The Hydrogen Revolution in EMEA

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Contents

Foreword

As the world begins to emerge from the shadow which the pandemic has cast over it, focus will turn to global economic recovery. It is already apparent that many of the world's leading economies see investment in green energy as a key component of their strategy to revive and revitalize their economy. It is a fiscal strategy which also sits comfortably with their commitment to take active steps to address climate change and to build towards a more sustainable future.

It is in that context that hydrogen will have a valuable role to play, with perhaps the biggest question being whether it will dominate major economies or merely fill in gaps as part of a broader and more varied energy portfolio.

Hydrogen, and its use as an energy supply, is not a new phenomenon. Its unique qualities as an energy source and fuel because of its high energy content per unit of weight has long been recognized. Indeed, demand has grown significantly and consistently since 1975, and that is expected to continue. What is new is the perfect storm of that increasing demand, improved technology to generate clean (or cleaner) hydrogen than traditional methods of hydrogen production (which have a significant emissions profile), decreasing production costs and the broader prioritization being given to decarbonization.

That perfect storm gives rise to an incredible opportunity, across a range of sectors (most notably energy intensive, high emission industries) and geographies for energy players and investors.

In this publication we analyze, with the benefit of commentary from both key individuals in the space and DLA Piper lawyers, how the hydrogen market is developing, and the approach that is being taken in key jurisdictions. In particular, we look at developments in Europe, the UK, Germany, the Middle East and North Africa. Those diverse geographies are linked by their existing commitment to hydrogen and the work that is being done in recognition of its future potential. All shine a light on the scale of the opportunity which clean hydrogen presents.

A solid uptake of hydrogen across a number of applications could see it accounting for around a quarter of total energy supply by 2050, providing more than five million jobs across the globe. With the number of projects and policies within the energy space growing, coordinating intervention across the piece – from policy and regulation, to the role played by the private sector – will be essential to ensure a smooth journey towards sector maturity. We hope that this report provides useful insight into the point that has been reached on that journey, where the journey is going, and what its ultimate destination may be.

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1. Introduction

Hydrogen is the most abundant element in the universe. As it can provide a clean, alternative energy source, it is also a crucial part of future energy systems as countries across the globe drive towards zero carbon economies. Hydrogen's immense potential is demonstrated by the fact it is an energy carrier with an energy density more than twice that of natural gas.

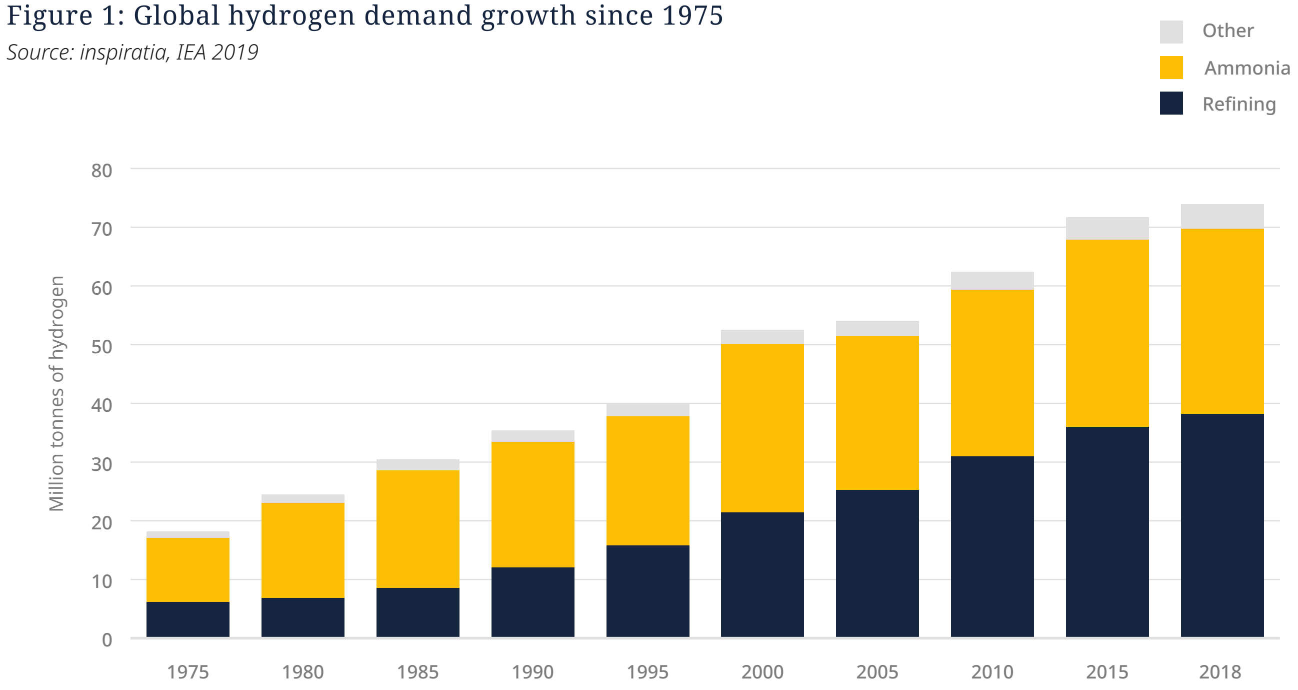
The use of hydrogen in a range of processes is not a new phenomenon, and demand currently comes from a wide array of sectors, led by petroleum and agriculture:

- Just under half of all current hydrogen consumption occurs in petroleum refining as hydrogen is used to crack heavier oils into lighter oils for use as petroleum and other oil and gas products.
- The second-largest use of hydrogen is in agriculture where it is used to produce ammonia for fertilizers (by combining hydrogen with nitrogen).
- The remaining 10% of hydrogen demand comes from across the food, metals, electronics, and methanol industries.

In these sectors, demand for hydrogen has grown steadily since 1975 (*see Figure 1*) to reach a global demand today of over 70 million tonnes per year with an estimated market size of more than USD115 billion. That trend is expected to continue and be a central feature of the energy transition away from traditional energy sources.

Figure 1: Global hydrogen demand growth since 1975

Source: inspiratia, IEA 2019



Current forecasts anticipate that demand for hydrogen will continue to steadily increase towards 2050. With so many sectors considering hydrogen as a zero-emission energy carrier or fuel, steady demand from existing off-takers will be augmented by the rise in demand from customers in new sectors. Current data suggest that global hydrogen demand will require additional generation of 35-1,100TWh per year by 2030, increasing to 300-19,000TWh per year by 2050.

Particular demand growth is anticipated in those sectors which are traditionally regarded as difficult to de-carbonize, such as the steel and cement industries, where clean sources of hydrogen (which are expected to be available in increasing volumes at increasingly lower cost) are likely to have a vital role to play. Other drivers of increased demand will include fuel cell vehicles (cars, buses, trucks, and trains), heating for buildings and power generation, with each of these aided by improvements in costs and processes as wells as excess renewables generation used to power electrolyzers.

As mentioned above, the availability of improved, and cheaper, production processes generating increasing volumes of clean (i.e. low or zero carbon emission) hydrogen will also be a driver of demand. That will be a major step change for global hydrogen production in circumstances where 98% of current demand is met by hydrogen sources which are not clean, or as clean as they could be.

- Coal gasification produces what is referred to as "brown" hydrogen. That production method accounts for 23% of current hydrogen demand. It is one of the cheapest means of hydrogen production but creates significant amounts of CO2 as a by-product.
- Around 75% of hydrogen demand is currently met by a production process known as steam methane reforming (SMR), which uses natural gas as a feedstock. At present this process is done almost entirely without carbon capture and storage (CCS), and as a result is not a clean source of hydrogen. However, the hydrogen which it produces is known as "blue" hydrogen because it is a cleaner process than others such as coal gasification (brown hydrogen).

The impact of these processes is significant; far from being an environmentally positive solution in all cases, brown and blue hydrogen production are responsible for huge emissions. In 2019 alone, 830 million tonnes (MtCO2/yr) of CO2 emissions were created by producing hydrogen across the world.

Part of the solution is the increased use of CCS, both in new facilities and by way of retrofit to existing SMR and coal gasification plants. However, the rate of adoption is relatively slow as the technology is currently expensive and, in most cases, fails to capture all carbon emitted.

It is in those circumstances that if hydrogen is to fulfil its potential, greater utilization of clean production methods is paramount. Currently only 2% of hydrogen demand is met by production using water electrolysis, which uses proton exchange membrane (PEM) electrolyzers which can separate hydrogen from the oxygen in H2O without emitting CO2 as a by-product. This production method is known as green hydrogen. It has the potential to make a material contribution towards zero carbon economies, and its feasibility as a power supply increases as costs associated with photovoltaic solar panels and wind turbines decline.

As we will see when focusing on the hydrogen industry in Germany, there are some who think that CCS based hydrogen (i.e. blue hydrogen) is not a long term solution, and should only be part of a transition period in which we move to green hydrogen generated using renewable energy.

