Hydrogen Market Pathways

Scaling-Up the Hydrogen Market

Dialogue Insight Report

June 2022

INTERNATIONAL ENERGY FORUM

ICE

www.ief.org/events/hydrogen-market-pathways

An **International Energy Forum** report written with the Intercontinental Exchange and Anne-Sophie Corbeau

June 2022

Written and produced by:

Mason Hamilton	mason.hamilton@ief.org
Allyson Cutright	allyson.cutright@ief.org
Egbert-Jan Schutte-Hiemstra	egbert-jan.schutte@ice.com
Anne-Sophie Corbeau	ac5010@columbia.edu

The **International Energy Forum (IEF)** is the world's largest international energy organization with members from 71 countries and includes both producing and consuming nations. The IEF has a broad mandate to examine all energy issues, including oil and gas, clean and renewable energy, sustainability, energy transitions, new technologies, data transparency, and energy access. Through the Forum and its associated events, officials, industry executives, and other experts engage in a dialogue of increasing importance to global energy security and sustainability.

The **Intercontinental Exchange (ICE)** was founded in 2000 to digitize the energy markets and provide greater price transparency. It is an American Fortune 500 company that operates global exchanges and clearinghouses and provides technology, data, and listing services. The company owns exchanges for financial and commodity markets and operates 12 regulated exchanges and marketplaces. ICE combines world-class technology with leading data services and operating expertise to add transparency and enable customer efficiency gains.

Anne-Sophie Corbeau is a Global Research Scholar at the Center on Global Energy Policy at Columbia University's School of International and Public Affairs. Her research focuses on hydrogen and natural gas. Anne-Sophie has over 20 years of experience in the energy industry and is a recognized expert. She is the author of many publications focusing on gas, LNG markets, Asia, China, India, and Africa, including the book "LNG markets in transition: the great reconfiguration" (Oxford, 2016). She is also a member of the Gastech governing body.

Table of Contents

Acknowledgments

Discussions held during two expert panel workshops co-hosted by the IEF and ICE in December 2021 and March 2022 informed the content of this report. The authors would like to thank the workshop participants for their engagement and feedback, including expert contributions from Dr. Kirsten Westphal (H2-Global), Marco Chiesa (SNAM), Sally Prickett (bp), Jose M Bermudez Menendez (IEA), Patrick Heather (OIES), Daria Nochevnik (Hydrogen Council), René Schutte (HyNorth), Erik Rakhou (BCG), Neil Brown (KKR), and Peter van Ees (ABN AMRO).

Executive Summary

Where are we headed?

- Low-carbon energy sources and carriers will need to replace high-carbon ones to meet growing energy demand during the energy transition. Many energy forecasts expect hydrogen to play a vital role in decarbonizing the energy system, particularly in hard-to-abate sectors or where electrification is impossible, such as high-temperature industrial processes, heavy road transportation, and shipping. Hydrogen is also expected to play a role as a source of flexibility in the power sector.
- The current energy crisis is likely to accelerate hydrogen market development. Europe quadrupled its low-carbon hydrogen supply target for 2030 from 5.6 Mtpa to 20.6 Mtpa as part of its REPowerEU strategy to reduce reliance on Russian natural gas. Over 500 large-scale projects have been announced in the last couple of years, and >50% of those have just been announced in the past 12 months.
- The hydrogen market will likely develop in several phases and over several decades from (1) local point-to-point transactions to (2) isolated, bi-lateral trades to (3) larger contracted international deliveries to (4) a potentially globally traded commodity. The market will move from localized to regional to international/interconnected, but the pace of development will differ across regions and sectors.
- However, despite playing a role, hydrogen is not a 'silver bullet' for achieving decarbonization goals or energy security. In many cases, it is the second-best solution. Direct electrification is more efficient in many applications. Policies and business models need to target supply chains that make the most sense technically and financially.

How do we get there?

- The hydrogen market is still in its infancy, and development is needed along the entire supply chain. Low-carbon hydrogen production and utilization must increase from ~1 million tons per annum (Mtpa) today to hundreds of Mtpa by 2050. Market growth will involve expansion and development in production, transportation, storage, and end-use. Scaling-up hydrogen will require new business models, pricing, contracts, regulations, standards, certificates, and policies.
- The first immediate step will be to replace hydrogen made by unabated fossil fuels with low-carbon hydrogen. This will remove the challenge of creating new demand while reducing CO_2 emissions from unabated fossil fuels in hydrogen production.
- Hydrogen's high-cost relative to its alternatives is the most significant obstacle to market development today. Costs will need to decrease significantly during the coming decade. Production from renewables is currently around \$3-8/kg (equivalent to \$26-70/mmBtu, LHV). Policy support is key to lowering production costs and incentivizing consumers to switch to hydrogen. Different tools will be at the disposal of policymakers, including contract for difference, production tax credit, carbon pricing, and carbon neutrality targets for specific sectors.
- International partnerships will be an essential component of developing the hydrogen economy, providing off-take certainty, and enabling scale. Broad-based collaboration within and across industries and governments will be needed as well as a commitment to

capital and sharing resources and technology. In addition, partnerships will help facilitate long-term contracts that will be key in scaling-up, accessing financing, and establishing proven business models.

- Hydrogen development is primarily a means to support decarbonization. Future hydrogen markets and trade rules will have to consider the carbon intensity of hydrogen and any carriers or derivatives. The hydrogen market will be based on carbon-intensity and not 'color' designations. Therefore, measuring and tracking carbon intensity needs to be standardized, and corresponding certifications and guarantees of origin will be essential elements enabling international trade.
- There is value in studying the development of business models used in the renewables and LNG sectors. Lessons from the evolution of these sectors can support the scale-up of hydrogen and serve as a model for the formation of initial long-term contracts, such as including modified take-or-pay commitments to support projects' CAPEX that are adapted to the specificities of hydrogen development.
- Despite parallels between hydrogen and other market development pathways (such as natural gas/LNG), regulation should not be systematically imposed in the same way, especially in the early stages. There is still room for innovation in hydrogen technology and business models that over-regulation could hinder. Regulation that is "fit for purpose" can help mitigate risk inherent in a new market. Providing regulatory certainty will be essential to attract investment early on. However, a delicate balance is needed to leverage hydrogen in the energy transition but also ensure hydrogen becomes competitive and cost-effective.
- Energy policies should remain technology-neutral to allow accelerators that leverage public finance rather than crowd it out. Technology-neutral funding will help enable a faster market launch and long-term cost-efficient supply.
- Hydrogen molecules have an important advantage over electrons, they can transfer energy over time and distances and be stored more efficiently. Hydrogen can unlock otherwise stranded energy assets such as remote and isolated renewable energy sites. It can connect places with ample renewable energy resources but no effective means of delivering it to market with concentrated demand hubs. Infrastructure and transportation developments will be needed to unlock these arbitrage opportunities.
- Hydrogen market data is currently limited and lacks standardized definitions and conventions. Greater data transparency and standardization are needed to empower analysts, investors, and policymakers to make informed decisions.

Introduction: Jump-Starting the Hydrogen Market

Hydrogen will play a key role in decarbonizing the energy mix, but massive investment and development along the supply chain are needed

Interest and momentum surrounding hydrogen has grown in recent years, but the idea of using hydrogen as an energy carrier is not new – it has come in and out of fashion since the 1970's. Yet, despite decades of interest and research, there are still many obstacles to overcome for the hydrogen market to scale-up.

Currently, hydrogen accounts for only ~1% of the energy mix, is predominately produced using unabated fossil fuels, and is mainly used on-site where it is produced.

For hydrogen to play a role in the energy transition, it must be available in sufficient volumes, at a competitive cost, and with low carbon intensity associated with its supply chain. The entire supply chain must be developed and scaled-up.

Different demand forecast scenarios show hydrogen consumption growing by as much as six-fold by 2050 (with low-carbon hydrogen growing by 500-600-fold).

Such growth makes it increasingly plausible that hydrogen could become an internationally traded commodity in the coming decades. Understanding the likely pathways and drivers of maturation is essential for reducing risk and attracting investor and government buy-in.

For hydrogen to achieve its potential, decisive policy action will be needed, as well as significant infrastructure investment, to drive scale. Developing hydrogen will require a significant development of renewable capacity beyond what will be used to decarbonize the power sector.

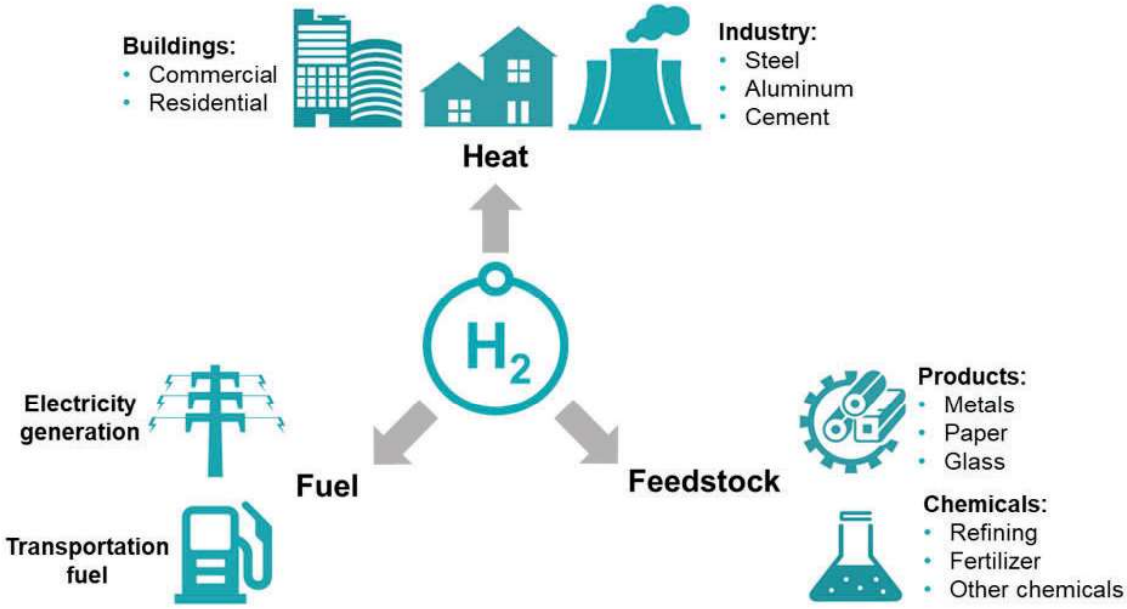
Large-scale hydrogen networks will be necessary to connect production and storage resources to end-users. Scaling-up the supply chain can lower supply costs, increase security, enable competitive markets, and facilitate international trade.

