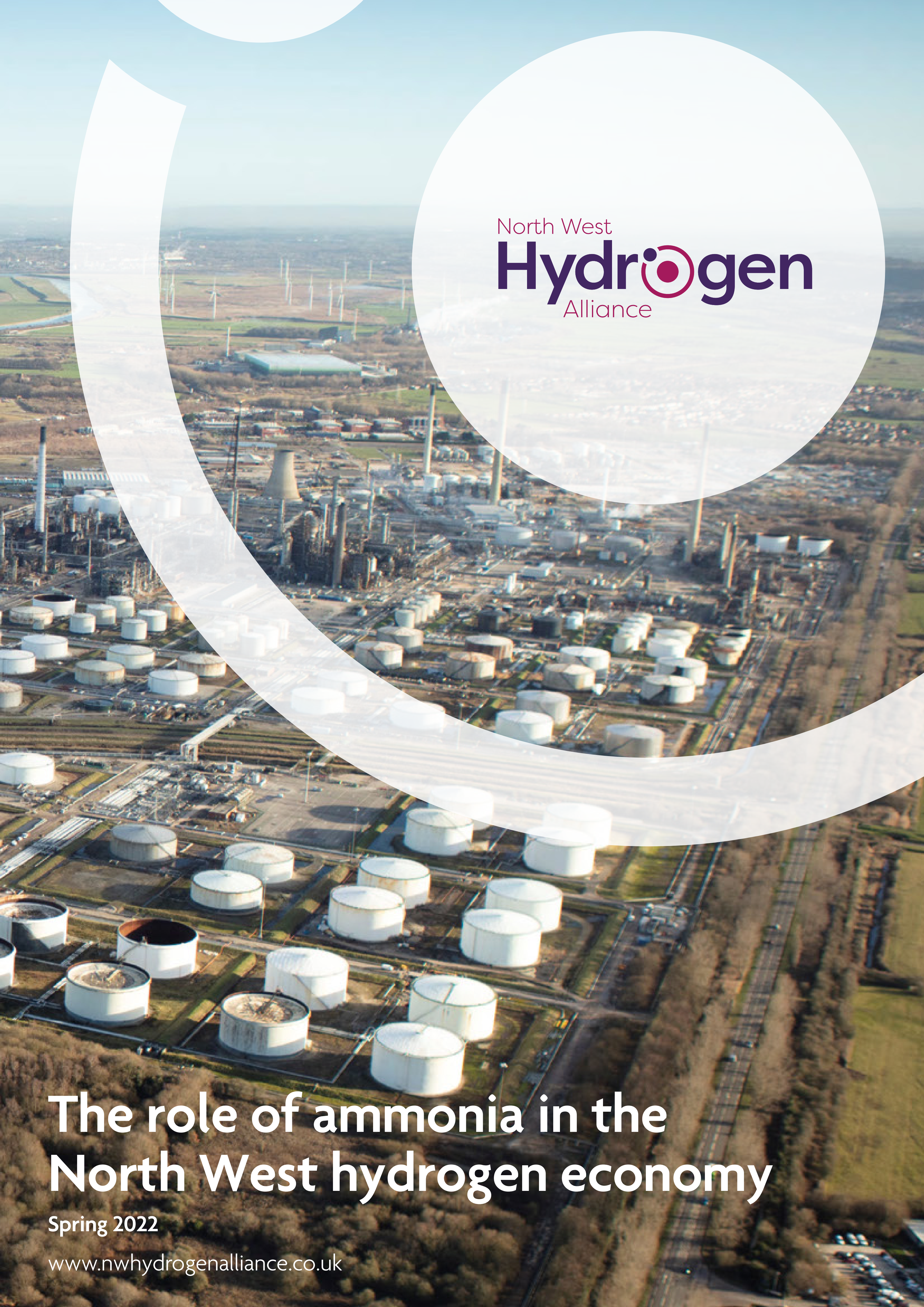
North West Hydrogen Alliance



The role of ammonia in the North West hydrogen economy

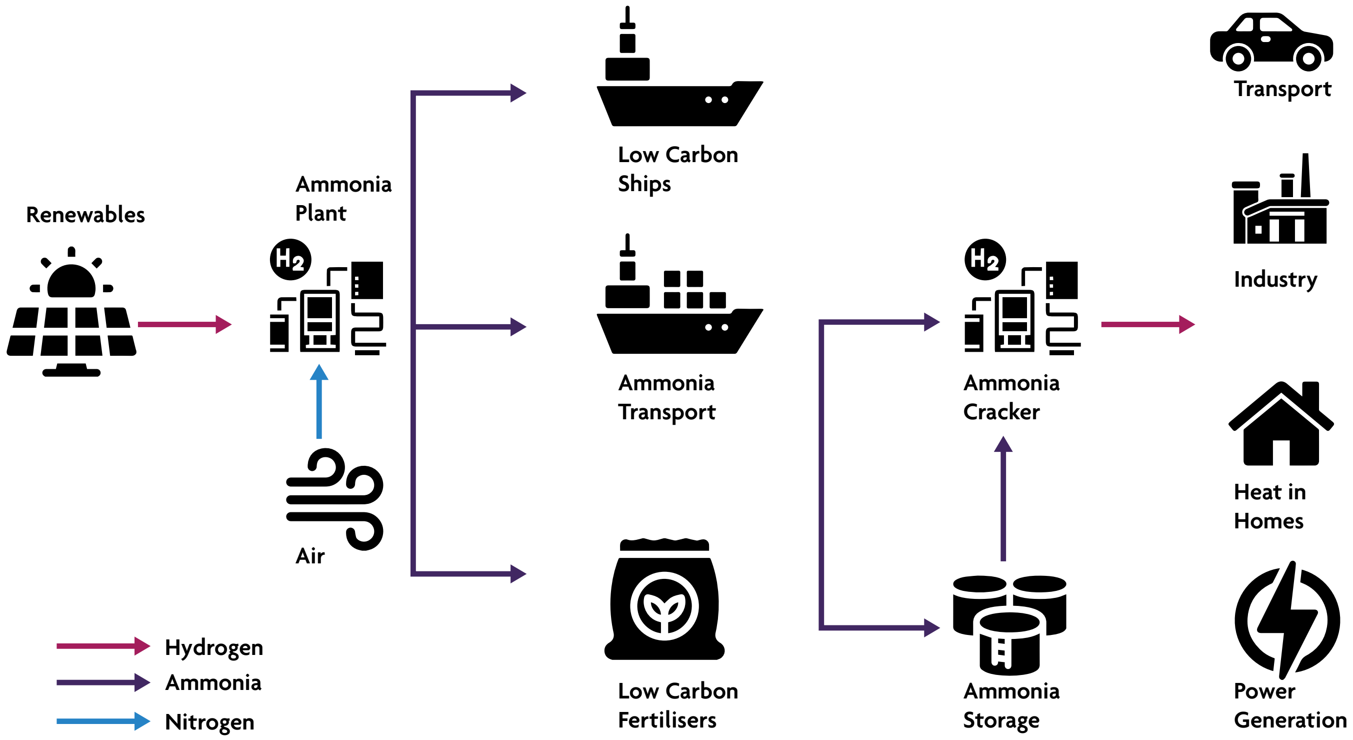
Spring 2022

www.nwhydrogenalliance.co.uk

The Ammonia Story

Ammonia plays a big role in our industrial and agricultural sectors and represents a $67bn global industry[1]. Current global ammonia production is about 176 million tonnes per year and is predominantly achieved through the steam reforming of methane to produce hydrogen to feed into ammonia synthesis via the Haber Bosch process.

In the future it will be necessary to utilise low carbon hydrogen either via electrolysis and renewables or via Carbon Capture, Utilisation and Storage (CCUS) to produce the hydrogen required for ammonia. Ammonia will also have a wider role to play in enabling us to transport clean energy globally. Ammonia produced via low carbon hydrogen can be used to transport clean energy from areas where it can be produced cheaply to where it is needed. Ammonia that is produced using low carbon hydrogen could also be used as a low carbon fuel in shipping.



Green Ammonia as a Future Shipping Fuel

Green ammonia is seen as one of the most promising decarbonisation options for large scale maritime applications.

This is because it has higher energy density than lithium ion batteries or hydrogen and does not need to be stored in cryogenic tanks like hydrogen. It can be either utilised in an internal combustion engine or in a fuel cell. There are a number of pilot projects that are exploring the use of ammonia in shipping. In Finland, Wärtsilä have tested ammonia in a marine combustion engine[2]. Germany's MAN Energy Solutions and Samsung Heavy Industries are developing the first ammonia-fueled oil tanker which will be completed in 2024[3]. By 2024, Viking Energy, an offshore supply vessel chartered by Equinor that currently runs on LNG will be retrofitted to be powered by an ammonia fuel cell[4].