Unlocking hydrogen pathways

The challenge for hydrogen then, is to unlock pathways to the production of blue and (in particular) green hydrogen, and to serve increasing demand with decreased reliance on those methods of production which do not serve the zero carbon agenda. As it stands the choice for businesses (and to a degree the sectors in which they operate) is between electrolysis using renewable power or by fitting CCS to SMR and coal gasification processes. Deciding which to choose will depend on several factors such as the size of required investment, the level of government support, scale of operations, and available feedstock.

For the oil and gas sector, SMR plants fitted with CCS allow continued use of existing production assets while simultaneously reducing carbon emissions from hydrogen production operations. This blue hydrogen approach would enable industrial-scale volumes of carbon-neutral hydrogen to be produced. Economies of scale could then be exploited to simultaneously develop smaller-size green hydrogen production to help accelerate the development of all forms of hydrogen technology.

Elsewhere, relative newcomers to the hydrogen economy, such as fuel cell electric vehicle (FCEV) technologies, represent a new source of demand and so will likely need to coalesce around a green hydrogen-led approach in order to comply with net zero carbon targets. These greenfield hydrogen production projects can be developed in a number of ways. The most beneficial from an environmental standpoint is electrolysis powered by renewable energy sources, typically wind or solar. Where wind and solar are not available, developers in most cases must invest in SMR or gasification with CCS.

There are emerging technologies currently in testing or pilot programs that offer additional potential routes for clean hydrogen production in the future, although commercial use and scalability are still a long way off. One of these, Trigeneration[1], is gaining traction. This is a process which produces electricity, hydrogen and hot water using agricultural waste. Another is power-to-X (P2X) which creates synthetic fuels from renewable electricity generation using gas and liquid reconversion, which broadens the potential offtake options for the power generation sector so that energy produced by projects can be indirectly used in areas such as chemical production. These synthetic fuels can also replace fossil fuel use in other areas.

It is in this context that different actors in the hydrogen scene are exploring different avenues to produce clean hydrogen. "Our view is that hydrogen from nuclear power is just as green as hydrogen from wind and PV. Electrolytic hydrogen based on low carbon electricity is a far lower CO2 emitting option from a lifecycle perspective than blue hydrogen produced by SMR, even when it is combined with CCS." says *Etienne Briere*, Director of Storage, Renewable Energy & Environment at EDF – R&D.

1 Trigeneration (combined cooling, heat and power), allows for heat offtake from a combined heat and power plant to be used to chill water for air conditioning in refrigeration processes.

The central importance of production costs

Inevitably, the key to unlocking the right hydrogen pathways is cost. Today, coal gasification and SMR without CCS are the lowest cost options for hydrogen production (which in part explains why they satisfy 98% of current demand), followed by natural gas SMR with CCS. This, coupled with legacy investment concerns (e.g. potential stranded investments in fossil fuelled hydrogen production without CCS), has contributed to holding back interest in, and support for, clean (blue and green) hydrogen production.

However, those concerns are not shared by all, and a number of significant players are leading the way towards a greener hydrogen future. As *Dr. Graham Cooley*, CEO of ITM Power, comments on the price trajectory of cleaner hydrogen: "People say electrolyzers are too expensive, but at ITM Power we have more than halved the cost of our electrolyzers over the last three years. Volume is now key to further cost reduction. The cost of green hydrogen depends on the cost of the renewable power. An electrolyzer is a black box for converting renewable electrons into renewable molecules. The cost that dominates is the levelized cost of electricity (LCOE)[2]. The capex of electrolyzers and load factor are secondary to the LCOE." That optimistic view places primary emphasis on achieving increased volumes alongside decreased process and power costs; in the view of many there is a route to achieving those goals.

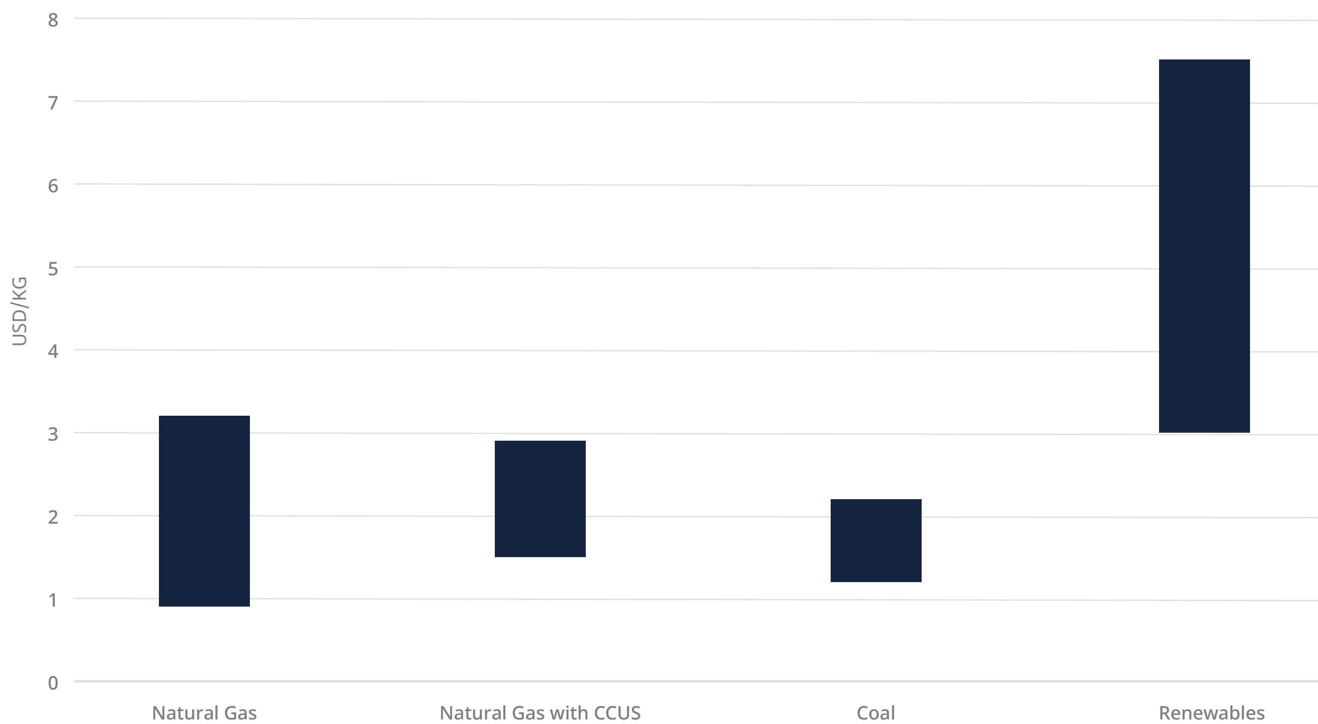
Current cost levels have led to limited consideration of hydrogen as an energy source or fuel for end-use in sectors such as storage, transport, industrial heating and metals manufacturing, and in the gas grid for buildings and residential heating. Finding a solution for these sectors is particularly important given the long-term environmental costs associated with the enormous carbon emissions which they generate. Many agree that reducing the cost of renewable power is the key. As *Figure 2* below illustrates, there will be limited commercial incentive to invest or to change while there remains such a significant discrepancy between the cost of renewable power for the purposes of hydrogen production and the cost of power for less green hydrogen production processes.

2 LCOE is a of electricity generation from a generating plant over its lifetime. It is calculated as the ratio between all the discounted costs over for a plant, divided by a discounted sum of the energy produced by the facility.

3 Natural gas used as a feedstock in SMR hydrogen production plants.

Figure 2: Production cost of hydrogen by source[3]