This report first looks at the current hydrogen market and supply chain and then examines what will shape and determine market and business model development under the assumption that economics and technology evolve favorably. Next, the study examines what external contractual and regulatory support can help guide a successful scale-up.

Status Quo: A Nascent and Niche Market

Hydrogen is the lightest and most abundant element in the universe, but it barely exists in a pure form on Earth. Instead, it is abundant in chemical compounds, most notably bonded with oxygen in water or carbon to form hydrocarbons like fossil fuels. For that reason, hydrogen is not considered an energy source but an energy carrier or vector.

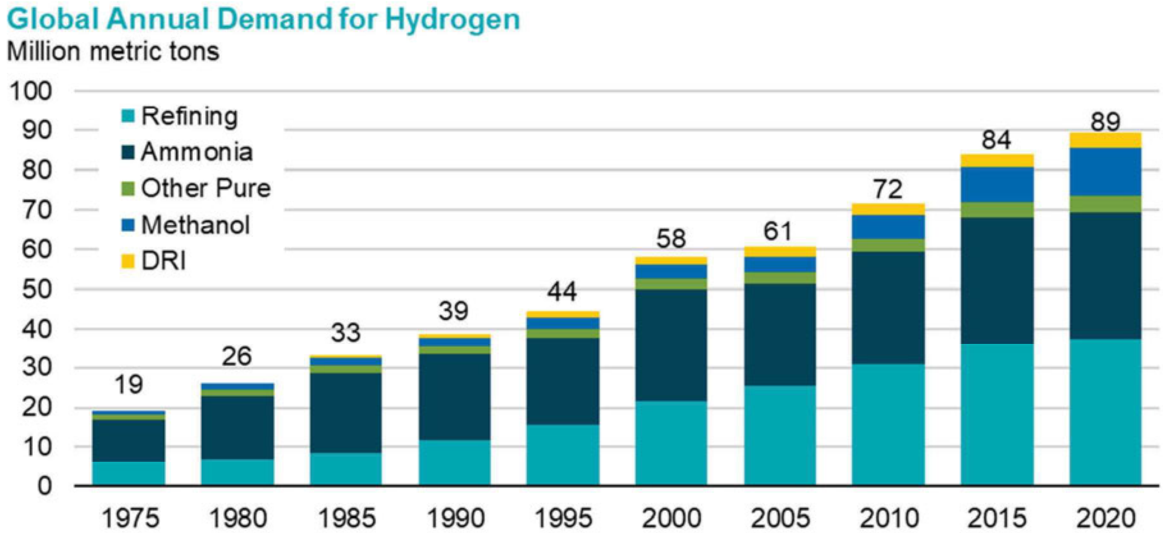
Once separated from other elements, hydrogen's utility increases: it can be converted into electricity through fuel cells, it can be combusted to produce heat or power without emitting carbon dioxide, used as a chemical feedstock, or as a reducing agent to reduce iron ores to pure iron for steel production.



Source: IEF, adapted from BloombergNEF *Hydrogen Economy Outlook*

Demand for hydrogen totaled 89 Mt in 2020, contributing to only 1% of the energy mix

Hydrogen demand has increased by 53% over the past 20 years, from 58 million tons (Mt) in 2000 to 89 Mt in 2020, a market worth $150 billion[i]. Most of this demand was for pure hydrogen (72 Mt), with 18 Mt for hydrogen mixed with other gasses used in methanol and steel production.



Source: IEF, IEA *The Future of Hydrogen*, Qamar Energy

Petroleum refining and chemical processes account for 96% of hydrogen demand

Petroleum refining accounts for almost ~42% of total global hydrogen demand. Refining processes such as hydrodesulphurization (removing sulphur from natural gas and refined products), and hydrocracking (transforming long-chain hydrocarbons into shorter chains).

Non-fuel chemical processes account for ~54% of total demand, with the majority used in the production of fertilizer products (ammonia) and methanol production. Around 4% of hydrogen demand is used in the iron and steel industry.

As of 2022, there are currently negligible amounts of hydrogen used in the transport sector, with only 50,000 Fuel Cell Electric Vehicles (FCEV) in the world, out of an estimated 1.3 billion global vehicle fleet[ii].

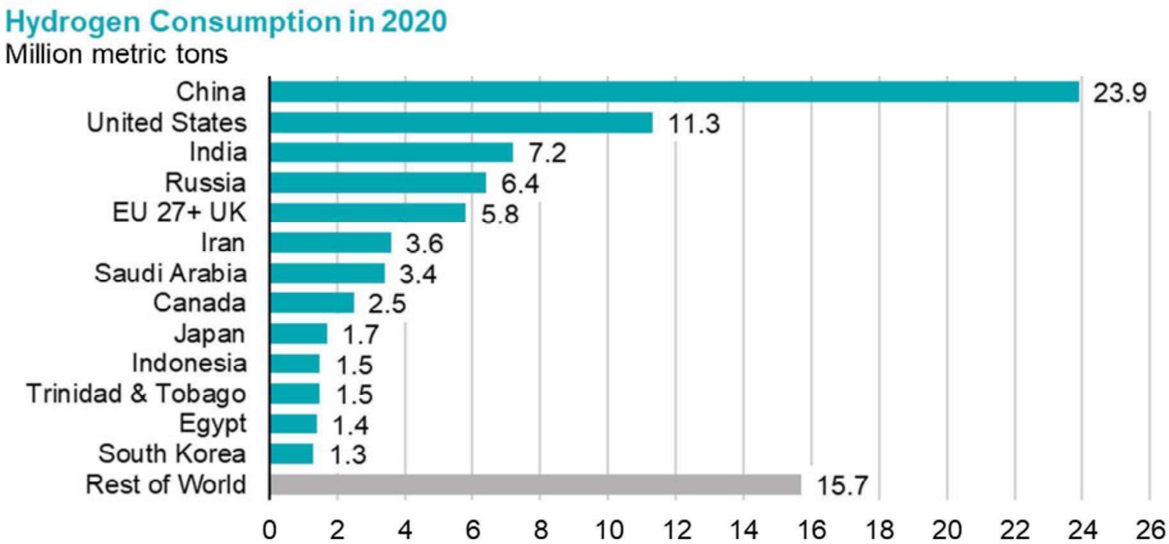
China produces/consumes ~25% of hydrogen globally

China, the largest consumer of hydrogen[iii], uses the molecule in the chemical industry to produce ammonia and methanol, and in petroleum refining.

In the United States, the second-largest hydrogen consumer, the petroleum refining industry accounts for two-thirds of hydrogen demand and ammonia production accounts for the remainder.

The Middle East consumes over 10 Mt of hydrogen in petroleum refining, chemical production, and steel production.

India consumed over 7 Mt of hydrogen in 2020, including around 45% used for refining, 35% for chemicals and almost 20% for iron and steel. India, as the world's largest producer of steel using the Direct Reduced Iron (DRI) route, it accounts for one-quarter of global DRI hydrogen demand.



Source: IEF, IRENA *Geopolitics of the Energy Transformation: The Hydrogen Factor*

Non-abated fossil fuels currently dominate hydrogen production

Hydrogen production uses various methods and technologies but only two principal sources, fossil fuels and renewable sources.

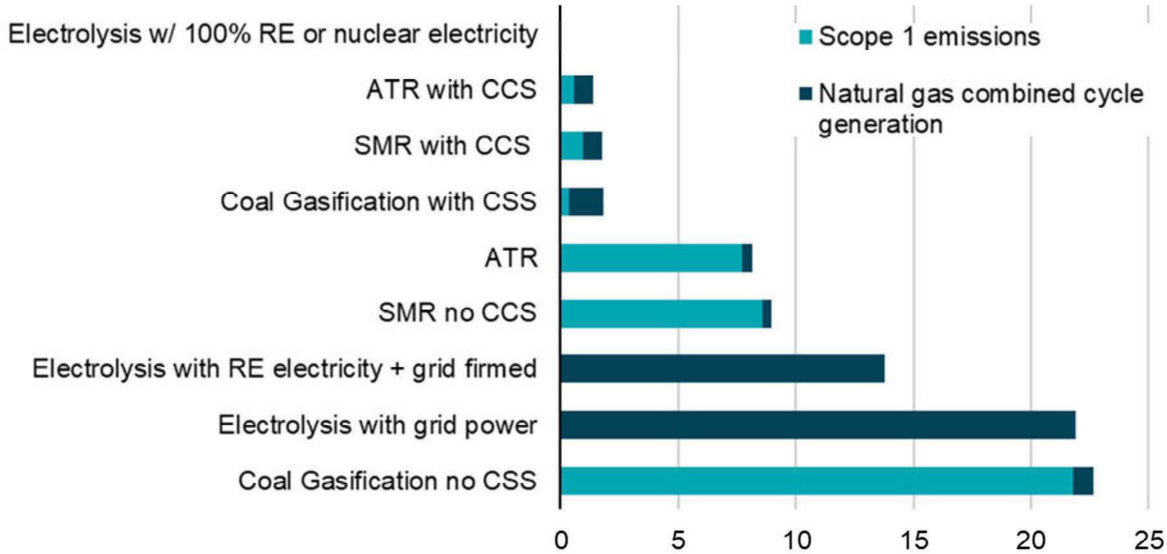
Currently, >99% of hydrogen production comes from the reforming of natural gas, coal, or oil products and produces 2.5% of global energy-related CO_2 emissions.

Natural gas-based hydrogen production represents around 60% of total production and only a marginal amount is paired with Carbon Capture Utilization and Storage (CCUS) technology. The resulting natural gas consumption is estimated at around 240 Bcm (or 6% of global gas demand).

Meanwhile, coal represents 19% of hydrogen production, with the majority located in China and India.

Only 0.2% of global production comes from electrolysis (using electricity to split hydrogen from oxygen in water).

