.

The emissions standard discussed above would enable transparent pricing for different 'characteristics' of hydrogen. Defining and quantifying these would help develop options to reduce the cost gap.

5. Enabling Infrastructure and scale

Enabling infrastructure is needed for both large scale production and distribution and hence for markets to develop. The use of hydrogen will require new networks and storage capacity, as well as integration with electricity and gas networks. Where infrastructure does exist, it is optimised for the trading volumes of current products in existing locations, so these will need to expand. Infrastructure investments are characteristically large and long-term. Investors will aim to minimise the risk of future policy or regulation adversely affecting their investment.

Clarity on issues involving particular carriers or pathways, derived from deeper analysis of individual supply chains under existing WTO regulation would help investors decide between different export and import infrastructure choices, enabling market scale and trading.

6. Technology innovation and up-scaling in manufacturing

Although the production of low carbon hydrogen and distribution methods have been demonstrated, most technology in the value chain has not yet been proven or fully developed at commercial scale. Further **technology development, up-scaling in manufacturing** capacity and gaining of long-term operating experience are required before the trade of hydrogen and its carriers can be implemented at large-scale. However, these steps must be taken without a full understanding of the possible implications of trade and other policies.

As above, clarity on the most efficient and effective production, transport, and storage pathways, as well as on relevant government policy related to the different 'characteristics' of the hydrogen distributed, will help de-risk these investments.

7. Financing and investment

Global trade in hydrogen will need **large, patient capital investments** from sources including governments, industry, international financial institutions, and investment houses. To be considered bankable, initial projects will require long term fixed price offtake contracts with creditworthy off takers, likely structured on a take-or-pay basis. Today there is little predictable low carbon hydrogen offtake as there is a limited creditworthy off-taker pool with the risk appetite and downstream distribution network to offtake low-carbon hydrogen at utility scale. Enabling finance may include grant funding, concessional loans or underwriting of risk by governments or multilateral bodies. It will be important that these kinds of enabling actions do not violate trade rules or otherwise prejudice future investment and roll-out.

One could gain further insights through a more detailed investigation of supply chains outlined above, coupled with a targeted set of scenarios around possible investment mechanisms and any trade (or other) implications they might have.

8. Collaboration and transparency, with clear leadership

Hydrogen trade will require **global collaboration**, and hence coordination between governments, producers, consumers, technology suppliers, financial institutions, researchers, non-governmental organisations etc. The voice of the different stakeholders should be heard early on in any process to help ensure alignment, so that implementation can take place with little or no pushback. While **Government leadership** is needed to help lay the groundwork, a convening body may be helpful in ensuring consideration of different issues and perspectives.

Establishment of some type of forum to identify the different stakeholder perspectives, and their real or possible impact on trade, could help to ensure that future legislation and pathways respond to many of these perspectives and hence, face fewer hurdles in implementation.

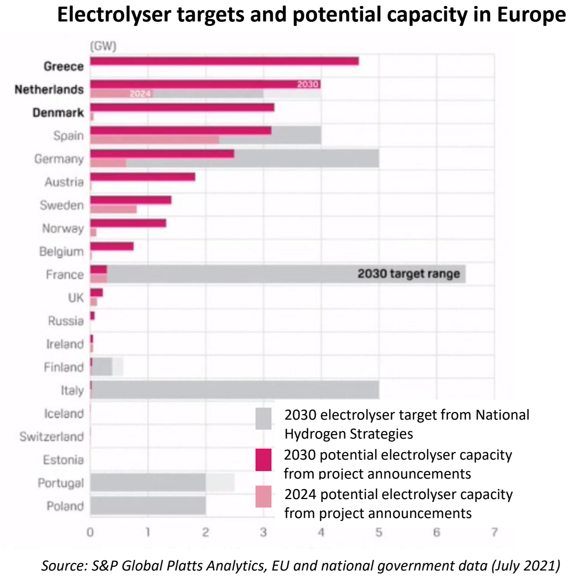
7 Abbreviations

Agreement on Subsidies and Countervailing Measures (ASCM)
Alkaline Fuel Cell (AFC)
Ammonia (NH_3)
Anion Exchange Membrane (AEM)
Anti-dumping Agreement (ADA)
Autothermal Reforming of natural gas (ATR)
Business-to-business (B2B)
Carbon Border Adjustment Tax Mechanisms (CBAM)
Carbon Capture, Storage and Use (CCSU)
Carbon Contracts for Difference (CCfD)
Contracts for Difference (CfD)
Corporate Social Responsibility (CSR)
Dibenzyltoluene (DBT)
Direct Air Capture (DAC)
Dispute Settlement System (DSS)
Emission Trading System (ETS)
Energy Charter Treaty (ECT)
European Union (EU)
Feed-in Tariff (FIT)
Fossil Fuel Subsidies (FFS)
Free Trade Agreements (FTAs)
Fuel Cells and Hydrogen Joint Undertaking (FCH JU)
General Agreement on Tariffs and Trade (GATT)
General Agreement on Trade in Services (GATS)
Greenhouse Gas (GHG)
Gross Domestic Product (GDP)
Guarantee of Origin (GO)
Harmonised System (HS)
Important Projects of Common European Interest (IPCEI)
Internal combustion engine (ICE)
International Energy Agency (IEA)
International Maritime Organization (IMO)
International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)
International Standards Organisation (ISO)
Least developed countries (LDCs)
Lifecycle Analysis (LCAs)
Liquid Hydrogen (LH_2)
Liquid Natural Gas (LNG)
Liquid Organic Hydrogen Carrier (LOHC)
Liquid Petroleum Gas (LPG)
Local Content Requirements (LCRs)
Low Carbon Fuel standard (LCFS)
Lower Heating Value (LHV)
Methylcyclohexane (MCH)
Most Favoured Nation (MFN)
National Hydrogen Strategies (NHS)
National Treatment (NT)
Organization of the Petroleum Exporting Countries (OPEC)
Preferential Trade Agreement (PTA)

Production and Process Methods (PPM)
Proton Exchange Membrane (PEM)
Renewable Energy Directive (RED)
Renewable Fuels of Non- Biological Origin (RFNBO)
Renewable Transport Fuel Obligation (RTFO)
Research and Development (R&D)
Solid Oxide electrolysis cell (SOEC)
Solid Oxide Fuel Cell (SOFC)
State-owned trading enterprise (STE)
Steam Methane Reforming (SMR)
Technical Barriers to Trade (TBT)
Technology Readiness Level (TRL)
Trade Related Aspects of Intellectual Property Rights (TRIPS)
Trade-Related Investment Measures (TRIMS)
Transmission System Operator (TSO)
World Trade Organization (WTO)

8 Appendix

8.1 Low carbon hydrogen production and demand reported in National Hydrogen Strategies



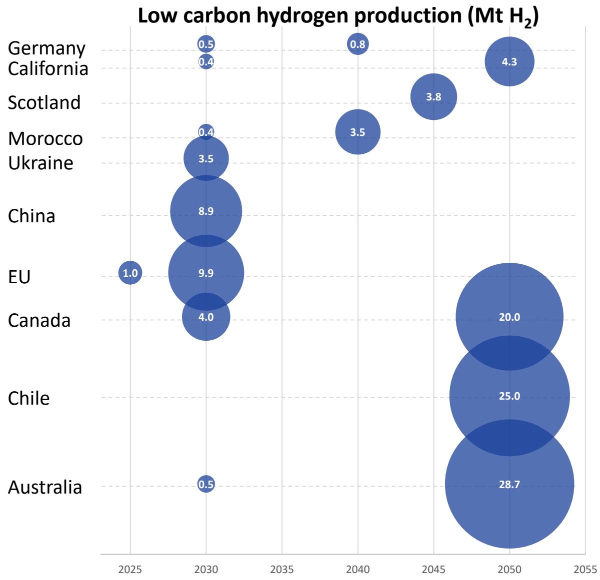


Figure 12: Hydrogen production – Announced electrolyser targets and potential capacity to 2030 (left). Targeted low carbon hydrogen production (right) reported in NHS (All converted to Mt H_2)

Source: S&P Global Platts Analytics, EU and national government data (July 2021)

Source: Data Reported in National Hydrogen Strategies converted to Mt H_2

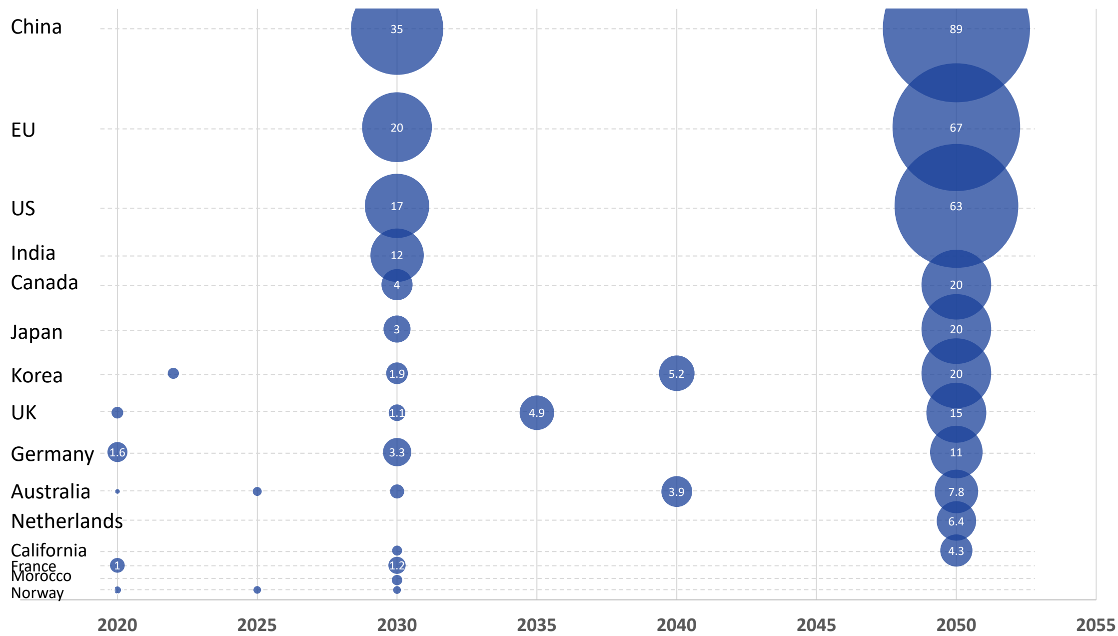


Figure 13: Overall expected annual H_2 demand reported in NHS and converted to Mt H_2

