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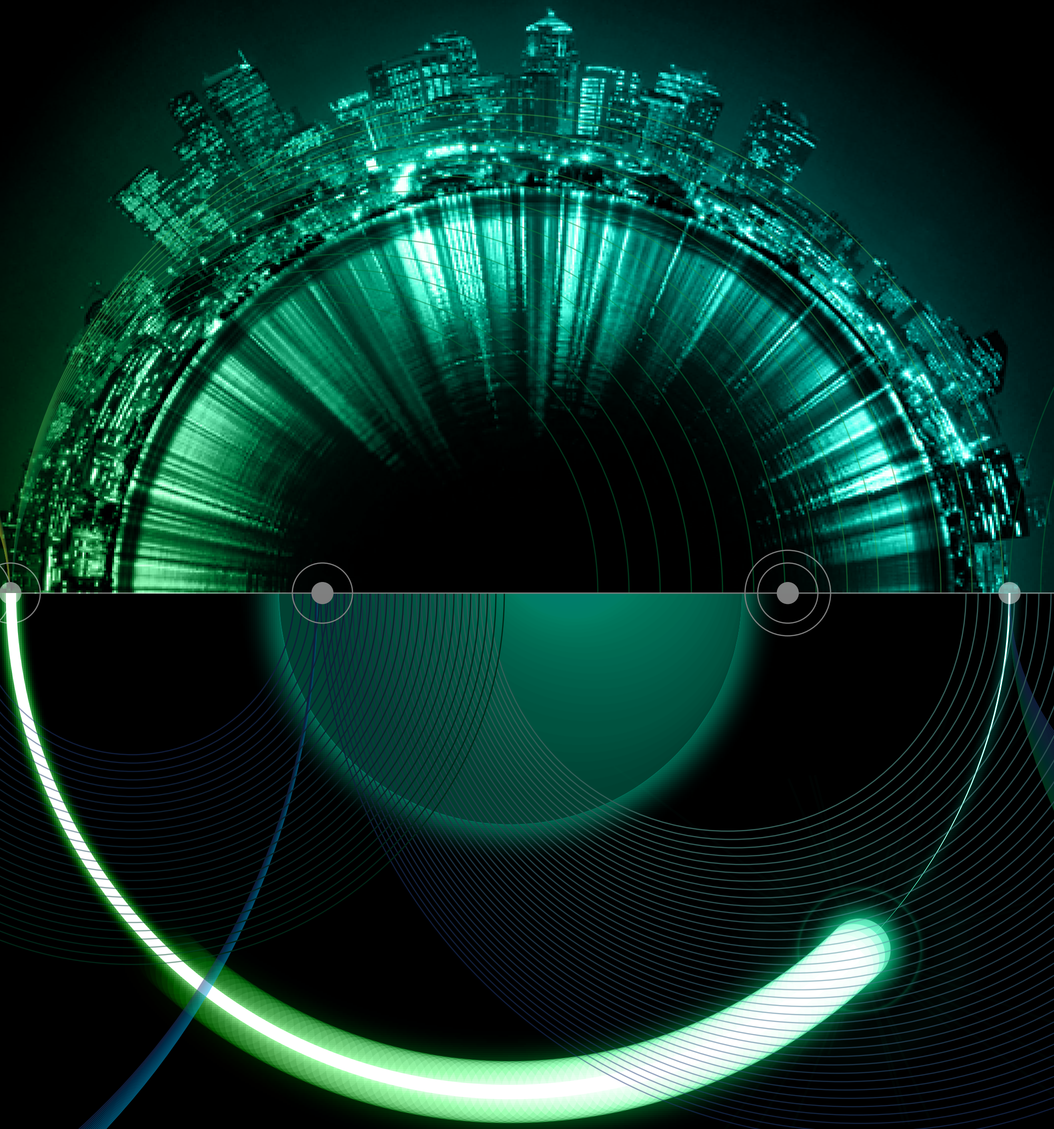

Hydrogen bonding
China and the UK

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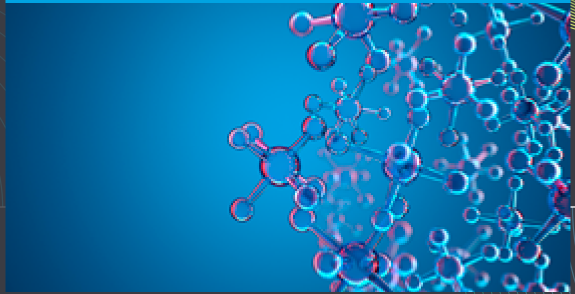

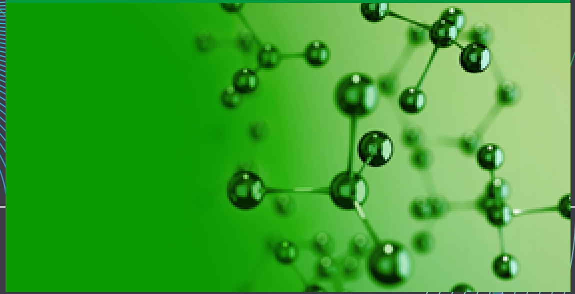

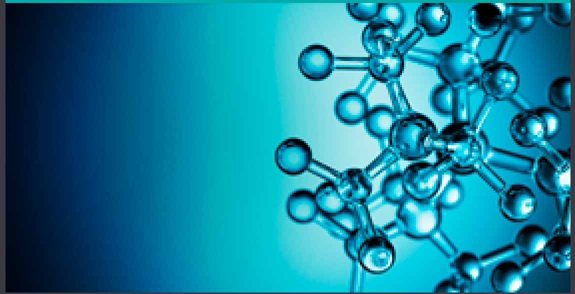

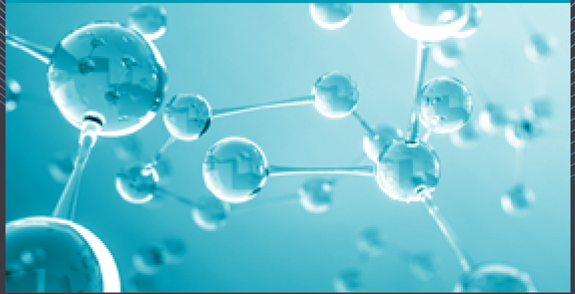

Foreword

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Currently, there is much space for improvement in the relationship between China and the UK.

Various political sensitivities have impacted the ease of collaboration in a number of areas.

Matters relating to climate change are not, however, thus constrained. The subject is of huge importance to both countries and is simply too important to be put aside, given that the route to addressing the issue requires intense global collaboration.

With the urgent imperative of the energy transition, it's now evident that low-carbon hydrogen will have an important role to play in the future global energy economy. The science of hydrogen as a mechanism for storing energy has been understood for centuries, and the manner of its deployment in future is now a matter of finance, engineering, and government policy.

As such, hydrogen has been selected as the topic of this paper, being an area where evidently the capabilities of the UK and China are complementary. The benefits from cooperation are attractive – there are opportunities for mutual trade, as well as to learn from and support each other on the hydrogen road.

Hydrogen has not hitherto been familiar to the many people who in future will be driving the energy transition to the net-zero future, in particular – as we will see – those who will be coordinating the provision of the necessary funds to make the transition happen.

The demands of a tremendous breadth of stakeholders – as encapsulated in the ESG (environmental, social and governance) paradigm – mean that it's perhaps already the case that 'all finance is sustainable finance', and certainly this is the case for hydrogen.

"We need to accelerate transition to a green and low-carbon economy and achieve greener recovery and development."

Xi Jinping, President of the People's Republic of China

"Climate change is the greatest commercial opportunity of our time."

Mark Carney, UN special envoy for climate change and former governor of the Bank of England

"Building greater mutual understanding between the UK and China is essential to a relationship that benefits the economies and societies of both countries."

Mark Tucker, Group Chairman, HSBC Holdings

Executive Summary

Written to build on the COP26 meetings in Glasgow, the purpose of this paper is to explore the hydrogen economies of both the UK and China and identify opportunities for collaboration in future.

It's clear that society has no choice but to head down the path away from fossil fuels, and hydrogen inevitably has a role to play.

The paper frames how low-carbon hydrogen will be deployed in the energy system in future, detailing the likely paths of development for both the supply and demand sides. As part of this, it takes us on a journey to encounter many different participants in the new hydrogen economies of both China and the UK.

We discuss in depth the readiness (or otherwise) of finance to engage with the topic of hydrogen, covering the perspectives of banks and investors. We also look at the mechanisms being developed by governments to underpin investment in, and lending to, the low-carbon hydrogen sector in future.

We approach the topic with eyes wide open, mindful that coupled with tremendous opportunity there is a real risk of failure in the sector both from a project and a technological perspective.

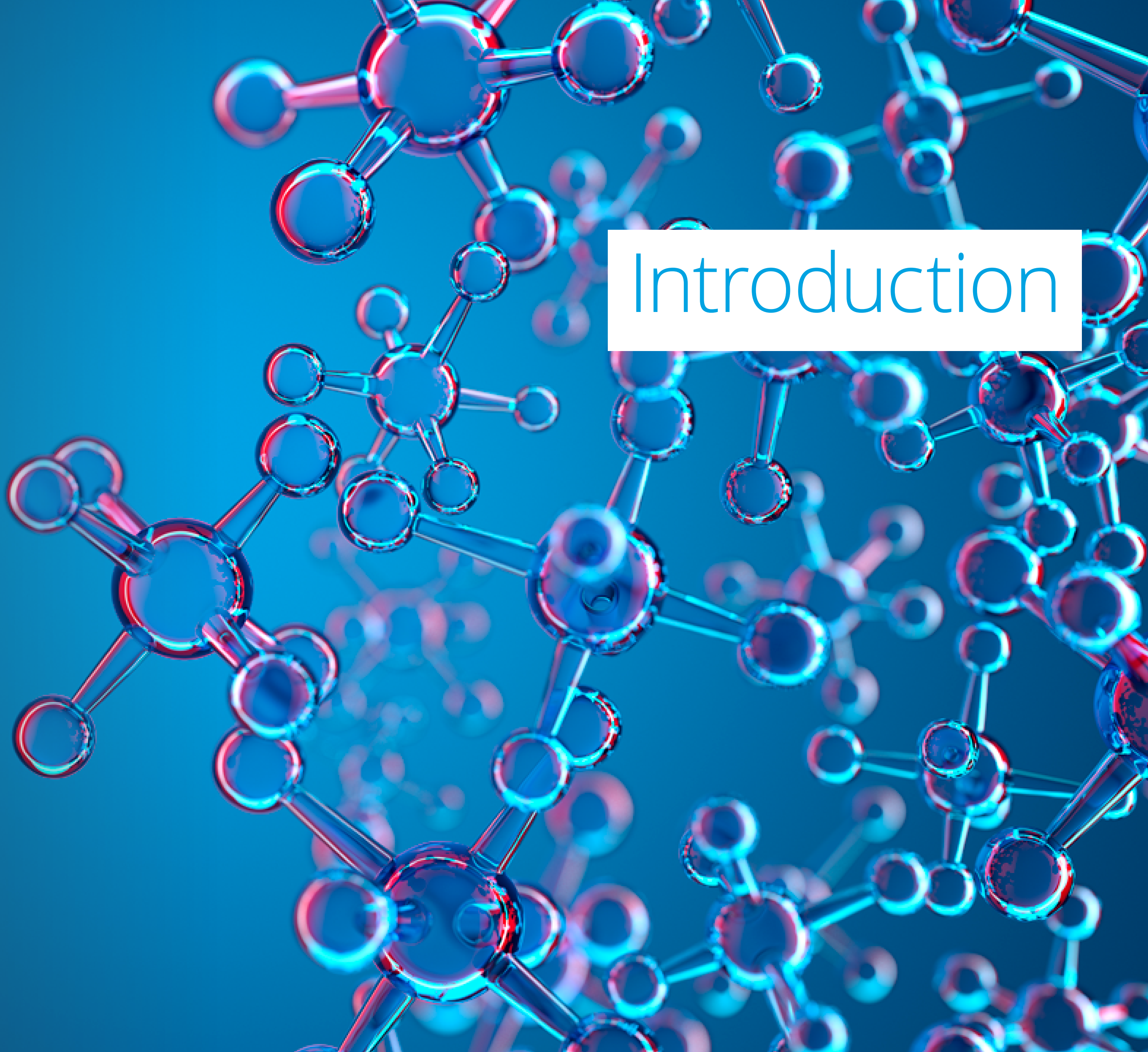
We have chosen to explore the hydrogen future of the British city of Manchester. As the hub of a sizeable regional economy, the city faces typical challenges common to other similar-sized areas in both China and the UK.

As well as a large population with complex energy needs, the city has an industrial base and considerable academic infrastructure. Furthermore, connections between Manchester and China are long-standing and the opportunities for partnership numerous.

We finish with some sharp recommendations, not just for those in the sector but also people in government and in finance.

The paper is written as much for the layman as for the informed industry expert. It aims to be informative and accessible so that there is something of value for every reader.

If your interest is piqued – whether about hydrogen, China and the UK, finance, or all of the above – please do come and speak to us at Deloitte. Our tremendous depth of expertise and the breadth of our client network means there are a great many ways in which we can add value for our clients.



Introduction

Global warming poses a formidable challenge to societies everywhere. Average temperatures today are about 1°C higher than before people started burning coal at scale. Most climate scientists anticipate that by 2100 temperatures will be 2–4°C higher than before 1750.

The increase in temperature is an outcome primarily of the burning of hydrocarbons – coal, oil and gas. This releases massive volumes of carbon dioxide and thereby changes the properties of the atmosphere, resulting in more of the sun's energy being retained by the planet than previously.

The impact of global warming can already be seen around the world. Weather patterns are changing everywhere. Melting glaciers and polar ice caps are causing sea levels to rise. Storms are stronger and more frequent. Food production is becoming more difficult. Reports of extreme heat, fires and drought are more common.

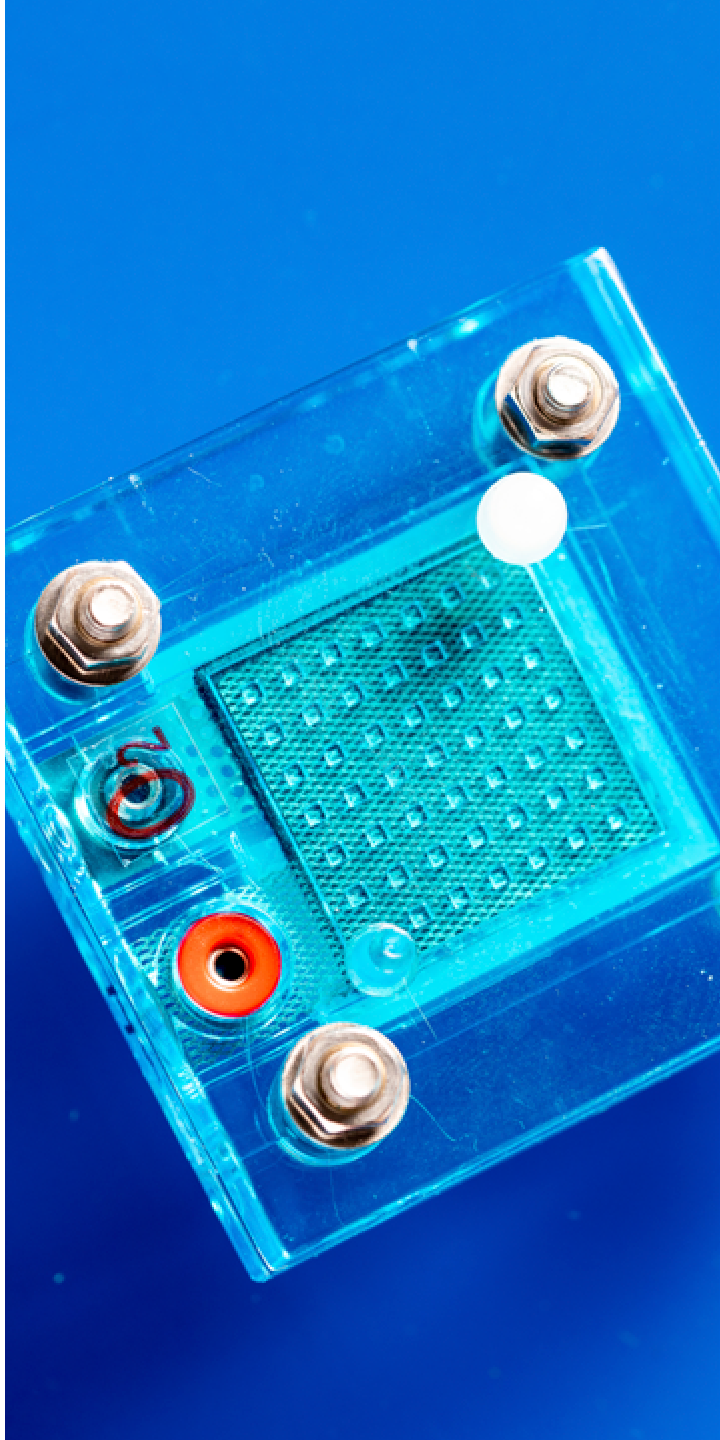
Although all this was predicted by many scientists a long time ago, it has taken a long time for governments to find responses that can start to address the multiple serious challenges posed by global warming.