Emissions Intensity of Hydrogen Production Technologies
kg CO_2/kgH_2



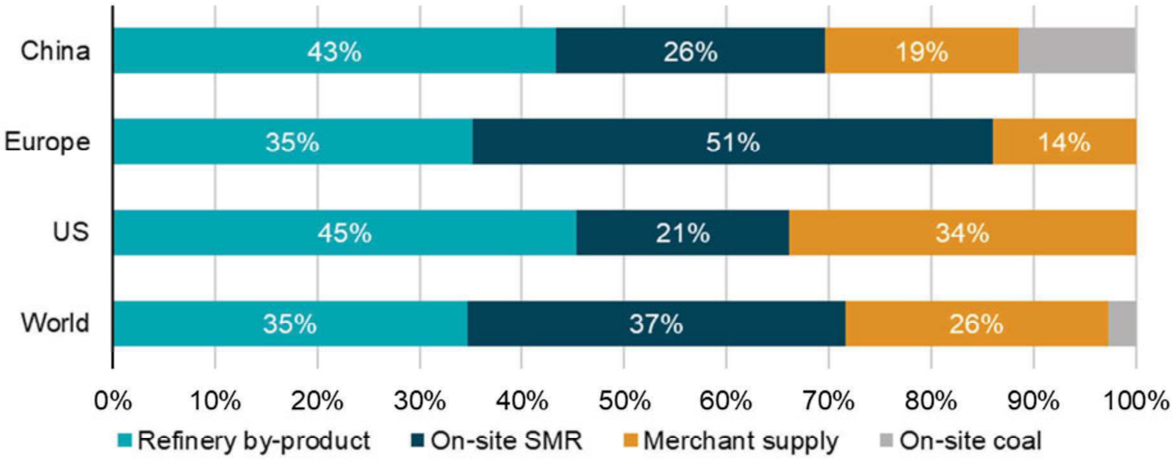
Source: IEF, Global Carbon Institute *Blue Hydrogen*

Most hydrogen is produced on-site

Around 85% of hydrogen is captive, produced and consumed on-site, mainly at petroleum refineries.[iv]

In limited occurrences, hydrogen is produced elsewhere and transported to the consuming site – known as merchant production. Typically, one petroleum refinery will sell excess hydrogen production to a nearby petroleum refinery or chemical facility.

Sources of Hydrogen Supply for Refineries (2018)
Percent of total



Source: IEF, IEA *The Future of Hydrogen*

The EU is currently the only region in the world where hydrogen is regularly transported across national borders and this is limited to the Northwest region (Belgium, France, Germany, and the Netherlands). This is done on a business-to-business basis and primarily through a dedicated hydrogen pipeline network.

Pipelines and overland transport used now

The bulk of merchant hydrogen is currently transported by pipeline.

There was ~4500 km of hydrogen pipeline in the world as of 2016, with 2600 km in the United States and around 1600 km in Europe (mostly located in Belgium, Germany, France, and the Netherlands). The rest of the world accounts for 340 km, with about half of this in Canada.

In the United States, hydrogen pipelines are concentrated in the Gulf Coast region where large hydrogen users such as refineries and chemical plants are located[v]. In these regions, merchant hydrogen can meet over a third of total hydrogen demand[vi].

When transported overland, hydrogen is transported either by truck or by rail and at high pressure or in liquid form. Liquid transport is usually for short distances or where there is no pipeline system.

Pure or elemental hydrogen can be combined with other chemical elements to produce “hydrogen-based fuels” such as synthetic methane, ammonia, and methanol. These can be somewhat easier to handle and transport than hydrogen and can be used as feedstock in industrial processes.

Although, ammonia is widely traded, it is mainly for use in fertilizer markets and not as a hydrogen or energy carrier.

Storage is currently limited

The technology of using geologic salt caverns to store hydrogen is proven; however, there is limited practical experience with large-scale hydrogen storage.

Currently, hydrogen storage in salt caverns is limited to only four operational sites in the US and the UK[vii].

Existing hydrogen storage facilities mainly serve as backup supplies for industrial hydrogen consumers when hydrogen production facilities are under maintenance or experience disruptions.

Pricing is opaque

There is very little transparency on how hydrogen is priced today, and there is a lot of confusion between price and costs. Most discussions are currently around the current and future cost of hydrogen, not how it will be priced in the future if a full-fledged market is developed.

With most hydrogen produced and consumed on-site in many markets, there are few transactional norms established and limited information to be used in price discovery for a spot market. It is likely that hydrogen supply will be initially priced on a cost-plus model.

Meanwhile, the cost of hydrogen is dependent on the production technology, the cost of the feedstock, and power. As most hydrogen production currently uses natural gas as a feedstock, the price of hydrogen is likely to be highly correlated with the price of natural gas in a particular market.

While transportation and storage are also part of the current cost of hydrogen, the fact that most hydrogen is consumed on-site makes it difficult to understand how these costs are reflected in the price of merchant hydrogen.

Customers are expected to see a wide range of price differences depending on their geography, delivery method, and quantity.

While the production costs of hydrogen are an extremely important variable in hydrogen's market development, this report assumes that technological improvements will eventually bring hydrogen production costs lower, notably the cost of hydrogen made with renewable-powered electricity which is a magnitude higher than the cost of hydrogen made from fossil fuels (apart from hydrogen production based on natural gas in Europe or certain Asian countries). Therefore, this report does not examine hydrogen production costs in-depth.

Strengths and Opportunities: Why is the Hydrogen Market Expected to Grow?

Demand – a solution for hard-to-abate sectors and a source of power systems flexibility

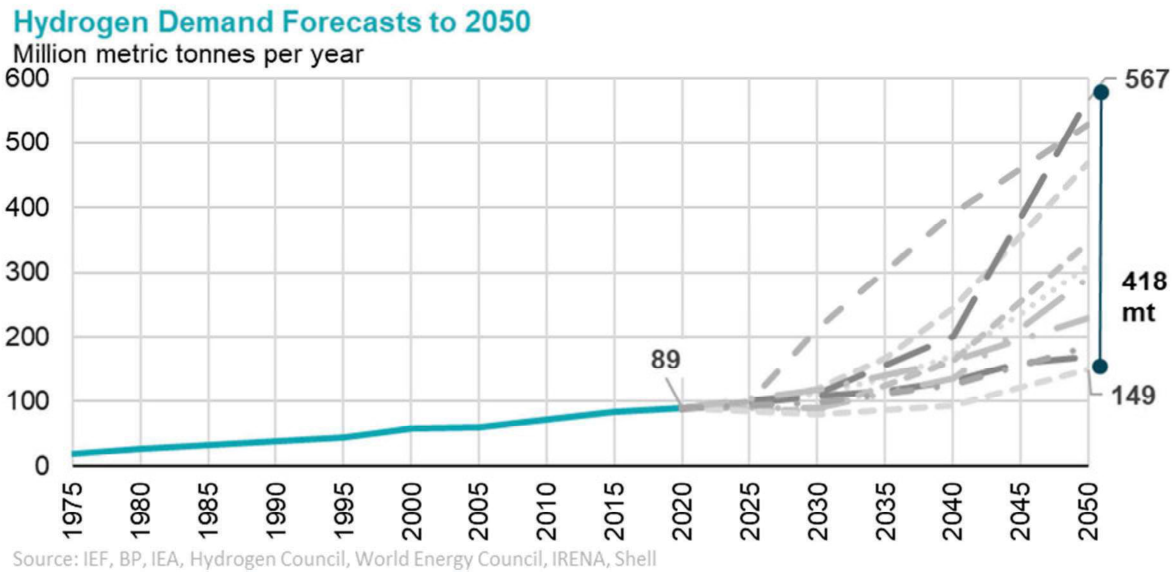
The current hydrogen market is in its infancy, but decarbonization efforts will create growth opportunities.

The most attractive applications for hydrogen uptake are in hard to abate sectors, where direct electrification is difficult, uneconomic, or technically unfeasible. These include steel and cement making, chemicals, high-temperature heat in industry, dispatchable electricity generation beyond a few days, aviation, shipping, and heavy-duty transport.

Additionally, low-carbon hydrogen will need to replace hydrogen produced from unabated fossil fuels, which is currently used in sectors such as petroleum refining, chemical industry, and fertilizer production.

However, because the size and scale of hydrogen adoption by each of these industries can and will vary, hydrogen demand forecasts vary significantly.

A survey of current forecasts shows a gap of 418 Mtpa between the low and high outlooks in 2050 (excluding BloombergNEF's outlier Green scenario which puts hydrogen demand above 1,300 Mtpa in 2050). This gap is more than 4.5 times greater than the current market size.



Interest in hydrogen has accelerated in the past five years as decarbonization targets have moved to the top of government priorities. More than 50 countries have developed, or are in the process of developing, a national hydrogen strategy.

The EU has quadrupled its low-carbon hydrogen supply target for 2030 from 5.6 million metric tons per annum (Mtpa) to 20.6 Mtpa, as part of its REPowerEU strategy to reduce reliance on Russian natural gas.

Over 500 large-scale projects have been announced in the last couple of years and >50% of those have just been announced in the past 12 months (as of April 2022).

There are many ambitious targets, but it is not clear how they will be achieved. Uptake and demand stimulation will be needed to reach these goals and market development progress.

Hydrogen can offer flexibility and be stored

Hydrogen molecules have flexibility and storability that can complement and balance intermittent renewable energy sources[viii].

Unlike battery storage, hydrogen can be transported over long distances, and stored underground almost indefinitely with minimal energy content loss over time[ix] – ideal for grid-scale long-duration storage. The use of salt caverns to store hydrogen is already a proven technology, while the use of depleted fields remains to be proven.

As countries increase their share of renewables, flexibility requirements will increase on a weekly to annual horizon. Hydrogen, as well as synthetic gas (made from hydrogen), can play a significant role in meeting longer-term flexibility needs of the power system.