Source: "Hydrogen: A Renewable Energy Perspective" (2019), IRENA



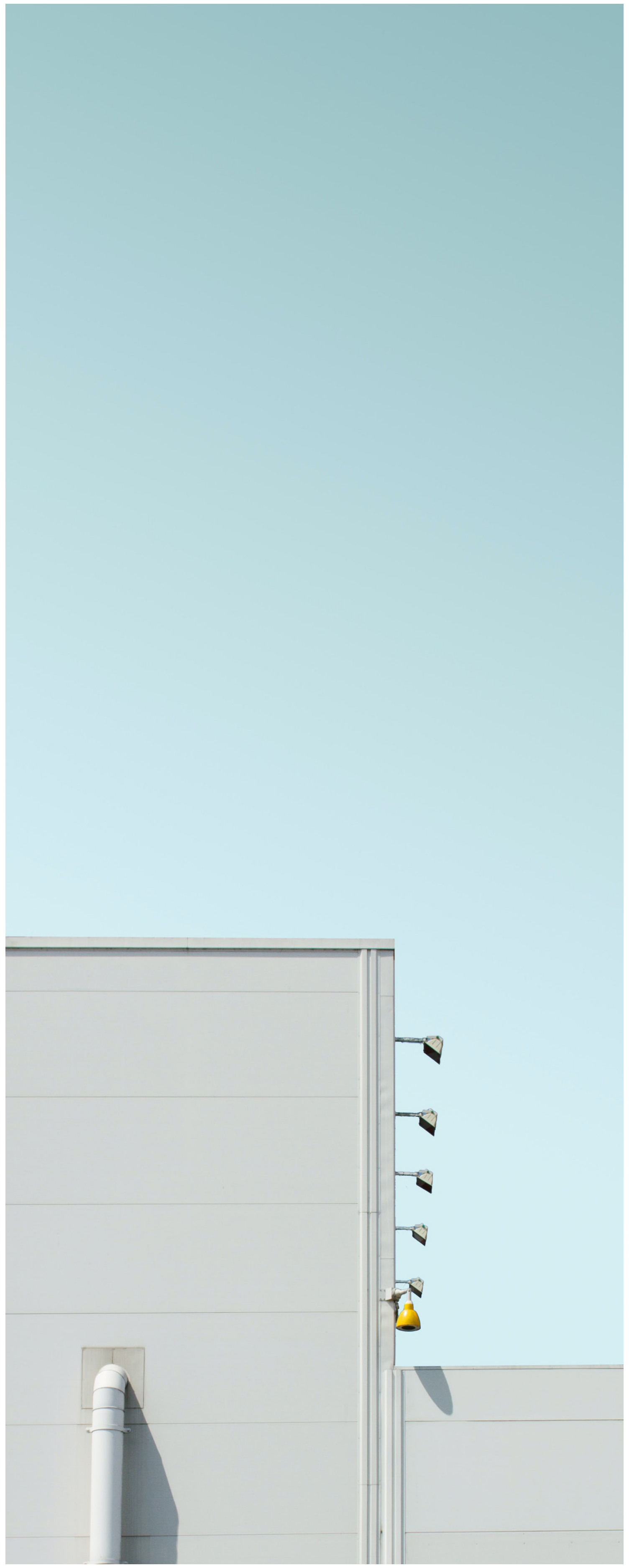
Filip Smeet, Senior Vice President of the Hydrogen Electrolyzer Division at Nel Hydrogen ASA endorses the view that the cost of power is key, but is also optimistic. As he puts it: "I believe the cost of generating electrolytically green hydrogen will follow the same path of solar and wind, despite being several years behind. Between 70% and 80% of your business case is your power cost – LCOE. So, abundance of cheap and renewable power is key."

The trends which both ITM Power and Nel Hydrogen ASA see as important to drive change – cost and volume – are heading in the right direction. There have been recent declines in the cost of electricity from renewable energy and considerable strides made in the evolution of electrolysis equipment which is closing the cost gap. According to a study by the Hydrogen Council, green hydrogen production costs are on track to reduce by 50-60% by 2030. That forecast is causing investors, developers and end-users to take notice, with the consequence that hydrogen has surged back to the top of the agenda for decarbonizing future energy supply. "Before 2050, green hydrogen will be priced at USD1.6/Kg down to USD0.8/Kg – equivalent to methane – making it the lowest cost and net zero," says *Dr. Graham Cooley*, CEO of ITM Power.

Using renewable-based electricity to produce hydrogen is therefore beginning to make more sense as each year passes. "As happened in the renewable energy sector, there is an added benefit in the value of a new resource rather than just the cost of production. So, it is more about the cost of energy and comparing it against the right comparable source rather than just a pure capex discussion," says *Andreas Gunst*, Partner at DLA Piper.

Despite this it is important to bear in mind that cost calculations are not the only factor when appraising the requirements of a new technology. As *Tim Williams*, Legal Director at DLA Piper, says: "It is important, notwithstanding the costs, to look at what the objective is and that is obviously decarbonization, so there is a third element to that kind of cost-benefit analysis, which is what achieves the objective."

This report examines the role of hydrogen in the path towards a decarbonized economy in certain key regions in EMEA and APAC. *Tracey Renshaw*, Partner of DLA Piper comments that "whilst hydrogen is increasingly being seen as a key part of the future energy mix and there is collaboration between countries at both a governmental level and a supply / demand level, local economic, political and geophysical factors are driving developments on a country-by-country basis".



2. Europe

As one of the world's major energy markets, with a clear commitment to address climate change, Europe presents an immense opportunity for the development of the use of hydrogen, as hydrogen presents an immense opportunity for the EU. That mutuality of interest enthuses those with an interest in both reducing carbon emissions and developing hydrogen as an energy and fuel source, making Europe a regional leader in hydrogen projects. An analysis of the European hydrogen market and its future therefore is a useful bellweather for the role hydrogen can play on a global scale.

Market overview

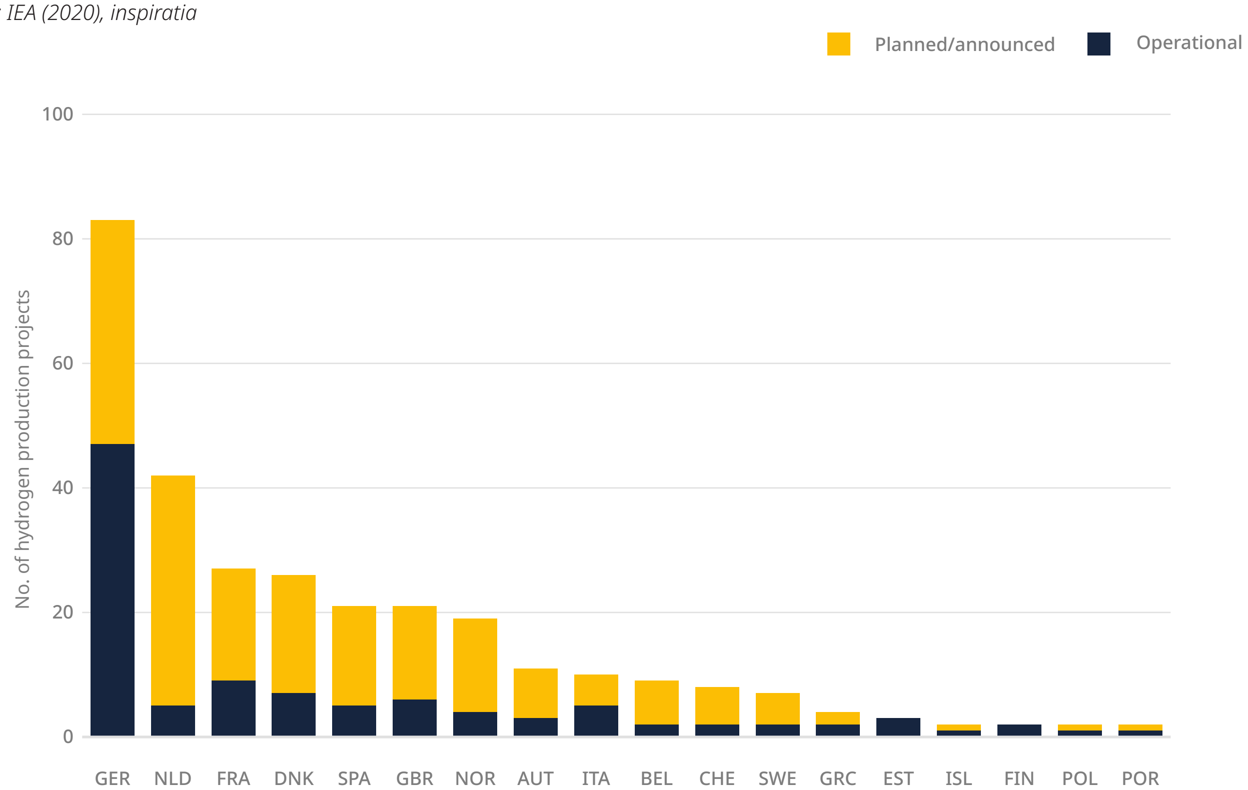
Europe's energy system, like most around the world, is currently undergoing a transition which will clean up its emissions. Most notably, European Union (EU) member states signed and ratified the Conference of the Parties Paris (COP21) climate accord to limit global warming to less than 2°C above pre-industrial levels while aiming to go further by striving for a temperature ceiling of 1.5°C. To achieve this goal, upper limit of 770 MtCO2/yr of emissions from the EU's energy sector must be achieved by 2050. Retrofitting existing SMR and gasification operations with CCS, and developing new clean hydrogen production capacity, can make a material contribution to that given the current emissions profile of hydrogen production. Scaling up supply to meet increased demand driven by decarbonization efforts in other sectors can also have a significant impact. As *James Carter*, Partner at DLA Piper puts it, "We have the ability to generate more renewable energy than we can actually store, and the scalability of renewables is where a lot of demand for hydrogen will come from, driving the renewable economy on."

Power-To-X (P2X)

As of 2020, Europe is a world leader in operational hydrogen production projects, with a significant pipeline of projects announced and planned to come online in the next decade.

Figure 3: Hydrogen projects in Europe, 2020

Source: IEA (2020), inspiratia



Transporting hydrogen in dedicated networks is something that has been carried out in Europe for decades. However, these networks have traditionally been part of on-site production operations in the oil and gas and industrial sectors.