The 1992 United Nations summit in Rio de Janeiro established the first international environmental treaty framework; the **Kyoto Protocol** was signed in 1997, and then supplanted by the **Paris Agreement** in 2016. This established a long-term goal to keep the rise in temperature to well below 2°C, with carbon emissions to be reduced as soon as possible and to reach net zero in the 2nd half of the century. ('Net zero' represents the point when the amount of greenhouse gas produced is no more than the amount removed from the atmosphere).

The **Intergovernmental Panel on Climate Change** (IPCC) provides an objective analysis of climate change. The sixth assessment report was published on 9th August 2021. It outlined that if the world did not begin to drastically cut emissions within a few years, it would no longer be possible to prevent 1.5°C of warming. To do this would require emissions to be cut by 50% by 2030 and 100% by 2050.

UN Climate Change Conferences happen annually, with the 2021 meeting, known as COP26, being in Glasgow, United Kingdom in early November.

"If the world does not begin to drastically cut emissions... it will no longer be possible to prevent 1.5°C of warming."



The role of hydrogen

Hydrogen (H2) is the most common element in the universe. On earth it can be found everywhere, whether combined with oxygen in the form of the water molecule (H20) or together with carbon and other elements in the complex organic molecules which constitute living organisms. It is very rarely found in its elemental form hydrogen (which at room temperature is a gas). Hydrogen burns rapidly in oxygen, releasing energy and a single byproduct, water.

An energy system powered by hydrogen was first proposed in 1923 by the British biologist J.B.S. Haldane, who foresaw the exhaustion of coal for power generation and proposed a network of hydrogen-generating windmills. The idea has regularly been proposed as a potential solution to addressing the issues related to the use of fossil fuels, particularly in the United States and Japan. However, to date there has been little adoption beyond the development of pilots and test concepts.

But this will not remain the case in future. Society and governments are taking action with increased urgency to mitigate climate change and meet commitments to net zero; industrial participants are preparing to scale up, often in partnership with academic institutions which bring innovation and new technologies; and banks and investors are preparing to deploy the enormous sums of capital needed.

Within the energy transition, low-carbon hydrogen is certain to play an important role, although exactly how and where remains a topic of speculation. Julio Friedman, a senior research scholar at Columbia University's Center on Global Energy Policy has termed hydrogen the 'Swiss army knife of decarbonisation' in recognition of the tremendous versatility of the fuel. In contrast, Michael Liebreich, founder of Bloomberg NEF, has stated "Hydrogen is going to have to win, use case by use case, but it will not be easy. Not only does it have to beat the incumbent technology, but it also has to beat every other zero-carbon option for that use case". A great deal can be done with electrification before hydrogen needs to be deployed. Liebreich memorably paraphrases Heineken: "hydrogen decarbonises parts of the energy system electricity cannot reach".

> *"Hydrogen decarbonises parts of the energy system electricity cannot reach."*

The language of hydrogen

Colloquially hydrogen is ascribed a colour depending on its manner of production:

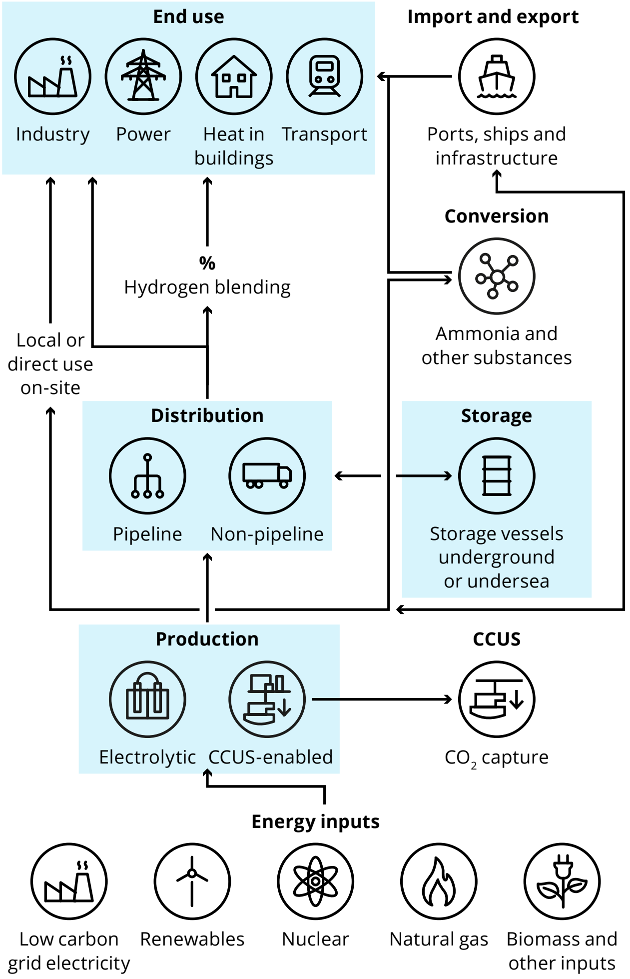
- **'Grey' hydrogen** represents the most common form of hydrogen produced today. It uses natural gas in a steam methane reformation (SMR) process, releasing carbon dioxide as a byproduct. Grey hydrogen is already produced in volume for industrial purposes, in particular for the production of fertilisers and in oil refining. In 2018 73.9m tonnes of grey hydrogen were produced globally (International Energy Agency).
- **'Blue' hydrogen** is created through the same industrial process as grey hydrogen. However here the carbon is retained rather than being released into the atmosphere using an industrial process called carbon capture and storage (CCS).
- **'Green' hydrogen** refers to hydrogen formed by running electricity through water in electrolysers, with the power coming from a renewable energy source such as wind or solar power. This mechanism itself is 'clean', producing no direct greenhouse gas emissions.

Of these, grey hydrogen is currently the cheapest (but highest-carbon) form of production; green hydrogen is the lowest-carbon but most expensive. Hydrogen's success in the future depends on the economic viability of moving to green and blue forms of production. This is driven in turn by inputs such as the cost of renewable energy, the cost of constructing and maintaining infrastructure, and the cost of capital – all of which promise to reduce as the scales of deployment increase.

Additional colours include 'black' hydrogen (produced from coal), 'pink' hydrogen (electrolysis using nuclear power), 'turquoise' hydrogen (thermal splitting of methane), and 'white' hydrogen (naturally occurring).

There is a lively debate in the sector as to the viability, economics, appropriate investment and timelines for the various colours of hydrogen.

"Green hydrogen is produced using electrolysers which can be located close to the source of renewable energy."



Source: UK Hydrogen Business Model, BEIS 2021

Production & conversion

Green hydrogen is produced through electrolysis using electrolysers, which are typically located close to the source of renewable energy (offshore/onshore wind, solar, tidal etc). Blue hydrogen is produced in industrial locations alongside carbon capture and storage facilities.

Whether low carbon or no carbon, the biggest costs in the hydrogen system are manifested at this stage.

Hydrogen can be combined with other chemicals to create forms suitable for storage: for example, ammonia, metal hydrides, or dissolved in toluene.

Storage

One of the great advantages of hydrogen as an energy vector is that it can store energy for extended periods with minimal degradation or leakage (unlike batteries, for example, which can go flat). Storage is most effectively done in compressed gas containers, or (for large quantities) in underground salt caverns.

Hydrogen is technically complex to manage, however, requiring either high pressures (350-700 atmospheres) or low temperatures (minus 253°C). It is highly reactive, embrittling metal components such as iron, and prone to leakage.

Transport & distribution

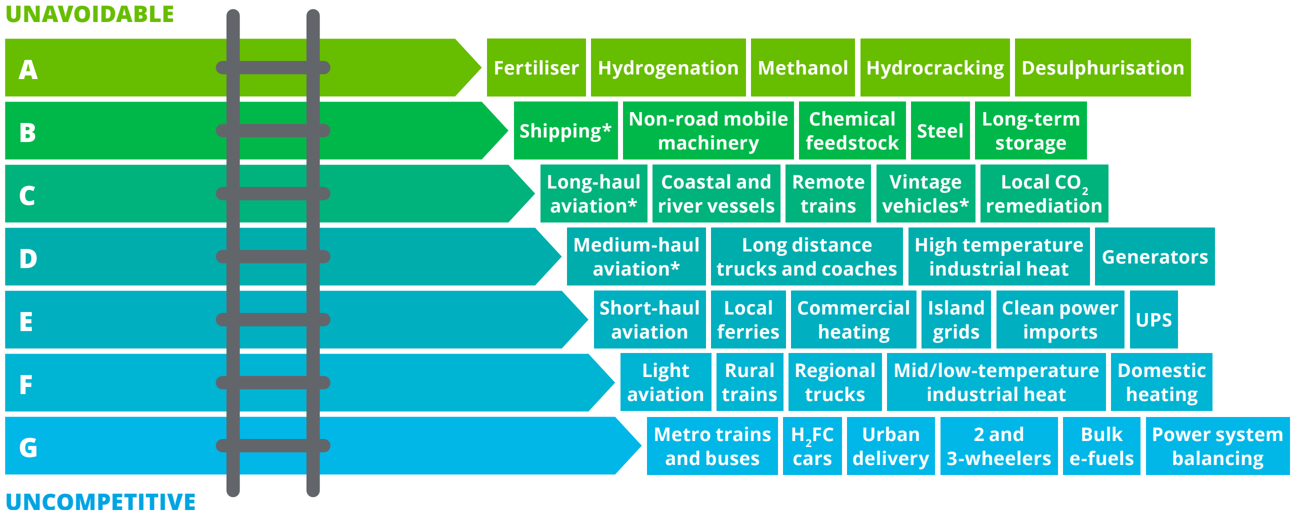
The long-distance transport of hydrogen is most cost-effective through pipelines in a gaseous state. Trailers are likely to be used to serve sectors where smaller-scale transport is needed for shorter distances.

Application & usage
There are many ways in which hydrogen potentially can be deployed in future. The answer to the question of which will ultimately be adopted at scale depends on each one's ability to overcome technical and economic challenges, and achieve scale adoption.

Commonly considered applications include:

- Adoption of hydrogen as a fuel in the transport sector, in sectors where electrification is not possible or practical. Use cases include private vehicles and public transport, as well as heavier commercial vehicles, rail, shipping and aviation.
- Deployment in the power sector. Low-carbon hydrogen could be used to store excess renewable energy at low cost, in turn increasing short-term and seasonal system flexibility.
- Use in the industrial sector, both for existing processes such as fertiliser production and for new applications (as the demise of hydrocarbons drives a need for new manufacturing techniques, for example in plastics).
- Domestic and commercial heating. Hydrogen could replace natural gas and provide low or zero-carbon heat for buildings.

The Clean Hydrogen Ladder puts the cases of hydrogen into an order of merit as not all are equally likely to succeed. It starts with examples of where grey hydrogen is used today and finishes where there are almost certainly other better solutions (generally direct electrification and batteries).



Source: Michael Liebreich/Liebreich Associates, **Clean Hydrogen Ladder, Version 4.1, 2021**.Concept credit: Adrian Hiel, Energy Cities.

The economics of hydrogen

The economics of the energy sector is intensely complicated, and low-carbon hydrogen needs to overcome a series of daunting barriers if it is to prevail over incumbent fossil fuels,

- The high cost of low-carbon hydrogen relative to high-carbon alternatives
- High technological and commercial risks for innovative investments
- Demand uncertainty due to current limited use of low-carbon hydrogen
- Lack of market structure and long-term policy and regulation
- Barriers relating to distribution and storage
- Policy and regulatory uncertainty including lack of established standards

This suggests that policy interventions in some form are necessary in order to support sustainable and resilient hydrogen markets. External factors (such as higher carbon prices) or one-off interventions (such as capital support to hydrogen producers or end-users) will not on their own be sufficient to allow low-carbon hydrogen to prevail over fossil fuels.

The complexity of the hydrogen value chain means that a variety of solutions are required to stimulate the hydrogen market. It is not the case that there are existing distribution networks that can take on hydrogen, and it's anticipated that the hydrogen market will largely operate on a localised scale, with projects matching together production, distribution and end-use.

The primary incentive to switch to low-carbon hydrogen is financial. Consumers will make such decisions based not just on the cost of the hydrogen option, but also on the cost of the higher-carbon incumbent, which varies significantly depending on the application. For example, per unit of energy, the fuels used in transport are considerably more expensive than those used to heat buildings.

In addition, costs are different depending on production characteristics. For blue hydrogen, the main driver of cost is the cost of the feedstock itself (in the form of natural gas). By contrast, for electrolytic green hydrogen the cost comes in the form of electricity, which is cheapest if sourced from dedicated low-carbon electricity sources rather than accessing grid power.

Important points to note:

- The production of hydrogen requires an energy source – whether methane reformation or low carbon electricity – and this creates system dependencies with CCS networks and electricity systems respectively.
- Production technologies are at different levels of maturity today.
- Limited physical infrastructure exists for hydrogen distribution and storage today.
- Very little low-carbon hydrogen is produced and consumed globally today. It is not an established commodity with a clear market price.
- Many of the technologies required for end-users to switch to hydrogen are not yet commercially available or proven to be safe.
- The first projects will be in the form of clusters, where production and consumption are in the same locality.

The financing of hydrogen
British financial institutions have evolved in recent years towards a greater emphasis on purpose. Purpose seeks to consider an institution's raison d'etre and considers how to accommodate appropriately the jostling priorities of the organisation's various stakeholders, which as well as shareholders include customers, staff, regulators, community and society itself. The corporate social responsibility ecosystem includes the ESG concept which seeks to score an institution against environmental, social and corporate governance criteria. Purpose and ESG are a strong boardroom force and in banks there is ever more CEO talk of environmental factors, including making organisational commitments to 'net zero'.

Independent of the rhythm coming from the top floor, at the working level a financial institution's business is ultimately led by demand. Bankers respond to the needs of clients, and those taking on credit risk will look for positive cash flow and high-quality counterparties to provide debt finance. The challenge for all in the hydrogen sector is to engender such scenarios as promptly as possible.

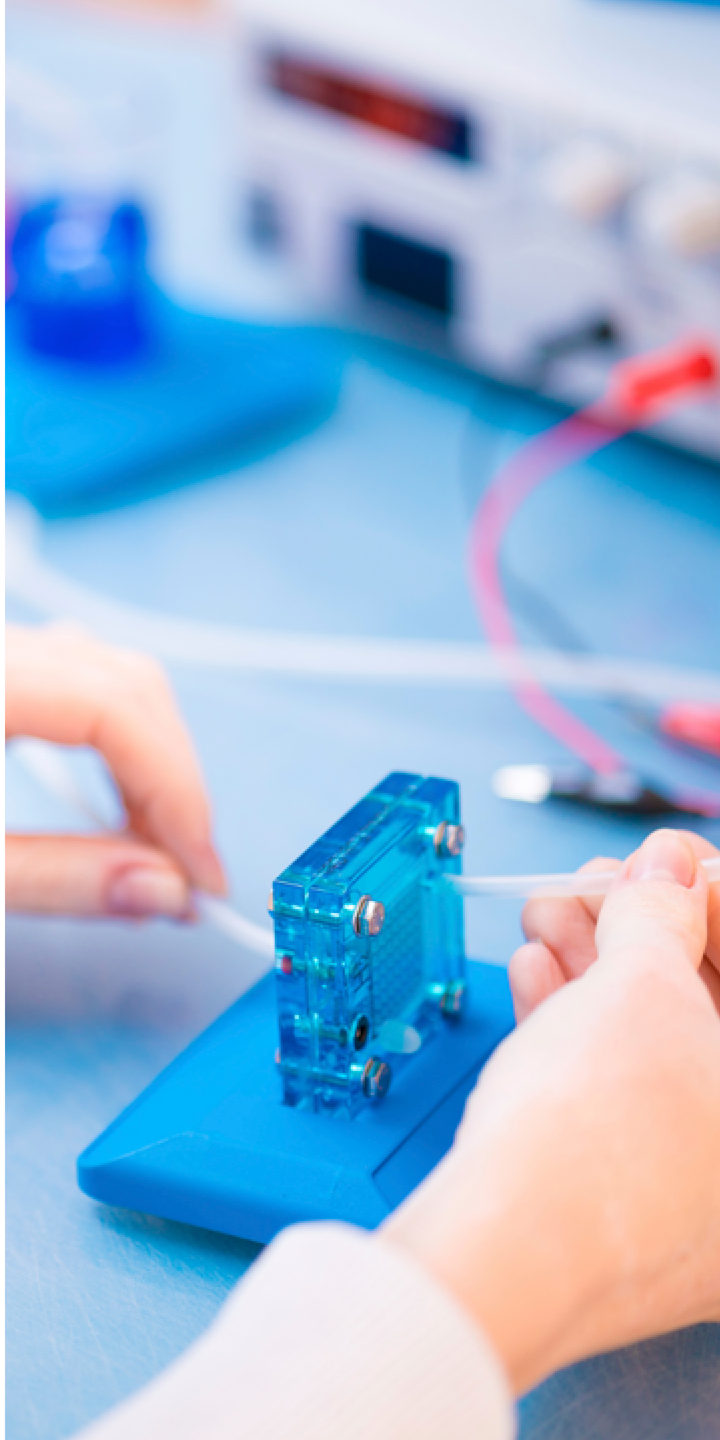
The equity scenario is contrasting. Capital flows towards where future growth is anticipated and with the excitement about low-carbon hydrogen, both institutional and private investors are considering how to position portfolios in relation to the energy transition, which includes hydrogen. The possibilities of long-term significant upsides are tempered by likely short-term volatility and the certainty that there will be losers in the sector as well as winners. Nevertheless, as with banks, equity investors are looking for government support.