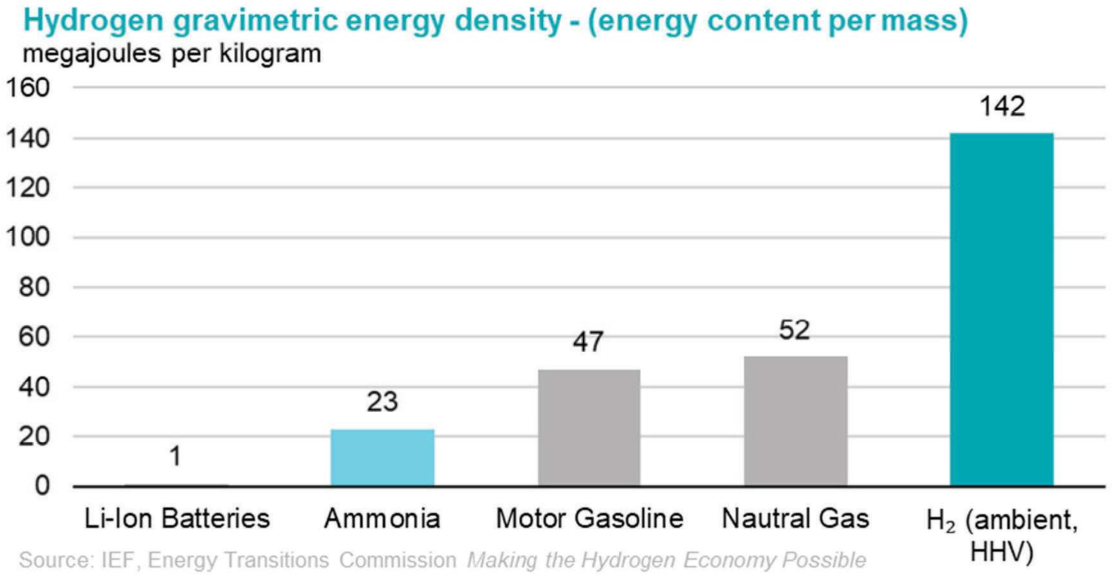
Hydrogen can be used to mitigate the seasonal variations of renewable production against electricity demand: as the world electrifies, higher hydrogen production through excess renewable electricity during one season can be used to meet higher electricity demand during another season when renewables are insufficient to meet demand.

Hydrogen can be used to unlock “stranded” renewable energy assets, such as those in remote, off-grid locations, with little to no access to a suitable market or means of long-distance electrical transmission. These renewable energy assets can generate electricity which is then used in electrolysis to produce hydrogen. This hydrogen can then be stored, transported, and shipped from these remote locations to market. Storage will be particularly important in helping hydrogen to play its role as a source of flexibility in power systems.

Hydrogen can also be stored in large quantities to serve as a strategic reserve with multiple end-use applications. This can help bolster energy security and mitigate energy price volatility and energy crises.

High energy density per mass

Hydrogen has a significantly higher energy density per mass than any other energy source. One kilogram of hydrogen contains a significant amount of energy, making it an efficient and lightweight energy carrier. Therefore, hydrogen is attractive in transport applications where large amounts of energy are required at minimal weight such as aviation, shipping, and long-distance trucking.



Source: IEF, Energy Transitions Commission *Making the Hydrogen Economy Possible*

The hydrogen economy goes beyond hydrogen

While talking about the hydrogen economy, it is important to understand that this concept goes beyond pure hydrogen. It also includes other energy carriers based on hydrogen such as ammonia, methanol, as well as synthetic methane, which are easier to transport.

Ammonia could be used in shipping and is currently being tested in Japan in the power sector mixed with coal; methanol is being tested in shipping by Maersk while synthetic methane can be produced from hydrogen and captured CO_2 and therefore use the current natural gas infrastructure.

Less vulnerable to geopolitical weaponization compared to traditional energy sources

It is technically possible to produce low-carbon hydrogen anywhere in the world, based on various energy sources ranging from wind, solar, biomass, nuclear, hydro as well as natural gas (with CCUS).

Countries can leverage hydrogen to diversify their energy sources and trade partners as many countries will likely become hydrogen producers and consumers.

Once the market has scaled, hydrogen is less likely to be successfully weaponized by an exporter nor give a massive importing country undue market power given the number and diversity of potential hydrogen exporters. Using hydrogen to augment the energy mix can help ensure energy security.

Synergy with existing industries

Hydrogen has many similarities with existing oil and gas industries and renewable industries.

The oil and gas sector has extensive engineering experience in modifying, transporting, and selling molecules.

Additionally, established oil and gas companies with cash flow positive non-hydrogen assets will also be able to access credit and invest in hydrogen whereas new hydrogen-only market entrants may struggle.

Existing gas infrastructure may also be repurposed for hydrogen, avoiding the issue of stranded assets. For example, several studies are currently looking at how the current natural gas network can be reused and expanded to accommodate hydrogen. This includes using inter-regional pipelines as well[x]. Particular attention should be given to the conversion of gas storage into hydrogen storage. Finally, the development of CCUS is likely to be performed by the oil and gas industry.

The recent REPowerEU strategy is prompting the EU to build an increasing amount of LNG import infrastructure, with several project sponsors pledging to make this import infrastructure "hydrogen ready" – although this definition still requires clarification.

There will be also increasing synergies with the power industry (sector coupling), including the use of renewable and other clean sources of electricity as sources of clean hydrogen, as well as the role of hydrogen as a source of flexibility in the power sector.

Weaknesses and Threats: What Will Limit Hydrogen's Growth?

While hydrogen has attributes that make it an attractive energy vector, there are limitations that should be considered. Past waves of interest have not translated into sustained investment or policy support, and between 2008 and 2018, global spending on hydrogen declined by 35%[xi].

Costs must fall further, infrastructure must be expanded, the chicken-and-egg problems must be solved, and there must be new applications of existing technology.

Hydrogen is not a panacea for the energy transition and policies and business models should remain focused on the applications that make technical and financial sense.

Reducing the cost of hydrogen

The cost of hydrogen represents a challenge for two reasons:

1. Hydrogen is expensive on an energy content basis: $1/kg represents $8.8/mmBtu (LHV), which was the average price for natural gas in Europe before the current crisis;
2. The cost of producing hydrogen from renewable electricity is currently much higher than hydrogen produced from unabated fossil fuels.

Cost reductions can be achieved by reducing the cost of electrolyzers and renewable electricity and improving the efficiency of electrolyzers and the load factor.

Levelized Cost Comparison Between Hydrogen Production Methods (2021)

Hydrogen Production Method	Cost Range ($/kg of H_2)
Unabated fossil fuels	~$0.5-1.7
Natural gas + CCS	~$1.0-2.0
Renewables	~$3.0-8.0

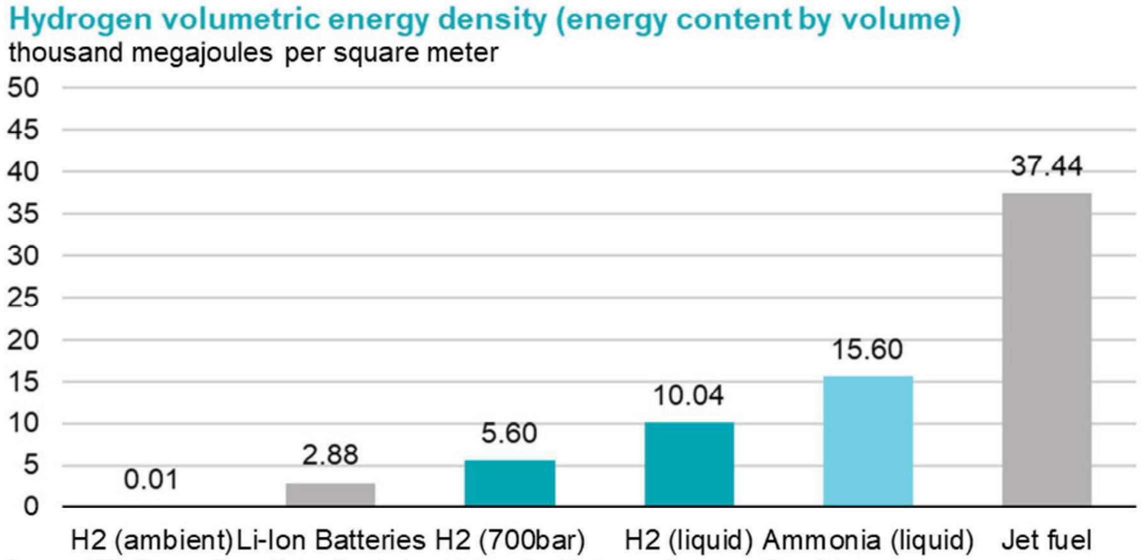
Source: Adapted from IEA *Global Hydrogen Review 2021*

Low energy density per volume

Per volume, the energy content of hydrogen is significantly lower than other fuels and energy carriers.

Consequently, storing or using hydrogen at atmospheric pressure and temperature requires a significant amount of space or requires significant amounts of energy to compress or liquefy.

Ammonia and synfuels have a higher energy density, making them more attractive than pure hydrogen for longer distance uses such as long-distance aviation and shipping.

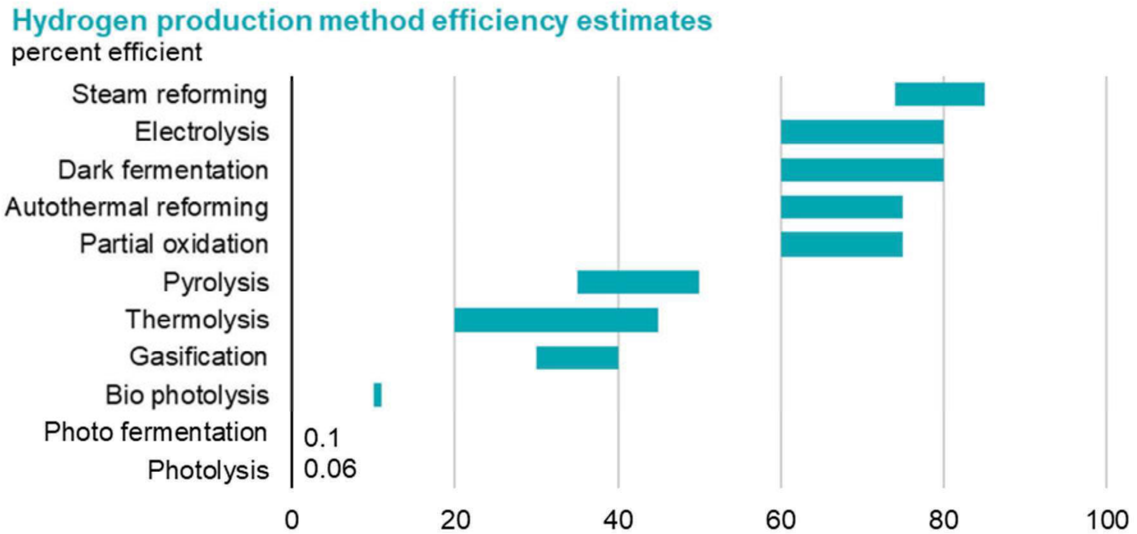


Source: IEF, Energy Transitions Comission *Making the Hydrogen Economy Possible*

Energy-intensive production and inefficient energy carrier

Breaking molecular bonds and freeing hydrogen requires substantial amounts of energy and has varying degrees of efficiency depending on the technology employed.

