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The World of Hydrogen

Energy Industry Report

The Al-Attiyah Foundation

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Hydrogen has emerged as an important fuel and energy carrier in the global race to tackle climate change and to reach net-zero emissions by mid-century. Global regulatory policies, technological developments, affordability, and scalability are converging to create an unprecedented drive for the expansion of the low carbon hydrogen economy.

What are the emerging trends in the world of hydrogen? How will hydrogen production tackle a growing and changing demand? What will drive investments in hydrogen supply chains? And what are the market opportunities in the hydrogen industry across the United States, European Union, the GCC, and the wider Middle East?

ENERGY REPORT

This research paper is part of a 12-month series published by the Al-Attiyah Foundation every year. Each in-depth research paper focuses on a current energy topic that is of interest to the Foundation's members and partners. The 12 technical papers are distributed to members, partners, and universities, as well as made available on the Foundation's website.

- Low carbon hydrogen, as a fuel and energy carrier, will play a critical role on the global path to net-zero by 2050 and forms a key interconnecting pillar between other low carbon technologies such as renewables, into battery and energy storage systems, and carbon capture, utilisation, and storage technologies.

Demand and Supply:

- Hydrogen demand scenarios show a diverse range of estimates given the differences in the pace and extent of hydrogen penetration across various industries. The expansion of the hydrogen industry in a net-zero by 2050 scenario, could lead to the global demand for low carbon hydrogen increasing by 7x from 2020-levels to more than 630 Mt H2 / year in 2050.
- At present, grey hydrogen dominates global supply, but the hydrogen rainbow is expanding with low-carbon blue and green supplies, a key step on the path to global carbon neutrality by 2050-60.

Investment and Economics:

- The IEA estimates that a net-zero by 2050 scenario will require US$ 1 trillion of cumulative direct investments in global hydrogen supply chains by 2030 and an additional US$ 9 trillion between 2030 – 2050.
- The levelised cost of producing low-carbon blue hydrogen is highly dependent on the price of natural gas and the scale-up of carbon capture and storage technologies.
- The levelised cost of producing green hydrogen will benefit from a fall in the levelised cost of renewable electricity, an increase in load factors, and a reduction in electrolyser CAPEX costs as manufacturers pass on reduced production costs through economies of scale.
- Green hydrogen could achieve cost parity with grey hydrogen before 2030, depending on how regional natural gas prices and markets evolve.
- As projected hydrogen production costs decline, the cost of transporting hydrogen gains in importance. The emerging plans for exports of hydrogen to Europe, South Korea, Japan, and China are driven by differences in production costs across these countries, due to variable renewable resources endowments relative to demand, lack of natural gas and hydrogen storage sites, weak existing relevant infrastructure, and land use constraints.
- GCC countries could supply green hydrogen at competitive prices to countries with poor or moderate renewable resources, but this depends on keeping down transport costs. Liquefied hydrogen or liquid organic hydrogen carriers appear the most favourable transport methods for pure hydrogen. However, for users able to take ammonia, shipping ammonia is much more competitive and is likely to be the primary export product until the ammonia market is saturated.

Regional Insights and Market Opportunities:

- At present, several countries have explicitly announced their hydrogen strategies and targets, which amount to ~130 GW of green hydrogen installed capacity by 2030 and is > 400x the installed electrolyser levels in 2020.
- The United States has entered the hydrogen wave through a US$ 10 billion public expenditure plan under the Infrastructure and Jobs Act.
- GCC countries such as Saudi Arabia and the United Arab Emirates (UAE) have taken major steps on creating their low carbon hydrogen production with large-scale projects for green and blue hydrogen.

Table 1: The Hydrogen Rainbow

Green Hydrogen: produced by electrolysis of water using renewable electricity	Turquoise Hydrogen: produced by the thermal splitting of methane to yield solid carbon
Pink / Purple / Red Hydrogen: produced by electrolysis or thermal splitting of water using nuclear power	Grey Hydrogen: produced from gas or oil without CCUS
Yellow Hydrogen: produced by electrolysis of water using grid electricity	Blue Hydrogen: produced from natural gas with carbon capture & storage (CCUS)
White Hydrogen: naturally occurring from the ground	Brown Hydrogen: produced from coal without CCUS

Over the last two years, there has been a rapid acceleration in net-zero and climate-neutral pledges by countries and corporations. At the 2021 United Nations Climate Change Conference (COP26) Australia, Malaysia, UAE, United States, and Thailand joined the United Kingdom, European Union, and South Korea in introducing policy-backed net-zero legislation; and Bahrain (2060), Saudi Arabia (2060), and Turkey (2053) made political pledges to reach net-zero[i].

At the end of 2021, 63% of the current global CO_2 emissions were backed by national policy-based net-zero and climate-neutral pledges, whereas 20% were covered by declared political pledges (not backed by policy or legislation at present)[ii]. Almost half of the CO_2 emissions that are covered by policy-backed pledges (i.e. 35% of the global CO_2 emissions) aim for net-zero by 2050 or earlier, whereas the rest aim for net-zero by 2060 or later[iii].

Low carbon hydrogen as a fuel and energy carrier, will play a critical role on the path to net-zero by 2050 and forms a key interconnecting pillar between other low carbon technologies such as renewables, battery / energy storage systems, and carbon capture, utilisation, and storage (CCUS).

Hydrogen enables decarbonisation for hard-to-abate industries such as aviation and shipping, steel and chemicals production, high-temperature heating, and long-term energy storage. Hydrogen could abate 15% of the current global GHG emissions and 20% of the current global CO_2 emissions if widely deployed in these industries[v].

The renewed push to decarbonise energy demand has also encouraged global regulatory policies to adopt low carbon hydrogen. At the end of 2021, more than 30 countries have released national strategies that emphasise the vital role of hydrogen in decarbonising industry and transport.

Figure 1: CO2 Emissions by Country[iv]

At the end of 2021, 63% of the current global CO_2 emissions were backed by national policy-based net-zero and climate-neutral pledges