Source: Data Reported in National Hydrogen Strategies converted to Mt H_2

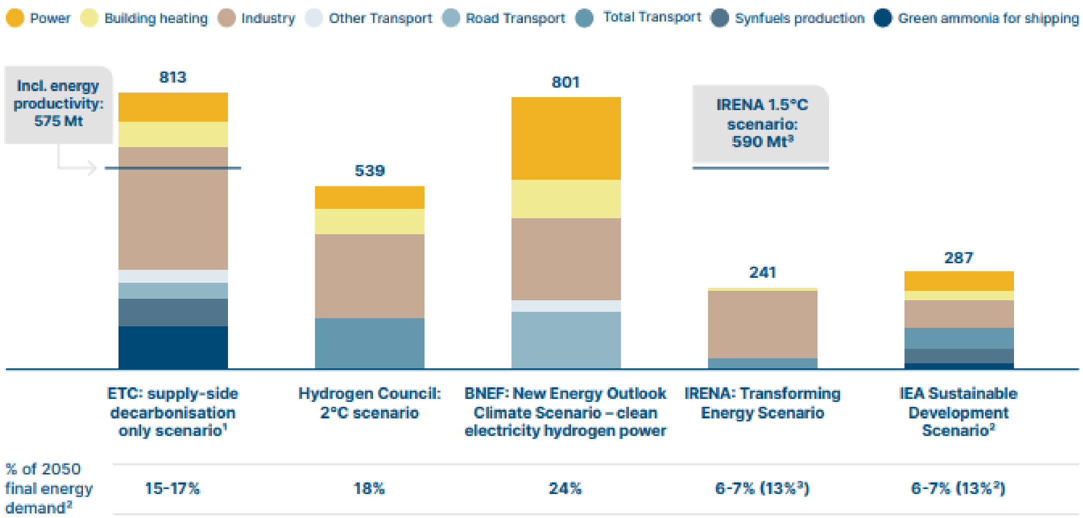


Figure 14: Global 2050 hydrogen demand in Mt hydrogen/year and % of 2050 final energy demand

Source: Energy Transitions Commission 'Global Hydrogen Report'

8.2 Importing countries

Japan

Japan is one of the leading countries in hydrogen activities and its 2014-18 Cross-Ministerial Strategic Innovation Program (SIP) looking into 'Energy Carriers' was an important driver for the global appreciation for the use of hydrogen and its carriers as energy vectors. It had the first government-backed hydrogen energy plan in the world and anticipates being very reliant on imports of hydrogen and its carriers, especially post the Fukushima nuclear disaster.

In June 2021, the Japanese government formulated the 'Green Growth Strategy Through Achieving Carbon Neutrality in 2050'[121]. This states the aim to develop commercial-scale supply chains by around 2030 to introduce 3 million tons of hydrogen per year, of which the amount of 'clean' hydrogen (defined as produced from fossil fuels with CCUS or carbon recycling, renewable energy, etc.). 20 million tons of demand is predicted by 2050[122]. Japan is aiming to use 0.3 Mt/yr of hydrogen and 3 Mt/yr of ammonia in the power sector by 2030.

The possibility to co-fire existing coal plants with ammonia has received increasing attention in Japan. The Hydrogen Energy Supply Chain Pilot Project will demonstrate the import liquid hydrogen produced from the gasification of coal in Australia. Kawasaki Heavy Industries is aiming to build 80 more hydrogen carriers to import 9 million tonnes of hydrogen a year by 2050, after building two commercial-scale ships to import 225,000t by 2030[123]. Chiyoda Corporation has already demonstrated the importation of hydrogen shipped within LOHC from Brunei to Japan. Under METI's Road Map for Fuel Ammonia, Japan will import 3 Mt/yr 'clean' ammonia by 2030, rising to 30 Mt/yr by 2050. METI also acknowledges that the volume of 'clean' ammonia traded in the wider Asia-Pacific region in 2050 may be as much as 100 Mt/yr.

[121] https://www.meti.go.jp/english/policy/energy_environment/global_warming/pdf/ggs_full_en.pdf
[122] https://www.meti.go.jp/english/policy/energy_environment/global_warming/pdf/ggs_full_en.pdf
[123] https://www.nortonrosefulbright.com/en/knowledge/publications/116d4601/is-the-middle-east-the-key

Japan is not currently recognising the carbon intensity of hydrogen imports and the focus is on cost reductions. Higher cost, lower emission products are therefore unlikely to be cost competitive and Japanese stakeholders are actively pursuing many natural gas + CCS ammonia import supply chains with countries such as the Middle East, Canada and Australia. Eneos with Saudi Aramco, and METI with ADNOC, have signed MoU's to explore potential opportunities for such ammonia supply chains between the Middle East and Japan. These actions are on top of the successful shipment in 2020 of 40 tons of natural gas derived ammonia from Saudi Arabia to Japan for use in power generation[124].

Japan has signed a memorandum of collaboration (MOC) with the UAE, and ADNOC has sold three shipments of natural gas-based ammonia to Itochu, Idemitsu and Inpex in Japan[125]. Japan and Australia have committed to a government level partnership to jointly support initiatives that will help drive the transitions to net zero emissions including 'clean fuel ammonia, clean hydrogen and derivatives such as steel and iron ore'[126]. Certification will be important to ensure products (e.g., labelled 'blue') do not actually have a higher carbon intensity than the direct use of fossil fuels.

Korea

In Korea, after 2030 it is envisioned that hydrogen will be imported, and it has been stated this can be produced from both renewables and brown coal 'produced in an eco-friendly way'[127]. Korea currently imports all of its ammonia (1.24 Mt NH_3 per year) and imports will likely have to exist in the future. Hyundai and Saudi Aramco have signed MoU's to explore potential opportunities for natural gas-based ammonia supply chains between the Middle East and Korea.

In South Korea, the Renewable Portfolio Standard Policy (established in 2012) already requires large power producers to meet a minimum portion of their power generation from new and renewable technologies, including fuel cells. Non carbon (hydrogen and ammonia) fuel will be supported by the Korean government with policy aid following the Carbon neutral scenario draft released by the Carbon Neutral Council on the 5th of August. Revision of the Korean Hydrogen Economy Law has been proposed (2021) to establish 'Clean Hydrogen Energy Portfolio Standards (CHPS)' and a national clean hydrogen certification system. Hydrogen fuel supply facilities must sell a certain percentage of clean hydrogen, and power generation operators are required to purchase power generated from clean hydrogen. The ratio will be announced annually by the Ministry of Trade, Industry, and Energy after review by the Hydrogen Economic Committee[128]. The goal is to expand domestic clean hydrogen production and usage.

The European Union

In its hydrogen strategy the EU has targeted 40 GW electrolyser capacity internally by 2030. A roadmap for this capacity shows a 6 GW captive market (i.e., hydrogen production at the demand location) and 34 GW merchant hydrogen market (i.e., hydrogen production near the resource). The hydrogen strategy also includes 40GW capacity in Europe's neighbourhood with export to the EU by 2030[129]. North Africa and Ukraine[130] have been highlighted, with 7.5 GW hydrogen production

---

[124] https://www.aramco.com/en/news-media/news/2020/first-blue-ammonia-shipment
[125] https://www.japantimes.co.jp/news/2021/08/19/business/corporate-business/uae-blue-ammonia-japan/
[126] https://www.pm.gov.au/media/japan-australia-partnership-decarbonisation-through-technology
[127] https://www.cliffordchance.com/content/dam/cliffordchance/briefings/2020/10/focus-on-hydrogen-korea-new-energy-roadmap.pdf
[128] http://www.businesskorea.co.kr/news/articleView.html?idxno=68380
[129] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
[130] https://www.waterstofnet.eu/_asset/_public/WIC/Hydrogen-Europe_2x40-GW-Green-H2-Initative-Paper-1.pdf

suggested for the domestic markets and a 32.5 GW hydrogen production capacity for export[131]. The EU is in a unique situation in that it is made up of both countries in favour of self-sufficiency and countries who will look to international trade to meet their needs. Germany, Netherlands, Belgium, and Spain have signalled intentions to import renewable hydrogen. However, in June, Estonia, France, Hungary, and Poland against spoke out hydrogen imports[132].

In 2020, the European Commission adopted a proposal to revise the TEN-E Regulation to end support for natural gas pipelines and include cross-border hydrogen networks as infrastructure eligible for EU support as Projects of Common Interest instead. The proposal covers both new and repurposed assets for dedicated hydrogen transport and large-scale electrolyser projects linked to cross-border energy networks. Another significant step taken by the European Commission in adopting low-carbon hydrogen technologies came from proposals to modify directives and regulations announced in July 2021 as part of the Fit for 55 Package. If approved by the EU Council and the EU Parliament, these proposals will incorporate into EU legislation several targets (Table 3) for using hydrogen and hydrogen-based fuels in industry and transport, and for developing required infrastructure.