Current estimates show that steam reforming and electrolysis have an efficiency range of 60-85% but are also at the low and high end of cost estimates, respectively.



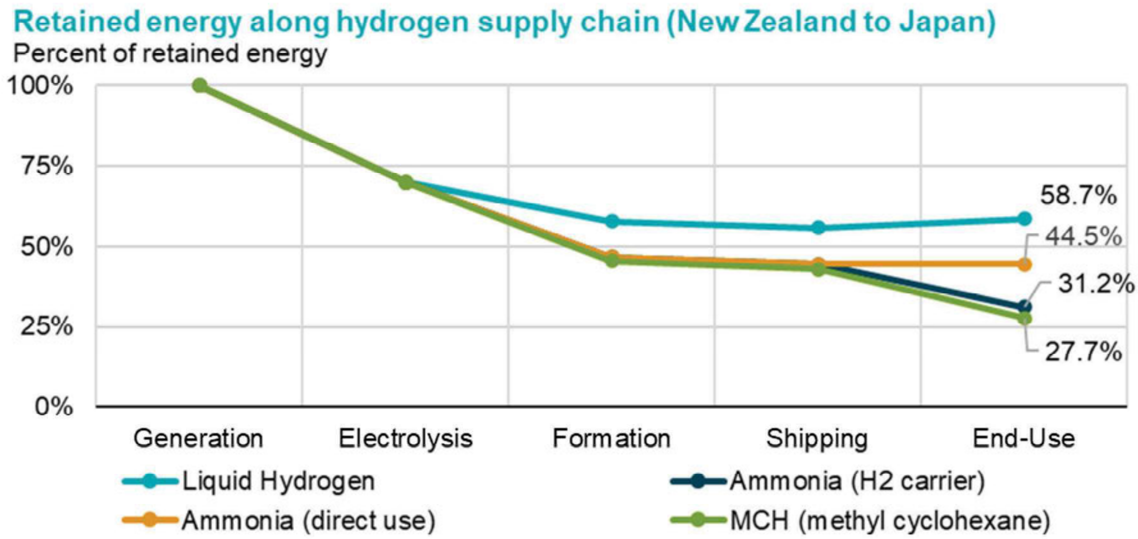
Source: IEF, *Kumar & Himabindu MSEI (2019)*

Storing and transporting hydrogen in compressed or liquified form requires additional energy inputs that substantially reduce the retained energy value.

The transport of hydrogen internationally across oceans is particularly challenging as the cost of transport is likely to be in the same order of magnitude as the cost of production. Transporting hydrogen by pipeline is the least costly option, at cost of $0.08-0.12/kg per 1000 km in repurposed pipelines ($0.16-0.24/kg per 1000 km in new pipelines)[xii].

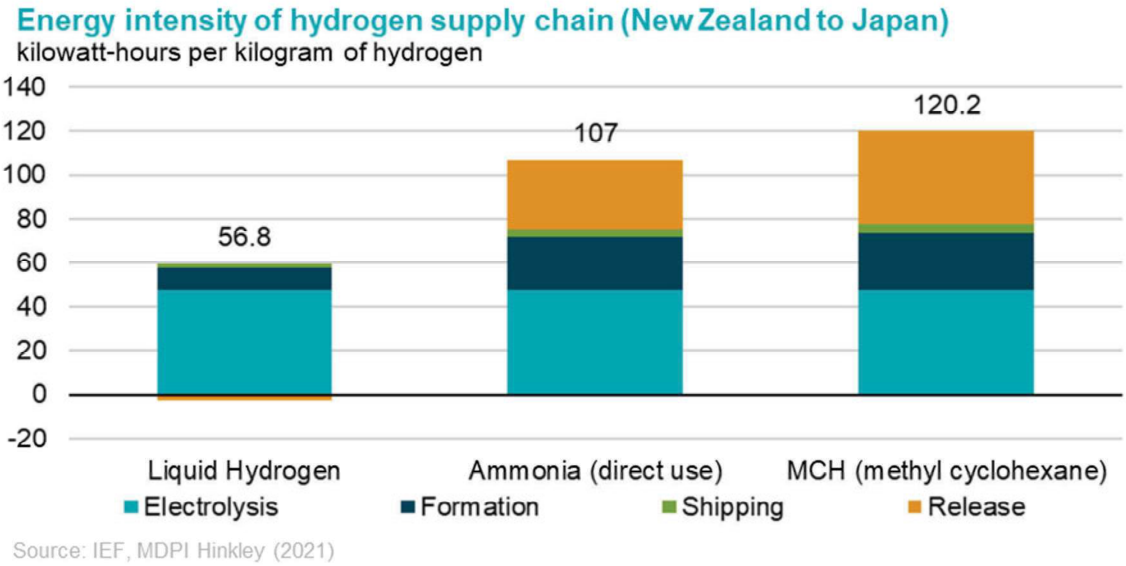
Other hydrogen-related fuels can be used to transport hydrogen such as ammonia. However, it might not be possible to use ammonia directly for other applications requiring ammonia to be transformed back into hydrogen when arriving at the importing country, unless it is used directly in the fertilizer and shipping sectors.

When comparing exporting countries, it is therefore recommended not to compare hydrogen production costs, but to compare delivered costs at the delivery port using the same transportation pathway. If the analysis compares various transport pathways, it is recommended to compare the delivered cost to the end user.

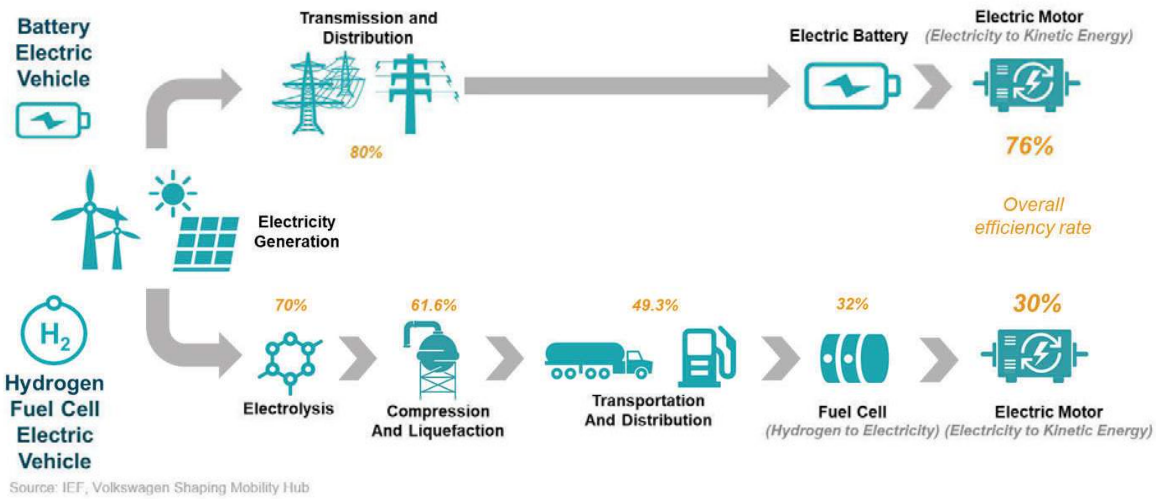


Source: IEF, MDPI Hinkley (2021)

Current estimates show that from production to end-use, liquified hydrogen retains approximately 58.7% of its original energy value, while converting hydrogen to Methylcyclohexane – which is one form of Liquid Organic Hydrogen Carriers (LOHC) – retains only 27.7%.



Then there are efficiency losses when converting hydrogen from one energy form to another. For example, converting electricity into hydrogen, shipping, storing, and converting it back using a fuel cell can entail a 70% loss of the original energy content. An electric vehicle retains 76% of its initial energy, through generation, transmission, storage, and conversion into kinetic energy.



In our currently energy-poor world, such energy-intensive means of production and energy losses complicate rather than alleviate the situation.

Lack of existing dedicated infrastructure, carbon capture, and critical minerals

Currently, hydrogen infrastructure is extremely limited, except for a few chemical industry pipelines.

Building out export and international trade infrastructure will require massive investment, but financiers will want a guaranteed buyer. However, demand and production need access to infrastructure before scaling-up. Producers will not produce more than they know they can transport and disseminate to end-users.

The lack of infrastructure is part of a “chicken-and-egg” problem that is a key obstacle to overcome.

Therefore, many hydrogen projects focus on hubs or valleys, especially in ports which often gathers sectors such as industry, shipping, potentially refineries and fertilizer production, and heavy-duty transport to minimize issues surrounding transport.

Beyond pipelines and other transport and storage infrastructure, low-carbon hydrogen scale-up will require significant levels of investment and expansion of the electrical grid and carbon storage facilities. It is estimated that producing around 700 Mt of hydrogen from renewable sources would require more electricity than is currently produced globally today[xiii].

Developing green hydrogen will require a very significant expansion of renewable capacity as well as the development of electrolyzers capacity at the GW scale rather than the 10/100 MW scale.

However, it makes more sense to decarbonize the power sector first with renewable energy, rather than building up renewables specifically to produce hydrogen.

Regions with strong ambitions of hydrogen exports such as the Middle East should therefore also focus on decarbonizing their power sector where the current share in renewable is currently low.

Europe faces the same challenge as it tries to build up renewable electricity to both replace gas-fired plants and produce green hydrogen, according to its new REPowerEU strategy.

Similarly, the development of low-carbon hydrogen from natural gas depends on the development and significant ramp-up of CCUS. According to the Global CCS Institute, there was only 50 Mtpa of CCS capacity under construction and advanced development as of September 2021; assuming 8 kg of CO_2 captured per kg of hydrogen produced[xiv], that would be sufficient for around 6 Mt of hydrogen.

Renewable energy sources, the electrical grid, and electrolyzers also use critical minerals. Critical minerals are a significant cost component of electrolyzers. A sharp increase in critical mineral demand, as expected with the energy transition, could impact hydrogen's financial competitiveness.