[1] Fortune Business (2020)

[2] www.wartsila.com/media/news/30-06-2020-world-s-first-full-scale-ammonia-engine-test---an-important-step-towards-carbon-free-shipping-2737809

[3] www.lr.org/en/latest-news/industry-leaders-join-forces-on-ammonia-fuelled-tanker-project

[4] www.ammoniaenergy.org/articles/viking-energy-to-be-retrofit-for-ammonia-fuel-in-2024/

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Meeting UK Hydrogen Demand

Hydrogen is an important solution for decarbonising the UK energy system. The characteristics of hydrogen make it the perfect complement to electrification, delivering a more resilient energy system and decarbonising areas of the energy system which are hard to electrify.

It is estimated that the UK could require between 200-425TWh of hydrogen by 2050 if it is to deliver its Net Zero target. This would require the UK to develop a hydrogen domain that is roughly the size of the electricity domain today over the next 30 years. This presents a significant challenge.

The risk associated with delivering sufficient hydrogen production capacity to meet projected UK hydrogen demand would be reduced through the introduction of international hydrogen markets, allowing the UK to import hydrogen to meet any shortfall in domestic production and allowing the UK to access low-cost hydrogen.

The Need For Hydrogen Carriers

Hydrogen has a high energy density by mass, but a low energy density by volume compared with the most commonly used transport molecules (Figure 1). This presents challenges when looking to transport hydrogen over long distances.

Hydrogen is currently transported in gaseous and liquid states using tube trailers. For shorter distances, typically less than 60 miles, hydrogen is transported in gaseous state in 250kg tube trailers with the quantity of hydrogen limited by the weight of the steel tubes required to transport and the weight limits on roads. For longer distances, 200-300 miles, liquid hydrogen is transported in cryogenic tanks that typically carry 2000kg of hydrogen. There are significant losses associated with boil off with liquid hydrogen. A US study estimated hydrogen losses of up to 25% across the supply chain.

Energy density comparison of several transportation fuels (indexed to gasoline = 1)

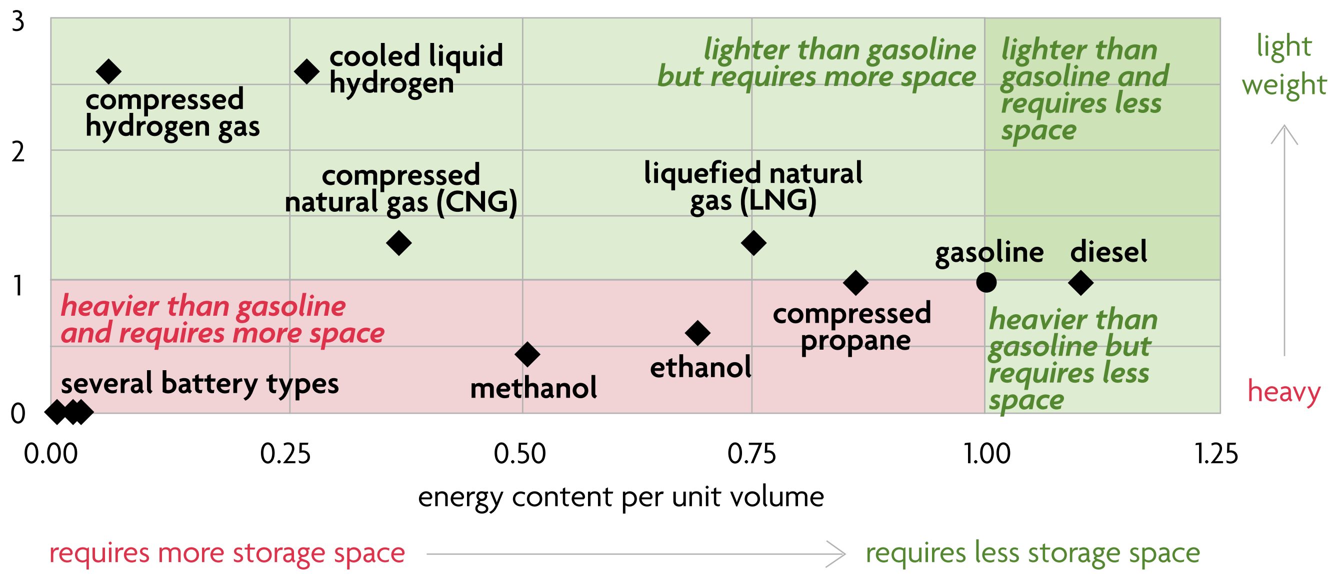

Figure 1 – Energy density comparison of transportation fuels (indexed to gasoline=1) 5