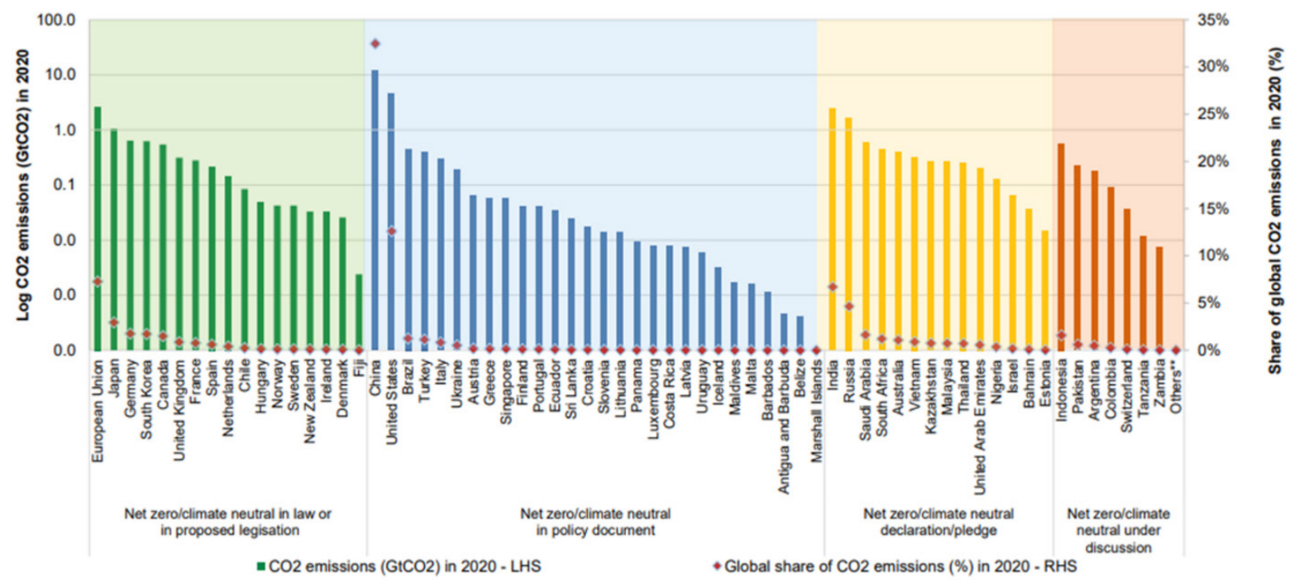
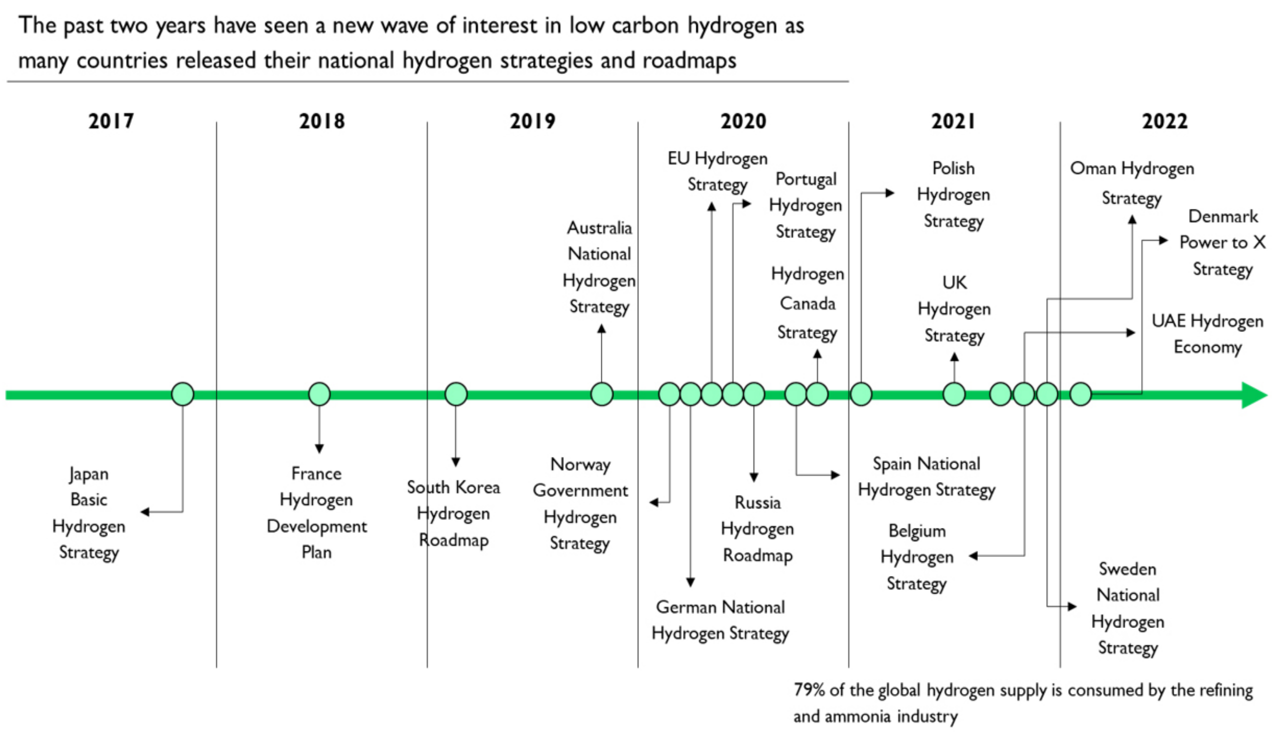


Figure 2: Timeline of Selected National Hydrogen Strategies and Roadmaps

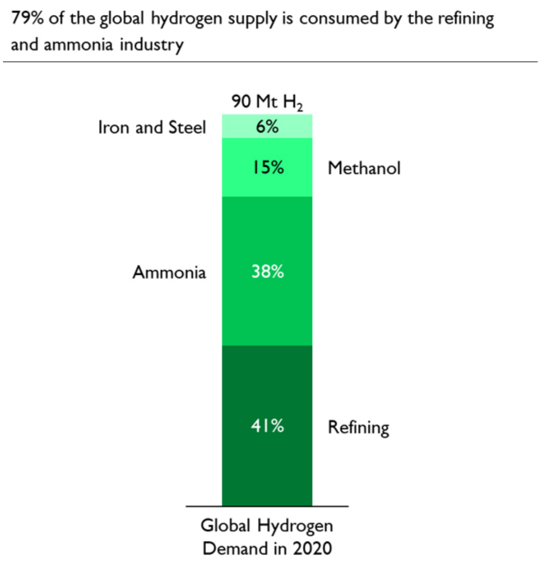


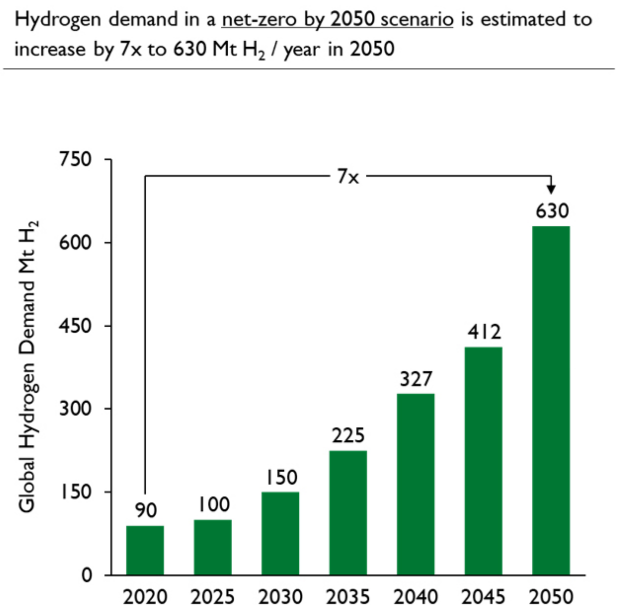
While some of these national strategies are not backed by binding policy mechanisms or legal provisions, they are a significant milestone.