Spring 2020 brought announcements in Europe that positioned renewable energy as a catalyst to activate a strong recovery from the COVID-19 pandemic. The European Commission is planning to align its COVID-19 economic strategy with the European green deal strategy in a post-pandemic recovery plan which includes an accelerated push to renewable energy.

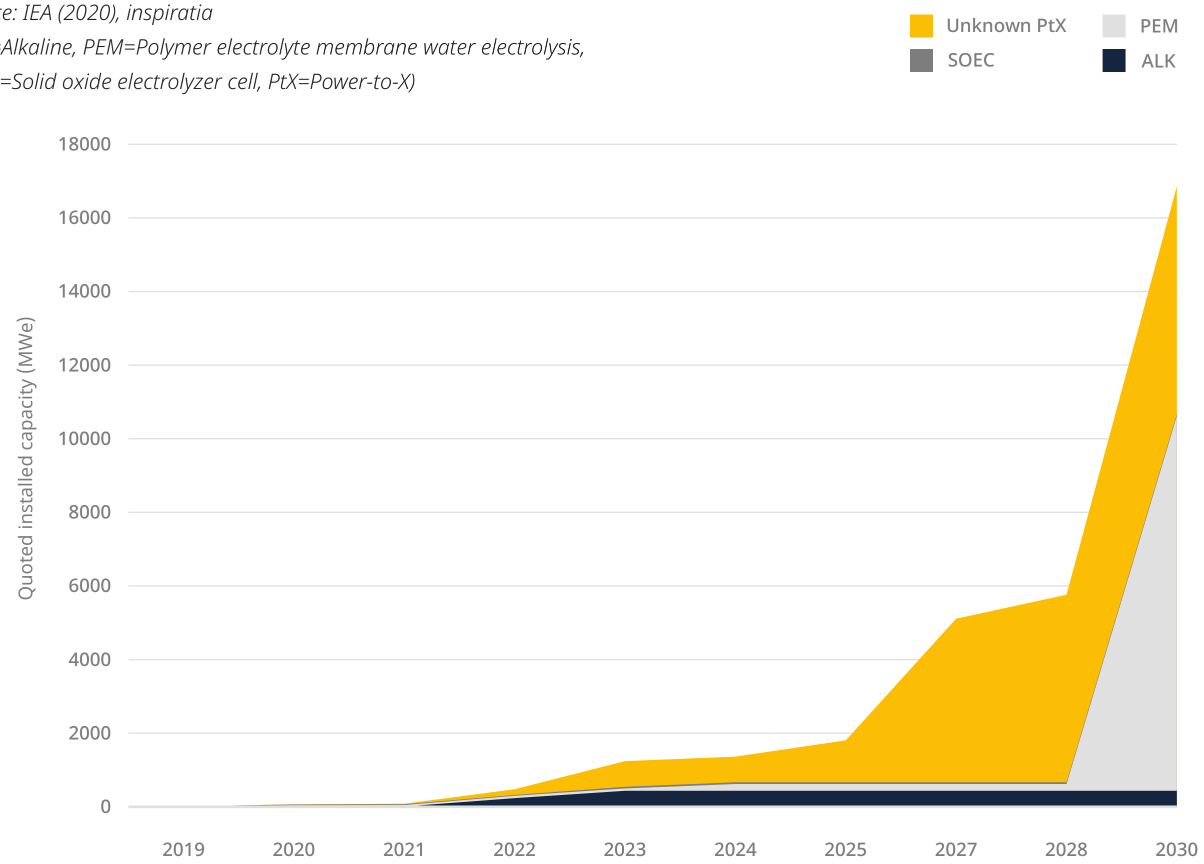
As of June 2020, plans and announcements to scale up electrolysis operations in Europe to approximately 17GW of installed capacity by 2030 – and the potential for significantly more in subsequent decades – have been catalogued in the IEA Hydrogen Project database. To put that in context, under 1GW of hydrogen electrolyzers have currently been installed across the continent. These targets may of course be aspirational rather than realistic. The largest electrolyzer under construction in the EU today has a capacity of 10MW, so achieving 17GW of installed capacity will require a rapid upscaling of electrolyzers in development and production.

As *Figure 4* (below) illustrates, there are multiple options when it comes to electrolysis. Of the currently available technologies, alkaline electrolysis is the most mature, having been available since the 1920s and used in industrial application, although it is difficult to scale while keeping production costs low. Solid oxide electrolyzer cell (SOEC) is a far less mature technology and so currently possesses prohibitively high production costs. In that context Power-to-x (using surplus electricity generation to produce hydrogen) and PEM (water electrolysis, which uses proton exchange membrane (PEM) electrolyzers) are expected to become the dominant hydrogen production processes over the next decade.

The data in *Figure 4* shows that interest in clean hydrogen technologies as a route to a decarbonized energy future continues to accelerate at an unprecedented rate in Europe. These numbers are supported by the EU's Green Deal initiative and its stance on hydrogen infrastructure development across many other European governments in collaboration with industry and private sector leaders.

Figure 4: Quoted installed capacity (MWe), 2019-2030

Source: IEA (2020), inspiratia
(ALK=Alkaline, PEM=Polymer electrolyte membrane water electrolysis, SOEC=Solid oxide electrolyzer cell, PtX=Power-to-X)



PEM electrolyzers are a particularly attractive technology because of their potential application to another increasingly significant problem: balancing the grid. Balancing the grid is recognized as becoming ever more challenging as a result of the increasing amount of renewable energy within the European energy system, which has increased the frequency of temporal mismatches between supply and demand. Conventional grid balancing techniques, such as ramping up a gas or coal power plant, produce CO2 emissions so a new approach is needed for managing the emerging low-carbon power system. However, PEM electrolyzers can be used to absorb additional renewable energy on the electricity network and to provide increased and decreased response to help stabilize frequency and voltage variations. The hydrogen that the electrolyzers generate can also be stored in underground caverns, for instance, then used to generate renewable power at times when the wind is not blowing, or the sun is not shining – via fuel cell or hydrogen gas turbines.

To participate in European decarbonization, companies such as Hynamics – an EDF Hydrogen subsidiary – were formed. "We aim to reduce these CO2 emissions offering two different low-carbon hydrogen solutions: for industrial customers, for whom hydrogen is a necessity, Hynamics installs, operates and maintains hydrogen production plants. For mobility providers, we link up different areas with service stations to provide hydrogen to recharge fleets of commercial vehicles and heavy mobility vehicles," says *Christelle Rouille*, CEO of Hynamics. The increasing investment of market leading power companies historically associated with more traditional methods of power generation is not only a sign of the growth in hydrogen in the short term; it is a sign that the major players in the energy sector are committed to realizing a greener future, and see hydrogen as a key catalyst for that.

Buildings and the gas grid

Buildings of all types create huge demand for energy and presently account for a vast amount of emissions: 530 MtCO2/yr in the EU according to recent measurements. In order to stay within the bounds established in the Paris climate agreement, building-related emissions are required to fall by 57%. Older buildings are disproportionately accounted for in terms of levels of emissions produced in this area, for obvious reasons.

However, progress is slow. By way of illustration, according to the Fuel Cells and Hydrogen Joint Undertaking (FCH JU)[4] the retrofit of older buildings with improved energy efficiency capabilities is only currently happening at a rate of around 1% of stock per year in Germany. This rate will have to more than double to achieve emissions ambitions in this area, presenting a formidable challenge. This is a challenge which hydrogen can contribute to.

The most popular way to heat buildings across Europe is currently via natural gas, with around 42% of all residences – or 90 million – supplied in this way. The scale of gas use presents a challenge: either these homes are fitted out with electric heat pumps, which will be a costly and time-consuming program to undertake, or by overhauling gas distribution grids to carry low-carbon gases, or a mix of both. While most existing gas grid infrastructure is not outfitted properly to distribute pure hydrogen and

[4] The Fuel Cells and Hydrogen Joint Undertaking is a public-private partnership for research, technological development, and demonstration (RTD) activities for hydrogen and fuel cells across Europe. https://www.fch.europa.eu/page/who-we-are

such a change would require customers to upgrade to hydrogen-compatible boilers, blended hydrogen and natural gas could be distributed almost immediately in most places throughout Europe. No upgrade would be required for grid infrastructure or end-users' heating systems. That is an opportunity which, as yet, has not been fully utilized but the potential for change (given the scale of emissions from buildings) is obvious.

In this context, in September 2020 the European Federation of Energy Traders released a contract that can be used to buy and sell hydrogen based on environmental tracking certificates, built on guarantees of origin or national certificates. Although this is a very early step, it is clear a trusted system tracking the environmental value of hydrogen is needed.