Table 3: Hydrogen related targets proposed by the European Commission in the Fit for 55 Package

Proposal	Current state of the market (2020s)
Renewable Energy Directive (RED) Modification – Industry	50% renewable hydrogen consumption in industry by 2030
Renewable Energy Directive (RED) Modification – Transport	At least 2.6% share of Renewable Fuels of Non-Biological Origin (RFNBOs) in 2030 (which include hydrogen and hydrogen-based fuels produced from renewable energy)
ReFuelEU Aviation	0.7% share of synfuels in aviation by 2030, increasing to 5%, 8%, 11% and 28% by 2035, 2040, 2045 and 2050 respectively.
ReFuelEU Maritime	Sets out a regulation for a well to wake GHG target for certain ships and journeys. GHG intensity of energy used on board needs to decrease by 2% by 2025; 6% by 2030; 13% by 2035; 26% by 2040; 59% by 2045; 75% by 2050.
Regulation on deployment of alternative fuels infrastructure (AFID)	1 Hydrogen Refuelling Station (HRS) of over 2t H_2/day capacity dispensing 700 bar every 150km along major routes. 1 HRS with LH_2 every 450km.
Energy Tax Directive (ETD)	Low tax rates for hydrogen. OEMs must reduce emissions of new vehicles 50% by 2030 ad 100% by 2035.
Revisions to the EU ETS and alignment with proposed CBAM	Extension to include maritime, aviation, road transport, industry, power generation
Continuation of the Innovation Fund	To support low carbon hydrogen projects across the EU and add to the financial resources from the Recovery and Resilience Facility. At least 37% of the Facility will go to energy and climate investments such as those to develop hydrogen
Hydrogen and gas market decarbonisation package	The EU will revise its Gas Directives in December 2021 and is expected to include hydrogen in any new legislation

Source: European Commission 'Fit for 55' Policy proposal package

[131] https://dii-desertenergy.org/wp-content/uploads/2020/04/2020-04-01_Dii_Hydrogen_Studie2020_v13_SP.pdf
[132] https://www.euractiv.com/section/energy/news/electricity-giants-call-for-carbon-tariff-on-eu-hydrogen-imports/

Germany

Germany is, and expects to remain, highly dependent on energy imports. Germany plans to import 76-96 TWh (2.3-2.9 Mt) of renewable hydrogen, 85% of total demand, by 2030. The Government has signed MoU's with Canada, Saudi Arabia, Namibia, and Chile and a bilateral alliance on hydrogen production and trade with Australia[133]. Germany already has some bilateral relationships with nearby sources such as a MoU with Morocco, a package of measures with Nigeria and initial talks and an MoU with Ukraine. A feasibility study is looking at building a renewable ammonia import terminal in Wilhelmshaven for which Uniper has signed an off-take agreement to import ammonia from Oman (HYPORT)[134].

In March 2021, the German government launched the 'H2Global' import initiative for renewable hydrogen (electrolyser projects of 100 MW and above) as well as imports of the produced hydrogen into Germany. It is a double auction-based mechanism to promote a timely and effective PtX market ramp-up on an industrial scale. It intends to pave the way for PtX products produced from renewable energies in partner countries to be available in Germany and Europe. Overall, the government has ear-marked €2 billion for international cooperation/partnerships to develop the hydrogen energy sector, and €900 million of this funding will be available to H2Global.

To match supply and demand, an intermediary, the Hydrogen Intermediary Company (HINT.Co), will conclude long-term (10 year) hydrogen purchase contracts on the supply side, and short-term sales contracts on the demand side. Based on a mechanism similar to the Contracts for Difference (CfD) approach, the difference between supply prices (production and transport) and demand prices will be compensated by the funds available from the German government. Bridging the cost gap with subsidies will accelerate electrolyser projects and integrate imports. Hydrogen and its derivatives will therefore be supplied to a range of customers in Germany who may have a lower willingness to pay than current production costs.

The advent of H2Global means that operators and investors receive the planning and investment security necessary for the development of large-volume electrolysis capacities, as they can base their business and financing model on long-term purchase agreements with a solvent contract partner at cost-reflective prices. On the offtake side of HINT.Co, it enables the integration of PtX products into the economic cycle at market-reflective prices. Foreign trade partnerships will be established with countries in which renewable hydrogen can be produced efficiently due to their geographical location. In addition, renewable electricity-based technologies will be established in partner countries where the local energy transition will be supported, and a contribution made to meet the massive demand for PtX products in Germany and Europe. Requirements for the use of the €900 million funds includes the definition of the sustainability criteria to be met in the production, processing, and transport of the products.

The Netherlands

The Netherlands via Rotterdam is where 13% of total energy demand in Europe enters the EU. The Netherlands aims to retain the current hub function of its ports as the gateway for international

[133] Declaration of Intent between the Government of Australia and the Government of Germany on the Australia-Germany Hydrogen Accord https://www.pm.gov.au/media/australia-and-germany-partner-hydrogen-initiatives

[134] https://www.uniper.energy/news/hyport-duqm-signs-cooperation-agreement-with-uniper-to-explore-green-ammonia-offtake

energy flows into the mega chemical cluster and industrial heartlands of Northwest Europe where over half of European hydrogen consumption currently takes place.

The Transhydrogen Alliance is aiming to import 2.5 Mt of renewable ammonia per year into the Port of Rotterdam with MoU's with the South Australian state government[135], Chile's Ministry of Energy[136], Iceland[137], Portugal, Morocco, Uruguay[138], and countries in the Middle East. The Port is also reportedly a potential commercial partner in Namibia's renewable electricity-based hydrogen mega-project[139]. The total demand in Rotterdam is expected to be up to 20 Mt of hydrogen, equivalent to 100 Mt of ammonia, in 2050, according to Port of Rotterdam estimates[140].

8.3 Exporting countries

Australia

Australia aims to become a major renewable and low-carbon hydrogen exporter and several studies suggest Australia could supply up to 10% of global hydrogen demand by 2050[141]. The majority of this is expected to cater to demand in the Asia-Pacific, where Australia is highly competitive due to established trade networks. Hydrogen export is the major driver behind the development of hydrogen supply chains, but the strategy also foresees a wide range of future domestic applications. The Australian government has invested AUS $314 million in seven hydrogen hubs that centralise users geographically, thereby minimising infrastructure costs[142].

Australia's potential to produce hydrogen from renewables is considerable. Currently, nine projects with a capacity over 1 GW are under development or at early stages. Australia has already entered, or plans to enter, into a number of bilateral agreements with trading partners to promote trade and investment in hydrogen, including with Japan[143], South Korea[144], Singapore[145], Canada[146], Germany[147]

[135] https://www.portofrotterdam.com/en/news-and-press-releases/feasibility-study-export-south-australian-green-hydrogen-rotterdam
[136] https://www.portofrotterdam.com/en/news-and-press-releases/ministry-energy-chile-and-port-rotterdam-authority-sign-mou-green-hydrogen
[137] https://www.portofrotterdam.com/en/news-and-press-releases/study-shows-shipping-green-hydrogen-from-iceland-to-rotterdam-to-be#:~:text=Energy%20transition-,Study%20shows%20shipping%20green%20hydrogen%20from%20Iceland,to%20be%20realistic%20before%202030&text=Landsvirkjun%2C%20the%20National%20Power%20Company,hydrogen%20from%20Iceland%20to%20Rotterdam.
[138] https://www.government.nl/documents/diplomatic-statements/2021/11/10/joint-statement-of-uruguay-and-the-netherlands-on-collaboration-in-the-field-of-green-hydrogen-import-and-export
[139] https://www.ammoniaenergy.org/articles/namibia-looks-towards-its-first-green-mega-project/
[140] https://www.horisontenergi.no/horisont-energi-and-port-of-rotterdam-sign-memorandum-of-understanding-regarding-blue-ammonia/
[141] Kimura, S. & Li, Y. Demand and Supply Potential of H2 in East Asia. ERIA Research Project FY2018 No.01
[142] https://www.minister.industry.gov.au/ministers/taylor/media-releases/future-hydrogen-industry-create-jobs-lower-emissions-and-boost-regional-australia#:~:text=%E2%80%9CAustralia%20has%20the%20potential%20to,year%20in%20GDP%20by%202050.
[143] Joint Statement on Cooperation on Hydrogen and Fuel Cells January 2020
[144] Letter of Intent to develop a Hydrogen Action Plan 2019
[145] Agreement to pursue a Memorandum of Understanding on low-emissions technologies 2020
[146] Memorandum of Understanding to collaborate on the commercial deployment of zero emission hydrogen and fuel cell technologies 2020
[147] https://www.pm.gov.au/media/australia-and-germany-partner-hydrogen-initiatives

and the UK[148]. The Australian Government's goal is to achieve hydrogen production at under AUS $2/kg H_2. The Government is also progressing a domestic Hydrogen Guarantee of Origin scheme. This complements Australia's efforts to help shape the design of a methodology to guide a future global trade in hydrogen.

Chile

Chile is targeting 5GW of hydrogen electrolysis capacity operating and under development by 2025 and have just closed an RfP bidding process for US $50 million for projects to be operating in 2025 with electrolyser capacity of at least 10 MW. Chile is targeting 25GW of electrolysis and achieving hydrogen price below US$1.50/kg by 2030, and to be among the top three exporters by 2040. By 2050, the country targets a potential production of 25 Mt/yr of renewable hydrogen.

Chile has several MoU's, such as with Singapore, Korea, the Port of Rotterdam and the Port of Antwerp. Chile also has Joint Statement's with France, Germany, the Netherlands and the UK. Other parts of Latin American are eyeing the opportunity for exporting energy, in particular **Uruguay, Brazil, Argentina and Costa Rica**, who are evaluating the role of hydrogen within their national energy strategies.

The Middle East

Several countries in the Middle East are positioning themselves for low carbon hydrogen exports due to excellent renewable resources (i.e., renewable electricity) and natural gas derived hydrogen, their strategic location, and existing ammonia production capability as an emerging carrier of choice. **Saudi Arabia, the United Arab Emirates, and Oman** have been the most active to date, having several projects under development and participating in various international co-operations.

These countries are likely to become major exporters, particularly to Europe and Japan and Saudi Arabia has announced intentions to the biggest supplier of hydrogen globally[149]. In 2020, Saudi Aramco, the Institute of Energy Economics, Japan, and SABIC successfully carried out the world's first shipment of ammonia produced from fossil fuels with CCUS, shipping 40 t of ammonia from Saudi Arabia to Japan for use in electricity generation while the captured CO_2 was used in EOR and chemical production in Saudi Arabia.

There have already been further announcements of natural gas with CCS based ammonia off-take to Japan and Korea from the UAE via ADNOC[150]. In March 2021, the Saudi government signed a collaboration agreement with Germany to lay the groundwork for developing an international hydrogen (or ammonia) supply chain and the UAE have signed an agreement with Japan to collaborate on hydrogen production technologies and create an international supply chain.

---

[148] https://www.minister.industry.gov.au/ministers/taylor/media-releases/australia-uk-partnership-drive-low-emissions-solutions

[149] https://www.reuters.com/business/energy/saudi-arabia-wants-be-top-supplier-hydrogen-energy-minister-2021-10-24/#:~:text=Saudi%20Arabia%20wants%20to%20be%20top%20supplier%20of%20hydrogen%20%2D%20energy%20minister,-Reuters&text=DUBAI%2C%20Oct%2024%20(Reuters),al%2DSaud%20said%20on%20Sunday.