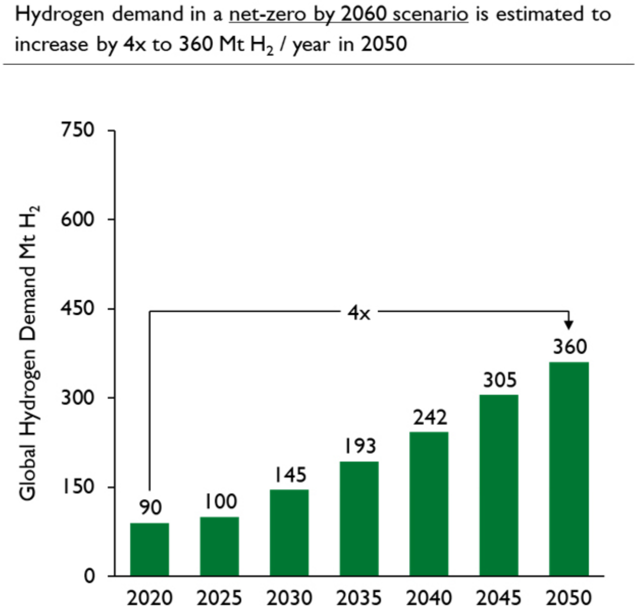
The momentum for low carbon hydrogen is expected to increase over the next decade, as global regulatory policies on hydrogen converge, and the economics of hydrogen production continues to improve; along with the increasing penetration of low cost renewables, and the electrification of energy infrastructure.

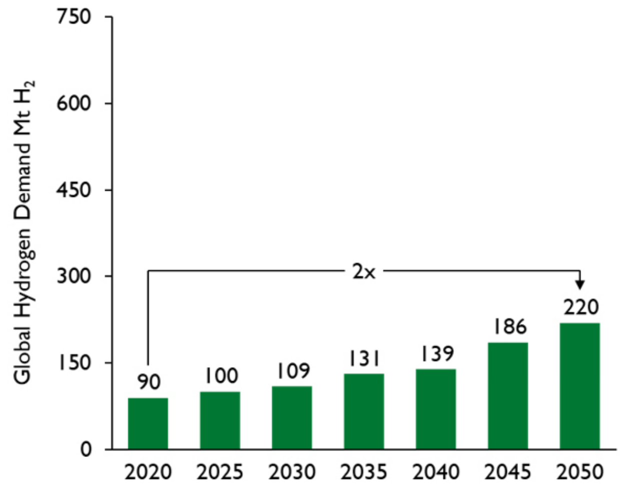
The expansion of the hydrogen industry in a net-zero by 2050 scenario could lead to global demand increasing by 7x from 2020-levels to 630 Mt H2 / year in 2050[vi]. In the net-zero by 2060 scenario, low carbon hydrogen demand is estimated to increase by 4x to 360 Mt H2 / year in 2050[vii]. In the net-zero by 2070 scenario, demand is projected to increase by 2x to 220 Mt H2 / year in 2050[viii].

Figure 3: Scenarios for Hydrogen Demand









Yet, further penetration is dependent on new uses, long-term electrification trends, and the role of other competing technologies across the energy, industrials, materials, and utilities sectors.

At present, emerging and high growth opportunities exist in industries such as long-distance aviation and shipping, high-temperature heat production, petrochemicals and steel production; where direct electrification is restricted by existing technological modes of operation, and hydrogen technologies face few other viable competing technologies.

Hydrogen demand scenarios by various energy think-tanks show a diverse range of estimates given the differences in the pace and extent of hydrogen penetration across various industries. Some scenarios for net-zero by 2050, such as the BNEF Strong Policy, the Hydrogen Council's H2 for Net-Zero, and IRENA 1.5oC, estimate hydrogen demand to increase to 614-696 Mt H2 / year in 2050[ix]. These scenarios assume a larger and broader global policy coordination between countries on achieving carbon neutrality than currently.

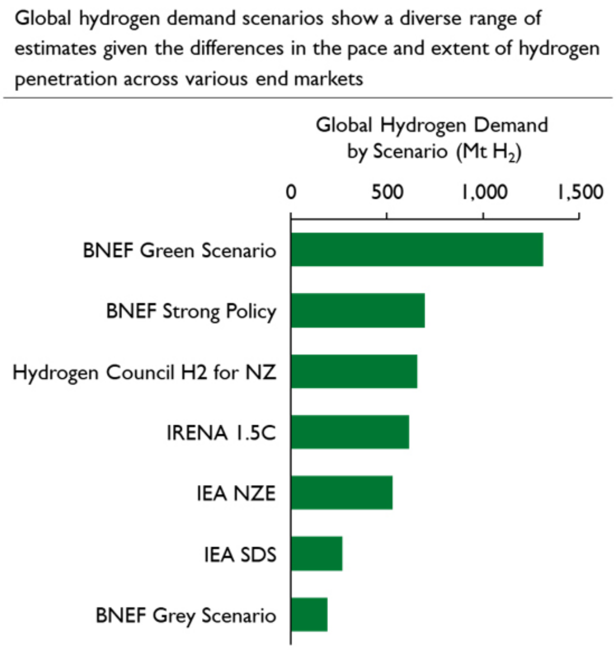
In contrast, other net-zero by 2050 scenarios, such as the IEA SDS and IEA NZE, project hydrogen demand to 269-528 Mt H2 / year in 2050, assuming moderate improvements in energy efficiency, a smaller change in energy consumption patterns by 2050, and a slower-increase in hydrogen demand across the power, aviation and maritime, and industrial sectors[x].

As of 2021, global hydrogen production stands at 90 Mt H2 / year, with 72 Mt H2 / year coming from dedicated hydrogen production units, and the remainder a by-product of other materials.[xi] Almost all dedicated supplies of hydrogen come from fossil fuels (i.e., brown or grey hydrogen), with 1% produced from renewables, and 1% from fossil fuels with CCUS technologies[xii].

Over the next 5 years, utility-scale low carbon hydrogen production (i.e., green hydrogen or blue hydrogen with CCUS) will be a high growth market.

However, at present, green hydrogen produced through renewable electricity lacks commercial viability at a large-scale. It also shows a wide range of variability in terms of electrolyser capital expenditure (CAPEX) and the cost of renewable electricity generation.

Figure 4: Other Global Scenarios of Hydrogen Demand



Similarly, CCUS has been largely underinvested over the last decade, and has not experienced the gains in cost competitiveness that other technologies such as utility-scale solar PV and offshore wind have. Blue hydrogen, however, is currently lower cost than green (if input natural gas costs are low) and is essential for the industry to reach a large scale. This, in turn, will reduce the costs of the transport, reconversion and end-use sectors, and so facilitate the introduction of green hydrogen. Some countries, such as Germany, are putting much more emphasis on green hydrogen from the very start, and the success of this strategy will depend on subsidies to ramp up output rapidly and bring down costs to the point of economic viability.