Table 2: Hydrogen pathways to decarbonizing the gas grid

Source: Fuel Cells and Hydrogen Joint Undertaking (FCH JU) (2019)

	H2 – METHANE BLENDING	PURE H2 NETWORKS
DISTRIBUTION INFRASTRUCTURE	Blending of gaseous hydrogen into existing natural gas pipelines is possible up to a concentration of 5-15%,[5] modifications to existing pipeline monitoring and maintenance practices are necessary to ensure safety.	Retrofitting or replacement of existing steel pipelines to noncorrosive and nonpermeable materials (e.g. polyethylene, fiber-reinforced polymer pipelines) and leakage control is required for the transportation of pure gaseous hydrogen.
GAS HEATING AND COOKING APPLIANCES	Use of hydrogen-methane blending in existing end-user appliances is possible up to a concentration of 5-20% when calorific values are kept within tolerance bands; research even suggests 30% is possible, allowing for a proper margin of safety.	Conversion or replacement of end-user appliances (gas boilers, hot water tanks, gas cookers) is required.

According to the FCH JU, a hydrogen and heat pump mix is more cost-effective than full electrification. This mix is particularly advantageous in that it can avoid the expected large seasonal imbalances in electricity grids that full electrification of heating would bring, particularly in colder regions, while also using hydrogen – partly or even fully – in existing gas grids to supply premises where the retrofit of heat pumps would be prohibitively expensive.

Why is hydrogen appealing in the heating and gas grid context, particularly in jurisdictions such as the UK and other countries which use gas as a source of heating? The challenge in that transition process is not very different from biogas, as *Andreas Gunst*, Partner at DLA Piper, comments: "There is a need for a system that identifies pure hydrogen or hydrogen mix sellers against natural gas in the grid. Currently, the solution is the Guarantees of Origin[6]. Then, there is the concept of mass balancing and structures to allocate environmental value to hydrogen sales."

Industrial heat

Industrial heating operations in Europe must reduce CO_2 emissions by 56% (i.e. 220MtCO_2 annually) by 2050 to reach decarbonization goals.

With annual energy demand of 3,200TWh, industrial heating is the third-largest energy consuming sector in Europe, pumping out more than 390MtCO_2/yr. Energy-intensive industries such as cement, refining, aluminum, iron and steel, petrochemicals, and paper and pulp consume 60% of all final energy. Within these sectors, high-temperature heat is the largest source of demand, accounting for around 40% of the total industrial heating demand (or 24% of European consumption as a whole). According to the FCH JU, high temperature heat processes are also responsible for over 30% of industrial CO_2 emissions in the EU.

Temperature plays a part in the suitability of different power production processes and technologies in this significant industrial segment.

5 While there are numerous trials of the direct blending of renewable hydrogen in the mains gas supply, there are limits to the amount of hydrogen that can be mixed before the performance of gas appliances (e.g. stoves and hot water systems) are affected due to the different burn characteristics of hydrogen.

6 Guarantees of Origin is a certification process that allows buyers to confirm that any power purchased was generated from a renewable source. It is currently a voluntary system.

- While temperatures below 100°C are usually sufficient for space heating and hot water, industrial processing can exceed 1,000°C. In European industrial sectors, the dominant range is above 500°C. That level of heat needed for processes in chemical, steelmaking and cement production.
- High temperature ranges (i.e. above 500°C) account for more than 50% of industrial heating requirements.
- When the goal is to produce heat in the high-temperature range over 1,000°C, energy produced from renewable energy sources (particularly concentrated solar power) and synthetic gases such as hydrogen (i.e. released following an industrial process) are promising options which have demonstrated technological and cost breakthroughs in recent years.
- At the lower end of the heating requirement scale for industrial applications, electrification should be the choice for a relatively affordable way to decarbonize, due to both the reasonably priced equipment required to achieve this in addition to continued falls in the price of renewable electricity supply. Hydrogen could be used, however, as a back-up power source for times of peak demand.
- For high-heat industrial processes (e.g. chemicals and cement) there are few viable alternative to hydrogen, with the consequence that it is in this space that hydrogen is arguably the most attractive option if the goal is decarbonization.

There are of course several different options for decarbonizing industrial heating operations, with the use of hydrogen representing one option which can (and should) be used alongside others. Those options include:

- Demand-side measures to help manage resources by increasing recycling and reuse of products
- Energy efficiency measures which adapt production equipment in order to lower energy use per production volume
- Electrification to replace fossil fuels with renewable heating
- Replacing fossil fuels with biomass boilers
- Low-carbon hydrogen, through CCS or electrolysis, but also potentially through production powered by nuclear generation plants

On this last point, there are many that believe nuclear could be the most advantageous option available for producing hydrogen for industrial heat requirements.

"Decarbonizing heat is the most challenging application to decarbonize and nuclear power – a venue for hydrogen production – is the safest way to make electricity [according to the OECD] and has the same life-cycle carbon emissions as wind [according to the IPCC]. It is hard to maintain a constant and affordable supply of clean electricity while offering jobs, so we believe nuclear power should be part of the energy mix," says *Etienne Briere*, Director of Storage, Renewable Energy & Environment at EDF – R&D.

Nuclear is indeed an intriguing prospect for hydrogen production and one that could be ideal for decarbonizing industrial heat, as it can deliver huge volumes of low-carbon, and predictable electricity supply, which can then be partly used to power electrolyzers to create hydrogen. The US Department of Energy calculates that a 1GW nuclear reactor (for reference, the UK's new Hinkley Point C plant will be 3.2GW) is able to produce 200,000 tonnes of hydrogen per year, and as some countries look to nuclear to provide low-carbon baseload electricity it would make sense to also bring hydrogen into the equation for additional benefits.

There are many available options to address the significant challenge of carbon emissions generated by the industrial heat segment. Given the scale of the challenge, the solution needs to be on a significant scale, and it may be that, despite its detractors, nuclear power generation provides the best of the available options for Europe.

Hydrogen 2050 Roadmap

The study, "Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition," developed by the FCH JU and 17 European industrials, analyzes the effects of a high-hydrogen-uptake scenario towards 2050. By documenting a potential route for future decarbonization, a picture can be created of where the more prominent investment opportunities within the hydrogen space may lie over longer timescales.

HEATING AND POWER FOR BUILDINGS:
According to the FCH JU's CertiHY project, hydrogen would be supplied into the natural gas grid with a blending ratio of 7% by volume (25TWh of hydrogen) by 2030, which would equate to about 1% of residential and commercial buildings' demand for energy for heat. Exclusively hydrogen gas grids at a commercial scale could begin to emerge in the subsequent decade.

Thereafter, penetration levels could ramp up to around 18% of European residential heating being provided by hydrogen. There is expected to be major variation in uptake between countries, with some giving over 80% of their gas grids to pure hydrogen, with others making slower process by merely blending hydrogen with natural gas in a limited capacity.

According to the FCH JU, hydrogen would provide 7% of the heating needed for buildings in 2050, leading to a hydrogen demand of about 190TWh.

INDUSTRIAL HEATING:
By 2050, hydrogen could fuel more than 20% of European high-grade (i.e. temperature) heat processes, about 8% of medium-grade processes, and around 5% of low-grade processes.

High-grade processes could lead to a hydrogen demand of around 160TWh. In total, hydrogen could cover 240TWh by 2050.

INDUSTRY FEEDSTOCK:
By 2030, 10% of hydrogen from SMR could feature CCS (turning it from brown to blue). Then, by the mid-point of the century, more than 75% of hydrogen from SMR could be fitted with CCS and all the hydrogen currently used for industrial feedstock could be fully decarbonized in some way. If this is achieved, then some 70Mt of CO2 emissions will be averted.

TOTAL HYDROGEN DEMAND:
Yearly hydrogen demand is predicted to increase to 2,250TWh in 2050, up from 325TWh in 2015. As shown above, while there is sizeable scope for hydrogen use within heating for buildings (190TWh by 2050) and industrial processes (240TWh), this represents only a relatively small slice of total volumes expected by the mid-point of the century. That said, they will both provide plentiful investment opportunities over the coming years, but with industrial feedstock being viewed as a venue for more significant hydrogen use it is within that segment that the more meaningful opportunities could arise. Fitting CCS to SMR facilities, supply chains, and distribution networks will be of critical focus for investment over coming years.

The path laid out by the roadmap creates clear high-level targets for hydrogen deployment, staged over three phases, as illustrated above. In many ways, the flourishing hydrogen sector that the plan describes will echo the development of the renewable electricity sector which took place in the early part of the 21st Century. But, just like with technologies like wind and solar, firm state support and rapid cost reductions will also be required within the hydrogen market for these aspirations to be realized.

"The journey of renewable energy shows what is possible when it's supported by a proper regulatory regime and the right incentives are in place. Hydrogen needs the same support," says *Tim Williams*, Legal Director at DLA Piper.

European Commission: A hydrogen strategy for a climate-neutral Europe

The EU Hydrogen Strategy, unveiled in July 2020, sets out a phased approach for a gradual transition:

In order to achieve the objectives of the first phase, there will need to be a step-change in the manufacturing of electrolyzers, including large ones up to 100MW. To make best use of the planned new electrolyzers, they should be placed next to the sites of highest demand, such as steel plants, chemical complexes, and oil refineries. In transport, the success of hydrogen fuel-cell vehicles – trucks, buses, and cars – will be largely dependent on the presence of adequate refuelling infrastructure.