Public acceptance and safety

Expansion of hydrogen infrastructure and markets will need widespread public acceptance – a challenge for any energy source. Hydrogen has its own challenges in this regard, it has a wide range of flammable concentrations in air and lower ignition energy than gasoline or natural gas, which means it can ignite more easily[xv].

Hydrogen is also a very small molecule and is known to easily leak into the atmosphere – escaping from the smallest of holes or gaps in pipeline or canister connections. Hydrogen can also embrittle steel in pipelines and other equipment.

Additionally, there have been several recent studies on the climate consequences of hydrogen leaks that could impact government and consumer buy-in.

While zero- and low-carbon hydrogen hold great promise to help in decarbonization efforts, hydrogen is also a short-lived indirect greenhouse gas whose warming impact is not yet well-characterized.

The studies show worst-case hydrogen leak rates could yield a near-doubling in radiative forcing relative to fossil fuel counterparts in the first five years[xvi].

It will be important for hydrogen stakeholders, including policymakers, and energy industry players, to make sure they improve the current understanding of hydrogen leakage rates in the new and future production and consumption sectors, the policy to tackle this (potential) challenge, and the tools to measure leakage.

Crucially, hydrogen will need to pass the “not in my backyard” threshold, where other energy sources/infrastructure has failed.

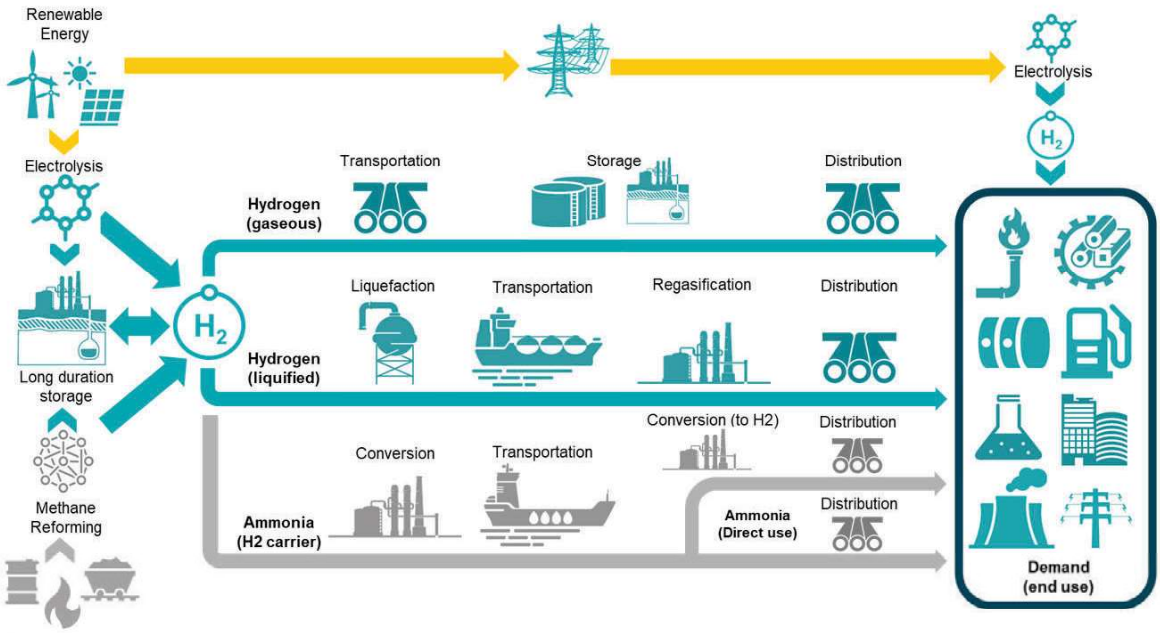
Solutions and Keys to Success

Scaling-up the supply chain

Creating a global hydrogen market will require the creation of entire new supply chains, from various production methods to the development or improvement of technologies consuming hydrogen.

Technical and economic decisions will need to be made on how and where to produce, how to transport, how to use, and where to consume.

There is still a lot of uncertainty on how the evolution of the hydrogen market may occur, assuming economics evolve favorably, and what will impact the development of the various parts of the supply chain.



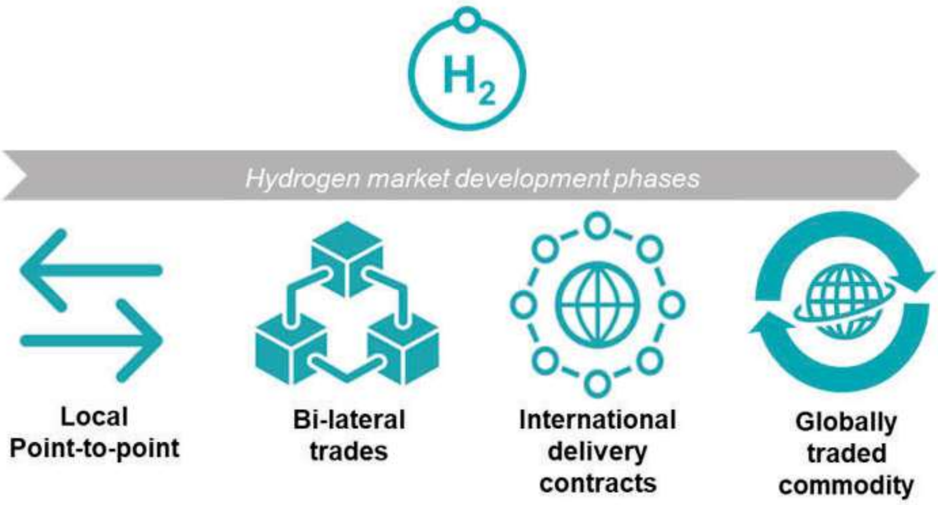
Source: IEF

Moving from localized to global markets

The first LNG shipment was in 1959, as a point-to-point market anchored with long-term contracts, but a more liquid market for LNG, with spot purchases and more active trades, is only a recent development over the past decade.

Likewise, the hydrogen economy will likely take decades to evolve from a localized point-to-point to a globally traded market, but the pace of development will differ across regions and sectors.

The hydrogen market will likely develop in several phases from (1) local point-to-point transactions to (2) scattered, bi-lateral trades to (3) larger contracted international deliveries to (4) a, potentially, globally traded commodity.



Currently, hydrogen is largely consumed on-site of production. This reflects the convenience of not having to transport hydrogen, the lower cost of on-site production and the fact that it is easier to transport natural gas to the production/consumption site.

Hubs at ports and industrial clusters will represent the first demand hydrogen centers, offering to producers an area on which they can concentrate. But as demand and infrastructure grows, producers can achieve economies of scale by increasing output and selling whatever cannot be consumed locally.

Additionally, production hubs will be advantaged in regions where input cost are lowest, which may not be where the highest demand volumes are located.

As a result, more merchant hydrogen will be sold through bi-lateral or “over-the-counter” transactions first locally, and then regionally.

Bi-lateral trade may then evolve into sectoral trade, where one producer sells to multiple buyers in a specific industry (e.g. steel).

Once economics, technology, and infrastructure support trade through shipping, the market will likely resemble the LNG market from the early-2000s – point-to-point shipments anchored on long-term contracts.

Unlike LNG, there will not be a unified hydrogen market, as hydrogen will likely be bought and sold in many forms, including ammonia, liquid organic hydrogen carriers (LOHC), liquified hydrogen, etc. Some long-term energy outlooks, such as IRENA’s, point to ammonia as the long-term solution for international transport, but there is still discussion on what will be the key transport medium.

Low-cost or stranded energy will help grow production hubs

Technology, manufacturing capacity, input costs and industry experience will influence where production hubs emerge.

Locations of low carbon energy surpluses depend on geography and on regulation, both affect supply capability and cost competitiveness.

Regions with low-cost renewables, excess nuclear, or cheap natural gas resources combined with CCUS and access to water (if using electrolysis), and experience in producing and trading molecules will have higher production potential. But the cost of the delivered molecule will also be important for importing countries.

Cost of financing, supporting policies, and a clear regulatory framework will also be crucial factors.

For countries looking at exports overseas, port infrastructure, as well as the distance of the production centers from these ports, will also matter.

Additionally, production will need to be established by creditworthy entities and in locations with strong rule of law and established permitting procedures.

However, the deployment of hydrogen export hubs should not be done at the expense of the decarbonization of the exporting country's energy system. Some principle of additionality – whereby the renewable capacity dedicated to hydrogen production is on top of that for the power sector, not diverting away from it – should apply.

Transportation infrastructure crucial in market scale-up

While hydrogen can borrow and use some existing infrastructure, entirely new hydrogen-dedicated transportation means, and infrastructure will need to be developed for sufficient scale.

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 (e.g. gas purity).

Otherwise, the current methods for transporting hydrogen are sufficient for distances up to a few thousand km, but they would not be cost-competitive or make sense for trans-regional transport across oceans, for example Japan importing hydrogen from the Middle East, Australia, or Chile.

There have been trials to transport hydrogen across seas, either as ammonia or using LOHC, or studies to transport it as liquid hydrogen, but this is not at a commercial stage yet.

In 2020, Saudi Aramco transported 40 tons of blue ammonia to Japan, however, to put things in perspective, annual global ammonia production is over 180 million tons.[xvii] The same year, Japan also imported hydrogen from Brunei, transported in the form of methylcyclohexane (MCH).[xviii] Similarly, transporting liquid hydrogen from Australia is being considered with the launch of the first liquid hydrogen tanker.[xix]

There is also not yet a clear winner among these different transport technologies as they all have pros and cons. Many export projects or import initiatives, such as the Port of Rotterdam, appear to be looking at ammonia in the first stage. However, Japan, which has clearly identified imports as the main source of national hydrogen supply, is actively looking at different technological solutions.

Storage development is needed to bolster security of supply

While current use of hydrogen storage has been limited in practice so far, it will become increasingly important in cases of intermittent renewable generation and to store energy over extended periods.

Intermittency could create seasonality in hydrogen production that does not exist in demand, such as in the industrial sector which is likely to require stable hydrogen supply. Investing in hydrogen storage and building up seasonal and strategic reserves will be critical for security of supply.