Figure 5: Global Hydrogen Supply

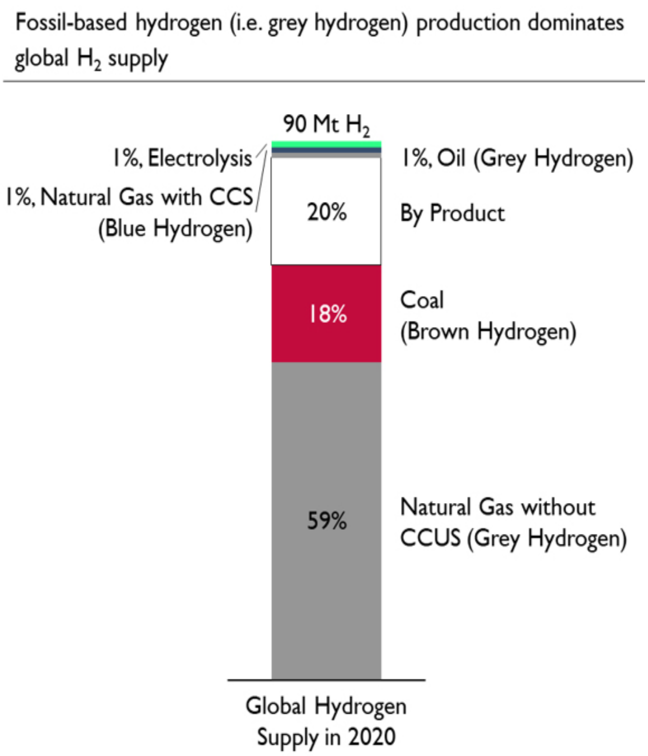
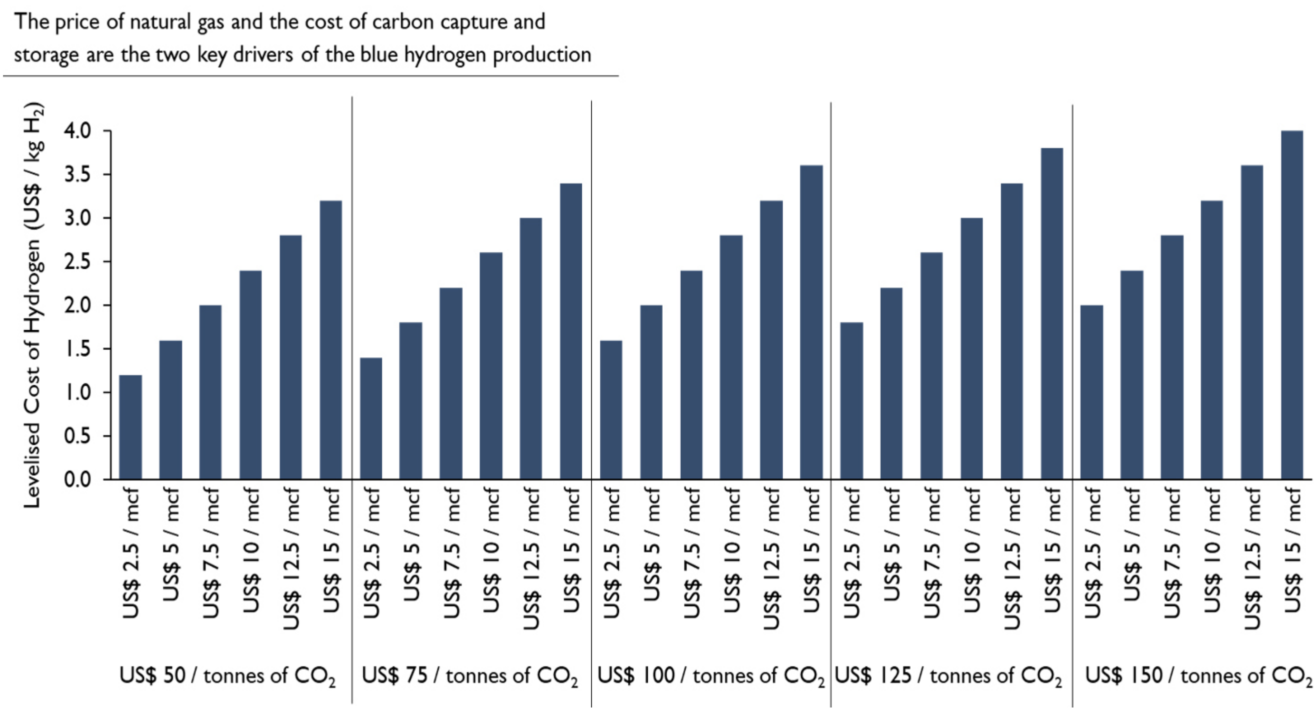


Figure 6: Levelised Cost of Blue Hydrogen



INVESTMENT AND ECONOMICS

Investments in global hydrogen supply chains over the next two decades will be critical in the expansion of the global low carbon hydrogen industry. The IEA estimates that a net-zero by 2050 scenario will require US$ 1 trillion of cumulative direct investments in hydrogen supply chains by 2030 and an additional US$ 9 trillion between 2030 – 2050[xiii]. Most of capital will be directed towards CAPEX for electrolyser systems and upstream CAPEX associated with renewable electricity generation.

Government expenditure will be crucial in encouraging greater private capital deployment. For example, Germany, as part of its national hydrogen strategy, has announced a €9 billion financial package, which is expected to attract to an additional €33 billion of follow-up private capital[xiv].

The levelised cost of producing blue hydrogen is highly dependent on the price of natural gas and the scale-up of carbon capture and storage. Both factors vary significantly across different regions, along with the technical ability and cost of sequestering the carbon dioxide, with onshore sequestration being more cost competitive than offshore. The availability of subsurface storage space is not an issue at a global level, but some areas, such as Japan, South Korea and parts of Europe, face geological/geographic constraints or a lack of public acceptance.

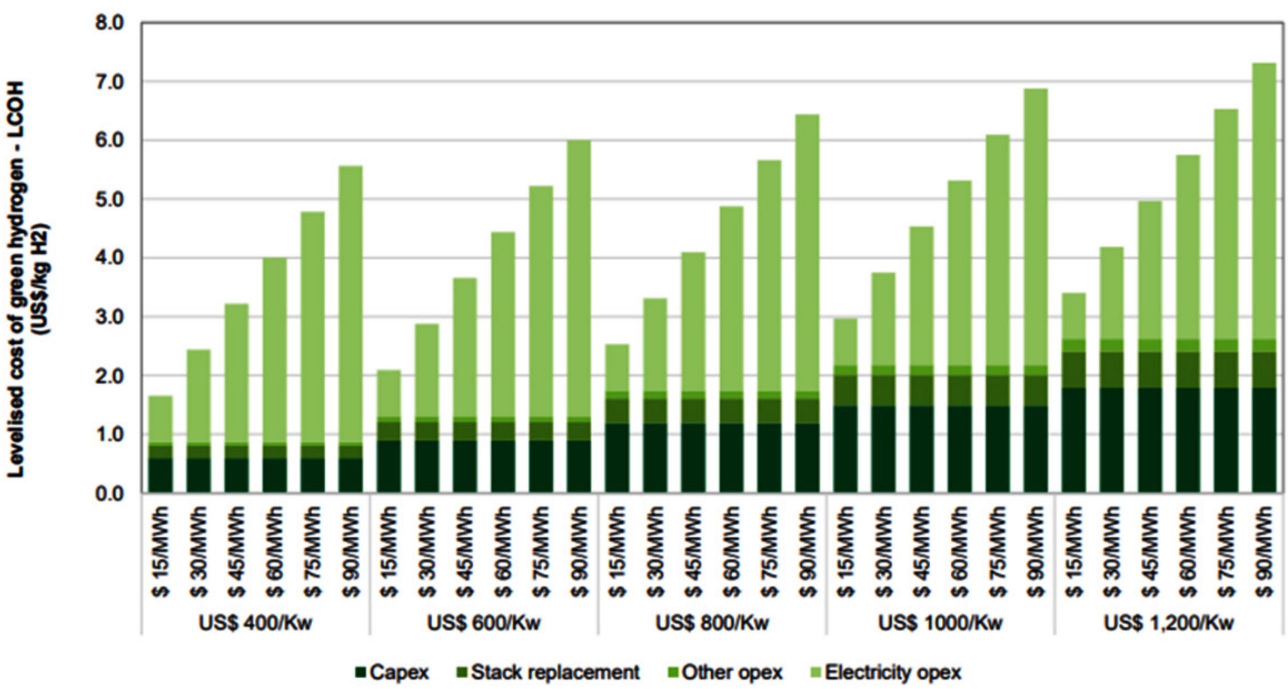
Steam Methane Reforming (SMR) is the most common method for blue hydrogen production. Combining an SMR unit with CCUS could result in a 90% decline in CO_2 emissions[xv]. Currently, 30% - 40% of the CO_2 emissions in an SMR unit come from natural gas used as a fuel source to produce heat and steam, which emits a dilute CO_2 stream. The remaining natural gas split into hydrogen, which produces 60% - 70% of CO_2 emissions through a concentrated stream.