Table 4: A hydrogen roadmap for the EU

Source: European Commission Hydrogen Strategy (2020)

1

FIRST PHASE: 2020 TO 2024
Install at least 6GW of renewable hydrogen electrolyzers in the EU and the production of up to 1 million tonnes of renewable hydrogen, to decarbonize existing hydrogen production.

2

SECOND PHASE: 2025 TO 2030
Hydrogen needs to become an intrinsic part of an integrated energy system with a strategic objective to install at least 40GW of renewable hydrogen electrolyzers by 2030 and the production of up to 10 million tonnes of renewable hydrogen in the EU.

3

THIRD PHASE: 2030 TOWARDS 2050
Renewable technologies should reach maturity and be deployed at large-scale to reach all hard-to-decarbonize sectors.

The European Clean Hydrogen Alliance is set up with the intention of making these plans a reality. Presently, up to 2.3GW of new electrolyzer projects are at a serious stage of development and around another 22GW of green hydrogen production schemes are planned.

Additionally, the Strategic Forum for Important Projects of Common European Interest (IPCEI) will be used to bring stakeholders together to progress larger developments within an array of hydrogen production methods and applications.

There are a series of funding instruments within the European Commission's recovery program, such as Next Generation EU – a new EUR750 billion recovery plan offering financial support in relation to the digital and green energy transitions – and the Strategic European Investment Window of the InvestEU program, as well as the ETS Innovation Fund which is designed to kickstart widespread investment in newer renewables technologies[7].

In the second phase of the EU's hydrogen strategy, green hydrogen should reach cost-parity with other methods of hydrogen production, and will find its way into steel manufacturing[8], trucks, rail and other transport modes, including maritime applications.

Within transport, *Dr. Graham Cooley*, CEO of ITM Power, agrees that FCEVs are some of the most feasible applications. "One of the great advantages of hydrogen is that you can use existing petrol forecourts to get energy into the vehicle, which is difficult to do with battery electric vehicles (BEV). The heavy-duty vehicles [HDV] business model is easier because of the return-to-base principal."

The same philosophy is shared among electrolyzer manufacturers with regard to transport applications, particularly with big players developing in North America, as *Filip Smeet*, Senior Vice President at the Hydrogen Electrolyzer Division at Nel Hydrogen ASA, says about Nel Hydrogen and Nikola Motor's recent partnership: "The same applies in the US, we can see that funding has increased annually. In California, a lot of funding schemes have rolled out for mobility applications. I believe we will face surmountable challenges, such as scaling up the technology and the manufacturing capacities to meet the market expectations."

7 Renewable electricity can decarbonize a significant part of European energy supply by 2050, but some harder-to-reach areas will likely not be able to be cleaned up using this method. Hydrogen can be used to decarbonize some of this through its storage properties, as well as to link generation sites to far flung demand centers.

8 It takes around EUR160 million to EUR200 million to convert a typical end-of-life steel facility to hydrogen. Meanwhile, the installation of an additional 400 small-scale hydrogen refueling stations could require between EUR850 million and EUR1 billion of capex.

Table 5: An investment agenda for the EU

Source: Fuel Cells and Hydrogen Joint Undertaking (FCH JU) (2019)

FROM 2020 TO 2030	• Between EUR24 and EUR42 billion in electrolyzers. • Between EUR220 and EUR340 billion to scale up and directly connect 80-120GW of solar and wind energy capacity. • EUR11 billion in retrofitting half of existing plants with CCS. • EUR65 billion will be needed for hydrogen transport, distribution and storage, and hydrogen refueling stations.
FROM 2020 TO 2050	• Between EUR180 and EUR470 billion in production capacities in the EU.

Given the uncertainty of a clear supply-demand arena in hydrogen, the value of building partnerships increases the reach to new markets and mitigates risks – particularly, financial risks – as *Taichi Katayama*, Business Development Director at Eurus Energy Europe, says: "We are assessing our options of risk-sharing between the buyer, producer and equipment manufacturer of hydrogen. It is quite common in the renewable market that the equipment supplier provides a long-term basis service contract, so I believe that would be the strategy to make hydrogen a bankable project."

As part of the EU hydrogen strategy, an interlinked grid network across the continent needs to be created alongside hydrogen refueling infrastructure developed along strategic corridors. Legacy gas transmission assets could be put to use to carry green hydrogen from source to demand centres – sometimes across national borders – and the development of large-scale storage sites would become necessary.

Member states hope to have built a strong free market across the continent for hydrogen supply and trade by 2030, with the product finding use cases in various sectors.

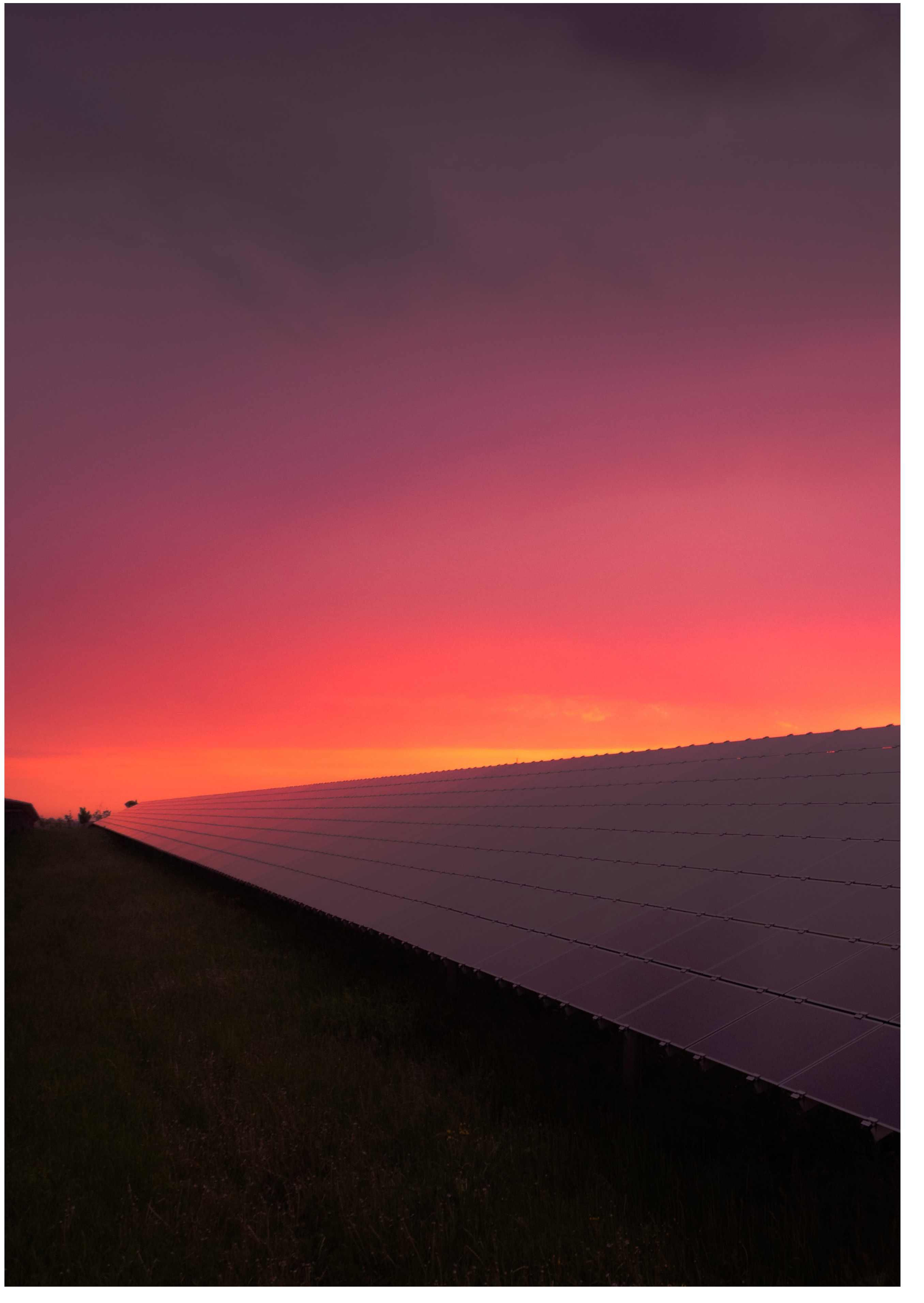
In the third phase of the European strategy, the focus will be centered on upping output from the renewables sector so it can be used for hydrogen production. By 2050, the strategy envisages around 25% of all renewable generation being used for this purpose.

As shown in *Table 5* (above), to create the hydrogen market of the future, finance must be moved in this direction. As is well-known, capital – in general terms – is currently abundant across Europe and has been since the recovery from the Global Financial Crisis over a decade ago. But, in another lesson that can be learned from other renewables technology, that capital will initially need support, be it with incentives or price floors, and will above-all require long-term certainty in terms of regulatory frameworks and solid policy commitments to the sector.