"Bankers respond to the needs of clients... those taking on credit risk look for positive cash flow and high quality counterparties."

However, the situation in China is somewhat different. In essence, strategic direction is set by the national leadership and central government, and then execution is delivered by local and regional governments and state-owned corporations along with significant engagement from private enterprises. In addition to delivering commercial returns, state-owned banks have a significant role to play in driving the deployment of capital to target sectors.

All those with a financial stake in the hydrogen sector face an interrelated set of risks. These include market price risk (that the cost of inputs such as electricity and natural gas is not covered by the price of hydrogen itself), volume risk (that there is insufficient demand for the product), and technological risk (that equipment fails, is costly to maintain, or is made obsolete by more productive iterations).

Therefore all sectors seeking to engage with this new technology will have to develop a more sophisticated understanding of the dynamics of the entire low-carbon hydrogen ecosystem.



The view from China

Chinese government climate commitments

China has made clear commitments to reducing its carbon intensity. The country contributes over 25% of global CO_2 emissions each year, and so it is not surprising that the government is looking to invest in green energy to reduce its carbon footprint. In September 2016 China officially ratified the Paris Agreement and submitted its Nationally Determined Contribution. Key amongst its commitments was a pledge that it would aim to have CO_2 emissions peak before 2030.

Beyond the targets established as part of the Paris Agreement, four years later in September 2020, President Xi Jinping announced the nation's goal to archive carbon neutrality (i.e. net-zero carbon emissions) by 2060 at the UN General Assembly[8].

To this end, the latest 14th Five-Year Plan called for the implementation of a nationally determined contribution target for climate change in 2030, with a focus on controlling fossil fuel consumption[9].

There are plans to develop the infrastructure to meet these goals. Having set out clear targets to reduce its carbon footprint, China launched its framework for a national emissions trading scheme (ETS) in 2017, after running various regional pilot programmes. In 2021 the framework was given legal force and will begin trading in the latter half of 2021.

The scheme will initially only cover the power sector, which makes up roughly 30% of domestic emissions. Nevertheless, given the size of the Chinese economy, this will make it the largest emissions trading system in the world in terms of CO_2 covered, even when including "only" the power sector. It will cover approximately 3.5 billion tonnes of CO_2, compared to the European Union's scheme – the world's current largest system – which covers roughly 2 billion tonnes[10].

Currently, the scheme has generous quotas with a surplus amount for power companies. This grace period is expected to last the length of the current 5-year planning cycle. As of 27 August, carbon emission allowances (CEAs) have traded for around RMB 50 per tonne (a bit under USD 8)[11], which is notably lower than Europe's current price of over EUR 50 (roughly USD 60). Trading of CEAs only began on 16 July, so the volume of trades so far has not been significant. However, once the scheme is fully established and the grace period has ended, like in Europe, there will be a tightening of surplus allowances, pushing up the price in the long run. The introduction of the ETS will also provide the backbone to expand to other sectors of the economy, such as chemicals, steel, building materials and domestic aviation[12].

8 http://www.china.org.cn/china/Off_the_Wire/2021-02/01/content_77177529.htm
9 http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm
10 https://www.vox.com/energy-and-environment/2017/12/22/16804594/china-carbon-trading-system
11 https://www.caixinglobal.com/2021-09-02/china-carbon-watch-emissions-allowance-market-prices-hold-firm-despite-slump-in-trading-101767891.html
12 https://www.paulsoninstitute.org/green-finance/green-scene/analysis-how-chinas-national-emissions-trading-scheme-will-work/

Chinese government green and renewables strategy

China's energy transformation will require a broad range of technologies – including green hydrogen. To reduce Chinese emissions will not be easy, however, given the size of China's economy. China has relied heavily on coal power to fuel its impressive growth over the past few decades. The country cannot rely on one single technology or path to reduce its footprint and will take a comprehensive approach, including wind, solar, hydrogen, gas, nuclear power, transport electrification, carbon sinks and increasing energy efficiency.

The Chinese government has not outlined specifically the forecast technological mix it expects to need to reach its climate goals. Nevertheless, to achieve its goals, the bulk of electricity production will need to move from coal to renewable sources. This will probably be led by wind and solar, due to their rapidly decreasing cost. But green hydrogen will play a key role too.

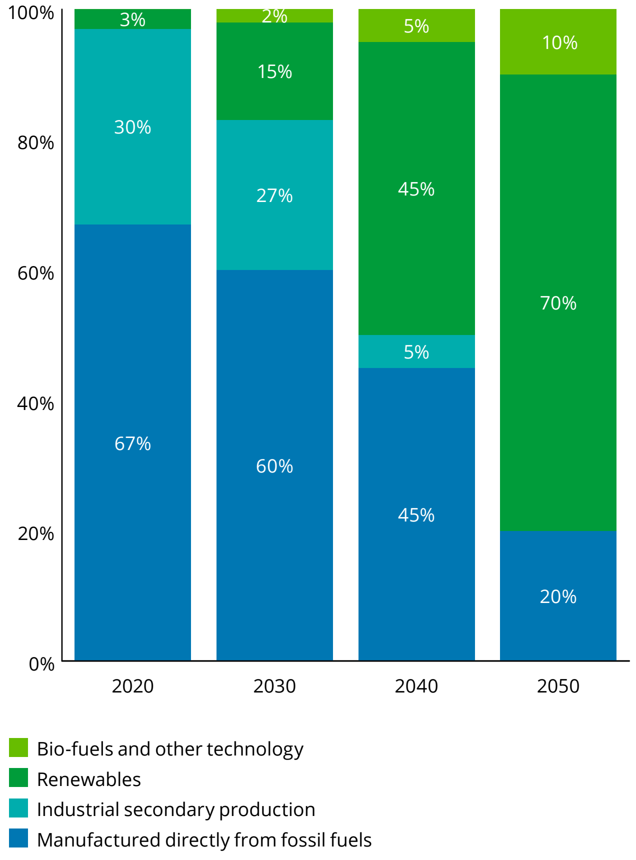
Green hydrogen will develop an important niche as a counterbalance to solar and wind's intermittency problem. Renewables, such as solar, and hydrogen can act as a complementary technology, where the energy generated by solar during periods of excess supply can be used to generate hydrogen from the electrolysis of water. Hydrogen can play a key role as a store of energy in areas of China rich in solar and wind resources, but relatively unpopulated, such as Inner Mongolia, where China is already planning large-scale green hydrogen projects using solar and wind power[13].

Illustrative demonstration projects

Operator	Location	Capacity
Demonstration project	Ordos and Baotou Cities Inner Mongolia	66,900 tonnes of green hydrogen
Sinopec	Ordos, Inner Mongolia	20,000 tonnes per annum
Sinopec	Kuqa city Xinjiang	20,000 tonnes per annum
Beijing Jingneng Power	Ordos, Inner Mongolia	400,000 to 500,000 tonnes of hydrogen a year

An implication of this is that as renewable energy becomes cheaper, green hydrogen becomes more competitive compared to generating hydrogen from fossil fuels such as coal (so-called black or brown hydrogen) or gas (grey hydrogen). Currently, without subsidies, green hydrogen is more expensive than black or grey, though industry figures suggest that if renewable energy prices – which are trending downwards – keep falling by another third, it will become economical[14].

Forecast sources of hydrogen energy in China



Source: China Hydrogen Alliance

13 https://www.fr24news.com/a/2021/08/china-wants-huge-new-green-hydrogen-plant-operational-in-2023.html
14 https://asia.nikkei.com/Spotlight/Caixin/China-s-hydrogen-roadmap-4-things-to-know

Chinese government hydrogen strategy

The Chinese government is looking to support low-carbon hydrogen. There has been increasing notice of hydrogen at a national government level in recent years. In 2016 hydrogen was listed as one of the 15 key focus areas of China's energy strategy and technology innovation plan[8]. In 2019's Two Sessions (the annual meeting of China's two main deliberative bodies) hydrogen was mentioned in the government work report for the first time. Continuing the trend, the latest 14th Five-Year Plan especially names hydrogen energy in its forecast plan for future industries, advocating incubation and acceleration plans for the sector[9].

In September 2020 the national Chinese government launched its hydrogen support policy. The policy is aimed at a city level. Individual cities (or city alliances) that meet the central government's criteria will be considered hydrogen "demonstration cities" and be eligible to receive support. The central government will provide a "reward in place of subsidy" to hydrogen demonstration cities' local governments. These cities' governments can then match the reward as they pass it along to key industry players in accordance with that city's development plan. Which cities will be eligible for the support will be determined by five central ministries, including the Ministry of Industry and Information Technology.

A key part of the central policy is that the national government does not directly subsidise companies, and instead support is mediated through local governments.

In late August 2021, Beijing was chosen as the first demonstration city, centred on a cluster of 12 districts in the Beijing-Tianjin-Hebei region. This was likely to be followed by news that Shanghai and Guangdong are set to receive approval[10].

National hydrogen projects

Responding to support from the central government, local governments are getting involved in low-carbon hydrogen, and over 20 provinces have developed plans for hydrogen energy facilities.

Beijing has targeted 3,000 fuel cell electric vehicles (FCEVs) by the end of 2023 and 37 filling stations, ramping up to 10,000 vehicles by 2025. The city already boasts 150 hydrogen-related companies and institutions but aims to develop 10 to 15 globally influential hydrogen enterprises. The hydrogen energy industry chain in the Beijing-Tianjin-Hebei region is expected to be valued at over 100 billion yuan (USD 15.4 billion) by 2025[11].

8 Fueling the Future of Mobility, Deloitte
9 http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm
10 https://www.caixinglobal.com/2021-09-03/hydrogen-cars-get-boost-as-shanghai-and-beijing-given-go-ahead-to-grow-fuel-cell-sector-101768566.html
11 http://europe.chinadaily.com.cn/a/202108/18/WS611c5d3da310efa1bd669724.htm

Guangzhou in Guangdong Province has released a development plan to build an entire hydrogen energy industry chain. Guangzhou is looking to establish itself as a hydrogen energy hub for southern China, with the city's hydrogen energy sector industry value targeted to exceed 20 billion yuan (USD 2.8 billion) by 2022 and 200 billion yuan by 2035[12].

Shanghai has selected low-carbon hydrogen energy as one of its six industrial development focuses in its local 14th Five-Year Plan. The city already has 1,500 FCEVs and nine stations and has announced plans for over 70 filling stations (especially in new planned satellite districts). Jiading district in Shanghai aims to be China's 'hydrogen port'. The district is a key hub for automobile manufacturing in Shanghai, so is well placed to invest in fuel cell technology. Auto manufacturer SAIC has invested over RMB 1 billion (around USD 150 million) in the development of fuel cell stacks and systems, electronic control, and vehicle integration in the region[13].

In 2017 Foshan in Guangdong Province became the site of the first commercially operated hydrogen fuel cell-powered bus line in China. As of 2020 Foshan has developed three hydrogen energy industry bases, with almost 100 hydrogen energy enterprises. The city has 15 hydrogen filling stations, 28 hydrogen energy transportation lines and 1,400 fuel cell vehicles[14], and has plans to become a hub for the manufacture and use of hydrogen-energy forklifts[15].

A number of big players in the Chinese economy have – or plan to – enter the hydrogen market. More than a third of Chinese SOEs have some plan to be a part of China's hydrogen power development, whether through hydrogen power production, storage, refuelling or other technology applications.

Conclusion

Demand for hydrogen will depend on the degree of certainty of government support. The **China Hydrogen Alliance** (a government-supported industry group) estimates that the industry's size will grow to RMB 1 trillion (USD 153 billion) by 2025. They further forecast that by 2035 hydrogen will account for 5% of China's energy system, rising to 10% by 2050 then 20% by 2060[16]. By then, the vast majority of hydrogen will be from green sources.

However, the supply of hydrogen is likely not to be sufficient unless there is government support in place for developing green hydrogen, especially in terms of infrastructure.

For example, businesses will be hesitant to purchase fuel cell vehicles if sufficient reliable refilling infrastructure is not already in place, but such infrastructure is unlikely to be profitable without a mass base of fuel cell vehicles on the road. Here the central and local governments can play a role to help industry develop the underlying infrastructure needed for a low-carbon hydrogen economy.

Likewise, more investment in hydrogen pipes is needed. Currently, most hydrogen in China is transported by truck, which is more expensive than using pipelines. Using pipes would increase the efficiency of transporting the gas and lower long-run costs, but comes with substantial upfront investment costs[17].

"Demand for hydrogen will depend on the extent of government support."

12 http://eng.hp.gov.cn/2020-06/29/c_504695.htm
13 http://english.jiading.gov.cn/2019-06/11/content_37480663.htm
14 http://en.foshannews.net/News/202010/t20201020_6362412.html)
15 http://en.foshannews.net/News/202103/t20210304_6367390.html
16 https://asia.nikkei.com/Spotlight/Caixin/China-s-hydrogen-roadmap-4-things-to-know
17 https://asia.nikkei.com/Spotlight/Caixin/China-s-hydrogen-roadmap-4-things-to-know

"Ultimately the hydrogen industry has an important role to play in meeting China's climate change goals."

Currently, there is some degree of uncertainty around subsidies for low-carbon hydrogen, such as which cities remain eligible for central support, the recipients of the support and how long it will be sustained. If the industry is to attract long-term investment, there is a need to remove the uncertainty around subsidies.

At the same time, there will need to be stricter economic penalties for using carbon-based hydrogen production to encourage green hydrogen. As renewables become cheaper and fossil fuels more expensive, it becomes relatively more economical to generate hydrogen from green sources. This will involve tightening ETS policies for instance, by reducing credits in the market and increasing its scope. Without these steps, the business case for hydrogen will be restricted to relatively niche uses.

Ultimately, the hydrogen industry has an important role to play in meeting China's climate change goals, acting as an important complement to other more intermittent renewable technology. China has the manufacturing experience, technological expertise and economies of scale to successfully develop a full-scale hydrogen industry, but the industry needs certainty around policies and support to make the case.

The view from the UK

"The UK has a fantastic opportunity to lead on H2. We are well placed geographically and from a technology standpoint. We are well placed to go big and build a large hydrogen economy."

Renewables financier at a leading investment bank in the UK

In the UK a large oil and gas legacy suggests a potential for blue hydrogen; smaller volumes of industrial production means less grey hydrogen, but is there sufficient excess capacity to produce green hydrogen as cars move to battery and heating decarbonises?

UK government climate commitments

The UK is a signatory to the **United Nations Framework Convention on Climate Change** through the Kyoto Protocol and the Paris Agreement.

The country's provisions are formalised and made legally binding through the 2008 Climate Change Act. This was amended in 2019 to include a commitment that the country would achieve 'net-zero' greenhouse gas emissions by 2050.

The Act also requires the UK to set five-year statutory caps on greenhouse gas emissions. The Sixth Carbon Budget, covering the period 2033-37, is the first budget set in line with the new net-zero targets.