The levelised cost of producing green hydrogen will benefit from a fall in the levelised cost of renewable electricity (LCOE), a rise in load factors, a moderate increase in electrolyser efficiency, longer electrolyser lives, and a reduction in electrolyser CAPEX as manufacturers pass on reduced production costs through economies of scale. Renewable electricity typically accounts for 58% of the levelised cost of producing green hydrogen, whereas the CAPEX of a water electrolysis unit accounts for 25% of the overall costs[xvi].

The decline in LCOE for renewable electricity over the last decade has brought green hydrogen much closer to large-scale economic viability. Since 2010, solar PV generation costs have declined by 80%, and offshore wind generation has fallen by 60%[xvii]. The decline in LCOE for both technologies is mainly driven by reductions in CAPEX, itself primarily because of manufacturing cost reductions through learning and economies of scale. Technological improvements and falls in the cost of capital have also played important roles.

Figure 7: Levelised Cost of Green Hydrogen

LCOE and electrolysers CAPEX are the two key contributing factors to the levelised cost of 'green' hydrogen, which is estimated to vary between US$ 2 / kg H_2 - US$ 7 kg / H_2



The cost of the electrolyser system is the second most important determinant of the levelised cost of hydrogen, which varies depending on the electrolyser technology. Alkaline and Proton Exchange Membrane (PEM) electrolysers are much more technologically mature than Solid Oxide Electrolyser Cell (SOEC).

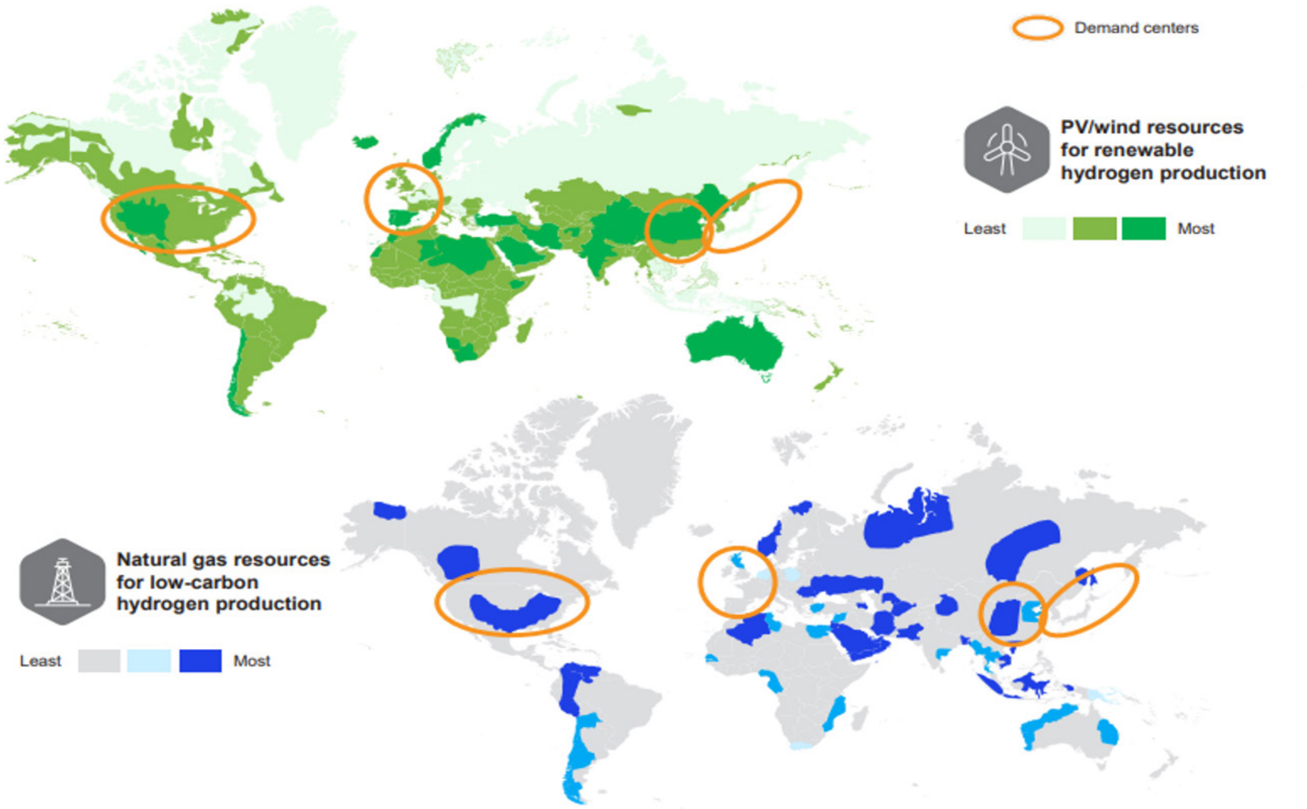
The cost of alkaline and PEM technologies has been declining over time, though PEM electrolysers remain somewhat more expensive. PEM electrolysers are more flexible than SOCEs and alkaline electrolysers, since they are able to change output quickly in response to varying electricity supply, in addition to having faster start-ups, less corrosion problems, and simple and fewer components.

Still, further improvements alkaline, PEM, and SOEC electrolyser stack designs and cell composition will improve their operational efficiency, and combined with economies of scale and an increase in module sizes, will unlock additional CAPEX cost reductions.

As the electrolyser manufacturing industry grows, by 2030, the cost of alkaline electrolyser units could decline by 50%, and by 65% for PEM units[xviii]. In the long-term, the cost of both types of electrolysers is likely to converge to ~US$ 300 / kW – U$ 400 / kW by 2030, with PEM electrolysers enjoying a slightly higher learning rate in comparison to alkaline electrolysers[xix].

As the LCOE for renewable electricity and the CAPEX for electrolysers continue to decline, green hydrogen could achieve cost parity with grey hydrogen before 2030, depending on how regional natural gas prices and markets evolve.

Figure 8: Hydrogen Demand Centres[xx]



As hydrogen production costs are projected to decline, the cost of transporting hydrogen will become increasingly important. The emergence of exports of hydrogen to Europe, South Korea, Japan, and China will be driven by differences in hydrogen production costs across these countries, due to variable renewable resources endowment, domestic demand for renewable electricity, lack of natural gas and hydrogen storage sites, weak existing relevant infrastructure, and land use constraints for domestic hydrogen production.

Hydrogen can be transported globally through trucks and pipelines for short and medium-range distances, or through ships and pipelines for long-range distances. The optimal choice of transportation also depends on the targeted end-use, and the terrain to be covered.

For short and medium-range distances, retrofitted pipelines can achieve hydrogen costs of US$ 0.1 / kg for up to 500 km[xxi]. However, these costs are only feasible if an existing pipeline network is available and suitable for retrofitting, with high throughput guaranteeing high utilisation rates.