There are various potential solutions for large-scale storage of hydrogen and hydrogen derivatives, such as ammonia, but geologic salt caverns are the most mature. Salt caverns are already used to store hydrogen on a small scale. However, large-scale salt-cavern storage of fuel gases is expensive.

Additionally, suitable geology that could potentially be used for salt cavern storage are not evenly distributed globally. North America and parts of Europe have abundant options, but there are few in East Asia, South America, and sub-Saharan Africa.

Two countries that are emerging as early hydrogen adopters Japan and South Korea, have no suitable salt deposits. Japan's lack of salt caverns has also been a problem for natural gas reserves. Japan relies on gas for nearly 40% of its electricity, but it holds only two weeks of natural gas inventories.

China has few salt deposits, and its demand for hydrogen is likely to grow significantly as its steel and cement industries transition to hydrogen.

Therefore, future importers such as China, Japan, and South Korea might need to develop other storage options.

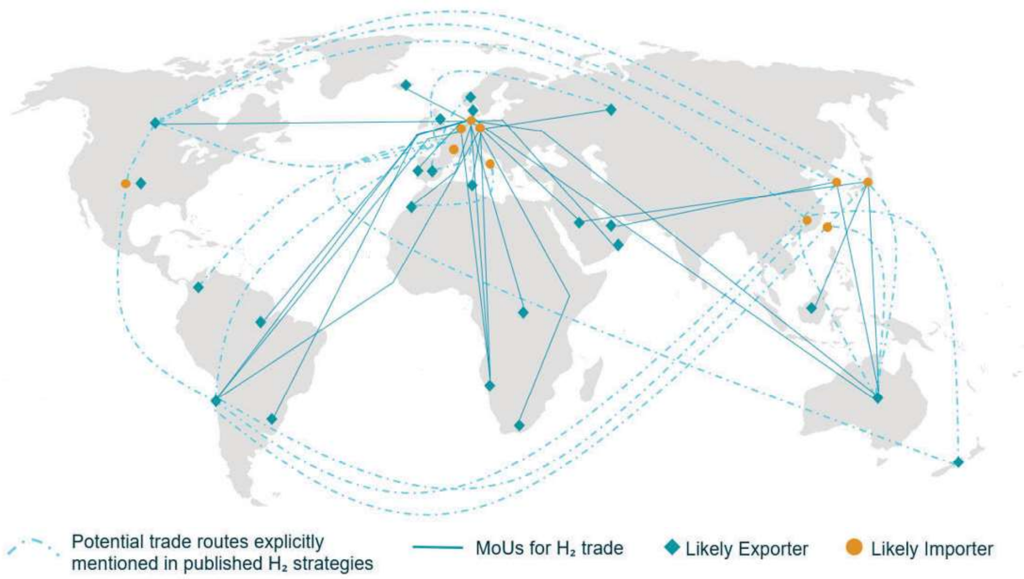
There is more uncertainty regarding the capability of either depleted fields or aquifers as storage options. Potential risks for depleted gas fields identified in studies include the potential conversion of hydrogen to methane or hydrogen sulfide (H_2S) —a toxic gas—due to microbial activity, potential porosity changes due to chemical reactions of hydrogen with the reservoir rocks or loss of hydrogen by diffusion[xx].

International partnerships

Developing a global market for hydrogen trade will require international dialogue and cooperation, across borders, regions, and the public and private sectors. Cross-border collaboration to ensure alignment and consistency in definitions, certification schemes, and import tariffs for hydrogen and its potential carriers will help address potential trade hurdles.

International trade agreements will also catalyze development of infrastructure and de-risk projects investments.

Proposed and likely trade routes of hydrogen and hydrogen derivatives



Source: IEF, IRENA (2022) *Geopolitics of Hydrogen*

Data transparency needed for investors and policymakers

Hydrogen market data is currently limited and lacks standardized definitions and conventions[xxi].

Statistics are essential to better understand the inner workings of any aspect of the energy system. However, there is hardly any data on how hydrogen is produced and very few statistics on consumption.

Where data does exist, it is frequently partial and does not cover all existing sectors or regions. Additionally, data is provided in different units and based on different heating values.

Greater data transparency and standardization are needed to empower analysts, investors, and policymakers to make informed decisions. Public access to well-defined, timely, and complete energy data will reduce uncertainty and facilitate stable energy markets. Market players need reliable data to assess market developments and investment needs.

Hydrogen can borrow from LNG contract structures

Financiers of hydrogen projects will desire projects with a predictable revenue stream and lower capital risk.

A stable contractual framework that avoids both unnecessary complexity and excessive simplicity will be foundational in market development and will help in securing financing by reducing cash-flow variability and investor risk.

While the market is still in its infancy, it is likely that the price of hydrogen will be linked to its cost by some cost-plus approach that could reflect both CAPEX and changes in OPEX (especially if the input is natural gas). How the price of hydrogen will evolve in a more mature market is still unknown at this stage, and there will be differences depending on whether the hydrogen is sold free-on-board with off takers providing transportation or whether it will be sold delivered ex-ship. As noted before, transportation will be a significant part of the final cost of hydrogen.

It is also likely that international export projects will need hydrogen sales and purchase contracts and that these include review clauses to take into account future changes in the market. Early low-carbon hydrogen projects will likely require long-term off-take contracts to be considered viable. These may resemble those that helped the LNG industry to develop but will have some key differences. Two contracts common in LNG and could be applied to hydrogen are tolling model or a sale-and-purchase model.

Tolling and sale-and purchase models:

In a tolling model, a creditworthy tolling customer would supply the inputs required to produce hydrogen, such as electricity and water, and pay a “tolling fee” to a hydrogen operator to produce it using the hydrogen operator’s electrolyzer.

The hydrogen operator would produce, convert, and store the hydrogen at its own facilities and then load the hydrogen product onto vessels provided by the tolling customer.

A tolling arrangement shifts certain risks (such as supply costs) from the hydrogen producer to the long-term tolling customer.

Under a sale-and-purchase contract, the hydrogen operator provides all raw materials and produces hydrogen that is sold to the customer.

Take-or-pay contracts:

A common feature of long-term LNG contracts is a take-or-pay clause.

Take-or-pay clauses require the customer to either take a specified quantity of a product on a periodic basis or pay a penalty. The penalty may be designed where the customer does not take but pays for the quantity and can claim delivery later.

These contracts give sellers some guaranteed returns even if buyers do not follow through on purchasing agreed amounts of a commodity. This type of clause was important in de-risking early LNG projects.

Take-or-pay clauses will be difficult to implement in hydrogen trade given the current small scale of the marketplace and the inherent high risk. However, it could be an important provision once demand is more established.

Colorblind hydrogen

Color codes are sometimes used as shorthand to reference how hydrogen is produced. However, the greenhouse gas emissions and environmental impacts vary considerably within production methods, especially when all supply chain components are considered.

While color terminology has entered the common vernacular, it is simplistic and inexact and does not provide a sound basis for future markets or trade.

As hydrogen development is primarily a means to support decarbonization, then the carbon intensity of the entire hydrogen supply chain will be the most important metric and not strictly the production method.

Therefore, hydrogen markets and trade rules will have to consider the carbon intensity of hydrogen and any carriers or derivatives and not ‘color’ designations.

Measuring and tracking carbon intensity needs to be standardized and corresponding certifications and guarantees of origin will be important elements enabling international hydrogen trade.

There will need to be alignment on how emissions are defined and managed between jurisdictions. Data transparency will also be crucial to measure and certify the GHG emissions associated with different types of hydrogen production. It will be also important to have a common framework (including a very clear definition of what is green/clean/low-carbon hydrogen that allows for international trade).

Standards for differentiating low-carbon hydrogen will need to be developed by governments or third parties. International cooperation will be necessary to develop rules and standards for benchmarking, measuring, and certifying emissions as export markets develop. IPHE has already developed a methodology to calculate these emissions, and more work is on-going in this area.

Guarantee of Origin or certification systems will help enable off-takers to make informed choices based on their own requirements such as greenhouse gas footprint and related costs. An early example of this is the European CertiHy scheme, which provides low-carbon guarantees of origin.

Price determination will evolve and become more transparent

As liquidity and the number of established off-takers increase, the hydrogen market has the potential to become a traded commodity.

Hydrogen contract prices may follow a formula based on fixed costs plus variable costs until a benchmark is developed. As the market evolves, contracts may include a change-in-law clause that also allows a review of pricing.

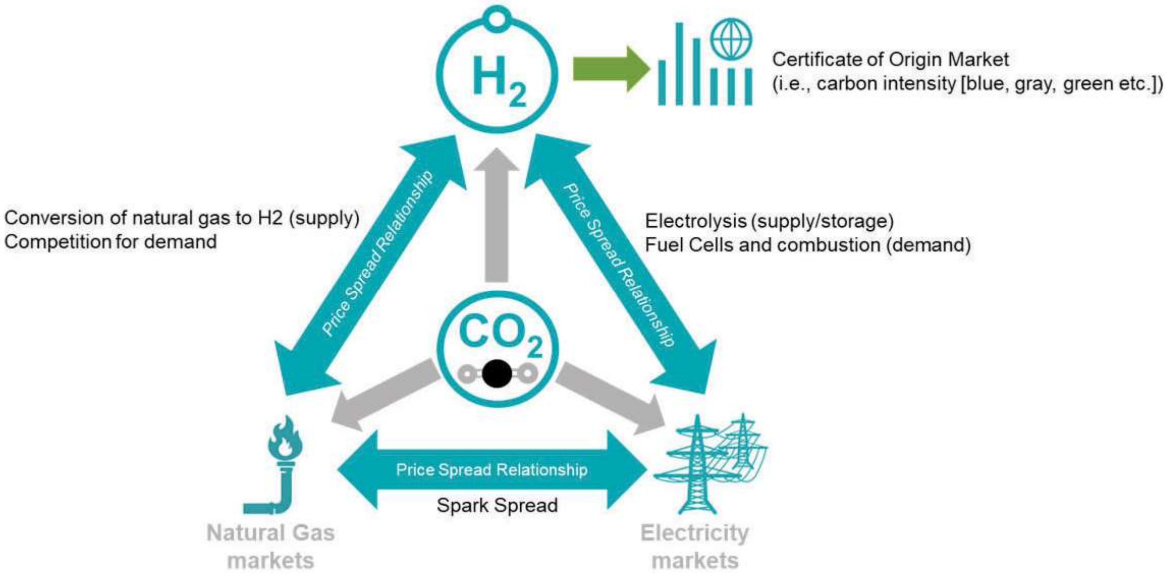
A robust and liquid hydrogen market also can play a unique role in financial risk management during the energy transition by sharing links with electricity, natural gas, and emissions/certificates of origin markets.