UK government green and renewables strategy

The UK government's **Ten Point Plan for a Green Industrial Revolution** in November 2020 established a comprehensive set of priorities to drive the energy transition in the UK. A central element in this is to drive the growth of low-carbon hydrogen, with a promise to deliver 5GW of low-carbon hydrogen production capacity by 2030 (and 1GW by 2025).

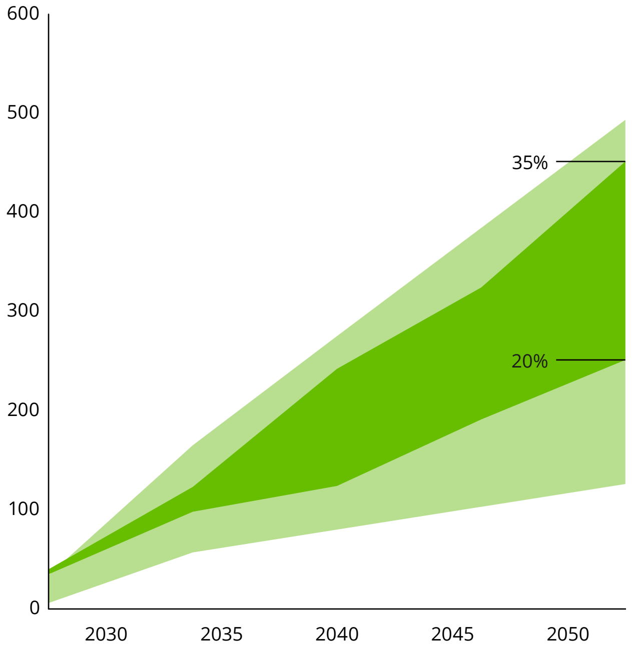
Hydrogen has relevance to most of the points in the plan, which includes:

- Quadrupling the country's offshore wind infrastructure, to deliver a capacity of 40GW by 2030.
- Delivering new and advanced nuclear power
- Accelerating the shift to zero-emission vehicles, including the end of sales of new petrol and diesel vehicles in 2030.
- Developing green public transport, cycling and walking, including a first-ever National Bus Strategy.
- Promoting low-carbon travel through green ships and planes ('jet zero').
- Development of greener buildings including moving away from fossil fuel boilers to lower-carbon alternatives.
- Investing in carbon capture, usage and storage (CCUS). This is a new industry that captures carbon dioxide from power generation, blue hydrogen production and industrial processes, and stores it deep underground where it cannot enter the atmosphere.
- Innovative green finance is necessary to accelerate the commercialisation of low-carbon technologies. Areas of focus include sovereign green bonds, mandatory reporting of climate-related financial information, and provision of investment including the £1bn Net Zero Innovation Portfolio.

UK government hydrogen strategy

In August 2021 the UK government's Department for Business, Energy and Industrial Strategy (BEIS) released the country's first-ever strategy for a hydrogen economy. This anticipates that 20-35% of UK energy could be from hydrogen-based sources by 2050.

Hydrogen demand and proportion of final energy consumption in 2050 (TWh)



Source: The UK Government Hydrogen Strategy, August 2021

Notably, the strategy outlines a twin-track approach emphasising both blue and green hydrogen. Key elements include:

- The **Hydrogen Business Model**. The primary incentive for users to switch to low-carbon hydrogen is financial. The UK government is considering how best to offer financial support to investors wishing to develop the infrastructure required to produce low-cost low-carbon hydrogen at scale and thus make it a price-competitive decarbonisation option. A framework similar to Contracts for Difference (CFDs) is proposed. For market price risk, a variable premium price support model is under consideration; for volume risk, a sliding scale mechanism is preferred. A public consultation is underway with the preferred model finalised in 2022 and the first contracts in place for 2023.
- A £240m **Net Zero Hydrogen Fund** – a portion of the £1bn Net Zero Innovation Portfolio – will support the at-scale deployment of low-carbon hydrogen production. The UK government is considering the type of funding to be offered, the technologies and activities to be supported, eligibility criteria and how the fund will be delivered.
- A **Low Carbon Hydrogen Standard** will define what is meant by 'low-carbon' hydrogen, including a methodology for calculating greenhouse gas emissions associated with production and a threshold against which different production pathways would be measured. Consultation is underway and businesses seeking support through the Hydrogen Business Model and Net Zero Hydrogen Fund are likely to need to meet the resulting standard.
- Through the **Hydrogen Advisory Council**, the UK government and industry work together to enable the supply of low-carbon hydrogen at scale across the energy system. The council is co-chaired by the Secretary of State for Business, Energy & Industrial Strategy and the UK country head of Shell. Institutions represented on the council include Shell, BP, Equinor, Ørsted, Energy Systems Catapult, Progressive Energy, Pale Blue Dot, Johnson Matthey, Siemens Energy, ITM Power, Ryze, BOC Linde, Mitsubishi UFJ Financial, Ofgem, Inovyn, the Energy Networks Association, SSE, Lloyds Register, Imperial College and the University of South Wales.
- A **Hydrogen Sector Development Plan** is to be articulated in 2022, which will describe the timeline to 2050. Immediate priorities are to put frameworks in place to ensure availability, price and volume of low-carbon hydrogen, as well as the safety of equipment. There is a focus on blending hydrogen into the existing gas supply (trialling neighbourhood/2023, large village/2025, town/2030). Existing hydrogen supply is to be decarbonised through CCS mechanisms. The government has also committed to seeking to understand how hydrogen storage facilities and distribution networks can be developed.

The UK hydrogen economy is anticipated to be worth £900m by 2030 and £13bn by 2050.

National hydrogen projects

A range of initiatives are underway or in development across the UK, including the following:

Tees – H2Teesside

This project will be the largest in the UK, producing up to 1GW of 'blue' hydrogen by 2027 – 20% of the UK's 2030 hydrogen target – and supporting the development of the region as the UK's first hydrogen transport hub.

The Northern Endurance Partnership will receive over £52 million for two projects, including a flexible gas power plant fitted with carbon capture and an offshore carbon dioxide transport and storage system.

The project will be located in Teesside. With a final investment decision (FID) in early 2024, production could begin in 2027 or earlier. BP has begun a feasibility study into the project to explore technologies that could capture up to 98% of carbon emissions from the hydrogen production process. Venator, one of the largest global producers of titanium dioxide pigments and performance additives, is scoping using this supply of clean hydrogen for its flagship Teesside plant. Northern Gas Networks (NGN), the gas distributor for the North of England, is considering how to use this hydrogen within its network, helping to further decarbonise both industrial customers and residential homes.

Other partners in the project include the Tees Valley Combined Authority, Sempcorp, Alfanar, Mitsubishi Chemical and CF.

Humber – H2H Saltend

£21 million has been allocated to the Zero Carbon Humber Partnership, including H2H Saltend, Equinor's blue hydrogen production project on the north bank of the Humber, plus carbon dioxide and hydrogen pipelines enabling industrial sites and power stations across the Humber to switch to hydrogen and/or capture and transport emissions.

A further £12 million has been awarded to Humber Zero, decarbonising the industrial complex at Immingham by creating a carbon capture and hydrogen hub. The Humber projects aim to capture 25 million tonnes of carbon per year.

Project partners include ABP, British Steel, Centrica, Drax, Mitsubishi Power, the National Grid, PX, SSE Thermal, Triton Power, Uniper and the University of Sheffield.

Humber – Gigastack

The Gigastack project is a collaboration between Ørsted, Phillips 66, ITM Power and Element Energy. collaborating. Hornsea 2 renewable electricity goes to an ITM electrolyser (100MW) which creates green hydrogen, to be used in the Philiips 66 refinery. A blueprint for further learning.

East Coast Cluster

A collaboration between Northern Endurance Partnership, Net Zero Teesside and Zero Carbon Humber, the East Coast Cluster aims to remove nearly 50% of all UK idustrial cluster CO_2 emissions. By deploying CCUS across the Humber and Teesside, the East Coast Cluster aims to create and support an average of 25,000 jobs per year between 2023 and 2050. In October 2021 the project was selected for government support.

"A range of initiatives are underway or in development across the UK."

Merseyside – Hynet North West

The project aims to decarbonise industry by capturing and storing emissions, creating a hydrogen economy across the North West, and repurposing oil and gas facilities for carbon transport and storage. It is to provide a blend of hydrogen and natural gas to local homes and businesses, in all reducing carbon dioxide emissions by 1 million tonnes per year from 2025, rising to 10 million tonnes per year from 2030. £33m allocated. The project led by Progressive Energy, Essar, Johnson Matthey, and SNC-Lavalin. In October 2021, the project was selected for government support.

Scotland – The Acorn Project

In Scotland, £31 million has been awarded to the Net Zero Infrastructure project funding offshore and onshore engineering studies connecting industrial sites across East Scotland to potential carbon dioxide stores under the North Sea.

Acorn is an ambitious programme designed to tackle climate change by dealing with industrial carbon dioxide emissions and other 'hard to decarbonise' sectors. By making use of oil and gas pipelines that are already in place, offshore geology that is ideal for permanently storing carbon dioxide, and a region that is embracing hydrogen as a fuel of the future, this project is an important catalyst for the next phase of the UK's journey to Net Zero.

There are two key elements to the Acorn project – a CCS project based in the North East of Scotland, and a project to reform natural gas into clean-burning hydrogen. In October 2021, the Acorn project was not selected for UK government support, instead being held "in reserve".

The project is a collaboration between Shell, Pale Blue Dot and Harbour Energy.

North Sea – Dolphyn

Environmental Resources Management (ERM) has been awarded £3.12m by the UK Government to further develop its ERM-Dolphyn project for the production of 'green' hydrogen at scale from floating, offshore wind turbines. The project will develop an innovative integrated system combining all of the technologies required to bring the latest floating wind and hydrogen production technologies together to enable offshore wind resources to contribute toward hydrogen production. Dolphyn will potentially be built in the North Sea off the north-east coast of Scotland.

HyPER

An international collaboration led by Cranfield University examines the potential for low-carbon hydrogen to be the clean fuel of the future. The HyPER project (Bulk Hydrogen Production by Sorbent Enhanced Steam Reforming) constructs a state-of-the-art 1.5 MWth pilot plant at Cranfield University to test a hydrogen production technology that substantially reduces greenhouse gas emissions, in partnership with Doosan Babcock and the Gas Technology Institute.

South Wales Industrial Cluster

A net-zero industrial zone will be created from Pembrokeshire to the Welsh/English border by 2040. This will include a CCS and hydrogen project aimed at addressing the region's emissions of nine million tonnes of carbon a year. £20m in government funding for green hydrogen has been provided, with the project led by Costain in partnership with the Welsh Government.

HydroFLEX

The HydroFLEX project is a partnership between the Birmingham Centre for Railway Research and Education and railway rolling stock company, Porterbrook. It demonstrates how hydrogen could be deployed across a rail network to offer a cleaner alternative to current diesel trains.

HyDeploy

This programme blends up to 20% hydrogen by volume along with natural gas, for use in the domestic environment (i.e. for heating and cooking). The first phase is taking place at Keele University, with the second phase scheduled to run in 650 homes in northeast England.

Grangemouth Refinery

In September 2021, the British chemicals company Ineos announced that it was upgrading its Grangemouth refinery to run on hydrogen, at an investment cost of more than £1bn. This is part of plans to slash emissions from one of Scotland's largest industrial sites by 60 per cent by 2030.

"The UK hydrogen sector is rapidly picking up speed… the opportunity is ripe for international investment."

UK hydrogen associations

Various national, regional and industry bodies are active in planning and promoting the future low-carbon hydrogen economy including:

- **UK Hydrogen & Fuel Cell Association**
- **H2FC Supergen**
- **UKH2Mobility**
- **Hydrogen London**
- **Greater Manchester Hydrogen & Fuel Cell Partnership**
- **Hydrogen East**
- **Midlands Hydrogen & Fuel Cell Network**
- **North West Hydrogen Alliance**
- **Scottish Government Hydrogen Policy**
- **HyCymru**
- **Hydrogen Northern Ireland**
- **Hydrogen UK**

Conclusion

We can see that the UK hydrogen sector is rapidly picking up speed. Government, industry and academia are collaborating, and a sizeable pipeline of projects has been established with many more to come. The opportunity is ripe for the sector to expand in terms of international investment.

Finance viewpoint

Deloitte has spoken with financial professionals in both China and the UK to get an understanding of awareness and appetite in relation to the future low-carbon hydrogen economy.

The strategic view across finance is that no other sector offers long-term opportunity like renewables and that low-carbon hydrogen will play a significant role in some form. The 'sexiness' of hydrogen is uncontested and a great deal of excitement is brewing with regards to the sector.

The energy transition is front and centre of many strategies in financial services, and there is no shortage of capital to be deployed, indeed quite the opposite. The scale of the opportunity and potential is there, but a great many obstacles have to be overcome.

In the parts of the financial services industry closest to sustainable finance and the energy sector, there is a sense that once there is clarity as to the business model the corner will be turned and finance can start to flow. However today bank clients are not yet initiating hydrogen-related business, and this gives plenty of time for talk and seminars as professionals consider what the financial model will be. Although strategic investors are initiating business, for now this is being financed on the balance sheet rather than requiring debt support.

The truth is that hydrogen won't be commercial in most areas until prices have dropped significantly, or until there is a standard way of supporting them. There is also little demand for hydrogen and correspondingly little supply and this also has to change in order for the product to prevail to maturity.

And even once this is the case, the risk profile remains complex compared to, for example, offshore wind which uses a standard technology with well-understood risks and a single use case – grid electricity.

For low-carbon hydrogen, the risks are around the technology and its performance, as well as the hydrogen market itself in terms of lack of clarity on price and uncertainty of demand. This will increase the cost of finance for clients, the end consumer and thus the sector.

Very little green hydrogen is produced through electrolysis today, and to scale will take a long time. Blue hydrogen, often leveraging existing infrastructure, will be cheaper to produce and will come online sooner – but there are questions as to the effectiveness of carbon capture.

But there can be little doubt that big change is coming, not just in China and the UK but also globally, with both the EU and the US having made very considerable investment commitments to initiate the sector.

For bankers, it's clear that, at least in the short to medium term, low-carbon hydrogen projects will be backed predominantly by the state, and this will remain the case until the low-carbon hydrogen sector becomes sufficiently economical or low risk and the demand has been built across many use cases.

"There is a sense that once there is clarity as to the business model, the corner will be turned and finance can start to flow."

The acceleration in adoption is noted. It could be that we are 10 years away from mass adoption, should it follow a similar curve to that of solar and wind power, but there is much more policy attention so a faster trajectory may be seen. Once low-carbon hydrogen scales, the cost will come down and the case becomes economic.

Strategy

British and International Banks

Globally the banking sector has an ever-increasing focus on providing finance that seeks to reduce society's impact on the environment and the climate. Environmental, social and governance reporting frameworks are increasingly robust and structured, with ESG impact increasingly being audited to the similar high standards as annual financial reports.

As such, whether prompted by regulators, shareholders, clients or employees, British and international banks are making ever more serious commitments in relation to the impact they and their clients have on society. For example:

- The international bank **HSBC** made a net-zero undertaking that by 2050 it will have reduced financed emissions from its portfolio to zero, and has promised to provide USD750bn-1tn of sustainable financing before 2030 in order to facilitate this.
- The purpose statement of the British bank **NatWest** outlines how it will tackle climate change by becoming climate positive by 2025, and by 2030 halve the impact funded projects have on the climate.

Here, the sustainable finance agenda is driven from the boardroom. Within the organisations themselves, there is an interest in knowing when the energy transition will be happening and how it will impact people. However the knowledge and literacy aren't there today, nor is there a sense of urgency and immediacy. Conversely, in divisions closer to impacted sectors (for example energy), bankers are further along the learning curve as opportunities for commercial benefit can be more easily foreseen.

One bank told us that although it's recognised that low-carbon hydrogen has a very important role to play in the transition to net zero, its day-to-day focus leans more heavily towards moving away from carbon-contributing finance, without there being an equivalent focus on financing the building of the new green energy paradigm.

Chinese Banks

The dynamic in China is somewhat different. Banks are very commercial and open to exploring new areas; additionally there is an implicit understanding between financing entities and state-owned enterprises (SOEs) that long-term projects have to comply with the national government's strategic priorities. In such cases, business is conducted on recoverable terms.

Banks and SOEs are required to support the delivery of the 14th Five Year Plan (14FYP) which runs between 2021-25. Energy and climate change are at the heart of the plan, which includes ambitious goals to reduce carbon dioxide emissions.