For areas that lack a hydrogen-ready pipeline system, road transport through trucks in gaseous or liquid form is the most attractive option for moderate distances and volumes, with costs of ~US$ 1.2 / kg per 300 km[xxii].

For long-distance transport, new and retrofitted subsea distribution pipelines are often cheaper than shipping, but not for all regions. Where cross-border / cross-jurisdiction pipelines are not available or feasible, the only transportation choice involves liquefying the hydrogen and shipping it, using a liquid organic hydrogen carrier (LOHC) or converting it to another form such as ammonia.

Figure 9: Hydrogen Distribution Options

Legend				
	< US$ 0.1 / kg	US$ 0.1 – 1 / kg	US$ 1 – 2 / kg	> US$ 2 / kg

		Distribution		Transmission		
		0 – 50 km	51 – 100 km	101 – 500 km	> 1,000 km	> 5,000 km
Pipelines[1]	Retrofitted	City Grid	Regional Distribution Pipeline	Onshore Transmission Pipelines	Onshore / Subsea Transmission Pipeline	NA
	New	City Grid	Regional Distribution Pipeline	Onshore Transmission Pipelines	Onshore / Subsea Transmission Pipeline	NA
Shipping	Liquid Hydrogen	NA	NA	NA	Liquid Hydrogen Car.	Liquid Hydrogen Ship
	Ammonia[2]	NA	NA	NA	Ammonia Ship	Ammonia Ship
Trucking	Liquid Organic Hydrogen Carrier[2]	NA	NA	NA	Liquid Organic Hydrogen Car.	Liquid Organic Hydrogen Car.
	Liquid Hydrogen	Distribution Truck	Distribution Truck	Distribution Truck	NA	NA
	Gaseous Hydrogen	Distribution Truck[3]	Distribution Truck[3]	Distribution Truck[3]	NA	NA

Notes:

(1) Assuming high utilisation
(2) Including reconversion to hydrogen, liquid organic hydrogen cost is dependent on benefits for last mile distribution and storage
(3) Compresses gaseous hydrogen

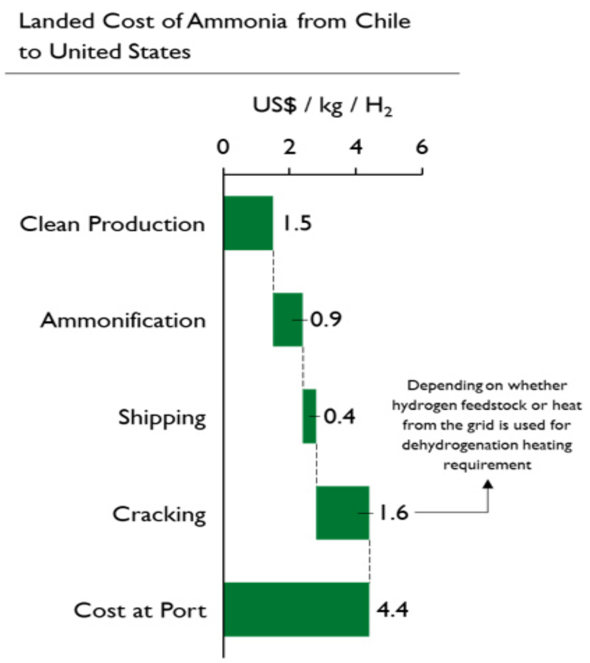
Hydrogen pipelines can effectively transport renewable hydrogen across long distances. These pipelines can transport 10x the energy at one-eighth the cost associated with electricity transmission lines. In addition to this, hydrogen pipelines have a longer lifespan than electricity transmission lines, and provide dual functionality, through transmission and storage of energy.

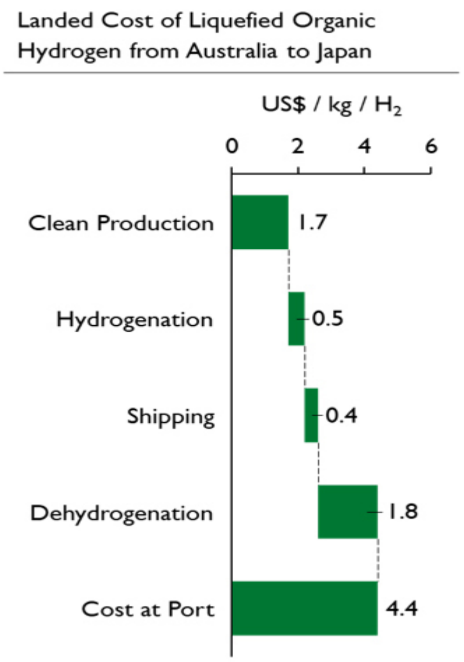
With hydrogen pipelines being the most cost-effective mode of transport, the actual costs transportation through a hydrogen network varies by type, length of the network, and the condition of the retrofitted pipeline itself.

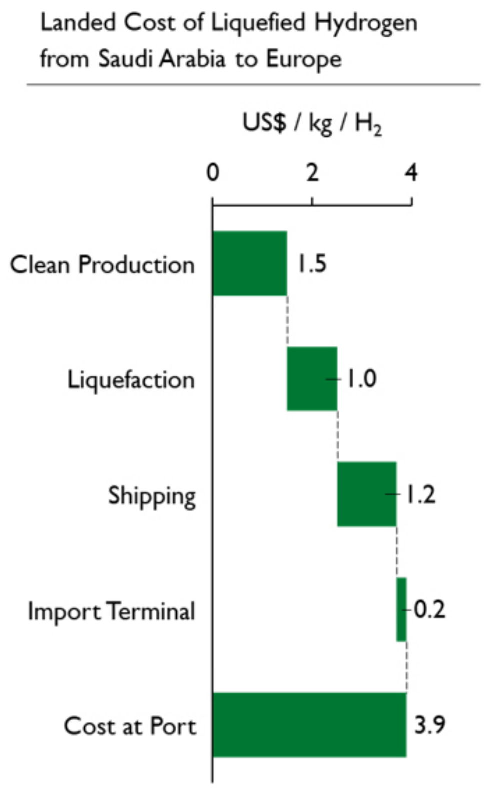
Typical CAPEX costs for an onshore transmission network ranges between US$ 0.6 – US$ 1.2 million / km for retrofit pipelines, and US$ 2.2 – US$ 4.5 million / km for new hydrogen pipelines, resulting in transport costs of US$ 0.13 – US$ 0.23 / kg / 1000 km[xxiii].

Currently, the most carbon-neutral sources of transporting hydrogen over long distances are by liquefy hydrogen and converting it to ammonia or supplying it through a liquid organic hydrogen carrier. However, the optimal choice of carrier depends on the intended end-use of hydrogen and its purity requirement.

Figure 10: Landed Cost of Hydrogen







Assuming large-scale production and transportation, hydrogen could be shipped from various ports in the GCC to projected demand centres at US$ 2 / kg – US$ 3 / kg[xxiv]. It can be seen from Figure 7 that the difference in green hydrogen production cost between a region with excellent renewable resources (USc1.5/kWh levelized cost of electricity) and with moderate renewable resources (USc6/kWh) is about $2.5-3/kg. Therefore, hydrogen could be competitive in these markets, but its economics are very sensitive to differences in production cost and to minimising transport costs. Figure 10 compares different likely trade routes and shipping methods. These suggest liquefied hydrogen or LOHC would be the most competitive transport method. However, for end-users able to use ammonia (shipping fuel, power plants, fertilisers), this is by far the most competitive transport method as the cracking step can be eliminated.