[150] https://www.adnoc.ae/en/news-and-media/press-releases/2021/adnoc-and-three-japanese-companies-to-explore-hydrogen-and-blue-ammonia-opportunities

Canada

Canada aims to become a major exporter of hydrogen-based fuels as stated in its Hydrogen Strategy (2020)[151]. As an energy rich nation with significant 'clean' hydrogen production capacity (includes both natural gas and renewable electricity derived hydrogen), established international trade partnerships, and strategic infrastructure assets such as deep-water ports and established pipeline networks, Canada is positioned to become top global supplier of 'clean' hydrogen.

Canada anticipates a domestic hydrogen demand of 4 Mt H_2 in 2030 and 20 Mt H_2 in 2050 with potential for significant expansion to meet global demand. A recent study indicates that hydrogen exports from Canada could reach CDN $50 billion by 2050, doubling the economic potential of the domestic market in that timeframe[152]

Ukraine

Ukrainian hydrogen export potential to the EU amounts to ca. 118 TWh H_2 per year by 2030 which can be transported via dedicated pipelines[153].

Russia

Russia aims to export hydrogen: 0.2 MtH_2 by 2024 and 2 MtH_2 by 2035[154]. Europe is considered as a potential export market for hydrogen from Russia. Natural gas-based hydrogen could be transported via the Nord Stream pipeline. Hydrogen energy based on nuclear power plants is also being funded. Rusatom Overseas, a Russian company, and METI have concluded a memorandum of cooperation for conducting feasibility study on hydrogen supply chains between Russia and Japan[155].

Gazprom is now set to boost its position in Russia's strategic hydrogen export market. As announced on several occasions in the past six months Gazprom considers the production of hydrogen from natural gas such as methane pyrolysis. Gazprom will start producing hydrogen beginning in 2024 under a new government plan to develop a hydrogen economy. Rosatom is also set to launch pilot hydrogen plants in 2024 and Novatek is investigating low carbon hydrogen production from both natural gas and renewable sources.

Portugal and Spain have indicated intentions to export

Norway

Norway emphasizes its role as provider of hydrogen through the production and export of natural gas and acceptance of returned CO_2 to be stored underground (CCS). For the time being, the concept is not to export the hydrogen itself derived from this natural gas as no business case has yet been identified. Another option addressed, is to potentially blend natural gas with hydrogen in the existing pipeline grid for export. Major cooperation partners for natural gas-based hydrogen with the CO_2 return option in Europe are the UK, Germany, and The Netherlands. Norway is focusing on the export of natural gas-based hydrogen 2025-2030 and renewable electricity-based hydrogen from 2030-2050.

---

[151] https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf
[152] The Transition Accelerator. (2020). Towards Net-Zero Energy Systems in Canada: A Key Role for Hydrogen.
[153] Hydrogen Europe 2020, FCH JU 2019
[154] 'Russia's Energy Strategy to 2035' – Released by the Russian Government June 2020
[155] https://www.meti.go.jp/english/press/2019/0927_002.html

Morocco

Morocco aims to be a premier exporter of renewable hydrogen, expecting to be able to provide 2-4% of global demand in 2050[156]. With a large Moroccan fertiliser industry and a large importer of ammonia today, renewable electricity based, and competitive ammonia production is seen as an important opportunity in the industrial sector, offering the potential for import independence as well as for diversifying the country's traditional markets. Based on the sizeable existing ammonia handling facilities already in place, it may also become a relevant export vector. However, Morocco is also a potential bridgehead for a hydrogen pipeline between the North African region and Europe.

United Kingdom

The **UK** already exports hydrogen technologies such as electrolysers and fuel cells. In the near term it is working on the domestic deployment of both electrolytic and CCUS-enabled hydrogen projects but also has an additional £2 billion earmarked to finance 'clean' growth projects overseas to create export opportunities for British businesses, including the hydrogen sector. The UK Hydrogen Strategy states the UK is also looking for opportunities to export hydrogen and ammonia produced from low carbon hydrogen, building on trade links that exist for high carbon ammonia today.

8.4 Future supply options in detail

8.4.1 Pipelines and trailers

Pipeline distribution requires compression to 30-80 bar depending on the pipe diameter and requires about 3% of the transported energy per 100 km[157]. Hydrogen can generally be blended up to 20%[158] into most existing natural gas pipelines without major impact to end-users[159]. This can support initial deployment and may be important in the early 2020s as a transitional solution. Repurposing existing gas infrastructure to carry pure hydrogen will be necessary and can reduce costs and speed up roll-out compared to building new infrastructure. In 2018, the first conversion of a natural gas pipeline took place, when a 12km section with a throughput capacity of 4 kt H_2/yr, was converted and put into commercial service by Gasunie in the Netherlands.

The European Hydrogen Backbone study[45] suggests conversion costs are 21-33% the cost of a new hydrogen pipeline and that of the 40,000 km of hydrogen pipelines expected in Europe by 2040, 70% will be repurposed. Based on project submissions, the latest Ten-Year Network Development Plan (TYNDP) from the European Network of Transmission System Operators for Gas (ENTSOG) suggests 1,100 km of EU gas pipelines could be converted to hydrogen by 2030, but Final Investment Decisions (FIDs) have not yet been secured for these projects. New, dedicated pipelines for 100% hydrogen distribution are also likely to be required to connect new end users to supply hubs.

High capacity (10-20 GW) and utilisation are generally required for low transportation costs by pipeline, so sufficient hydrogen offtake might be challenging during the early-phase of roll-out.

---

[156] W. Eichhammer et al. Study on the opportunities of "Power-to-X" in Morocco, Fraunhofer ISI, Karlsruhe, Feb 2019
[157] European Hydrogen Backbone – Analysing the future demand supply and transport of hydrogen 2021
[158] https://www.nrel.gov/docs/fy13osti/51995.pdf
[159] https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf

Currently there is a variety in the maximum legal and safely acceptable hydrogen concentration[160] in the natural gas distribution or transmission network[161]. Purity specifications will be required for trans-national hydrogen pipelines as the gas quality (composition, calorific value and Wobbe index) must match on either side of borders. Pipeline networks can also be used to store hydrogen gas as linepack. The most appropriate storage medium for gaseous hydrogen depends on the duration of storage and speed of discharge required. On a large scale, salt caverns are the most affordable and efficient option, but these are geographically limited.

Compression to these pressures requires 10-20% of the Lower Heating Value (LHV) of the underlying hydrogen. There is work underway to develop the world's first ship capable of transporting 2,000 tonnes of compressed hydrogen gas[162], but its low volumetric energy density means it may be unsuitable for longer distance transportation by ship. There are safety concerns associated with the high-pressure storage of hydrogen, as with other compressed gaseous fuels[163].

8.4.2 Liquid hydrogen

Whilst liquefaction is easily reversible, it is currently expensive and energy intensive, consuming the equivalent of 30% of the energy content of the hydrogen itself. However, efficiency increases are expected, and energy consumption is expected to be halved in the future, especially with the scale up of liquefier capacity [164]. Drivers for the use of LH_2 as a carrier include the fact that no significant reconversion infrastructure or major energy input is required for gasification at the importing site, and as this process produces high purity hydrogen, it would not require further purification. Where compression is required on delivery (e.g., for hydrogen vehicle refuelling), cryopumps can be used efficiently.

The very low boiling point of hydrogen may slow development of long-distance LH_2 supply chains due to the large energy requirements to retain the liquid state, and boil off losses of 1-3% per day occur during transportation. Widely used as rocket fuel[165], LH_2 is a potential future fuel for heavy-duty transport applications (e.g., ships, trucks) so this boil-off gas could be used directly as fuel if hydrogen propulsion were being used for its distribution.

Several projects are starting to develop ships to distribute LH_2:

- Kawasaki has built the world's first cargo ship 'Suiso Frontier' to transport LH_2 with a demonstration maiden voyage of 9,000 km from Australia to Japan expected by April 2022 as part of the Hydrogen Energy Supply Chain (HESC) project[166]. The ship has a capacity of 1,250 m^3 which can store 75 t H_2 but future LH_2 ships are expected to transport 11,000 tH_2. The next phase aims for a commercial demonstration by mid-2020s and full commercialization in the early 2030s.
- Korea Shipbuilding & Offshore Engineering is building a commercial LH_2 carrier[167].
- BKK, Equinor, Air Liquide and partners received PILOT-E support to develop a LH_2 supply chain for maritime applications in Norway. Wilhelmsen Group is working to build a "roll-on/roll-off" ship that will be able to transport LH_2 to be operational in 2024.

---

[160] Hydrogen Europe Clean Hydrogen Monitor 2020
[161] E.g., In Europe, Germany has the highest legal concentration of hydrogen allowed in the transmission network at 10%, for France, Spain, the UK and the Netherlands it is 6%, 5%, 0.1% and 0.02% respectively.
[162] https://gev.com/wp-content/uploads/2020/10/launch-of-compressed-hydrogen-ship.pdf
[163] http://www.hyresponse.eu/files/Lectures/Safety_of_hydrogen_storage_notes.pdf
[164] METI 2019
[165] https://www.nasa.gov/topics/technology/hydrogen/hydrogen_fuel_of_choice.html
[166] https://hydrogenenergysupplychain.com/
[167] https://www.reuters.com/business/sustainable-business/too-cold-handle-race-is-pioneer-shipping-hydrogen-2021-05-11/

Although liquefaction, LH_2 distribution, and handling technology is available and proven, upscaling and new infrastructure construction is required. Existing commercial hydrogen liquefaction plants worldwide[168] are not necessarily located in countries looking to export hydrogen. Even then, the US only has eight hydrogen liquefaction facilities (total of 241t/day capacity[169]), and no new plants have been added there since 1997 and only three hydrogen liquefaction plants are operating in Europe[170] (with 20t/day capacity). In South Korea, Linde and Hyosung are partnering to build the world's largest LH_2 facility (30 tpd), expected to be completed by 2022[171]. The IDEALHY project in Europe aims to develop a liquefaction plant which can operate at higher energy efficiency and capable of producing 50 tLH_2/day, scaling up to 40-200 tpd, which is much larger than any currently in operation. LH_2 may be able to leverage existing LNG/LPG infrastructure but materials consideration is required as hydrogen causes embrittlement which can cause stress cracking and loss of material strength.