A central pillar of the Chinese government's objectives is the Belt and Road Initiative (BRI), which is building transport infrastructure to better connect China to Asia, Europe and Africa. Another leading priority – perhaps less relevant in the context of low-carbon hydrogen – is to support the internationalisation of China's currency, the renminbi.

The national government is eager for banks to provide renewables/ESG financing; correspondingly there is an emphasis on moving away from investments that merely offer a commercial return (such as commercial real estate). Green or energy transition financing is seen to be where the long-term opportunities are; conversely oil and gas type finance has not been a priority for an extended period already. For banks investing in overseas strategic projects, ESG and renewables are increasingly at the core of such business opportunities.

For the bankers, it's evident that hydrocarbons will be replaced and the only question is how long it will take. The message from head office is that branches should be making efforts to do more green finance to support the energy transition as this is a principal strategy of the bank.

Chinese corporations are increasingly interested in the low-carbon hydrogen sector, having invested in wind, solar, hydro energy etc already. Even in the UK, Chinese investors have looked at opportunities, (for example when a delegation visited the Teeside industrial cluster where hydrogen was a topic of conversation).

"Institutions have a huge role to play in financing the infrastructure of the new energy economy."

Chinese banks are also eager to support on-the-ground initiatives in 'frontier markets'. On-the-ground assessments are very important in assessing risk. Because of the Belt and Road Initiative, many SOEs have become frontier market economists, and the banks rely on their clients to be their on-the-ground eyes and ears to assess project feasibility.

Institutional Investors

Institutions have a huge role to play in terms of financing the infrastructure of the new energy economy, but this has to be done in line with the objectives of funds themselves. The responsibility of pension fund managers is, essentially, to ensure that pensions are paid when due. As is the case for corporate and institutional actors, saving the planet is secondary to the delivery of business objectives.

Institutional investors are looking to match up with long-term projects which track inflation and have low risk, with predictable cash flows backed by high quality counterparties. Until a business model and subsidy framework are in place, it's unlikely that the assets owners of the world will be allocating money to low-carbon hydrogen.

The **Institutional Investors Group for Climate Change** (IIGCC)'s members together have USD39tn of assets under management. Some have more than USD400bn in a single fund. It's in these corners of finance where there is an opportunity for venture capital pioneering, to place strategic funds together with government subsidies and leverage the impact.

It's likely that the asset owners of the world will not be allocating a lot of money to low-carbon hydrogen. It's worth noting that those who are interested in a financial return may well prefer to avoid relying on governments and subsidies for the business model to make sense – bearing in mind previous experiences where support regimes were unilaterally changed by governments to the detriment of investors.

There isn't much infrastructure investment ready to invest in hydrogen projects, especially low-carbon hydrogen production, although this will change in due course.
An issue mitigating against institutional money coming into low-carbon hydrogen production is that the scale of projects is that much less.

On the China side, there is some interest in purchasing renewable assets overseas, for example, the China Three Gorges investment in the renewable arm of the Portuguese state energy company EDP, but in general, there hasn't been much institutional investment aside from port operations. (On the other hand, Middle Eastern sovereign wealth funds – ADIC, ADIA, PIF – have an appetite to invest in the renewables sector, including with equity money).

Financial centres

Global centres of capital and finance have an important role to play in supporting the development of the hydrogen economy. The UK and China host London and Hong Kong respectively. Each has large pools of capital and no shortage of liquidity, with huge active investor bases, deep secondary markets, and excellent legal and professional services firms. London also has the advantages of the English language and an accessible timezone, whereas in Hong Kong most bankers are tri-lingual in Mandarin, Cantonese and English.

For Chinese banks, London will continue to be important as a place to actively participate in the international financial markets. As has been noted earlier, renewables (and in future hydrogen) will inevitably form a very significant part of this portfolio.

Likewise, Hong Kong is the financial gateway of China, and for the energy transition, it will act as a platform bringing Chinese and international capital and industry together to finance the programmes of the future net-zero economies.

Risk

Appetite

As outlined above, until business cases are sufficiently mature the support of governments and public sector entities – in the form of policy, subsidies and guarantees – is needed so that capital can be deployed for infrastructure to be built and demand can be manufactured.

To be commercially viable from a bank lending perspective, something is needed to kickstart momentum and – unless hydrocarbon prices force the issue – it has to come from the government. This would replicate what happened for offshore wind which was expensive until volumes drove costs down, and mechanisms such as Contracts for Difference (CFDs) were deployed to take the risk out of programmes. However, others don't have an appetite for this type of risk and will only get involved as hydrogen heads to parity – which may happen through carbon pricing mechanisms rather than cost reductions.

Institutional investors are looking to match up with long-term projects which track inflation and have low risk. In the case of not-yet-economic programmes (like low-carbon hydrogen), they need to be funded by risk money and concessional money, which comes from early-stage equity risk, venture capital energy tech, or state-sponsored venture capital money. Furthermore, government subsidies will make these investments acceptable for infrastructure and institutional investors. Chinese banks are more competitive where lending is backed by guarantee (recourse basis), and when funding is in local currency; international banks are more likely to participate in non-resource projects where dollar or euro financing is sought.

Characteristics

For bankers in this sector, factors that ensure a client or transaction is financeable will include debt to equity ratio, present and future income generation capacity, guarantors, off-takers and providers and most critically the extent of government support.

Until there is positive revenue coming from low-carbon hydrogen projects, lenders are likely to look for support of the sort offered by Power Purchase Agreements (PPAs) and Contracts for Difference (CFDs). Because this isn't in place today, today's projects – even the largest ones – are financed 'on-balance sheet' rather than on a structured finance basis.

Lenders will look for evidence of positive cash so that the loan can be serviced (i.e. interest paid and principal repaid on schedule). Facilities will be priced in line with the risk and given the present uncertainties in the sector, this means a higher margin until there is less uncertainty.

There is also potential value in the underlying assets of a transaction, particularly for equipment for which there is an evident secondary market. Because of the breadth of the low-carbon hydrogen value chain, there are likely to be many opportunities – examples include electrolysers, fuel cells, vehicles, and industrial equipment.

Scale programmes are required to build the infrastructure for the future low-carbon hydrogen economy. Furthermore, the nature of hydrogen requires careful collaboration to match the supply and demand sides.

"Lenders will look for evidence of positive cash so that the loan can be serviced."

As such this means that we can expect project delivery to come through the formation of consortiums rather than stand-alone initiatives. In lending, the quality of the counterparty is critically important, and the partnership model allows the sum to be greater than the parts from a credit quality perspective. What is important here is the credit quality of the projects and related vehicles, as full recourse to the balance sheets of participants is not anticipated.

In terms of financing complex international projects, rather than waiting for public sector collaboration, often the private sector comes together to make deals happen together with the international development banks.

Clients

Banks expect to find themselves engaging with the hydrogen sector in concert with their clients, as they seek commercial benefits from the energy transition and endeavour to decarbonise their own activities.

For bankers directly involved in the energy sector, hydrogen is a topic coming up again and again. There is an interest in being the bank of choice at the forefront of strategic conversations, not just with clients but also with governments and multilateral development banks.

Many of the companies at the forefront of hydrogen are today dependent on fossil fuels (oil and gas, power and utilities). They are being asked about hydrogen and carbon capture and storage (CCS), and gearing up to be ready. The challenge for hydrogen is that two distinct infrastructures need to be built, one for supply and one for demand.

Oil and gas companies deal with a commodity that is not aligned to the future, and so face a big challenge to their business model. The sector isn't going to go away, but it – together with the power and utility companies – is changing rapidly, becoming energy companies with assets across the full length of the value chain. There are opportunities upstream (in the production) and downstream (in the distribution) of low-carbon hydrogen. There are also tremendous risks as existing infrastructure becomes redundant, with banks (and governments) being eager to avoid being landed with these 'stranded assets'.

From a development perspective, it's anticipated that consortia will come together in future with a combination of supply and demand – across oil and gas, power and utilities – with programmes which in due course will require project finance. These conversations are already happening for carbon capture and storage. This dynamic is having an impact on the structure of banks themselves, with Oil & Gas and Power & Utilities bankers increasingly coming together as Energy teams.

Products

Project finance

Project finance is very important for low-carbon hydrogen as it makes projects financeable. Early projects are expected to be equity driven, however once established and generating cash, debt can come into play as low-carbon hydrogen matures as an asset class.

Project finance has traditionally had a benign risk profile, but with low-carbon hydrogen there is a heightened risk profile and models would change, unless contracts are with investment-grade counterparties. There is a question as to exactly how much risk the banks can take?

However, it's still not clear what project finance will look like for low-carbon hydrogen, what the underlying income streams will be and where the risk will lie. Banks will want to manage the risk out of credit structures as much as they can, putting risk onto creditworthy counterparties.

European and Japanese bankers are particularly strong in project finance and better positioned than UK banks to get into the sector.

Asset finance

For a specialised product such as asset finance, banks have a very specific way of understanding the risk. There needs to be a clear understanding of the residual value of a product (at resale) and take risk at that level. For example, in machinery, it's important to understand the replacement cycle of components and the cost of maintenance. Banks don't want to take the credit risk or technology risk, and the intention is for the risk and reward to remain with the lessor.

Many of the underlying elements within the hydrogen value chain have great potential for asset finance. For example, this could be electrolysers upstream or public and commercial transport downstream. It's possible that hydrogen financing will be needed at smaller and more local scales (and thus higher volumes) compared to that for wind and solar.

Low-carbon hydrogen has great potential in commercial vehicles. The battery will likely win for the last 10 miles, but hydrogen is ripe for deployment in heavy goods vehicles with journeys of more than 500 miles. This promises interesting opportunities for asset financiers.

"Many of the underlying elements within the hydrogen value chain have great potential for asset finance."

Green lending
Green bonds are a well-established mechanism for providing debt funding to projects which promise environmental benefits. The Green Loan Principles were established in 2018, and are governed by the same principles as those developed for green bonds (a mechanism for providing debt funding to corporates for projects which promise environmental benefits).

For a loan to be considered 'green', its objective must be to promote environmental sustainability. However, it also needs to be certified by an external agency, confirming that it complies with relevant ESG criteria.

In China, the regulators (People's Bank of China and China Banking and Insurance Regulatory Commission) measure green performance in terms of 'Green Credits'. A loan is determined to be 'green' based on the characteristics of the client itself rather than the loan, and there is an increasing focus on having more 'green clients' within the portfolio.

It's anticipated that these mechanisms will prove suitable and popular for supporting the financing of hydrogen projects in future.

Syndicated loans
British and international banks have actively used syndicated finance to support scale development projects, and now Chinese banks have shown a keen interest in investing in renewables in syndication with multilateral development banks.

In the new phase of the Belt and Road Initiative, rather than taking direct bank credit financing, capital is being raised through private equity and smaller joint venture initiatives. Deals are increasingly complex, involving many countries and banks, and so Chinese banks use the multilateral development banks as a gauge. Projects supported by these institutions are regarded as high quality and banks are eager to participate rather than taking 100% of the risk.

For example, ICBC Bank is part of the syndication of banks financing the world's largest offshore wind farm, the £5.5bn Dogger Bank project, a deal backed by export credit agencies. Also in October 2020 ICBC Bank joined up with the European Bank for Reconstruction & Development, the Asian Infrastructure Investment Bank and the Green Climate Fund to provide £95m for a 100MW wind farm installation in Kazakhstan.

Investment banking & markets
With a tremendous role to play in the future global economy, and with incoming volumes of very sizeable investment, it's probable that the low-carbon hydrogen sector will in due course see transactional activities of interest to investment bankers.

This could come in the form of mergers and acquisitions opportunities, or companies seeking support for initial public offerings and equity capital markets activity.

In future, hydrogen will be a tradeable global commodity and we can anticipate that a market will develop with specialised trading houses looking to take on risk, as is the case for liquefied natural gas today.

Decarbonisation propositions
Banks and institutions are committing to decarbonising not just their own operations but also – in some form – their own portfolios. We can foresee the scenario where 'brown' customers are approached with a proposal to partner with their financiers on the journey to 'green'.

Sector funds
The fund management industry is always looking for new investment angles to attract investors and deliver returns, and given the current heat in the sector, the first hydrogen funds have been established.

In February 2021 the British investment managers Legal & General launched a hydrogen-themed exchange-traded fund (L&G Hydrogen Economy UCITS ETF). The fund aims to "provide exposure to companies engaged in the global hydrogen economy which seek to contribute to the reduced use of traditional fossil fuels and promote clean and sustainable energy".

"Now is the time for the finance sector to engage with hydrogen."

The fund's investments are a reflection of the mix of opportunities in the global hydrogen economy:

- An operator of industrial hydrogen production facilities which is investing in mobile hydrogen filling stations for vehicles.
- An engine manufacturer with the largest manufacturing capability of hydrogen fuel cell engines anywhere in the world.
- A manufacturer of the polymer electrolyte membrane (PEM) electrolysers essential in the production of green hydrogen.
- A power and offshore wind company which is developing offshore green hydrogen programmes.
- A manufacturer of hydrogen fuel cells.

The fund's present performance reflects the high volatility and lack of certainty in the sector today.

In September 2021 a £1bn investment fund was launched for the purpose of funding green hydrogen projects in the UK, with the founders having identified more than 40 companies in the hydrogen space for investment evaluation.

Conclusion

It is evident that now is the time for the finance sector to engage with low-carbon hydrogen. Banks and investors need to be talking to governments (and vice versa), and in the UK it's critical that banks participate in the consultation on the Hydrogen Business Model.

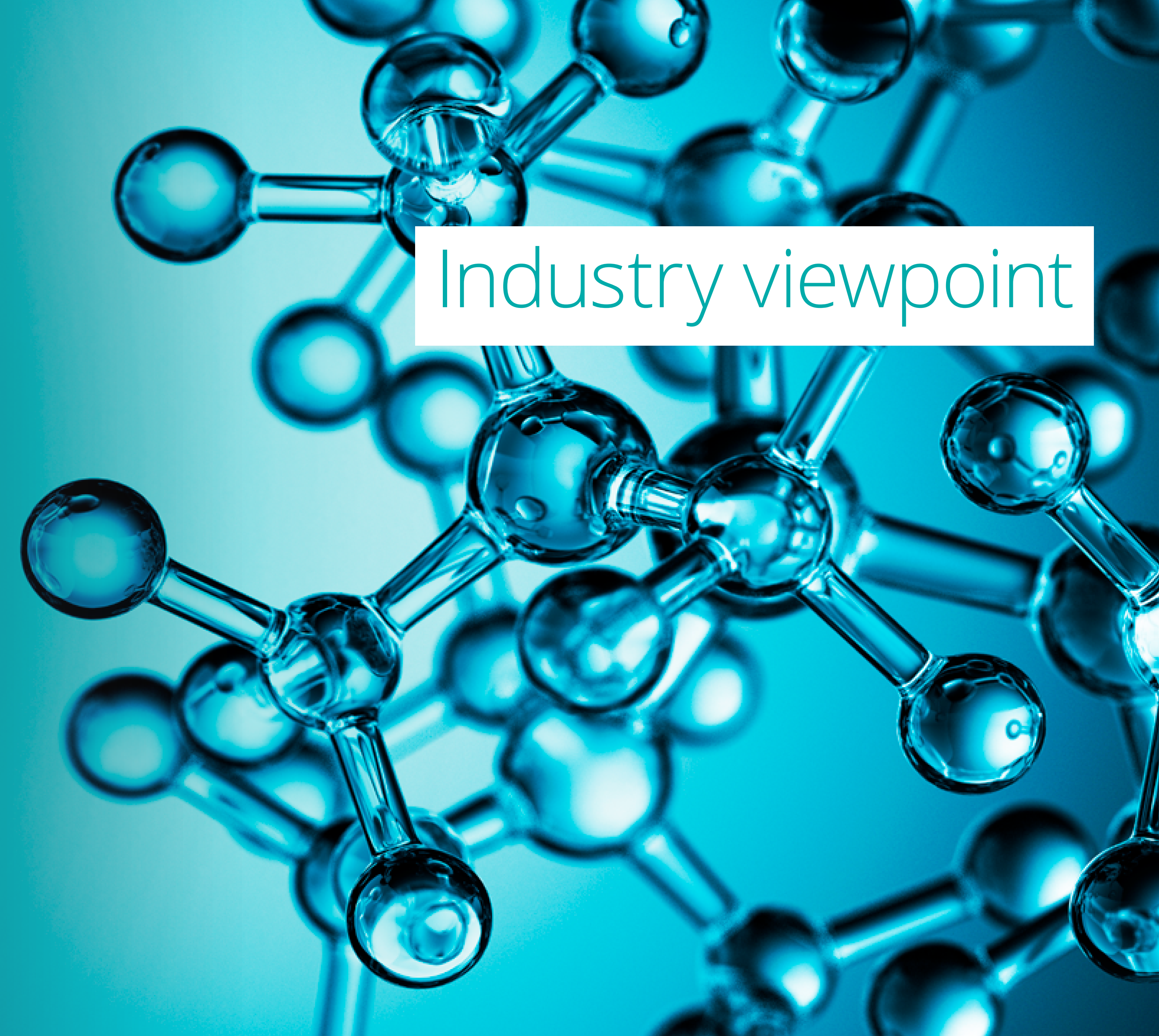
Across the entire finance sector both in the UK and China, there is a significant need for education and upskilling on the topics of net zero, the energy transition, hydrogen and other renewable energy mechanisms.