In order to open up international markets for hydrogen, hydrogen must be transported over significantly larger distances and at much greater volumes than is currently done today. Given the limitations of transporting hydrogen in its native form, several alternative options have been explored that would improve the economics of transporting hydrogen over large distances. These options include Liquid Organic Hydrogen Carriers (LOHCs), metal alloy hydrides and liquid ammonia.

The Role of Ammonia as a Hydrogen Carrier

Ammonia has several characteristics which make it well suited as a hydrogen carrier:

High hydrogen content
Ammonia has a high hydrogen content by mass (18%).

Zero carbon content
Ammonia is unique amongst hydrogen carriers in that the 'non-hydrogen' molecule is nitrogen rather than carbon. This can be obtained from the atmosphere and therefore does not need to be recycled or captured during the decomposition process.

Similarities to LPG
Ammonia has similar properties to Liquefied Petroleum Gas (LPG), meaning that there is scope to utilise existing storage, transport and terminal equipment.

Ease of liquefaction
Ammonia can be liquified under mild conditions. The vapour pressure of ammonia at room temperature is 9.2 bar. This combined with the high hydrogen content means that the volumetric hydrogen density of ammonia is 45% higher than liquid hydrogen. It also means that ammonia can be easily and cost effective stored and transported in a low cost pressure vessel.

Mature supply chain
Ammonia has a long history of large scale production for use in industrial processes such as fertiliser manufacture. Processes have been cost optimised and are well understood. Ammonia is currently transported at scale over large distances with good economics.

Ammonia is rapidly being considered the most promising long term molecule for global energy markets.

Type	MGO	LNG	Bio gas	Bio diesel	Methanol	Ammonia	Hydrogen
Carbon	Fossil Fuel		Carbon neutral				
Storage condition	Ambient temperature and pressure	-162°C	-162°C	Ambient temperature and pressure	Ambient temperature and pressure	-34°C or 10bar	-253°C
Relative fuel tank size	1	2.3	2.3	1	2.3	4.1	7.6
Relative CAPEX	1	1.3	1.3	1	1.15	1.2	Very expensive
Fuel cost & availability	Less expensive, high availability		Supply constraints mean this isn't a large scale option	Difficult to forecast due to unstable supply and food security issues	Expensive due to high cost of CO2 capture	Expensive compared to fossil fuel but low priced for carbon neutral	Reasonable fuel production cost. High storage and transport cost

[5] US Energy Information Administration (EIA) (2019)

The Economics of Utilising Ammonia as a Hydrogen Carrier

Global production of ammonia currently stands at 176 million tonnes per year. Most ammonia is produced at large scale via the Haber Bosch process where nitrogen and hydrogen react at pressures of up to 200 bar. The carbon intensity of the ammonia is dependent on the source of hydrogen. Almost all ammonia today is produced using natural gas or LPG as a feedstock and reformed to produce hydrogen.

In order to produce low carbon ammonia, a low carbon hydrogen source is required. The cost of low carbon hydrogen and therefore low carbon ammonia is largely driven by the economics and scale of production, with the input cost of renewable electricity for electrolytic "green" production or natural gas for CCUS-enabled "blue" production being the most significant factors. These costs are likely to be largely geographically driven. The low cost of solar energy in the Middle East and Australia means that hydrogen imported from these areas could be competitive with domestic production and could support the UK as it looks to meet domestic hydrogen demand.

Figure 2 shows an evaluation of the cost of hydrogen production from natural gas in different geographies. The CAPEX and OPEX of the reformation and capture process is the same for all locations, however the cost of gas has a large impact on the cost of hydrogen and varies by geography. The fragility of gas prices has been well documented in recent months, with the rapid rise in prices globally.