8.4.3 Other carriers

8.4.3.1 Ammonia

Ammonia is synthesised via the Haber Bosch process by combining hydrogen which has been produced (Section 2.2) with nitrogen obtained from the air. This requires roughly 7% of the energy contained in the precursive hydrogen. Ammonia has a high volumetric energy density (Figure 7) and a high hydrogen content, 17.8 % by mass (108-120 kg H_2/m^3) which makes it well suited for high volume export. It can be easily liquefied under moderate conditions by cooling to -33 °C or compressing to 10 bar. Ammonia storage in isolation is 99% efficient due to near ambient conditions. There is well established and cost-optimised infrastructure for its storage and transportation as ammonia is already produced in large volumes (185 Mt in 2020 with a $70 billion turnover[172]) for industrial applications, mainly as a fertiliser precursor as well as to produce construction/mining explosives.

Today, ammonia synthesis is a steady state process based on fossil fuels and is highly emitting, with global production responsible for 1.3% (450 Mt) of CO_2 emissions in 2020[67]. The use of ammonia as a hydrogen carrier is premised on the production of ammonia from renewable sources. This has yet to be demonstrated at large scale, and the intermittency of renewable sources and system integration on large-scale may present challenges. However, many projects and feasibility studies suggest it is technically feasible and that a commercial pathway exists.

Building new ammonia pipeline transport infrastructure can also be cost-effective as ammonia pipelines are approximately half the cost of natural gas, or a quarter the cost of hydrogen pipelines[173] and ammonia does not require compression to transport, just pumping infrastructure.

A driver for the use of ammonia as a carrier is that it has flexible end uses and can be used directly, either in its existing chemical applications, through combustion, co-combustion or co-firing (e.g., in internal combustion engines (ICEs), boilers or gas turbines), or used in a fuel cell (AFCs and SOFCs) to produce energy. There is potential for significant new off-take demand for low carbon ammonia in

---

[168] (PDF) Development of large-scale hydrogen liquefaction processes from 1898 to 2009 (researchgate.net)
[169] https://www.sintef.no/globalassets/project/hyper/presentations-day-1/day1_1430_decker_latest-global-trend-in-liquid-hydrogen-production_linde.pdf
[170] Linde Holds Ground-Breaking Ceremony For New Hydrogen Liquefier In Leuna - FuelCellsWorks
[171] https://www.linde.com/news-media/press-releases/2021/linde-and-hyosung-partner-to-develop-hydrogen-infrastructure-in-south-korea (2021).
[172] MacFarlane, D. R. et al. A Roadmap to the Ammonia Economy. Joule 4, 1186–1205 (2020)
[173] Black and Veatch - https://www.ammoniaenergy.org/wp-content/uploads/2020/12/Michael-Goff.pdf

the power generation, marine fuel and energy storage markets, as well as the need for its traditional markets to decarbonise.

As ammonia can be directly used as a fuel, there are potentially valuable synergies between the use of ammonia to decarbonise global shipping (which currently accounts for 2-3% of global carbon emissions) and the transport of ammonia via shipping. It has been estimated that ammonia could power 45-60% of shipping in 2050 net-zero scenarios[174] so ammonia could be used to power the ships used for its distribution. For a 10,000 km distance, losses caused by fuel demand (considering a two-way voyage) would amount to about 6% of the total payload[175]. These ships are envisioned to be operational by 2024[176] subject to technology and regulation developments.

Ammonia can also be cracked to reproduce hydrogen so the distribution of ammonia can benefit from the scale of combined low carbon ammonia and hydrogen demand. However, ammonia cracking requires substantial amounts of heat and electricity, resulting in an energy consumption of about 25% of stored energy[177]. Cracking produces a low pressure (< 2 bar) stream of hydrogen which in some cases can be used directly but would not be suitable for further distribution/storage without liquefaction or compression. Purification would also be required depending on the end-use, for example PEM fuel cells have a low tolerance to ammonia and 99.999% purity must be achieved. Ammonia cracking is still an early-stage technology with a low TRL and although small-scale ammonia crackers exist[178], the technology is not yet available or proven at large scale, (such as the scale required for transport applications). A feasibility study is looking at building a renewable ammonia import terminal in Germany, which would also have a cracking plant and would be the first scaled plant of its kind[179]. This project plans to supply 295 kt/yr of renewable hydrogen (from ammonia imports and 410 MW electrolysers) which is 10% of Germany's predicted 2030 demand[180].

The full levelized cost of delivered ammonia from export projects optimised along the full supply chain falls with increasing scale until about 10 Mt ammonia per year, which is about the size of many announced GW scale projects[181].

8.4.3.2 Liquid organic hydrogen carriers (LOHCs)

Currently, most LOHCs are generated from fossil-fuels, so may not represent the most carbon neutral form of hydrogen carrier and leads to questions over environmental considerations at the end of their life cycle. There are proposed pathways of LOHC generation using carbon neutral sources, but this requires further R&D.

A wide variety of carrier molecules have been discussed and the most promising LOHC candidates are derivatives of toluene (e.g., Dibenzyltoluene (DBT) (57 kgH_2/m^3 developed by Hydrogenious) and methylcyclohexane (47 kgH_2/m^3, developed by Chiyoda as part of the SPERA Hydrogen™ process). Around 22 Mt of toluene is currently produced annually for commercial products and in 2019, global toluene trade was $2.5 billion, 10% of its total market size, and it cost around $400-900/t[182].

---

[174] https://www.iea.org/reports/net-zero-by-2050
[175] IEA 2021 'The role of Low Carbon fuels in the clean energy transition of the power sector'
[176] https://shippingwatch.com/suppliers/article12359286.ece
[177] Ammonia as a Transportation Media, S.Giddey, ACS Sustainable Chem. Eng. 2017, 5, 10231-10239
[178] The largest non-forming gas NH_3 cracker demonstrated to date is a 10kg H_2/day system developed by CSIRO (Dolan, M. Delivering clean hydrogen fuel from NH_3 using metal membranes. AIChE Annual Meeting 2017)
[179] https://www.ammoniaenergy.org/articles/the-ammonia-wrap-world-bank-boosts-hydrogen-and-ammonia
[180] https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf
[181] https://www.ammoniaenergy.org/wp-content/uploads/2021/09/AEA_27082019_NickSalmon.pdf
[182] Toluene (HS: 290230) Product Trade, Exporters and Importers. https://oec.world/en/profile/hs92/toluene?

Other common LOHCs include dimethyl ether (DME), N-ethylcarbazole, naphthalene and ammonia borane-based systems, each with varying degrees of commercial readiness. However, the net useable capacity of LOHCs can be 10% less than quoted figures due to incomplete hydrogenation and dehydrogenation processes and Figure 7 shows LOHCs have limited hydrogen carrying capacity compared with LH_2 and ammonia.

In general, LOHCs are relatively easy and safe to distribute. Toluene is toxic (especially to sea life)[183], and would require careful handling, but DBT is relatively non-toxic. However currently DBT has high costs (€3-5/kg DBT) and is more expensive than toluene which is already a commercial manufactured and traded chemical. Scale-up depends on the specific route, as for example the toxicity of toluene means it requires chemical tankers rather than conventional ones, and multiple LOHC technologies at a single hub could hinder economies of scale. There is limited operated experience with LOHCs as a relatively new technology, and the dehydrogenation process is particularly novel. System durability, lifecycle of the LOHC molecule, hydrogen release rate and catalyst performance for long-term use need to be proven.

DBT is being considered for the 'Green Hydrogen @ Blue Danube' project and the 'Green Crane' Important Projects of Common European Interest[184] (IPCEI) in the EU. Additionally, Hydrogenious is exploring LOHC based propulsion systems for ships as a joint venture with Johannes Østensjø dy AS, with a commercial product expected by 2025[185].

8.4.3.3 Power-to-X fuels

Carriers that are not generally intended for reconversion are often described as Power-to-X (PtX) fuels and include methane[186], methanol[187] and Fischer-Tropsch fuels (synthetic diesel or synthetic kerosene). Their synthesis consumes hydrogen due to water being formed as a by-product, (50% and 33% of hydrogen is lost for methane and methanol synthesis respectively) meaning less energy is delivered or higher CAPEX is required. As carbon containing substances, these also require a CO_2 source which must be sustainable for a *bona fide* low carbon fuel[188], and they still emit CO_2 at the point of use. Currently there is limited consensus in policy on what constitutes eligible and suitable sources of carbon for these fuels. The associated CO_2 cost and possible carbon price will also greatly dictate the economics of production. Questions are also arising on the acceptability to off-takers of the resultant CO_2 emissions and how these are treated in policy.

8.4.4 Economic factors

Supply chains for the different hydrogen carriers and modes of transport have varying cost structures (Figure 15), GHG emissions, energy efficiencies and requirements for every step (Figure 8). These will accumulate across the value chain of hydrogen production, carrier conversion, distribution and possibly storage, import conditioning and purification if required. It is likely multiple distribution

---

[183] Gonda, M. International Journal of Hydrogen Energy vol. 39 16339–16346 (Elsevier Ltd, 2014).
[184] The IPCEI framework enables state aid funding for large scale cross-border projects and will help facilitate the development of an integrated hydrogen market.
[185] IEA World Energy Outlook 2020
[186] Reforming of synthetic methane to produce hydrogen would be analogous to SMR or ATR of natural gas but is unlikely to be efficient or cost effective from an emissions and life-cycle perspective.
[187] Methanol can be re-converted into hydrogen by reforming + purification, but its use exclusively as a hydrogen transport mechanism is untested at scale, presenting technology uptake risk for the reforming step
[188] Initially CO_2 may be sourced from hard-to-abate/non-avoidable industrial sources but it is likely biogenic or DAC sources will be considered more acceptable long-term options

methods will exist even in a mature market, and integrated analysis at the system level is needed to design efficient infrastructure for producing hydrogen and transporting it to end users. Figure 15 shows that the shipping cost is a small percentage of the overall cost.