At present, several countries have explicitly announced their hydrogen strategies and targets, which amount to ~130 GW of installed capacity by 2030 and is > 400x the electrolyser capacity levels in 2020[xxv].

From 2017 to 2019, the Asia-Pacific region was the epicentre of the global hydrogen industry with Japan, South Korea, and Australia being the first to announce their hydrogen strategies[xxvi].

The Japanese and South Korean strategies mainly focused on the development of a local hydrogen economy, by encouraging domestic consumption, and developing the supporting transport and distribution infrastructure. Whereas the Australian strategy focused on making the country a major hydrogen export hub by leveraging its vast natural gas and low-cost renewable resources for blue and green hydrogen production.

Following the wave of announcements in 2020, the geographical gravity of the hydrogen industry shifted to Europe, with the EU announcing its 2 × 40 GW electrolyser capacity target by 2030 as part of its strategy.

The European Union's Hydrogen Strategy 2020 has also set the platform for developing a regional hydrogen industry. However, meeting its net-zero goal will require ambitious development over this decade.

Currently, the EU produces 7 Mt H2 / year, with 4 Mt H2 / year consumed by the refining industry and 3 Mt H2 / year by the chemical industry[xxvii]. Similarly to the United States, 80% of the country's hydrogen supply is produced from natural gas, whereas the remainder is produced as a by-product in refineries[xxiii]. The bloc currently holds 60% of global electrolyser manufacturing capacity[xxix].

In 2020, the EU announced the EU Hydrogen Strategy and the European Clean Hydrogen Alliance. The strategy emphasised the use of hydrogen in industry and heavy transport, as well as the role of hydrogen in balancing variable offshore wind and solar PV generation[xxx]. The alliance brings together industry, national and local public authorities, civil society, and other stakeholders to implement the strategy[xxxi].

The strategy envisions three phases for hydrogen adoption:

- Phase I (2020 – 2024) focuses on scale-up, with an interim target of 6 GW of renewable powered electrolysis, aimed at decarbonising current production capacities, and triggering an uptake in new uses such as long-distance road transport;
- Phase II (2025 – 2030) focuses on hydrogen becoming an intrinsic part of an integrated energy system while green hydrogen becomes cost-competitive and reaches new applications such as steelmaking and shipping;
- and, Phase III (> 2030) aims to install 40 GW of renewable powered electrolysis, with the goal of taking supply to all hard-to-decarbonise industries.

The United States has entered the hydrogen policy wave through a US$ 10 billion public expenditure plan under the Infrastructure and Jobs Act.

Through the bill the United States will focus on advancing low carbon hydrogen use in transport, utility, industrial, commercial, and residential sectors by:

- legislating US$ 8 billion over the next four years for the development of regional hydrogen hubs across the United States;
- instructing the United States Department of Energy to develop a technologically and economically feasible national energy strategy, which facilitates the widescale adoption of low carbon hydrogen;
- and, introducing the Clean Energy Electrolysis Program, which provides a US$ 1.5 billion grant for the research, development, and commercialisation of low cost and low carbon hydrogen. The grant will be eligible to entities that can help reduce the cost of low carbon hydrogen to US$ 2 / kg by 2026.

The United States is already one of the largest producers and consumers of hydrogen. The country's hydrogen demand stands at 11 Mt H_2 / year, which accounts for 13% of the global demand[xxxii]. Approximately, 70% of the United States' hydrogen supply is consumed by its refining industry, with the remaining mainly used for ammonia production[xxxiii]. And ~80% of the country's hydrogen supply is produced through natural gas reforming, whereas the remaining 20% is produced as a by-product[xxxiv].

GCC countries, notably Saudi Arabia, the UAE and Oman, have taken major steps with large-scale projects for green and blue hydrogen.

The GCC has a formidable oil & gas resource and a tremendous solar PV (and in some places, wind) potential, which can enable low-carbon hydrogen production at a significantly lower cost than in most parts of the world. Further to this, countries such as Qatar have considerable experience in exporting LNG, and could learn from this in developing hydrogen and derivative exports. Qatar is one of the world's lowest-cost gas producers, and its large remaining reserves could allow it to become an important supplier of blue hydrogen.

Recently, QatarEnergy, the national oil and gas company, has outlined plans to increase its CCUS and solar generation capacity. The company aims to install a carbon capture capacity of 11 MT / year and an additional solar generation capacity of 5 GW by 2035. These projects will help QatarEnergy further reduce the carbon intensity of its LNG facilities by 35%, and the carbon footprint of its upstream facilities by 25% by 2035 – compared to previous targets of 25% and 15%, respectively.

QatarEnergy has also signed agreements with Shell and South Korea's Hydrogen Convergence Alliance (H_2Korea) to develop hydrogen projects in Qatar, whilst at the same time expanding its current LNG production capacity to 126 MT / year over the next five years.

Saudi Arabia, Oman and the UAE have been the most active with several projects under development. For example, in Saudi Arabia a consortium consisting of Air Products, ACWA Power, NEOM is developing a US$ 5 billion hydrogen production facility, which will produce 650 tonnes H_2 / day using solar PV and wind powered electrolysis[xxxv]. Part of the hydrogen produced will be transformed into ammonia for export to Air Products' clients globally.

In 2020, Saudi Aramco, the Institute of Energy Economics Japan, and SABIC carried out a world first of exporting ammonia produced from fossil fuels with CCUS, shipping 40 tonnes of ammonia from Saudi Arabia to Japan for use in electricity generation[xxxvi]. The captured CO_2 was sequestered for enhanced oil recovery and chemicals production in Saudi Arabia.

Saudi Aramco has entered an MOU with South Korea's Hyundai Motors to expand further the hydrogen ecosystem in South Korea and Saudi Arabia, along with developing a network for FCEV refuelling stations in Saudi Arabia. Separately, Public Investment Fund (PIF) has agreed an MOU with South Korean steelmaker POSCO and Samsung C&T for export-oriented green hydrogen projects in Saudi Arabia. Saudi Aramco has also signed five agreements with French companies McPhy and Gaussin, which included an agreement to explore the hydrogen-powered vehicle business with Gaussin. The agreement also aims to establish a modern manufacturing facility for on-road and off-road hydrogen vehicles in Saudi Arabia.

In 2021, Dubai Electricity and Water Authority (DEWA) and Siemens inaugurated the region's first renewable-powered electrolysis project at the Mohammed bin Rashid Al Maktoum Solar Park in Dubai[xxxvii]. Sharjah-based Beeah Energy is also developing the region's first waste-to-hydrogen project in partnership with Chinook Sciences[xxxviii].

Abu Dhabi National Oil Company (ADNOC) is currently developing a low carbon ammonia facility with a production capacity of 1 Mt NH3 / year at the TA'ZIZ Industrial Chemicals Zone[xxxix]. Mubadala along with ADNOC and ADQ has entered into an MOU to establish the Abu Dhabi Hydrogen Alliance, which aims to build a green hydrogen economy in the UAE. ADNOC and South Korea-based GS Energy signed an agreement to explore the development of value chains for blue hydrogen and carrier fuels, including ammonia.