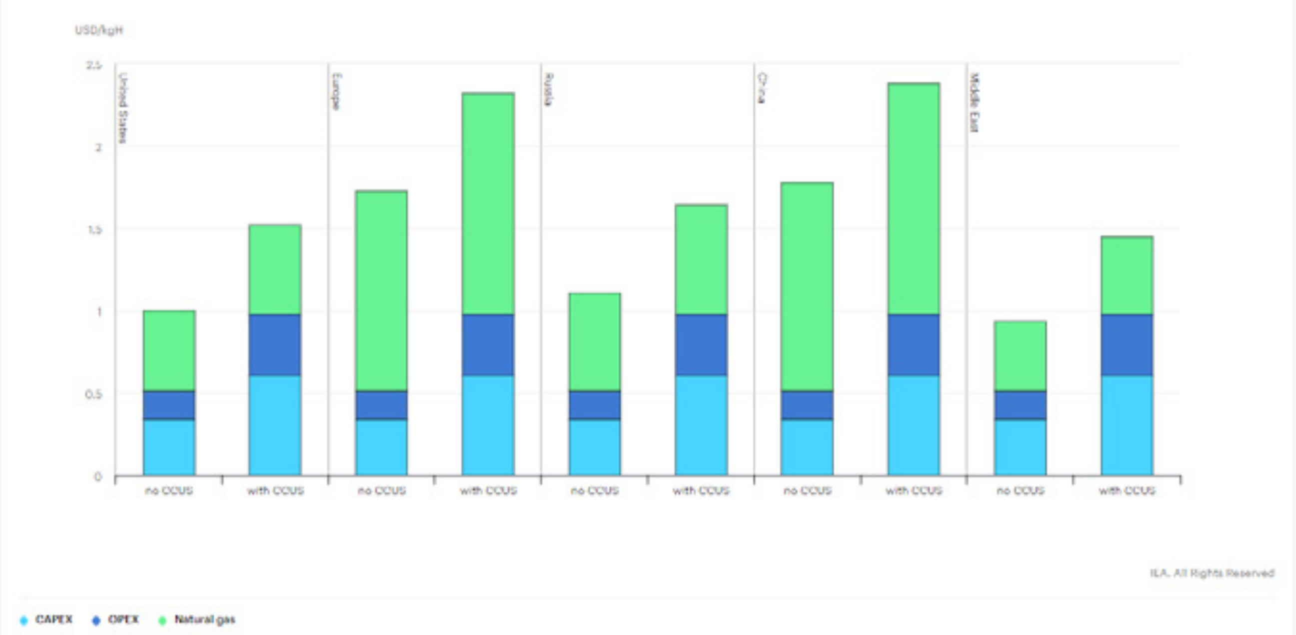

Figure 2 – Hydrogen production cost from natural gas by region6

Likewise the cost of renewably sourced "green" hydrogen will vary dramatically by region based on the input cost of renewables. Figure 3 shows that the cost of hydrogen could vary by up to $2.40/kg dependent on geography

[6] IEA The Future of Hydrogen (2018)