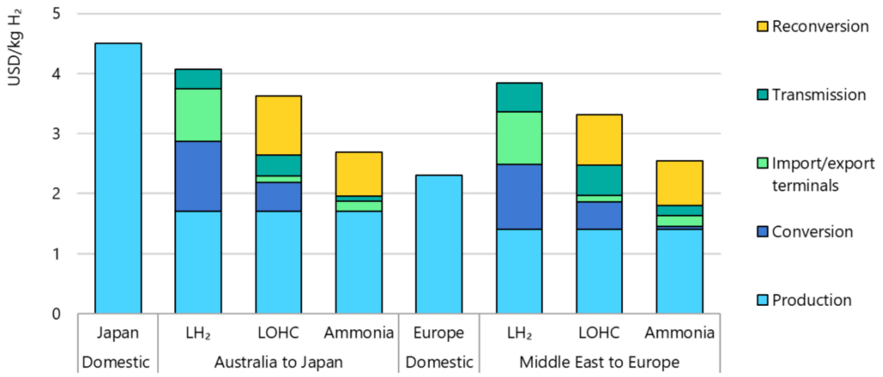


Figure 15: Projected costs and main cost elements of delivering large-scale imports in 2030[189]

Source: IEA Global Hydrogen Review 2021

The conditioning of gaseous hydrogen (as it is produced) into and/or from its transportable form can require a substantial amount of energy. To increase viability from an economic and efficiency perspective, it is likely that in the future, hydrogen will be exported in the form it is to be used to prevent reconversion costs and losses on delivery. Cracking ammonia or dehydrogenating LOHCs are particularly energy intensive steps which may be an issue in importing countries which by definition will be renewable energy poor.

The hydrogen released from ammonia and LOHCs may also incur additional energy and cost penalties for purification and onwards distribution. By comparison, most of the energy penalty for the LH_2 supply chain occurs in the exporting country (by definition renewable energy rich) and LH_2 can be re-gasified on delivery to produce high purity pressurised hydrogen. Converting hydrogen into carrier molecules may therefore be reserved for supply chains where the respective chemical can be used directly, and no reconversion is necessary. This would extend the scope of carrier molecules to synthetic fuels such as Fischer-Tropsch liquids and methanol which are not intended to be reconverted to hydrogen.

Selected examples:

- Electricity based Power-to-methane (**synthetic methane)** has high conversion technology maturity and there are several demonstration facilities in operation globally. It can be directly integrated as a drop-in replacement to existing infrastructure such as natural gas pipelines or LNG facilities so could be an immediate commercially viable hydrogen carrier for an international export value chain as where legislative frameworks exist, there is little uncertainty[190]. However, concerns on resultant CO_2 emissions on use mean it is not the preferred form of hydrogen carrier for many off-takers, and limitations on suitable sourcing of CO_2 and its associated capture costs present challenges for its early implementation as a hydrogen carrier.

[189] Storage costs are included in import and export terminal expenses. Hydrogen is produced from electrolysis using renewable electricity.

[190] In Canada renewable methane get CAN $31/GJ and if the fuel is used for the transport sector it can also get the LCFS which recently has been CAN $400/t so renewable methane is attractive from a subsidy perspective

Demand-specific implementation:

- Although not discussed in this study, **synthetic liquid fuels** will play a role in the export of energy for specific demand requirements. For example, Porsche and Mabanaft plan to off-take renewable electricity-based methanol and gasoline produced by Siemens and HIF in Chile to Germany. Although large-scale infrastructure for the distribution of the fossil analogues of these fuels exists and they are used as fuels today, the supply chains for low carbon alternatives have their own hurdles. Technologically these include production and scale up challenges (e.g., the reverse water gas shift reaction in Fischer Tropsch synthesis, 'methanol-to-jet' technology and direct air capture (DAC)). These synthetic fuels also face a lack of consensus on acceptable CO_2 sources and treatment of resultant emissions on use.

8.4.5 Customs and tax implications

Some hydrogen carriers are comparatively more costly to store than others, so there are time sensitive components of some supply chains (e.g., keeping LH_2 at cryogenic temperatures). Delays in, or overly cumbersome customs procedures could impact overall costs, but it would appear unlikely to have a significant role in the total cost of delivery. Generally, a very low percent of imports are checked and for certain types of trade, officials of the customs authorities can work with importers before the goods arrive to analyse the best way to do the physical check and inspection to ensure there are not undue delays or barriers (i.e., as in the WTO Customs and Trade Facilitation Agreement).

Until they are formally imported, goods can stay in a bonded warehouse or on a customs procedure and remain under supervision of customs. Instead of entering the customs territory, the goods could, depending on the jurisdiction, also be directly transhipped on to another country, or be processed in some way which is known as inward processing. This typically requires complicated legislation and specialist rules and would require higher authorization by specialists.

Depending on the jurisdiction and applicable rules, it could theoretically be possible for ammonia to be brought by ship to a bonded facility where it was cracked to produce hydrogen via inward processing whilst in the bonded state. This could also occur for the dehydrogenation of a LOHC. The rights would then be paid on hydrogen not ammonia/LOHC, if the dehydrogenation takes place before the customs clearance, and it would be hydrogen that would become free for circulation. This could either be done immediately so the hydrogen was available at the conversion facility, or the hydrogen could be transhipped in a pipeline to another customer/country and the customs clearance could occur there.

Hydrogen, ammonia, and LOHC are classified differently and have different HS codes, so different taxes and tariff rates may apply and there may be various other requirements (e.g., import licenses), but those would typically be the only differences from a customs perspective. If the customs duties were substantially different between hydrogen and its carrier, then there is a risk that inward processing when allowed could be used as a loophole to reduce customs duties. Therefore, consideration should be given to possible alignment between the applied duties for hydrogen, its carriers and potential co-products.

Import customs duties can be broken down into different components:

- **Trade tariffs/preferential treatment:** The WTO principle of non-discrimination means customs duties on a specific good are irrespective of origin. However, some developed countries give developing countries preferential treatment from a customs perspective

(Section 5.2). Bilateral Free Trade Agreements (FTAs) can also reduce or eliminate customs duties applied to the bilateral trade of specific goods.

- **Anti-dumping/countervailing duties:** Provided that they comply with WTO rules, countries can apply additional duties, depending on the outcome of a respective investigation procedure, to the common custom duty for imports from specific countries to counteract price dumping (anti-dumping duties) or injury caused by subsidies (counter vailing duties). These measures help protect domestic producers from unfair trade practices.
- **Safeguard duties:** Under Article XIX GATT and the WTO Agreement on Safeguards, countries can apply additional 'emergency' duties to protect a particular good from foreign competition when their imports have increased and threatened the domestic industry.
- **Excise duties:** Marine fuel used onboard a vessel sailing outside the jurisdiction of a specific country is often exempt from excise duty and the fuel could be delivered offshore. This requires special legislation and arrangement with bunkering[191] companies who bunker the deep-sea vessels, and a special license is required. Ammonia and LH_2 used as hydrogen carriers could also be used as marine fuel, whereas LOHC cannot. This could affect the attractiveness of certain value chains over others and/or increase the demand.

8.4.6 Supply chain costs and environmental considerations

A particular challenge of modelling international value chains for hydrogen and its carriers is the highly dynamic nature of key market factors which can greatly affect the overall economic viability. The various hydrogen production and distribution technologies are currently all at different levels of technology readiness and maturity, so have different cost-reduction and efficiency improvement potential. The levelized cost of delivered hydrogen will be sensitive to parameters including:

- Future technology capital costs and efficiency (e.g., electrolysis, pre and post conditioning);
- Energy costs (e.g., electricity for electrolysis, heat source for conditioning);
- Utilisation rates (e.g., of variable renewable generation, electrolysis, pipelines);
- Project scale and location (e.g., pipeline capacity, renewable resources, local cost of capital);
- Interest and depreciation (large share of infrastructure with long technical lifetime);
- Effective public policies (e.g., carbon taxes or access to subsidies); and,
- Transport distance, customs duties and taxes.

Of the various technical and economic factors that determine the cost of electrolytic hydrogen production, the most influential are electricity costs, capital expenses, conversion efficiency and annual operating hours. Currently, production dominates the cost of delivered renewable hydrogen (Figure 15), and renewable electricity costs can make up 50-90% of total hydrogen production expenses[192]. Therefore, siting production in locations with world class, abundant renewable resources to gain access to the lowest cost electricity and maximise the operating hours of high CAPEX electrolysers and reducing the need for buffer storage is required. For many supply chains, the cost reduction in hydrogen production this enables, is currently greater than the additional cost required for hydrogen conversion and distribution when compared to domestic supply.

In the future, electrolysers have significant potential for cost reduction as technology innovation progresses (e.g., improving efficiency and optimising components) and manufacturing processes are scaled up. This would mean that the utilization of electrolysers could be lower whilst still satisfying the Internal Rate of Return (IRR) hurdle rate. Regional cost disparities would shrink and may no

[191] Bunkering is the process of supplying and loading fuel onto ships for their own use
[192] Depending on both electricity costs and the full-load hours of the renewable electricity supply

longer cover long-distance transport costs enabling additional locations to be considered for siting, potentially reducing reliance on imports[193].

Additionally, policies affecting when and where electrolysers can be deployed are still uncertain (e.g., additionality rules and geographical/temporal electrolyser constraints). This could affect the ability to access support measures and therefore the aggregate cost competitiveness of the hydrogen produced. As renewble hydrogen production costs decrease, the relative significance of conditioning and transportation costs will be increasingly infuential, so the choice of carrier may be more important in the future.

Hydrogen production from natural gas with CCUS depends on the availability of low-cost natural gas and CO_2 storage ability, so is likely to originate from current natural gas producing countries and regions including The Netherlands, the UK, the U.S., the Middle East, Norway, North Africa, and Russia. Rising carbon taxes and increasingly stringent regulation may require the addition of CCS to current fossil-based facilities so there is a strong incentive for natural gas-based hydrogen from the production side. 45Q in the U.S. is seen by many as the most effective CCS-specific incentive globally[194]. Natural gas-based hydrogen may represent climate benefits compared to unabated production methods. However residual emissions and upstream natural gas leakages amongst other issues leads to important questions as to whether this production route will be considered a long-term and environmentally sustainable solution by different governments and market actors. Countries with a favourable regulatory and political environment to this hydrogen, and the companies operating within such countries, may be less willing to accept a price premium for renewable electricity derived hydrogen if it were to be more expensive at the point of use. This could affect the development of initial supply chains for international trade.