For hydrogen specifically, the versatility of the medium means that it will be touching a broad spectrum of players within the economy, and in turn this means a need for a wide engagement on the topic within finance.

Those who have the power to release the required funding need to have a much more in-depth and sophisticated understanding of the subject, so as to be able to ask the right questions of clients and governments.

Ultimately mechanisms and frameworks need to be in place such that both the the money can be made available to build the infrastructure on the supply and demand sides, and also that financiers can be confident of seeing the returns.

Furthermore, banks need to be ensuring that they have a place at the table as consortia come together to drive hydrogen programmes in future. An even better step would be for banks to bring together the consortia in the first place.



Industry viewpoint

In future, a great number of Chinese and UK businesses and organisations will be participating in the hydrogen economy. Here we use the hydrogen value chain to introduce companies that are active in the sector today.

Production

Electrolysers

Electrolyser technologies include alkaline water electrolysis, polymer electrolyte membrane (PEM) electrolysis, and solid oxidiser electrolyte cell (SOEC).

Chinese manufacturers

Also known as the 718th Research Institute, **Peric** (**Purification Equipment Research Institute of CSSC 第七一八研究所**) is a division of state-owned **China State Shipbuilding Corporation** (中国船舶集团有限公司), the largest shipbuilder in the world. CSSC manufactures commercial and military vessels as well as providing various ocean-related products and services. The institute has a legacy of experience, originating the production of technology for submarines, for which breathing oxygen is produced through electrolysis of water along with hydrogen, previously a waste product of the process.

Peric is the leading Chinese electrolyser manufacturer with 45% of the market, and a foothold in overseas markets (as the leading provider in India, for example). With the present rapid expansion of the low-carbon hydrogen market, the company is more than doubling its production capacity at headquarters in Handan City, Hebei Province.

Hot interest in the sector means the company's head office is receiving multiple delegations of domestic and international visitors every day, and there are plans to list 25% of the company to benefit from public interest in the hydrogen sector.

Chinese industry has a well-proven ability to deliver low-cost product at scale and the same can be expected for electrolysers over time. A key factor in the potential reduction of prices is the ability to produce more components locally rather than sourcing from overseas. For example, today the ionomer membranes used in PEM electrolysers must be sourced from 3M in Minnesota, United States.

Peric's Chinese competitors include **Tianjin Mainland** (天津市大陆制氢设备有限公司) and **Suzhou Jingli** (苏州竞立制氢设备有限公司), both established by former Peric executives. Suzhou Jingli operates a joint venture with the Belgian conglomerate John Cockerill Group. As the sector grows and electrolyser technology is better understood, we can expect other state-owned enterprises will consider entering the market.

British manufacturers

ITM Power is a British manufacturer of PEM electrolysers. The company was founded in 2001 and is listed on the London Stock Exchange. ITM's products are focused on fuel production for transport (hydrogen filling stations for cars, buses, trucks, rail and for shipping), energy storage (decarbonising heat, grid balancing, hydrogen islands, power-to-gas energy storage, hydrogen tube trailer filling, backup power, storing renewable energy, hydrogen lighting) and industrial hydrogen (refineries, methanation, ammonia, steel, glass, mining and methanol). ITM is a partner in REFHYNE (installing the world's largest H2 electrolyser at a **Shell** refinery in Germany), HyDeploy and H2Mobility.

"Chinese industry has a well-proven ability to deliver low-cost product at scale."

Producers

Green hydrogen

Sinopec (中国石油化工集团有限公司) – the world's largest oil refining, gas and petrochemical conglomerate – is the leading producer of hydrogen globally, with the capacity to deliver 4 million tonnes annually (predominantly from fossil fuel sources today). The company has been charged by the national government to lead the development of the Chinese clean hydrogen sector, having for example committed to establishing 1,000 hydrogen filling stations across the country.

Sinopec has committed to producing 500,000 tonnes of green hydrogen by 2025. An example project is the 2.6bn yuan (£300m) green hydrogen operation planned for Ordos, Inner Mongolia by 2025. The plant is designed to leverage solar and wind power to generate 20,000 tonnes of low-carbon hydrogen annually, which will be supplied to a nearby chemicals project. The project will be developed in strategic partnership with **LONGi Green Energy** (隆基绿能科技股份有限公司), one of the world's largest solar energy companies. A similar project is planned for Xinjiang.

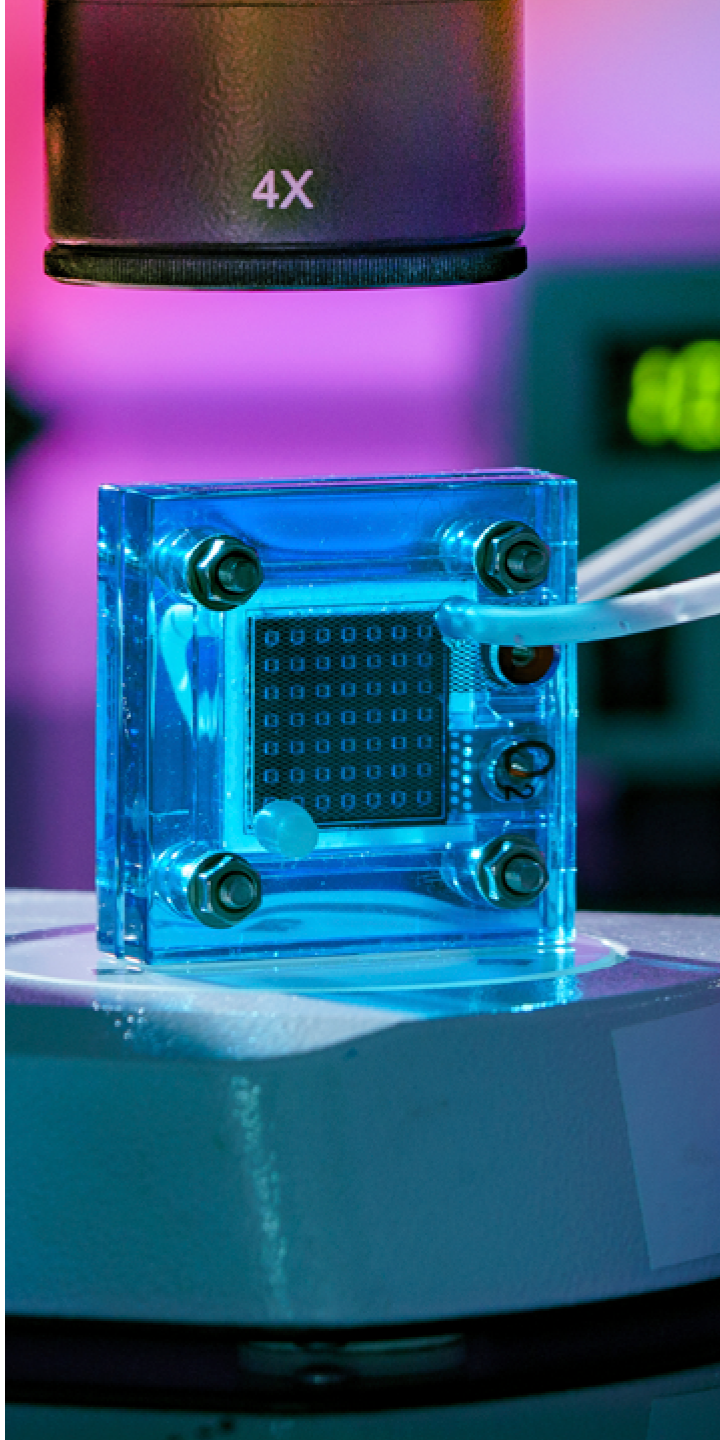
Ningxia Baofeng Energy Group (宁夏宝丰能源集团股份有限公司), a producer of coal-derived chemical products, recently opened the world's largest solar-powered green hydrogen plant in the Ningxia autonomous region in northwest China. The facility is powered by a 200 MW solar photovoltaic (PV) park.

In the UK, **Ryze Hydrogen** aims to install and operate green hydrogen facilities. Projects in scope include a facility in Kent situated near to wind farms and intending to supply the bus fleet; a 6MW electrolyser at the Sizewell nuclear power station in Suffolk; and a £45m project located near wind turbines in South Lanarkshire in Scotland, in partnership with **Hy2Go**. The owners of Ryze Hydrogen also operate the UK's first manufacturer of fuel cell buses, **Wrightbus**. Another operator of green hydrogen facilities is **Protium**, which is looking at small-scale deployments including a zero-emission proposition for the production of Scottish whisky.

Blue hydrogen

A legacy of the UK's large North Sea oil and gas sector, and related industry, the UK is a good market for the potential development of blue hydrogen facilities. Scale consortia are in place – along with government banking – to develop national low-carbon hydrogen projects such as those referred to in Chapter 3 "The view from the UK" (such as **H2Teeside**, **H2H Saltend** and **Dolphyn**). The development of carbon capture and storage capabilities is a critical factor in the success of such programmes.

The specialist materials corporation **Johnson Matthey** has an extensive proposition for the blue hydrogen sector, offering a technology 'blueprint' to the owners of production facilities which guarantees certain levels of performance and effectiveness, in concert with the company's high specification catalytic technologies.



Anglo-Dutch multinational **Shell** has announced its presence in the hydrogen market in China, signing a strategic agreement with **Shanghai Electric** (上海电气集团股份有限公司). The two companies will work together to explore carbon capture and storage, with the hopes of making grey hydrogen, generated from natural gas, blue[8].

Storage

The UK has a network of salt caverns used for storing natural gas, nitrogen and hydrogen, with locations in Cheshire, Staffordshire, Yorkshire and Teeside, among others. For example the existing Aldbrough Gas Storage facility – owned by **SSE Thermal** and **Equinor** – is being expanded to store 320GWh of low-carbon (blue) hydrogen by 2028, coming from the H2H Saltend project; the Stublach Gas Storage Project – operated by **Storengy UK** – is a salt cavern facility in Cheshire and now the largest onshore amenity in the country.

China has set a path to massively increase underground gas storage. In 2019 there were 25 facilities across the country (compared with 400 in the United States). The majority are managed by **China National Petroleum Corporation** (CNPC 中国石油天然气集团有限), which is establishing an additional 23 facilities by 2030.

Transportation and distribution

Hydrogen is not easy to move. It has a very low density and has to be transported as a pressurised gas or a cryogenic liquid; or combined in absorbing metallic alloys; or in a chemical form such as a metal hydride. Depending on the process, the energy loss in moving hydrogen can be of the order of 30%. For this reason, it's likely that in many cases hydrogen production facilities will be located close to the sources of demand (or storage).

For land transportation over any distance, pipelines are likely to be the most economic pathway, with transport in cryogenic tube tanker trucks or liquid tube trailers being deployed only at local level.

Pipeline

In 2020 the responsibility for China's national pipeline network passed to a new state-owned company **PipeChina** (国家石油天然气管网集团有限公司). The company has announced the development of hydrogen pipeline research as part of its 14th Five-Year Plan[9], and recently signed a memorandum with the Italian energy company Snam which included activities relating to the transport of hydrogen.

In the UK, the gas distribution networks are managed by **Cadent, Northern Gas Networks, Wales & West Utilities, SGN** and a number of independent gas transporters. For such operators, the blending of hydrogen along with natural gas is a priority, offering a significant reduction in carbon emissions.

Since 2002 the Iron Mains Risk Replacement Programme has been replacing Victorian-era iron gas mains with polyethylene pipes. As well as addressing safety issues and reducing leakage, the new infrastructure is suitable for transporting hydrogen.

Tanker and cylinder

Manchester-headquartered **Luxfer**, the largest high-pressure cylinder manufacturer in the world, has a growing focus on manufacturing hydrogen cylinders to be used within vehicles. The British renewable energy company **Octopus** operates a hydrogen division that coordinates the storage, delivery and dispensing of hydrogen.

"It's likely that hydrogen production facilities will be located near to the sources of demand."

8 http://www.h2weilai.com/cms/index/shows/catid/28/id/2871.html
9 https://asia.nikkei.com/Spotlight/Caixin/China-s-hydrogen-roadmap-4-things-to-know

Shipping

Renewable energy is not distributed equally across the globe, and over time places with particularly intense sun and wind (for instance the North Sea, Australia, the Arabian peninsula, the Sahara) may well develop as green energy 'superpowers'. Hydrogen is well-positioned to be the vector of choice for how this energy is transported to densely populated markets where it can be deployed – for example, the north-west part of Europe and the east coast of China.

A fleet of specialised vessels will be needed to transport the hydrogen in whatever form it is constituted. The first specialised liquified hydrogen tanker (LH2) launched in Japan in late 2019, keeping the fuel at atmospheric pressure and a temperature of −253°C.

Application

Fuel Cells

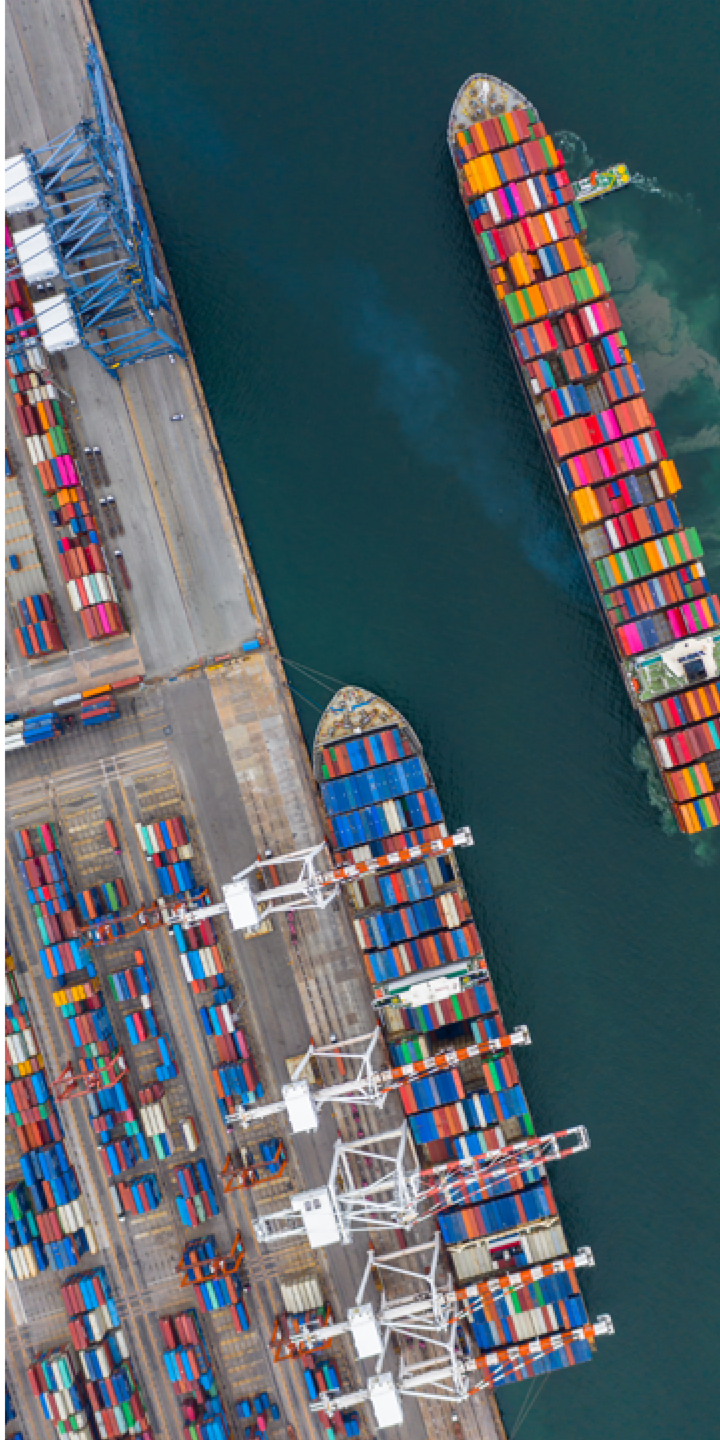
Hydrogen's chemical energy can be released simply by burning it to release heat, or by combining it with oxygen in a controlled manner within a fuel cell, to drive an electrical current (not dissimilar in some ways to a battery). The most immediate opportunities to apply fuel cells are in the transport sector.