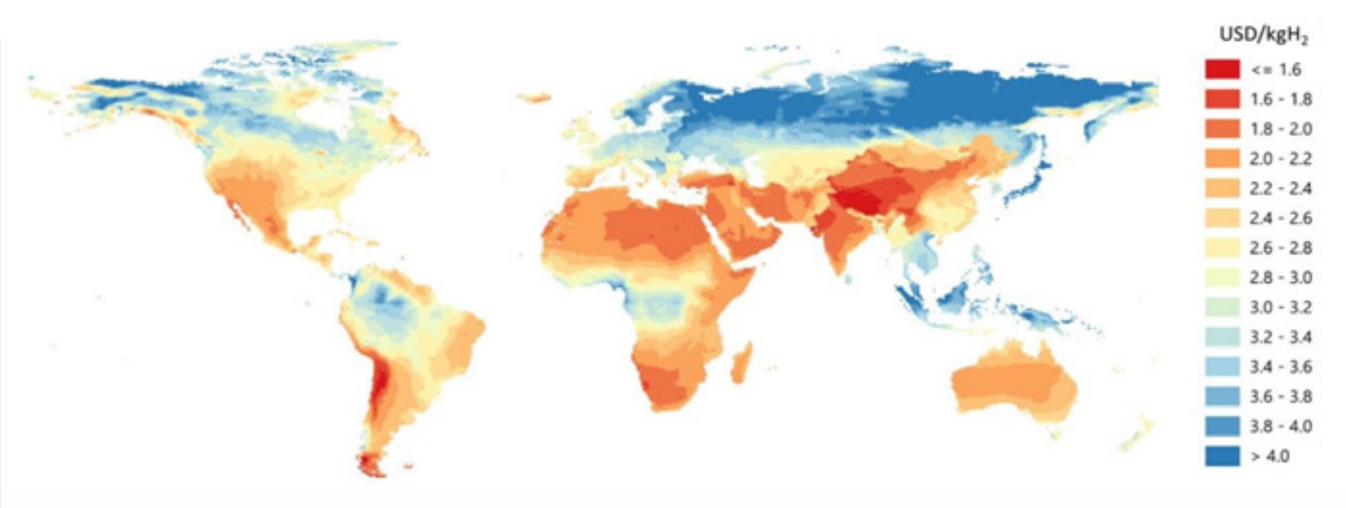

Figure 3 – Hydrogen production costs from hybrid solar PV and onshore wind in the long term

The disparity in hydrogen production costs between the UK and other parts of the world mean that hydrogen produced in areas such as North Africa and the Middle East could be utilised cost effectively in the UK. This will be dependent on the use of ammonia as a hydrogen carrier and the availability and cost of infrastructure to produce, transport, store and decompose ammonia.

Ammonia Safety

Ammonia is a very low reactivity fuel with a laminar burning velocity 30 times lower than that of hydrogen. Ammonia's flammable limits are higher than most fuels, but it can form flammable clouds and ignite. Even in highly congested environments, ammonia-air clouds do not produce damaging blast loads.

The main safety considerations regarding ammonia are due to its toxicity. Ammonia is a highly toxic fuel and as such cannot be handled by untrained personnel. For this reason it will never be used directly in cars or homes but will only be used directly in industrial and maritime applications.

Global Green Ammonia Production

Ammonia is viewed as a key future energy export commodity in several geographies which benefit from high solar gain. For example in the Saudi Arabian Neom industrial hub[7] there are plans for a $5bn 4GW green ammonia plant that will produce ammonia for export around the world where it will be cracked into hydrogen, primarily for use in transport.

Similarly there are plans in Chile for a 10GW renewable energy hub, H2 Magallanes[8], that will include an ammonia plant capable of producing 4.4 million tonnes of renewable ammonia per year. The plant is in feasibility stage but is due to launch in 2025 with production beginning in 2027.

[7] Ammonia Energy (Neom)
[8] Ammonia Energy (H2 Magallanes)

Ammonia in the North West

The UK currently imports around 200TWh[9] of energy in the form of LNG every year. The vast majority of this comes from Qatar (49%) and the US (27%). Ammonia and hydrogen offers the UK an opportunity to diversify and decarbonise our energy imports.

The North West has the opportunity to become a low carbon ammonia import hub and is well placed to do so for the following reasons:

High hydrogen demand
The North West has a high concentration of hydrogen demand due to its industrial activity. This makes it a strong candidate to support early uptake of hydrogen imports in the form of ammonia.

The presence of ammonia users in the region
CF Fertiliser's Ince and Billingham sites have capacity to produce material volumes of ammonia every year, predominantly used in fertiliser products at this time, but this usage continues to reduce over time. As a consequence safety and handling of ammonia is well understood in the region and the infrastructure exists to store and transport it.

Ports
The North West is home to one of the largest ports in the UK. The Port of Liverpool is the most centrally placed port in the UK. It has great diversity in handling various types of cargo ranging from agribulks, containers, automotives, dry bulk, forest products, energy products, metals, Ro-Ro, liquid bulks and project cargo. The port has a $400 million shipping terminal which welcomes mega vessels to the port. Given the role of ammonia within shipping the port provides an early opportunity to develop infrastructure to import and export ammonia.

In order to capitalise on this opportunity the North West should explore activities to support the development of ammonia as a hydrogen carrier:

Ammonia decomposition demonstrator
Ammonia decomposition is the least developed area of the decarbonised ammonia supply chain.

Explore opportunities for ammonia within the hydrogen economy both as a means of transporting and storing hydrogen within the region.

Explore opportunities to import or export ammonia.

Explore Explore the use of decarbonised ammonia in other applications such as maritime use and as an energy source off grid where hydrogen isn't available, including subsequent connections to the HyNet low carbon hydrogen network, under development in the North West, including a feasibility study to determine what would be required to facilitate ammonia update in the regional ports.

[9] DUKES 2021

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