Through a joint study agreement, ADNOC, INPEX, JERA, and JOGMEC agreed to explore commercial opportunities in blue ammonia production in the UAE. ADNOC is also keen to explore the hydrogen projects in India's, which support India's rising demand for energy and cleaner fuels. In 2021, BP, ADNOC, and Masdar signed a strategic agreement to develop 2 GW of clean hydrogen hubs in the UK and the UAE. The agreement will see the development of a 1 GW of hydrogen project in the UAE and 1 GW in the UK, which will be expanded further. Recently, Masdar has entered into an agreement with Hassan Allam Utilities to develop a 4 GW green hydrogen project in Egypt.

In Oman, state investment firm OQ, along with Kuwaiti clean energy developer EnerTech and Intercontinental Energy, is developing a 25 GW hydrogen project, which will produce 1.8 Mt / year of green hydrogen. In April 2022, US-based H_2 Industries announced it will develop Oman's first waste-to-hydrogen project with Oman's Public Establishment for Industrial Estates (Madyan) through an investment of US$ 1.4 billion. Once the project is completed, the facility will process 1 Mt / year of solid waste and will include the construction of a 300 MW solar PV unit and 70 MW of electricity storage.

An interconnected GCC-wide hydrogen infrastructure that is interconnected with the wider MENA region (similar to the EU Hydrogen Backbone) consisting of repurposed existing natural gas infrastructure, combined with targeted investments in new dedicated hydrogen pipelines and compressor stations, could enable cost competitive long distance transport and exports of hydrogen from the GCC to Europe via North Africa; and from Oman to India via subsea pipelines or from Oman to Eastern China via Pakistan.

However, developing such a project would incur institutional and structural issues, tariffs and regulatory challenges, and require significant efforts to harmonise and commercialise the up-scaling of hydrogen in the region. The GCC does not have an interconnected natural gas grid, which would be a first step.

The GCC could also play a leading role in low carbon hydrogen production. The region holds significant advantages in the production of green and blue hydrogen, due to its abundant and low-cost natural gas and solar resource. In the long-term, consumer demand will drive investments in the low carbon hydrogen value chain. However, in the short-term it is up to policymakers and regulators in the GCC to attract capital in order to create demand, which they can do by:

- developing national hydrogen strategies and roadmaps that outline the role of hydrogen in their energy and export mix;
- incentivising low carbon hydrogen and hydrogen-based fuels use across various end-use industries, through carbon credits, mandates and quotas for low carbon technologies, and a public auction mechanism that awards large-scale hydrogen capacities; which ultimately displaces domestic demand for fossil fuels;
- building international partnerships to ensure the import or domestic manufacture of critical technologies; help projects reach commercialisation quickly; and mobilising investments in large-scale hydrogen clusters and hubs;
- and, establish regionally coordinated certification, standardisations, and regulation regimes.

While all these measures are inter-related, the implementation of one of them will impact the potential outcomes. The natural first step would be to define a national energy strategy, which outlines the role of hydrogen. Yet, it is unlikely that role will materialise without sufficient regulatory and fiscal incentives to mobilise investments for low-carbon hydrogen production and use.

The extent to which demand can be created is dependent on how quickly innovative technologies are commercialised in the region, the amount of capital directed to the GCC's hydrogen sector (especially foreign investment in more capital-short countries such as Oman); and the establishment of certifications, standardisations, and regulation schemes, which ensure hydrogen exports are classified as low-carbon when arriving in Europe or other environmentally sensitive buyers.

These measures need to function in a coordinated manner to ensure the effective adoption of hydrogen at the required levels across the GCC countries over the next decade, which could ultimately lead to a GCC-wide interconnected hydrogen infrastructure.

The unprecedented interest that hydrogen has received is underpinned by a global shift of regulators, investors, and consumers towards decarbonisation, mitigating climate change, and achieving carbon neutrality by 2050-60.

Since 2020, more than 30 countries have announced their national hydrogen strategies, which emphasises the role of hydrogen in decarbonising their industries and transport.

If these strategies materialise, hydrogen demand is estimated to increase to 614-696 Mt H2 / year by 2050. Currently, most hydrogen supply is produced from fossil fuels without CCUS, which has created a tremendous market opportunity for low-carbon hydrogen.

The creation of a global low-carbon hydrogen industry will require US$ 10 trillion of direct investments in supply chains by 2050. The ultimate expansion of low-carbon hydrogen is dependent on the cost competitiveness of blue and green hydrogen, relative to each other and to competing alternatives such as (today) grey hydrogen and unabated natural gas, and in future gas with CCUS, biomass/ biogas, batteries, and electrification.

The cost of blue hydrogen depends on the price of natural gas at the point of production and the scale-up of CCUS. The cost of green hydrogen will continue to benefit from a decline in costs of renewable generation, and a reduction in electrolyser CAPEX costs as manufacturers achieve learning and economies of scale.

At the current rate, it is projected that electrolyser capacities will increase by 400x to ~130 GW by 2030, with the United States, European Union, Australia and the GCC being the most attractive target markets.

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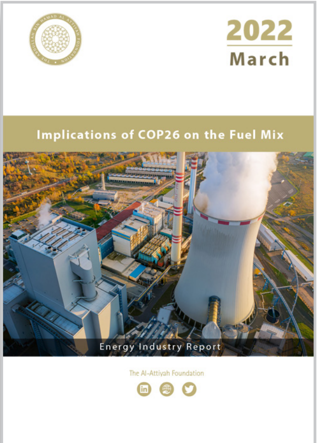

March – 2022

Implications of COP26 on the Fuel Mix

The outcomes from COP26 included major milestones such as the commitment to phase-down coal and fossil fuel financing, and the global pledge to reduce methane emissions by 30% by 2030. How will these pledges impact the sources of energy in the future?

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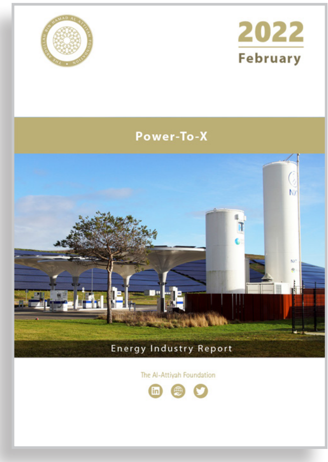

February – 2022

Power-To-X

'Power-to-X' is the concept of using electricity to produce useful fuels and chemicals from air, water and other basic inputs. Although hardly available today in a commercial manner, Power-to-X has gained interest for two main (and related) purposes: to convert excess renewables to a storable commodity, and to produce

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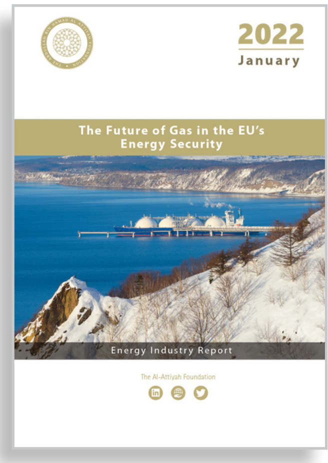

January – 2022

The Future of Gas in the EU's Energy Security

The European Union is currently seeing gas shortages and high prices, with declining domestic production and concerns over its relationship with Russia. Gas is also required as coal is being phased down. European countries vary in their attitudes to gas depending on domestic politics,resource position and energy mix.

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Our partners collaborate with The Al-Attiyah Foundation on various projects and research within the themes of energy and sustainable development.

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