Fuel cells operate according to the same electrochemical dynamics as electrolysers, each operating a reverse process to the other. As such the fuel cell is a primary arena where technology can be innovated and improved to deliver better performance and lower costs.

The FTSE-100 British company **Johson Matthey** has a leading role to play in the hydrogen sector. The company supplies highly specialised catalysts, catalyst coated membranes (CCM), and membrane electrode assemblies (MEA) technologies, essential in the manufacture of both fuel cells and indeed electrolysers. The company already operates at scale in China and is likely to continue to grow in line with demand for its products and technology.

AIM-listed **Ceres Power** is a British fuel cell producer and – worth more than £600m – the UK's most valuable cleantech company. Ceres was founded in 2001 using research from Professor Nigel Brandon of Imperial College London. The company's core product is the SteelCell, which can generate electrical power at very high efficiency from both sustainable fuels such as hydrogen and also conventional fuels such as natural gas.

Ceres Power has a strategic collaboration agreement with **Weichai Power** (潍柴动力股份有限公司), a Chinese manufacturer of engines and drivetrain components for buses and trucks. In 2020 Weichai completed the construction of a fuel cell industrial park that has the capacity to manufacture 20,000 hydrogen fuel cell systems per year. At the same time, the company has already put into operation 200 hydrogen fuel cell buses in Shandong[10].



10 https://en.weichaipower.com/about/culture/story/202005/t20200511_63636.html

Beijing SinoHytec (北京亿华通科技股份有限公司) produces hydrogen fuel cell engines, fuel cell voltage converters, compressed gaseous hydrogen systems, and other products. SinoHytec has announced a joint venture with Toyota, one of the world's leading fuel cell manufacturers, to produce fuel cell systems for commercial vehicles in China[11].

Shanghai-based fuel cell manufacturer **REFIRE** (上海重塑能源集团股份有限公司) has also entered the market with a portfolio of proprietary fuel cell systems. In July 2021, 1,200 Geely light trucks hit the road using the REFIRE Fuel Cell System[12], and the previous year REFIRE helped develop the world's first fuel cell-powered mixer truck[13].

Internationally the leading global fuel cell producer is the Canadian corporation **Ballard Power Systems**.

Industry

Chemicals industry

(Grey) hydrogen is used extensively in industrial processes today, both in China and the UK. It is deployed in hydrogenation, methanol production, hydrocracking, desulphurisation, and as a chemical feedstock. As the demand is already in place it is the first area to be prioritised in terms of decarbonisation.

Fertiliser

Ammonia (NH3), manufactured by combining nitrogen and hydrogen through the Haber-Bosch process, is a key constituent of fertilisers everywhere. Virtually all hydrogen used in fertiliser production today is 'grey' hydrogen, and as such the fertiliser sector presents a prime early candidate for decarbonising.

China is the largest manufacturer of fertiliser in the world, both for domestic and export markets. There are a great many fertiliser manufacturers, with the leading company being **Sinofert** (中化化肥有限公司). Manufacturers in the UK include US-owned **CF Fertilisers**, **Norwegian Yara International**, and **Origin Fertilisers**.

With the potential for green ammonia to be used to power ships – in addition to the essential role played in supporting crop yields – these companies have an even more significant future in the hydrogen economy.

Steel

The production of steel requires the batch delivery of intense amounts of energy over a short time period. As a fuel with high energy density, hydrogen can potentially be used in place of the coking coal used today in ore-based steel making. Indeed in 2021 the first ever green steel was produced in Sweden.

> *"Grey hydrogen is used extensively in industrial processes today... it is the first area to be prioritised for decarbonisation."*

Steel production is a major source of carbon emissions and in Britain's case the largest industrial emitter. Nevertheless, the UK Hydrogen Strategy contains little on the subject beyond a statement that the government is "considering the implications of the recommendations to set targets for... near-zero emissions by 2035".

In China, the sector produces 15% of greenhouse gas emissions, and the largest company (**China Baowu Steel** 中国宝武钢铁集团有限公司) is making efforts to reduce carbon by deploying hydrogen in the production process. Specifically, the company is researching low-carbon smelting technology and the development of hydrogen metallurgy.

11 https://www.yicaiglobal.com/news/toyota-sinohytec-to-set-up-hydrogen-fuel-cell-system-plant-in-china
12 https://www.refire.com/en/news/working-on-refire-fuel-cell-system-1-200-geely-new-energy/
13 https://www.refire.com/en/news/powered-by-refire-technology-sany-s-world-first-fuel-cell/

Power sector

In power generation, low-carbon hydrogen is one of the leading options for storing renewable energy, and hydrogen and ammonia can be used in gas turbines to increase power system flexibility. Gas turbine manufacturers are developing turbines that can combust 100% hydrogen both for peaking and baseload applications, as a decarbonised alternative to natural gas.

Surplus electric power can be converted to hydrogen for storage and consequent reconversion at a later point. This enables power providers to smooth supply to meet demand, which will be more complex to manage in the renewables future as power from solar or wind sources is more intermittent and variable than that from fossil fuels. It also enables the management of seasonal issues where more energy is available in summers, but more is needed in winters, for example. A major challenge is that of how to deploy flexible equipment into the power network.

The three power generation manufacturing giants in China (**Dongfang Electric 东方电气集团**, **Shanghai Electric 上海电气**, and **Harbin Electric 哈尔滨电气**) are moving towards hydrogen, albeit apparently with a focus on fuel cells and transportation more than directly within power generation per se.

In the UK, the focus of the energy suppliers leans towards 'blue' hydrogen, with research ongoing as to the feasibility of low-carbon hydrogen burning power plants, for example.

Transport

In a carbon-free future, fuel cell electric vehicles (FCEVs) will compete with battery electric vehicles (BEVs) for primacy. Cost and range will be key factors in determining which technology wins, use-case by use-case.

Public transport

Hydrogen is set to be a keystone of the 2022 Beijing Winter Olympics, with a pledge to deliver 1,000 hydrogen-powered buses for the event. A good many Chinese cities are already piloting hydrogen-powered buses, with fleets operating in the provinces of Shandong, Henan, Guangdong, Jiangsu amongst others. Hydrogen bus manufacturers include **Yutong Bus** and **Zhongtong Bus**.

In the UK, since taking on new owners in 2019, the Northern Irish bus manufacturer **Wrightbus** has been focused on delivering a fleet of 3,000 hydrogen-powered buses by 2024, and some of the company's hydrogen-powered buses can already be seen on London's bus route 7.

Britain's largest bus manufacturer **Alexander Dennis** has announced that H2.0, a 300-mile range hydrogen-powered double decker bus, will be on the road by the end of 2021.

Commercial vehicles

There is tremendous potential for low-carbon hydrogen to be effective for heavy and long-distance goods vehicles where batteries are not effective or suitable. For example in 2021 a division of **Great Wall Motor** (長城汽車股份有限公司) delivered 100 hydrogen-powered trucks for construction of the Xiong' An New Area in Hebei Province; Weichai Power has built a prototype hydrogen fuel/lithium battery mining truck, with production due to start later this year.

There is a great deal of interest in the deployment of hydrogen-powered vehicles in the logistics industry: for instance, the forklifts used in the enormous warehouses of e-commerce marketplaces such as Amazon and jd.com.

The British forklift manufacturer **Still** offers hydrogen fuel cell-powered vehicles. In China, **Hangcha Group** (杭叉集团股份有限公司) is a producer of such vehicles, and the Qingpu District development near Shanghai is trialling hydrogen fuel cell forklifts.

Refuelling stations

For hydrogen to become an effective fuel in the transport industry, an extensive network of filling stations needs to be in place. In China, this expansion is an area of particular enthusiasm, with networks of fuel pumps gradually expanding in China's largest cities.

The hydrogen division of the British oil and gas major Shell – expanded in terms of personnel by a factor of six in the past 12 months – is providing consultative and technical support to the Winter Olympics hydrogen project, with a particular focus on ensuring the safety of filling stations.

In Beijing, an International Hydrogen Energy Demonstration Zone has been set up by **Houpu Clean Energy** (長城汽車股份有限公司) in partnership with a French company. Houpu has previously supplied LNG refuelling stations to the UK market.

However, in the UK there are but a handful of hydrogen stations today, although this can be expected to change rapidly in the near future through the promotion of the UKH2Mobility programme.

Private vehicles

There continues to be interest in FCEVs for private transport, although battery electric vehicles (BEVs) are considerably further advanced in both China and the UK. An interesting development for BEVs is the possibility of using them as a distributed source of electricity storage, allowing flexibility across the national grid.

Globally the hydrogen vehicle sector is dominated by Toyota Motor. Within China, **Great Wall Motor** (長城汽車股份有限公司) has invested considerably in recent years to develop hydrogen power technologies that can be used for vehicles as well as marine and rail transport. The company's hydrogen-powered cars will be deployed at the Winter Olympics and the first hydrogen-powered SUV will be delivered later this year. The largest Chinese automaker **SAIC Motor** (上海汽车集团股份有限公司) has laid out an intention to have 10% of the hydrogen vehicle market by 2025, rolling out 5 models in the period.

There are currently no plans to develop hydrogen vehicles for the UK's large motor industry, with the only cars available in the market being produced in Japan and Korea.

The spirit of innovation remains strong however. For example, British cleantech company **Viritech** specialises in developing hydrogen powertrain solutions for the automotive, aerospace, marine and power industries.

Rail

Hydrogen power is a suitable energy vector for the rail industry for unelectrified parts of the network – representing 50% and 30% of British and Chinese tracks respectively. In 2021 the first hydrogen fuel cell hybrid locomotive was delivered by **CRRC** (中国中车股份有限公司). In the UK (where the government has committed to demising diesel traction by 2040), the HydroFLEX prototype – developed by **Porterbrook** together with the **University of Birmingham** – has been tested on the mainline, and the Breeze project is underway between Alstom and **Eversholt Rail** to develop a new class of British hydrogen trains.

Aviation

Aviation is a high profile area of focus in the energy transition, given the sector's significant greenhouse gas emissions. However, the societal and economic impacts of air travel have been such that it's a particularly difficult transition to make. A very high energy density fuel is required in order to propel a vehicle into the air, and the challenge is to find pathways that can be effective as kerosene has been.

Hydrogen does not have this density and so a challenge is that hydrogen-fueled aircraft will need to have bigger fuel tanks than conventional aircraft, and radical changes would accordingly need to be made to designs.

Nevertheless, it's likely that low-carbon hydrogen will have some kind of role to play in the future, alongside batteries and synthetic aviation fuels (SAF). For shorter-distance flights, the battery is well-positioned to prevail although there is also potential for hydrogen fuel cells; for longer distances, the challenge is around the adaptation of gas turbines to burn hydrogen directly.

The British industrial group **Rolls Royce** is a leading global manufacturer of aircraft engines, with an established presence in China; **Cranfield University** is a leading global research centre into aviation, and with a long-established reputation in gas turbine engineering – both have much to contribute in this space.

"Batteries will not be able to power the huge ships which carry international trade and this is where hydrogen can come into play..."

Marine

The bunker fuel used in ships is one of the most polluting fossil fuels commonly used today and the industry emits 3% of greenhouse gases. Furthermore, the lack of regulations in international waters and the desire to keep shipping rates down means there has historically been less pressure on the industry to clean up.

However, in 2018, the International Maritime Organisation committed to reducing carbon dioxide emissions in the industry by 70% by 2050, a declaration supported by both the UK and China. China is the largest shipbuilder in the world, and with ship lifetimes extending to 25 years, the imperative is to deliver zero-carbon vessels by 2030.

Batteries will not be able to power the huge ships which carry international trade and this is where hydrogen can come into play, possibly stored and used in the form of ammonia rather than directly from gaseous or liquid form.

China State Shipbuilding Corporation's Division 712 is charged with developing hydrogen-powered ships.

The UK government's Clean Maritime Plan 2019 places a great emphasis on the role hydrogen has to play in reducing carbon emissions in shipping. To date, hydrogen-powered vessels have been deployed at a small scale, for example, as island ferries and shore vessels.

Buildings

In order to meet respective net-zero commitments, changes are necessary for the way homes and buildings are heated.

In the UK, fossil-fuel burning gas and oil boilers will not be permitted in new-build homes from 2025. All homes built after this date must be zero-carbon ready, with heat provided using renewable low-carbon technologies.

Electrically powered heat pumps are likely to be the preferred solution where the mains grid is available; however, in low population areas located near hydrogen production facilities, it's possible that hydrogen will have a role to play.

There are several pilot hydrogen heating schemes in development around the UK. In Gateshead in the northeast of England, two semi-detached homes (funded with the help of the UK government's **Hy4Heat** Innovation programme) are using 100% hydrogen for domestic heating and cooking highlighting the potential of hydrogen as a low-carbon replacement to natural gas.

Also, at Keele University in Staffordshire, the **HyDeploy** programme is testing the blending of hydrogen with natural gas.

Case study: Manchester

"As Manchester moves towards net zero by 2038 and implements an ambitious hydrogen strategy, there will undoubtedly be significant opportunities for mutually beneficial collaboration with China."

David Percival MBE, Manchester – China Forum Chair

Profile

Manchester became the world's first industrial city in the early 1800s; the growth of the city's cotton industry drove the town's expansion, putting it at the heart of a global network of manufacturing and trade.

Greater Manchester is the economic centre of the northwest of England, with the most significant regional economy in the UK outside of London and south-east England. The city has long diversified away from the textile industry and today is a city of the arts, media, higher education and commerce.

Administered by the **Greater Manchester Combined Authority** (GMCA), the region lies within the UK's second-largest built-up area and has 2.8 million people. Transport for Greater Manchester (TfGM) delivers public transport in the region, and MIDAS is Manchester's inward investment promotion agency.

The region's universities host more than 100,000 students; the British Broadcasting Corporation (BBC) operates from MediaCityUK at Salford Quays; and the city hosts two of the world's wealthiest and best-known football teams, Manchester United and Manchester City.

Chinese people first came to the city in the early 20th century, and now the city has a sizeable Chinese population. Manchester is popular with students, with more than 10,000 Chinese people attending the area's universities, many of them graduate students involved in research.

At least 80 Chinese-owned companies operate in the region. Chinese firms have invested more than £6bn locally, including the £1bn Northern Gateway project and the £1bn Airport City development, where **Beijing Construction and Engineering Group** (北京建工集团) is a major equity partner and led the construction and development of the project.

Manchester has been twinned with the city of Wuhan in Hebei Province since 1986. The relationship focuses on encouraging trade and investment between the UK and China.

The Manchester China Forum is a public-private partnership with strong links and influence in both places. It focuses on driving the relationship forward and ensuring growth in commercial connectivity. The Forum is widely regarded as the UK's most successful city initiative in engaging China, and it gives Manchester a significant advantage when looking to collaborate with China.

Net zero

Like many other cities in the UK and worldwide, Manchester faces the challenge of reducing its emissions to limit the impacts of climate change and meet the targets of the Paris Agreement.

In 2019, the city's 5 Year Environment Plan pledged that Greater Manchester would become carbon neutral by 2038, 12 years ahead of the rest of the UK. The plan articulated actions by 2024 as follows:

- Reducing carbon dioxide emissions in the energy supply by investing in renewable electricity generation (an additional 45MW of solar, onshore wind and biomass, 10TWh of low carbon heating).
- Reducing carbon dioxide emissions by reducing the amount of fossil-fuel-powered travel (increasing usage of public transport, phasing in zero-emission vehicles, tackling the most polluting trucks and lorries, establishing zero-emissions buses and decarbonising freight transport).
- Reducing carbon dioxide emissions from the excessive use of energy in homes, public and commercial buildings, reducing heat loss by 57% (initiating retrofitting of 61,000 homes and reducing heat demand from existing and new buildings).
- Changing how resources are produced and consumed (reducing industrial emissions, limiting the increase in production of waste, increased recycling rates).
- Protecting the natural environment.
- Embedding concepts of climate change resilience and adaptation.

The GMCA has established a Low Carbon Hub, which oversees the delivery of the city's commitments concerning low carbon. Areas in focus include realising economic opportunities from the energy transition, supporting the achievement of carbon reduction targets, increasing awareness and understanding leading to behavioural change, and preparing Greater Manchester for the unavoidable effects of climate change.