Methane reforming for hydrogen production and hydrogen's use as a combustion fuel in heat and power markets can establish a financial relationship with natural gas markets.

Hydrogen's use in power generation (through fuel cells and combustion), as well as hydrogen production from electrolysis, can help financially link hydrogen with traded electricity markets.

Hydrogen's status as a non-carbon emitting source of energy, and the need for certificates of origin, links it with expanding emissions trading markets.

These relationships could establish hydrogen as a key risk management and trading opportunity.



Government Support Mechanisms

A range of policy interventions and regulations across the supply chain will be needed in the upcoming years to help overcome barriers, reduce risks, and support growth of a resilient hydrogen market.

There is a lot of risks inherent in a new market, but a combination of off-take agreements and public policy can help mitigate risks. Government support will be essential to help the hydrogen economy scale-up.

Hydrogen today is similar to renewables 10 or 15 years ago, when government support in the form of tax credits, feed-in tariffs, or guarantees was crucial for accelerating the pace of deployment and, in turn, reducing costs.

The growth of hydrogen economy can also be compared to the development of offshore wind projects where deliberate and strategic government programs played a major role. However, the off-take is less clear for the hydrogen market than it was for renewables at the beginning of the wind and solar revolution or the nascent LNG market.

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 and scalability.

Policies should support but not choose winners

Policies related to hydrogen should be technology-neutral and not choose winners. Government interventions should enable true market advancements, be hydrogen colorblind, and leverage public finance as well as private capital.

A clear carbon price would quickly guide corporate strategy and where capex is spent. It would also enable to account for the carbon footprint of various hydrogen production methods, including incentivizing carbon-negative hydrogen production (bio-hydrogen with CCS). Rather simply, a carbon price would move hydrogen up the energy-technology merit order.

However, this also requires the carbon footprint of hydrogen to be known and calculated, and therefore a consistent framework to be agreed upon to provide transparency to the market.

Some governments have used contracts-for-differences, subsidies, and other support schemes successfully with other energy sources and these could be used as support mechanisms for hydrogen.

A contract for difference trading platform where a government-based exchange buys hydrogen products for a fixed price and then sells the hydrogen on, could help remove the price risk and help projects gain financing. Germany is pursuing such a system with H2-Global.

The EU has announced an energy purchasing platform that will include hydrogen and help aggregate demand and optimize infrastructure use[xxii]. The platform will be a voluntary coordination mechanism supporting the purchase of gas and hydrogen for the EU and will help ensure the security of supply. However, the exact details of how the platform will work are still largely unknown.

As the market evolves, these policies too should evolve. Subsidies should reduce as the market develops, the costs of producing low-carbon hydrogen decline, and the value of hydrogen reflects the costs of producing it.

Policies should incentivize both the simultaneous development of hydrogen demand and supply – to avoid imbalances.

Despite parallels between hydrogen and other market development pathways (such as LNG), they should not be regulated in the same way. There is still room for innovation in hydrogen technology and business models, that over-regulation could hinder.

Regulation that is “fit for purpose” can help mitigate the risk inherent in a new market, particularly in attracting investment. A delicate balance is needed to ensure hydrogen helps in the energy transition but is also competitive and cost-effective.

The government needs to give a clear and strong signal and ensure a stable regulatory framework that will support the supply and demand side and provide long-term certainty. Regulation that fast-tracks permitting and citing can help infrastructure scale-up.

Conclusion: Scaling-up is part of the problem and the solution

The opportunities for hydrogen in decarbonizing the energy mix are significant, but the challenges are great.

Increased investment and clear and supportive policies and regulations will be needed to help development all along the supply chain. The magnitude of growth needed is enormous; production, infrastructure, regulations, demand, and even data collection are all currently fractions of what will be required.

Understanding the scale required is crucial. Low-carbon hydrogen production and demand need to increase by 500-600-fold over the next few decades. Meeting the EU's target of 10 Mt of hydrogen imports by 2030 will require more than 40 projects the size of NEOM in Saudi Arabia (currently the world's largest planned hydrogen-based ammonia project to be fueled by renewables, delivering an equivalent of 650 ton of low-carbon hydrogen per day).

Each part of the hydrogen value-chain has inherent challenges that will need to be overcome, almost simultaneously.

Scaling all components of the value chain is a major part of the challenge, but also part of the solution. Economies of scale will help in lowering costs and scale and diversified production sources will help lower risk for off-takers and enable competitive markets.

Scaling-up production will look different in different regions. Some producing countries will need to consider access to clean water and others will need to expand renewable power or CCUS.

There are also many uncertainties surrounding transportation, storage, and demand of hydrogen. Old technologies and methods will need to be proven for new applications.

As the market scales, clear winners will emerge: will ammonia or some other hydrogen derivatives be preferred for oversea trade? Establishing parameters of the market will help in securing finance and enabling scale.

Mobilizing public and private capital will be crucial to accelerate projects and support infrastructure development. More investment, research and development are needed to lower production costs and promote ramp up. Given the scale of the investments needed on the supply side, it is likely that some form of long-term supply contracts will be needed. Pricing structure, delivery terms, flexibility, hydrogen quality, review clauses will be crucial parts of the contract to be negotiated between buyers and sellers.

Cooperation between governments and the private sector can help these new business models secure capital. Governments can help shoulder some of the risks that are inherent in a new market, and they can assist by providing clear and stable regulations and policies. De-risking projects and prioritizing actual use cases that can be bankable will help enable market growth.

Broad cooperation is also needed in standardizing definitions, data collection, and certifications (including guarantees of origin).

The hydrogen market is still in its infancy, but the potential and momentum for market development have never been greater.

With the help of international cooperation and broad-based collaboration, the market can scale-up and play an important role in helping countries achieve decarbonization goals. However, this will not be an easy task and will require targeted government support, synchronized growth through the entire value chain, and innovative business models.

[i] Makaron and CRA, “Hydrogen Market Primer”, 2021, Makaron, https://www.marakon.com/insights/hydrogen-market-primer/

[ii] US Energy Information Administration, “EIA projects global conventional vehicle fleet will peak in 2038”, 2021, https://www.eia.gov/todayinenergy/detail.php?id=50096

[iii] K. Tu, “Prospects of a hydrogen economy with Chinese characteristics”, 2020, IFRI, https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[iv] FCHO Observatory, www.fchobservatory.eu/sites/default/files/reports/Chapter_2_Hydrogen_Molecule_Market_070920.pdf

[v] Ibid.

[vi] International Energy Agency, “The future of Hydrogen”, 2019, https://www.iea.org/reports/the-future-of-hydrogen

[vii] International Energy Agency, “Global Hydrogen Review”, 2021, https://www.iea.org/reports/global-hydrogen-review-2021

[viii] O. Guerra, J. Zhang, J. Eichman, P. Denholm, J. Kurtz, B. Hodge, “The value of seasonal energy storage technologies for integration of wind and solar power”, 2020, Energy & Environmental Science, https://doi.org/10.1039/D0EE00771D

[ix] M. Portarapillo and A. Di Benedetto, “Risk Assessment of the Large-Scale Hydrogen Storage in Salt Caverns”, 2021, Energies, https://www.mdpi.com/1996-1073/14/10/2856

[x] Gas for Climate, 2021 European Hydrogen backbone, 2021, https://gasforclimate2050.eu/sdm_downloads/european-hydrogen-backbone/

[xi] T. Van de Graaf, I. Overland, D. Scholten, and K. Westphal, “The new oil? The geopolitics and international governance of hydrogen”, 2020, Energy Research & Social Science, https://doi.org/10.1016/j.erss.2020.101667

[xii] IRENA, “World Energy Transitions Outlook 2022”, 2022, https://www.irena.org/publications/2022/Mar/World-Energy-Transitions-Outlook-2022

[xiii] BloombergNEF, “Hydrogen Economy Outlook”, 2020

[xiv] Global CCS Institute, “Blue Hydrogen, Circular Carbon Economy series”, 2021, https://www.globalccsinstitute.com/wp-content/uploads/2021/04/Circular-Carbon-Economy-series-Blue-Hydrogen.pdf

[xv] US Department of Energy, “Safe Use of Hydrogen”, https://www.energy.gov/eere/fuelcells/safe-use-hydrogen

[xvi] I. B. Ocko and S. P. Hamburg, “Climate consequences of hydrogen leakage”, 2022, Atmos. Chem. Phys. [preprint], https://doi.org/10.5194/acp-2022-91

[xvii] T. Brown, “Saudi Arabia ships low carbon ammonia to Japan”, 2020, Ammonia Energy Association, https://www.ammoniaenergy.org/articles/saudi-arabia-ships-low-carbon-ammonia-to-japan/

[xviii] Fuel Cells Works, “World’s first international transport of hydrogen from Brunei to Japan”, 2020, https://fuelcellsworks.com/news/worlds-first-international-transport-of-hydrogen-from-brunei-to-japan/.

[xix] Lloyd Register, “World first fort liquid hydrogen transportation”, 2020, https://www.lr.org/en/insights/articles/world-first-for-liquid-hydrogen-transportation/.

[xx] C. Hemme & W. van Berck, “Hydrogeochemical Modeling to Identify Potential Risks of Underground Hydrogen Storage in Depleted Gas Fields”, 2018, Applied Sciences, https://www.mdpi.com/2076-

3417/8/11/2282/pdf#:~:text=The%20risks%20of%20hydrogen%20storage,through%20the%20cap%20rock%20brine.

[xxi] A.S. Corbeau, “Hydrogen: A Hot Commodity Lacking Sufficient Statistics”, 2022, Columbia Center on Global Energy Policy, https://www.energypolicy.columbia.edu/research/commentary/hydrogen-hot-commodity-lacking-sufficient-statistics

[xxii] European Commission, 2022, “Energy Security: Commission hosts first meeting of EU Energy Purchase Platform to secure supply of gas, LNG and hydrogen”, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2387

Hydrogen
Market Pathways

INTERNATIONAL
ENERGY
FORUM

ICE

www.ief.org/events/hydrogen-market-pathways