The European hydrogen strategy is a first step as part of that process, but will need to be filled in along the way with detail on the various industries and sectors into which hydrogen solutions can be fed. As an initial step, the European Commission will try to ensure standardized certification based on life cycle carbon emissions is rolled out across its jurisdiction, set within the context of existing emissions legislation and sustainable investment to encourage action in the cleanest forms of development.

That particular ambition will be doubly important in a contemporary context with the blossoming of science-based decarbonization targets introduced across industry in recent years, as well as the expanding sustainable investment strategies seen in the financial world.

At a time when these forces are colliding, not to mention the sheer amount of capital which is seeking to be deployed in opportunities providing secure and attractive returns as well as the buzz being generated by the sector, hydrogen should be well poised to take advantage and expand across multiple industries within Europe as the century progresses.



2.1. UK

Around 50Mt of hydrogen is produced annually across the globe, with the UK accounting for only 0.7Mt[9] (roughly 1.4% of global annual production). There is huge potential for growth. The incumbent UK government has recognized that potential, putting hydrogen (and carbon capture) at the heart of its recently announced (November 2020) ten point plan for a greener economy, the Climate Change Committee's Sixth Carbon Budget and its much delayed Energy White Paper (entitled "Powering our net zero future"), which was published in December 2020. Key stated policy aims are to build 5GW of clean or low carbon capacity by 2030, and to invest GBP500m to ultimately create the first town in the world running entirely on hydrogen. These are significant commitments and policy objectives that reflect the anticipated significance of hydrogen in the UK's future energy mix.

However, those broad policy announcements shed relatively little light on where the real growth areas for the use of hydrogen will be. Whilst it may be part of an electric vehicle revolution, or as a mechanism which helps to balance the intermittent nature of the supply of energy from renewable sources, the primary focus of its application in the UK will, as in Europe more generally, be in relation to heating. According to the UK Department for Business, Energy & Industrial Strategy (BEIS), heating businesses and residences consumes 50% of the country's energy and produces a third of CO2 emissions, with 83% of homes heated by natural gas. The opportunity for hydrogen in providing heat for buildings and for industry is obvious, as is its potential as an alternative to natural gas.

Buildings

Almost all heating for UK buildings is powered by fossil fuels. Taking the residential sector as an example, some 85% of it is connected to gas grids for heating, while the vast majority of the remaining 15% use either oil or liquified petroleum gas as primary fuels for the same purpose.

Hydrogen could play a crucial role in heating UK buildings, sitting alongside electric heat pumps in a hybrid system, with the latter supplied with renewable electricity. According to the Climate Change Committee (CCC) – an independent non-departmental public body, formed under the Climate Change Act (2008) to advise the UK on climate policy – heat pumps should be the go-to option for the majority of decarbonized heat supply, but hydrogen has a major role to play on the coldest winter days when demand is at its highest.

Pairing the two technologies could almost entirely displace fossil fuel use in buildings, bringing down emissions to 138kg/CO2, compared to the circa 85Mt/CO2 produced by the residential heat sector today.

Industry

Hydrogen can also provide a heating solution for industry, particularly in cases where the heat source applied directly to the industrial process, such as in kilns and furnaces. Also, there are pockets of substantial heat demand in manufacturing that do not tend to be located in industrial clusters, such as in the food and drink industry, and hydrogen can also play a leading role in terms of decarbonization there too.

Power

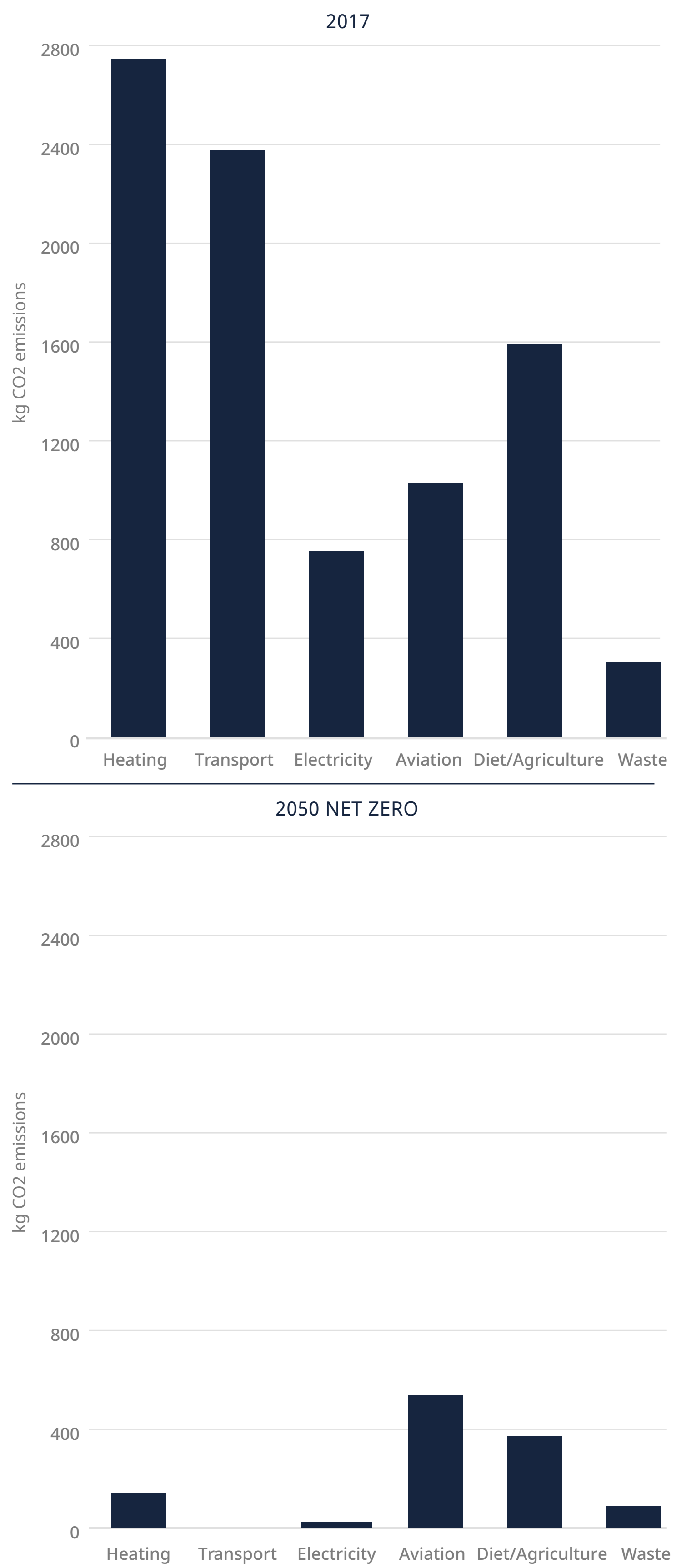
By 2030, the UK is planning for a very low carbon electricity system, with government support expected to be largely centered on new renewables and nuclear generation, which may be supported by peaking plants for high demand scenarios, with these facilities likely to be fed by natural gas and potentially featuring CCS. Hydrogen could also be used to replace the natural gas in this set-up entirely. This would be possible if new gas turbines are built to be adaptable for hydrogen use, which several manufacturers (Mitsubishi Hitachi Power Systems, Siemens, among others) are developing.

9 Energy Research Partnership (2016) Potential Role of Hydrogen in the UK Energy System. Around 15 sites provide current supply in the UK, with about half of this a by-product from other processes, mainly in the chemical industry.

10 The government has stated its ambition to become a world leader in CCS , and is aiming for the removal of 10Mt of carbon dioxide by 2030.

Figure 5: UK average household CO2 emissions in kg

Source: Climate Change Risk Assessment 2017 published by the UK Committee on Climate Change



As illustrated by *Figure 5*, dramatic changes must be made in the UK to meet emissions targets. For example, households and industrial process emissions from heating and hot water must be reduced by 95%, transport by 100%, and electricity by 97%, for the UK to reach 2050 net-zero targets .

In order to underpin this push towards net zero in household consumption and in energy use for industry and transport, *Dr. Tony Smith*, Commercial Strategy Manager at Peel NRE, shares his views on heating, "In the heating sector, possibly the most difficult to decarbonize, hydrogen could replace natural gas produced initially at scale through reforming technology which separates, captures, transports and stores carbon dioxide (CCS) from produced hydrogen."

Fortunately, in exploring hydrogen infrastructure and storage opportunities – particularly for CCS and blue hydrogen production – the UK finds itself in a good place. "In the North West, salt caverns, currently used for natural gas storage, may be used for storage of hydrogen. Underground hydrogen storage already exists in Teesside, northeast England, UK," adds *Dr. Smith*.