"In 2019 Greater Manchester pledged it would become carbon neutral by 2038."

The **North West Hydrogen Alliance** brings together regional and national stakeholders to present a compelling case for the region – including Manchester – to receive the government support needed to realise the benefits of hydrogen.

Manchester features all the necessary components to develop a hydrogen economy – a thriving industrial and manufacturing base, the capability to address the re-skilling of an existing workforce, local authorities that collaborate, and natural assets.

Hydrogen Strategy

Although Manchester doesn't have a single plan to meet its climate change targets, hydrogen and fuel cell technology are well-positioned as some of the many potential routes.

Manchester's focus is on the development of green hydrogen. The city's first Hydrogen Strategy was authored in 2021 by Manchester Metropolitan University. It included a series of recommendations:

Use public sector HGV vehicle to lead switch to fuel cell electric vehicles (FCEV)

The UK government is considering phasing out new heavy goods vehicles (HGVs) between 2035 and 2040.

In the public sector, refuse trucks are a suitable category for early decarbonisation. Indeed inspired by COP26, in 2021, the Scottish city of Glasgow received £6.3m of UK government funding to launch the world's largest hydrogen-powered fleet.

Manchester City Council has plans to purchase more than 200 hydrogen-powered public sector vehicles.

Utilise air quality policy to drive uptake by HGVs and buses

A Greater Manchester-wide Clean Air Zone is expected to launch in 2022. More than £120m in government funding is available to support businesses, people and organisations moving to cleaner vehicles.

> *"Manchester's focus is on the development of green hydrogen."*

Neighbouring Liverpool has plans for 20 hydrogen- powered buses. Manchester will follow. The city has plans to purchase more than 200 hydrogen-powered public sector vehicles.

At Manchester Airport, the 1,000 airside logistics vehicles are excellent candidates for hydrogen power in due course.

Planning for wider hydrogen refuelling station deployment

The UK H2Mobility consortium is responsible for delivering a national hydrogen refuelling infrastructure, including Manchester.

Today there are no hydrogen filling stations in Greater Manchester, although it's probable that the first – when it comes – will be at the Trafford Low Carbon Energy Park.

In September 2021, ITM Motive announced plans to build a network of hydrogen stations for trucks and buses in the north of England.

Evaluate hydrogen as a replacement for diesel rail

Greater Manchester lies at the heart of a largely non-electrified rail network today. The British government has committed to eliminating diesel traction in the UK by 2040, and Network Rail's Decarbonisation Network Strategy outlines an intention to electrify the bulk of unelectrified tracks today. A niche has been carved out for hydrogen and battery power, likely for low-speed passenger services on rural lines with low traffic volumes. Nevertheless, hydrogen could also play an interim role in removing diesel trains from service before the arrival of overhead catenary wires, given the latter's installation expense.

Department of Transport is planning for the Tees Valley to be a hub of excellence for hydrogen transportation.

Support innovation and demonstration of hydrogen for heat

Burning pure hydrogen in current household appliances is not possible, and the UK government's Hy4Heat programme is testing the idea of 100% hydrogen for domestic heating and cooking. The first tests are taking place in the north-east of England. Potentially Manchester could participate in a subsequent phase of the programme as the scale expands to cover a neighbourhood, then a large village and then a town.

The Manchester Civic Quarter Heat Network is a heat and power programme for some of the city's most iconic buildings. The project allows for the use of hydrogen in the fuel mix in future.

Prepare for the availability of large volume hydrogen supply
Current projects in place include:

HyNet

HyNet is an innovative, integrated low-carbon hydrogen production, distribution and carbon capture, utilisation and storage (CCUS) project. The £900m project will provide hydrogen distribution and CCUS infrastructure across Liverpool, Manchester and parts of Cheshire.

Cadent Gas, which owns and operates the gas distribution network in the area – is developing the project with **Progressive Energy**, an experienced clean energy project development company. **ENI** is the owner and operator of the Liverpool Bay oil and gas fields that will store carbon dioxide produced in the process.

The project comprises several different elements, including upgrades to existing facilities and the development of new infrastructure. Production will take place on the Wirral and supply hydrogen to Greater Manchester and other localities from 2026.

Low Carbon Hydrogen Hub

Manchester's first low-carbon hydrogen facility is to be in **Trafford Low Carbon Energy Park**. Developed by Trafford Green Hydrogen, the 200MW hydrogen fuelling hub will be the largest in the UK. It will provide businesses in the region with easy access to hydrogen fuel, both those that utilise hydrogen for transportation fleets and those with heating requirements. The hub will produce and store hydrogen at scale and integrate renewable energy through solar and wind power storage.

The initiative is a joint venture between **MMU**, **GMCA**, **Trafford Council**, **Carlton Power**, **Cadent Gas** and **Electricity North West**. Construction is due to begin in 2022, and commercial operations start in 2023.

Utilise academic expertise and facilities to support innovation
Manchester has extensive resources capable of participating in the establishment of a regional hydrogen economy.

- **The University of Manchester** hosts the **Henry Royce Institute**, the UK's national institute for advanced materials research and innovation, and the **National Graphene Institute**, visited by China's President Xi Jinping in 2015. In 2021 the University formalised a strategic engagement with the **National Physical Laboratory**, which sets and maintains measurement standards for the UK. Metrology has a vital role to play in the development of the hydrogen sector.
- In 2018 **Manchester Metropolitan University** (**MMU**) opened the **Manchester Fuel Cell Innovation Centre** (**MFCIC**). This £4m facility brings together technology, academics and industry professionals to create technology for clean electrolysers and fuel cells. The centre has a strategic partnership with Tsinghua University's **Sichuan Energy Internet Research Institute**.
- In the medium term, there are aspirations to establish a **Hydrogen Innovation Commercialisation Centre** and place Manchester at the forefront of the UK's hydrogen economy.

Support reskilling of those already in the labour market
The energy transition and the scale adoption of renewable energy promise to create new types of work, including:

- the operation of hydrogen production, storage and distribution facilities;
- the research, development and manufacture of specialised equipment for the hydrogen economy;
- the replacement of fossil-fuel-burning equipment with (or adaptation to) the hydrogen chain (for example, retraining gas engineers as hydrogen specialists); and
- the co-ordination and management of the energy transition, including providing advisory and consultation support and finance.

"There is a need to educate a broad audience about hydrogen across all economic segments."

Support educational institutions to develop courses that deliver skills for the hydrogen economy
Whether in Manchester, elsewhere in the UK, China, or globally, there is a need to educate a broad audience of people across all economic segments regarding the new renewables energy technology to be adopted in the future. Examples of content to be covered include:

- The knowledge of hydrogen-related technologies such as electrolysers, carbon capture and storage, and fuel cells
- The economics of the energy transition, specifically as relating to hydrogen
- The integrated dynamics of the new energy system.

Manchester Metropolitan University has developed the HySchools (Hydrogen in Schools) programme in secondary schools, which provides online educational resources to enable teachers to teach about hydrogen fuel cell technology.

Opportunities
Building on themes established through this paper, potential next steps for Manchester include:

Expand the plan
Even before a single hydrogen filling station has been built in Manchester, much progress has been made. Now, to build momentum, it will be essential to articulate a more detailed plan for Manchester's hydrogen future.

It will be easier to engage business and finance partners to initiate projects if a picture is painted of how Manchester will deploy hydrogen. This picture would include introducing the technologies to be used, how they will work, their impact on people and businesses in Manchester, and what will need to be done by when.

Engage finance
As has been demonstrated throughout this paper, the finance world is well aware of the coming energy transition. There is interest in large-scale, long-term government-backed hydrogen projects with demonstrable demand, which Manchester's future hydrogen economy offers.

It will be necessary to build relationships with a broad range of banks and potential investment institutions, understanding where there is an appetite to invest and where concerns and risks are foreseen.

The Hydrogen Business Model will lay out a clear framework for how the UK government intends to underpin this new economy and will thus play a vital role in investment projects.

Establish consortia
To be successful, large-scale complex programmes such as this require a broad range of stakeholders to collaborate, including asset owners, technical experts, equipment manufacturers, local authorities, finance providers, and professional service firms.

"Chinese capital could provide the investment required to establish a hydrogen economy in Manchester."

The China – UK opportunity

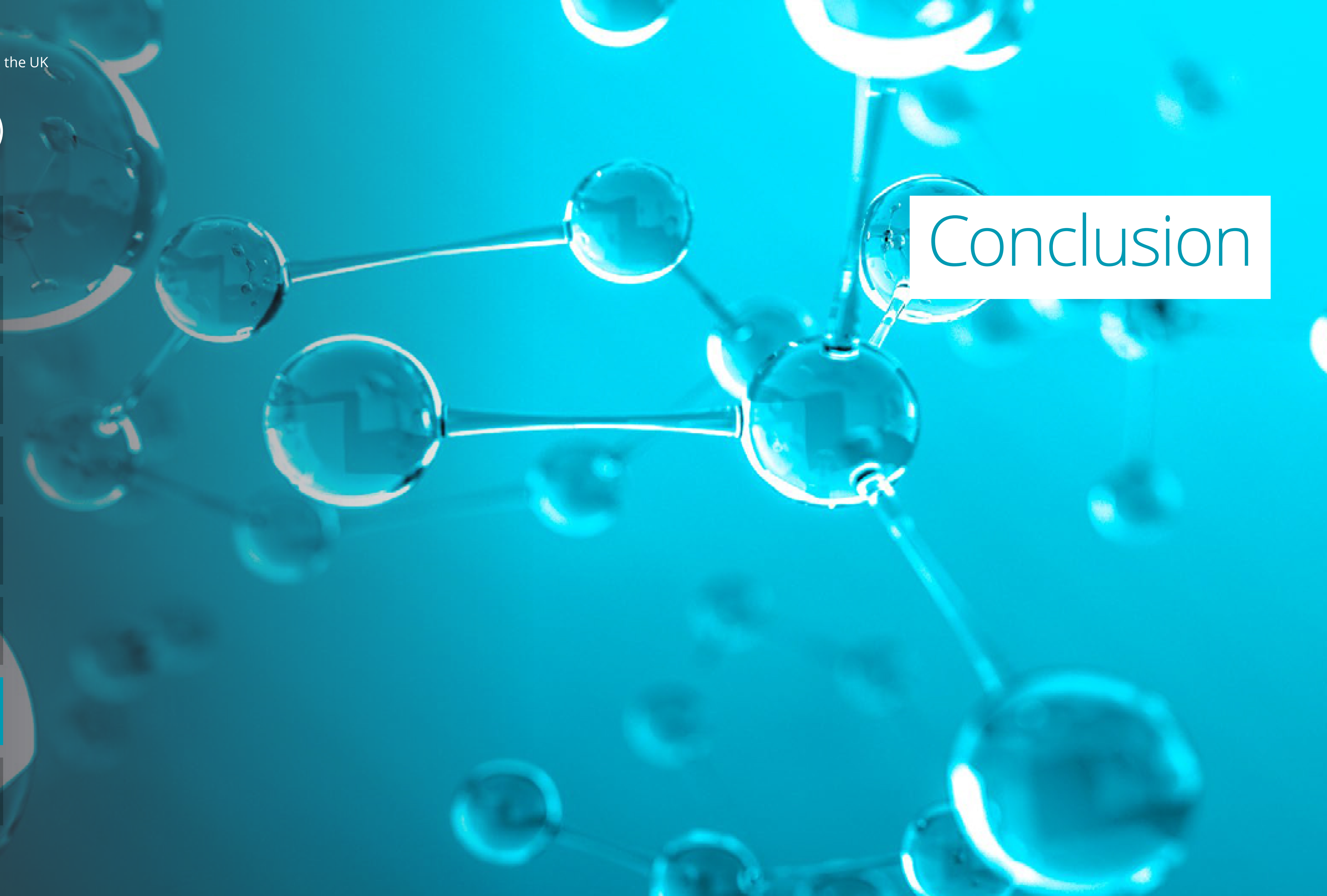
Chinese investment in the Manchester hydrogen economy
It's foreseeable that Chinese capital – whether state-managed or private – could be interested in providing the investment required to fund the type of projects needed to establish a hydrogen economy in Manchester.

Sourcing China-manufactured hydrogen equipment
As we have seen, China is going to have a strong offering across the hydrogen value chain. Although the UK government is promoting a 'Buy British' concept for the hydrogen economy, plenty of relevant products will inevitably be manufactured more economically in China – whether large-scale machinery or smaller specific componentry.

Deploying UK technical knowledge in China
Chinese corporations are often looking for the 'last 10% of technical knowledge. Such intellectual property can be found in corporations and academic institutions established in Manchester, and this means that China can be a target market for these British organisations.

Conclusion
Manchester's scenario is representative of how hydrogen has a critical role to play in local/regional economies in future. The strategy and approaches discussed here are relevant for city economies in both China and the UK, as is the opportunity for collaboration to mutual benefit.

Conclusion



It's clear that the time for action on climate change is **now**.

We have seen how the hydrogen sector faces very tangible challenges, in response to which we frame a series of recommendations.

1. Partnership

Challenge
The UK and China currently are experiencing political differences which have impacted trust on both sides.

Recommendation
Renewable energy, and specifically hydrogen, provide a 'safe' space where China and the UK must put political differences aside and collaborate. The possibilities are enormous and climate change is just too important to take a different approach. The opportunity stems from coupling China's ability to deliver at scale, and the UK's environment of advanced technological innovation, as well as the tremendous amounts of financing available in both countries.

Who should lead:
Governments, industry, finance, academia.

2. Engagement

Challenge
The topics of the energy transition, net-zero and renewable energy (not just hydrogen) are not yet well established across the finance sector.

Recommendation
Finance **must** engage with the topic of net-zero more quickly than is the case at the moment. In addition to the ESG/purpose-driven top-down approach, and the ongoing involvement of energy bankers who unavoidably are engaged on the topic, action has to be initiated by all in the finance sector. Due to the breadth of potential applications of hydrogen, it is an excellent medium through which the opportunities of the wider energy transition can be explored.

Who should lead:
UK- and China-based national and international banks.

3. Risk appetite

Challenge
Today the finance sector has little appetite to support the hydrogen sector.

Recommendation
Finance organisations, and specifically banks, should allocate risk appetite to the hydrogen energy transition. While this should be voluntary, policy also plays a role. Banks will need to prioritise the development of **innovative** risk mechanisms so as to create more willingness to lend. Ultimately, the business model needs to be right, with the risk profile of projects matching that of the supporting capital and funding.

Who should lead:
UK- and China-based national and international banks.

4. Understanding

Challenge
There is limited knowledge and understanding of hydrogen technology today, and of the role it will play in future.

Recommendation
It's important to recognise that the story of hydrogen will be **messy**, although ultimately **successful**. Because of the range of potential applications, we will see proofs of concept failing and investments not being recovered.

Very real barriers lie in wait, many (but not all) of which can be surmounted given sufficient **money** or clever **engineering** (or both). However, we can be sure that in the long run a large-scale hydrogen economy will be established, not just for the UK and China but globally.

On the **supply** side, although each of the colours of hydrogen has a role to play through the transition, ultimately the final outcome requires hydrogen from an entirely clear (carbon-free) source. On the demand side, it's important to understand where hydrogen will unavoidably prevail, and where it will not. Here the hydrogen ladder is an excellent tool.

Who should lead:
Governments, industry, finance, academia.

5. Collaboration

Challenge
By their nature, hydrogen projects require many different parties to collaborate.

Recommendation
Whether in the UK or China, huge amounts of **collaboration** are needed across industry, governments, academic and finance. All parties need to be actively seeking the formation of (or participation in) consortia, in order to get projects underway.

Who should lead:
Governments, industry, finance, academia.

Us
At **Deloitte**, we know that we ourselves have our own important role to play, as we couple our deep technical sector knowledge with our relationships with many of the organisations which will be driving the energy transition in future. It's an exciting time and we're looking forward to working with our clients in China and the UK to make an impact together.

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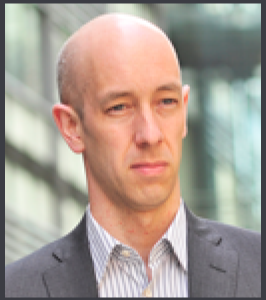

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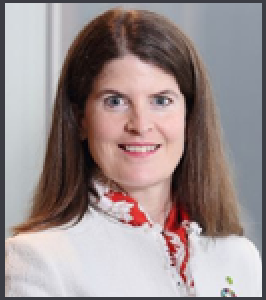

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