A huge number of studies have been carried out discussing the feasibility of each of these individual supply chains. However, pilot and demonstration projects are now needed to verify the viability of the concepts from a technical point of view and to identify and help remedy and hurdles that may arise, for example safety challenges. Such projects will also facilitate further assessment of cost-differentials between various supply chains and production locations.

So far, low carbon hydrogen projects have been predominantly small-scale to test and prove individual technologies, but in the coming years there will be both point-to-point and project-based infrastructure developments to demonstrate the viability of entire value and supply chains. Successful programs have been launched by the EU Fuel Cells and Hydrogen Joint Undertaking (FCH JU) including 'Hydrogen Valleys' under Mission Innovation as well as in the Netherlands and Germany[195]. As the supply and demand volumes grow, the development of international hydrogen markets and networks can be expected.

8.5 Policy considerations

Specific policy measures are expected to be required to support the development of low-carbon hydrogen. These may include:

- Quantitative **supply and demand targets** to provide clear long-term policy signals for private sector action. The guarantee of binding mandates rather than simply targets is expected to be needed.

[193] M. Fasihi et al., "Global Potential Based on Hybrid PV-Wind Power Plants", Applied Energy, Vol. 294, July 15, 2021
[194] The 45Q tax credit rewards CCUS projects at \$50/t CO_2 for geological storage or \$35/t CO_2 if used for EOR
[195] https://www.fch.europa.eu/page/mission-innovation-hydrogen-valleys-platform

- Effective **carbon pricing** to create broad incentives for end-use decarbonization. As of April 2021, 45 countries had in place national or supra-national carbon pricing schemes in the form of an emission trading system (ETS), a carbon tax (e.g., 45Q in the US), or a tradeable emissions performance standard such as proposed in Canada[196]. Current carbon prices are not high enough to close the cost gap between low-carbon hydrogen and fossil-based alternatives, though CO_2 prices are expected to rise increasing competitiveness. The International Maritime Organization (IMO) is considering a levy for bunkering fossil fuels, to accelerate clean maritime transport.
- **Demand-side support and equalisation measures** may be required to promote sector growth and reduce the offtake risk creating significant and secure demand. This could include introducing mandates for hydrogen blending, zero emissions vehicles, or for equipment to be hydrogen ready. Also, renewable energy quotas (such as in the EU[197], South Korea[198] and India[199]), Contracts for difference programs[200], banning fossil alternatives[201], carbon/emissions standards, procurement policies and long-term tenders, regulated asset-based models, auctions[202], Carbon Border Adjustment Tax Mechanisms (CBAM) or Carbon Contracts for Difference (CCfD) programmes.
- **Supply-side support** for hydrogen technologies and deploy infrastructure. This could include setting targets and public funding. The public sector can help mobilise private investment through mechanisms that take on some of the financial risk of early projects or provide other incentives for investment. Removing fossil fuel subsidies would also shorten the timeline for low carbon technologies to reach cost competitiveness
- **R&D, innovation and deployment support** for new technologies along the whole hydrogen value chain through public support e.g., renewables procurement, dedicated industry loans and competitions, complemented by private-sector action. Most critical technologies for hydrogen and hydrogen-based fuels are still being developed, requiring demonstration to reach commercialization so R&D will help lower costs and improve performance which would help de-risk deployment and attract investment.
- **International cooperation -** Multilateral initiatives and projects can promote knowledge-sharing, development technology and best practices to reduce costs and connect a wider group of stakeholders and many aim to develop future international hydrogen supply chains. Several bilateral agreements have recently been signed between governments[203], and international co-operation agreements have also been established between governments and the private sector. The CEM Global Ports Hydrogen Coalition[204] aims to strengthen collaboration between government policymakers and port representatives to scale up low-carbon hydrogen use.
- Supportive **public acceptance** and participation of local stakeholders.
- **Development of low carbon hydrogen hubs** through coordinated private-sector action supported by national/local government. Co-locating various end uses and consumers with producers and

---

[196] https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system.html
[197] https://ec.europa.eu/info/sites/default/files/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf
[198] https://thelawreviews.co.uk/title/the-renewable-energy-law-review/south-korea
[199] https://www.livemint.com/industry/energy/govt-charts-course-for-usage-of-new-age-fuel-11625078901655.html
[200] Germany has set aside €900 million for its green hydrogen import initiative 'H2Global' in which it will cover the cost gap between hydrogen purchase and supply agreements – See Section 7.2 in the Appendix
[201] https://www.reuters.com/business/retail-consumer/eu-proposes-effective-ban-new-fossil-fuel-car-sales-2035-2021-07-14/
[202] https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/061821-india-to-call-for-renewable-h2-production-bids-in-months-minister
[203] https://www.iea.org/reports/global-hydrogen-review-2021 Page 37.
[204] https://www.iea.org/programmes/cem-hydrogen-initiative

exporters in often coastal areas for international trade (e.g., ports part of the Global Ports Hydrogen Coalition) with a degree of existing infrastructure can help derisk off-take and supply risks and efficiently drive scale and innovation. Export markets provide the opportunity to invest at scale, but there will be a huge, shared benefit to domestic industries.

- **Coordination and harmonization of international regulations, codes and standards** on safety, purity and lifecycle GHG emissions along the value chain, particularly regarding imports and cross-border infrastructure. Project developers face hurdles where regulations and permit requirements are unclear, unfit for new purposes, or inconsistent across sectors and countries and unnecessary barriers should be eliminated. Current hydrogen policy and regulatory elements are distributed over gas, electricity, fuels, emissions and industrial frameworks, with limited overarching coordination. This may delay the necessary energy transition and can lead to fragmentation, overlapping and sometimes contradictory legislation and uncertainty for investors. In the EU, the 'Hydrogen Act' has been proposed[205] which is an umbrella framework aimed at harmonising and integrating all separate hydrogen related actions and legislations. A lack of harmonisation could lead to some countries developing hydrogen production just for certain markets to fit their legislative environment (Section 5.2.3 on the TBT Agreement).

8.5.1 Beyond policy

Consumer preferences and CSR targets are becoming an increasing motivator, particularly for public facing products where hydrogen can help decarbonise the supply chain. For example, coZEV is a group of multinationals, consumer-facing organisations including Amazon, Ikea, Michelin and Unilever which have committed to using only zero-emission ships to transport their cargo by 2040[206]. Therefore, the concept that there must be a policy environment that bridges the whole gap may not be necessary. There are different ways to de-risk such as subsidies or special regulation, and a renewable hydrogen industry is already emerging where regulation is in place, or the context is favourable. Some projects with confidence in the long-term market are going ahead without government support, either to learn the industry and technology, send strong signals or potentially capitalize on some first mover advantage.

The business cases arising are generally for specific partnerships where there is the opportunity to showcase and test technologies and share mutual benefits in pilot/demonstration projects. Especially in the next 5-8 years as the industry develops, initial projects are likely to be very collaborative with partnerships aiming to be mutually beneficial, sharing the risk. Niche applications are being targeted in the hope that with support from the private sector and/or governments, they can share learnings, scale up activities and realize cost reductions across supply chains.

8.5.2 The implications of emissions

To date, policy and support schemes have been mainly focused on developing domestic markets. These are required to kick-start commercial scale production and small-scale projects have reduced risk. However, with supply and demand volumes increasing, an international dimension to hydrogen markets is developing. Currently there is a lack of common metrics and recognised methodologies to compare and assess the GHG footprint of hydrogen produced in different geographies. In some cases, consideration has not yet been given to how imports would fit with existing, domestic focused standards and policies, for example the RTFO does not currently allow imports of renewable electricity to be used to make fuels, only UK renewable electricity[207].

---

[205] http://profadvanwijk.com/hydrogen-act-towards-the-creation-of-the-european-hydrogen-economy/
[206] https://www.cozev.org/
[207] https://www.gov.uk/government/publications/options-for-a-uk-low-carbon-hydrogen-standard-report

8.5.3 Considerations for trade

Exporting low carbon hydrogen leads to at least a small increase in CO_2 emissions in the exporting country during the production process, equivalent to a transfer of some emissions from the importer due to the displacement of fossil fuels. Therefore, there must be collaboration and recognition of this throughout the supply chain. The market is increasingly pricing in embedded emissions to many products, and these will be included in international trade, particularly for bulk commodities with traditionally high emissions profiles such as ammonia. This can be through penalties (carbon taxes) for high embedded emissions as well as premia (certification schemes) for low embedded emissions. Internationally transferred mitigation outcomes could also be used. For example, the Kyoto protocol included a mechanism by which developing countries could transfer emissions savings associated with a particular project to the country providing the finance, to try and motivate a reduction in emissions in developing countries. There could be a similar provision for low carbon hydrogen supply chains in which the emissions benefits could be shared along a supply chain between two countries to try and motivate them both to reduce overall emissions.

Quantifying GHG emissions therefore has implications for trade due to the interconnectedness of hydrogen with multiple other value chains. Further complexities arise for a low carbon hydrogen standard when full value chains are considered as low carbon hydrogen can be used as an input to reduce the emissions associated with the production of downstream products such as ammonia, electricity, or steel. Therefore, there is likely to be a need in the future to track and verify the emissions associated with these products too.

8.5.4 The role of the WTO

The WTO rules can be described in more detail:

- **Non-discrimination** through the **most favoured nation (MFN)** principle (Article I) and the **National treatment (NT)** principle (Article III). Most favoured nation means WTO members must apply the same regulations including tariffs to all other members, however GATT XXIV and GATS II provide exceptions allowing WTO members to conclude Free Trade Agreements. National Treatment means WTO members are not allowed to treat imported goods and services differently from domestically produced ones. This also applies to internal taxes, laws, regulations, and requirements. Exceptions include the imposition of tariffs which are border measures, the allowance for preferential government procurement of domestic products and the allowance for the payment of subsidies exclusively to domestic producers (strictly disciplined by the ASCM). For, services certain exceptions to the non-discrimination principle are permitted depending on how the agreement is negotiated.
- **Protection only through tariffs** (Article XI). Quantitative restrictions such as import and export bans, quotas, licenses or local content requirements on any imported or exported product are not allowed (with some rare exceptions) as they are considered to have a greater protective effect than tariff measures and are more likely to distort the free flow of trade. Import restrictions on foreign products (to help shield domestic producers from international competition) are coalesced into a single tariff which varies by goods and countries.
- **Obligation not to raise tariffs** (Article II). WTO members promise not to raise customs duties above certain thresholds (referred to as tariff binding). One of the long-term objectives of the WTO is to progressively lower or eliminate tariffs through negotiations. Some preferential treatment such as special rights or extra leniency (e.g., non-reciprocal preferential tariff schemes) are allowed for developing and least developed countries (LDCs). This could be of

relevance to hydrogen given the prevalence of high-capacity renewable energy resources in LDCs[208].

- **Regulation of subsidies**. The use of 'specific' subsidies (Section 5.2.3) is regulated under the Agreement on Subsidies and Countervailing Measures (ASCM), where some subsidies are prohibited or subject to countervailing measures depending on their characteristics.

The WTO does not regulate environmental issues. The WTO's Trade and Environment Committee states that the most effective way to deal with international environmental problems is through multilateral environmental agreements (MEAs) (e.g., the Montreal Protocol designed to protect the ozone layer). Around 200 of these exist outside the WTO and about 20 include provisions that can affect trade[209], for example, by banning the trade of certain products, or allowing countries to restrict trade in certain circumstances. If a trade dispute arises because a country has taken action on trade (e.g., imposed a tax or restricted imports) under an environmental agreement, then that forum should be used to settle the dispute. Only when the issue is not covered by an environmental agreement, or if one side in the dispute has not signed the environment agreement, then WTO rules apply, and it would be the relevant forum for settling the dispute.

8.5.5 The WTO and energy reform

Within the WTO, trade negotiations take place as Rounds, and the most recent Doha Development Agenda was launched in 2001. This Round aimed to stabilize the international trade and investment landscape in the energy field through a more open market, greater competition, and the spread of low carbon technology. It looked into addressing non-discriminatory third-party access to networks and grids to fix infrastructure boundness, regulatory transparency and the need for an independent regulator to oversee the networks and grids to ensure an equal system. It also looked at anti-competitive practices such as dual-pricing strategies and possible amendments to the ASCM.

The gradual liberalization of the energy sector and the rise of independent operators supplying energy services meant energy services were included as a separate category to be negotiated under the GATS in the Doha Round[210]. It also required negotiations to try and eliminate tariff and non-tariff barriers on environmental goods and services. However, in 2015 the Doha Round effectively ended, and these discussions failed to lead to any actionable outcomes at the WTO level.

Therefore, to date, no concrete steps have been taken at the WTO level towards rulemaking in the energy sector. However, other developments have contributed to changes in the energy landscape within the multilateral trading system such as a gradual evolution in references to energy in the accession protocols and commitments of major energy producing or transporting countries. For example, energy transit issues are increasingly discussed (Ukraine, Russia and Kazakhstan), export duties are being bound (China and Russia) and Saudi Arabia and Russia have partially committed to eliminate dual pricing policies. There has also been an increasing number of energy disputes in the DSS for example, over FIT programmes and subsidies for renewable energy, local content requirements in renewable energy schemes and anti-dumping disputes concerning solar panels and biodiesel.

[208] https://www.wto.org/english/thewto_e/whatis_e/tif_e/org7_e.htm
[209] https://www.wto.org/english/thewto_e/whatis_e/tif_e/bey2_e.htm
[210] Marhold, Anna-Alexandra. Energy in International Trade Law (Cambridge International Trade and Economic Law) Cambridge University Press.

8.5.6 The WTO and the ECT

The ECT is one of the few arenas where international energy transit issues, including gas pipelines are discussed. The ECT contains more elaborate transit rules than those in the WTO and it explicitly states that energy transit includes gas pipelines and grids, aiming to ensure reliable cross-border energy flows. Countries must facilitate the transit of energy resources, including by allowing new pipelines to be built unless they can prove it is against their national law to do so and prove that those laws do not discriminate according to the energy source's origins or other factors.

National sovereignty over energy resources is a core principle of the ECT. Governments can define the structure of their domestic energy sector and are free to decide whether and how national energy resources are developed, and the extent to which its energy sector is open to foreign investors. Each state has the right to regulate energy transmission and transportation within its territory respecting all relevant international obligations. The treaty does not deal with the ownership issues of the energy companies and there is no obligation to privatize state-owned energy companies, or to break up vertically integrated energy companies.

ECT trade provisions are intentionally based on WTO rules but are better adapted to the needs of energy trade. The ECT and WTO intersect and overlap in several places and many GATT Agreements are incorporated as one of the ECTs aims was to introduce the multilateral trading system to former communist countries that had not yet joined the WTO, intending to help with further accessions. However parallel applicability of some ECT and WTO rules poses conflicts on both substance and procedure. The ECT's energy trade provisions only apply to members who are not part of the WTO, as if members of both, WTO rules supersede. Due to the large number of accessions to the WTO since establishment of the ECT, ECT rules for regulating trade in energy are now only applicable to Azerbaijan, Bosnia and Herzegovina, Uzbekistan and Turkmenistan. Therefore, in practice, only the ECT rules on investment protection in the energy sector are now generally relevant. However, given the magnitude of investment that will be required to expand hydrogen production and the sector, this legal protection and regulation will be important. For example, for investors who want to develop hydrogen projects in third countries, the ECT provides a legal guarantee that that state cannot expropriate the investment or change regulation to render the investment worthless.

The ECT has come under criticism for being an obstacle to the transition to renewable energy. Transnational corporations who have invested in fossil fuel production and nuclear power can sue national governments for loss of profit on their investments if due process is not followed by governments in changing policies (e.g., as a result of the transition to renewable energy). Vattenfall has challenged the German government under the ECT over their decision to close nuclear reactors[211]. These challenges have meant energy trade discussions have been inactive under the ECT for a while, and since 2018 the ECT has been undergoing a process of modernization. By comparison, the increasing number of energy related trade disputes being raised in the WTO suggests that despite lacking specialized rules on energy, the WTO appears to be taking over from the ECT as the most appropriate forum for settling energy trade discussions. Therefore, the future of the ECT and its relevance remains unclear (Section 5.4.3).

8.5.7 Preferential Trade Agreements

Some of the new rules emerging across various PTAs enhance energy security through facilitating access to energy supplies and include broad commitments on energy transit and transport such as

[211] http://arbitrationblog.kluwerarbitration.com/2021/02/18/a-battle-on-two-fronts-vattenfall-v-federal

granting third party access to infrastructure[212]. Some include rules that take a more holistic approach to energy, the environment, sustainable development and climate change mitigation such as through widening the scope of energy-specific chapters to cover goods and services and/or trade and investment in energy. Many set standards, aiming to serve as a benchmark for global energy governance. In some FTAs, certain sectors like energy (e.g., electricity), can have exemptions to the agreed provisions as they are considered sensitive due to links with security of supply and sovereignty.

Through PTAs, many countries have provisions in place to prohibit certain behaviours and potential trade restrictions. These include prohibiting energy dual-pricing policies and for both imports and exports, limiting taxes on energy, prohibiting monopolies and addressing licensing. Most countries that are key hydrogen producers have at least some of these provisions in place as they are also large natural gas producers. However, there are issues that have not been solved for the natural gas market which risk contaminating discussions of the potential hydrogen market.

Some issues first raised and negotiated in PTAs have later developed into multilateral Agreements at WTO level (e.g., services, intellectual property, environmental standards, investment, and competition policies). Therefore, this could be a solution to a bottom-up implementation of solutions for hydrogen (Section 5.4.3). However, the proliferation of PTAs also creates a challenge for the WTO as it can lead to increased fragmentation and complexity of rules which could be harmful to the multilateral system. Therefore, the relationship between the WTO and PTAs should be considered.

8.5.8 Considerations for energy governance

It is clear the energy sector would benefit from being dealt with in a much more coherent manner and there appear to be several avenues the energy trading community could consider.

One option would be to try and find a solution multilaterally involving all WTO members. The current Agreements could be updated or refined based on the realities of today, fixing as many issues discussed in Section 5.3 as possible. However, given current trajectories, this would have to be done very fast and is likely to be unfeasible in practice. Within the WTO, decisions must be made by consensus, and getting all 164 countries to agree on solutions given the diverse range of economies within the membership is challenging, as exemplified by the failure of the Doha round after 15 years of negotiations. The rules of the WTO Agreements now appear to be essentially inflexible, and it appears unlikely that existing rules will be addressed or updated.

Co-operation in a specific area such as energy may be more realistic and a sectoral approach to energy trade regulation could help overcome some of the most pressing challenges. A new, separate Agreement could be drafted on energy trade tackling many of the issues described in Section 5.3 such as subsidy reform, eliminating dual-pricing practices and curbing FFS, removing non-tariff barriers and export restrictions and addressing domestic energy regulation and transit issues. This could be a specialized multilateral Agreement incorporated within the WTO framework like the Agreement on Agriculture, which was established specifically to address the intricacies of the agricultural sector that were not properly addressed under the GATT.

However, work on a more efficient system of energy regulation should not be limited to the WTO. Another option would be a separate plurilateral Agreement with an initial group of countries which could be expanded over time (similar to the ECT). There has already been attempts at this sort of solution. In 2014 a group representing 46 WTO members who account for most global trade in

[212] Marhold, Anna-Alexandra. Energy in International Trade Law Cambridge University Press.

environmental goods, launched plurilateral negotiations to establish an Environmental Goods Agreement[213]. This aimed to liberalize trade and eliminate tariffs on environment-related products including those that can generate low carbon energy, renewable electricity and control air pollution, so could be applicable to hydrogen. However, little progress is evident since 2016, although negotiations are on-going. Therefore, although the possibility to draft a new 'Agreement on Energy' exists, it may still be too lengthy and difficult a process.

Perhaps a simpler solution would be increased coordination and/or possible or partial integration of the WTO with the ECT. This could benefit both the ECT and WTO as they have complementary strengths for energy governance but are both currently at a stand-still. Whereas the ECT has a better framework for global energy trade and transit discussions, the WTO has a much broader reach including major energy players and a more solid basis for cooperation.

However, in the short to midterm, the proliferation of plurilateral and bilateral trade will continue and must be considered within the context of a future energy governance landscape.

[213] https://www.wto.org/english/tratop_e/envir_e/ega_e.htm

International Partnership for Hydrogen and Fuel Cells in the Economy
Website: www.iphe.net
Contact: media@iphe.net

Release February 2022
Photo credits: © iStock

FEBRUARY 2022