Dr. Smith's view about the opportunity for hydrogen in the UK heating energy mix (and the role of the North of England in that) has been endorsed by H21, a collaborative UK gas industry programme. In H21's North of England Report they state that supplying 100% hydrogen into existing UK gas network is technically and economically possible. The project will decarbonize gas supply by replacing methane with hydrogen, cutting emissions from the 180gm/kWh equivalent CO2 produced today down to only 50gm/kWh.

Key projects and deals

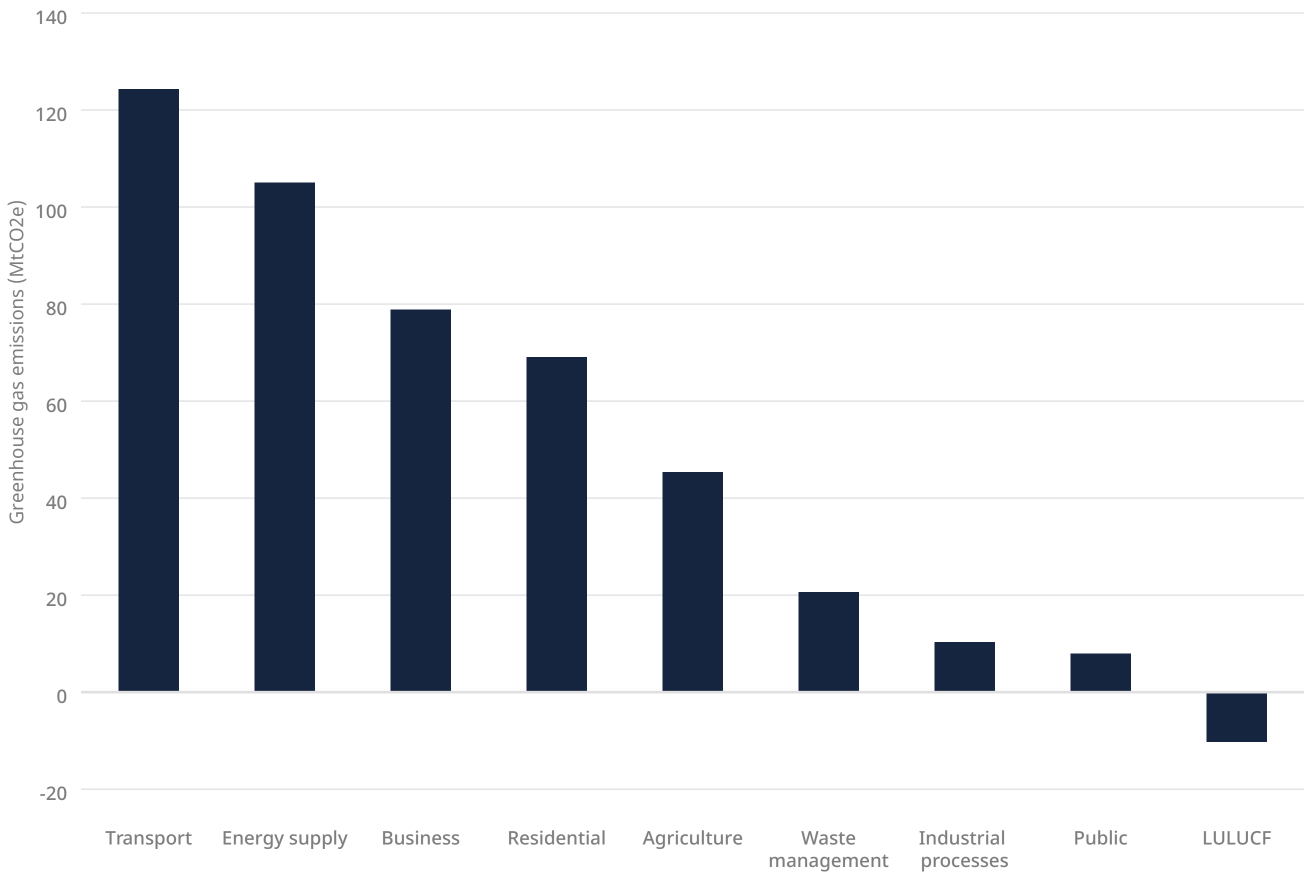
A consortium of UK gas grid operators – featuring Northern Gas Networks, Cadent, SGN and Wales & West Utilities – submitted a successful bid to Ofgem on behalf of the H21 project in 2017 as part of a Network Innovation Competition (NIC), securing GBP9 million in funds.

The H21 NIC will enter field trials from 2020. The Northern Gas Networks have made the bold statement that they intend to convert the city of Leeds's natural gas supply to 100% hydrogen by 2026. The H21 program, launched in 2016, began the discussion around hydrogen for heat. Since then, several industrial gas projects have evolved to demonstrate the benefits of such an energy transition.

In 2017, BEIS launched the Hy4Heat program to determine whether replacing natural gas with hydrogen for domestic heating and cooking is safe and feasible.

Figure 6: Greenhouse gas emissions by sector, UK, 2018 (MtCO2e)

Source: Final UK greenhouse emissions national statistics 1990-2018.
**LULUCF: Land use, land use change and forestry*



In 2018, the Health and Safety Executive (HSE) granted the HyDeploy consortium (led by Cadent, including partners such as Northern Gas Networks, Progressive Energy, Keele University, HSE-Science Division, and ITM Power) a trial to assess ways to blend hydrogen into the gas grid, which is ordinarily limited to only 0.1% of gas in UK pipelines.

As *Dr. Graham Cooley*, CEO of ITM Power, comments on the pioneering HyDeploy project, "Power-to-gas energy storage is also a huge market – the idea of putting hydrogen directly into the gas grid. We worked at Keele University with Cadent and the HyDeploy consortium putting 20% of hydrogen into the grid." The university was selected as an ideal pilot environment because it owns and operates an independent private gas network and so the project will not feature any interplay with the national gas grid.

HyDeploy will swap out a fifth of Keele's current gas supply and replace it with hydrogen to heat 100 homes and 30 faculty buildings. This demonstration will match the approach taken on another project in France managed by Engie, with the pair of schemes featuring the highest penetration of hydrogen in gas supplies anywhere in Europe. If this were to be replicated across the UK, it could avert 6 million tonnes of CO2 emissions per year.

There is a misconception about the safety of hydrogen. As *Tim Williams*, Legal Director at DLA Piper, points out, "If you talk generically about hydrogen people will say 'Oh, Hindenburg!' There are parallels people draw between the safety aspect of hydrogen and natural gas and there is usually a hesitancy there. Where you see hydrogen blended into the gas grid, I think those things will be useful to facilitate distribution level and gain acceptance in the market."

Thus, there will be a wider application of hydrogen in the series of pipeline projects in the UK and Europe looking how to interface with the existing gas grid. "I think those pipeline projects are going to be essential in understanding the limits of the existing gas grid and safety concerns going forward so we can start building the proper regulatory base," adds *Tim Williams*.

Another project, HyNet, focused on delivering hydrogen to the industrial power, transport and heating markets to over 2 million consumers across the UK's North West, and decarbonizing local industry, has been awarded GBP13 million in government funding.

HyNet will capture and store over 1 million tonnes of CO2 from industry and store it offshore using carbon capture utilization storage (CCUS) infrastructure in gas fields in the Liverpool Bay, currently operated by Eni. Subsequently, the project will produce hydrogen as a fuel for heating, power and transport. The first phase will be operational by 2024.

According to Cadent, HyNet will result in around GBP300 million invested in CCS infrastructure. In the long term, the overall investment in CCS and hydrogen in the northwest region is expected to reach around GBP1 billion.

From the series of projects referred to above (which are by no means the only hydrogen projects under way in the UK, it is easy to see the spectrum of applications of hydrogen in the UK. As *Dr. Tony Smith* points out: "Hydrogen will be produced and consumed locally, so I suppose there will be different regional hydrogen economies, probably starting with the major industrial clusters in the North West, Scotland, Net zero Teesside, Net Zero Humber, and South Wales. More such clusters are emerging, including the East of England and in the Cavendish project based on the Isle of Grain." Funding for these projects will need to be incentivized by the government with appropriate hydrogen and carbon dioxide pricing and market mechanisms. Business cases need to stack up for investment cases to be successful.

Etienne Briere, Director of Storage, Renewable Energy & Environment at EDF – R&D, follows the same lines for industrial decarbonization at a local level rather than isolated projects: "Usage identification goes hand in hand with the analysis of the territory. We develop projects in an area that appears attractive and dynamic in order to be able to create an ecosystem. Setting up a production asset in a geographical area based on initial uses and subsidies makes it possible to capture all the other future uses nearby."

International collaboration

The UK government is working on an international collaboration to find ways to reduce costs associated with CCS. The UK is working with Norway, the US, Canada, and Australia as part of the Carbon Sequestration Leadership Forum and North Sea Basin Task Force.

With respect to the UK's standing in the hydrogen space, *Etienne Briere*, Director of Storage, Renewable Energy & Environment at EDF – R&D, examines the country's strategic choices: "The UK sits in an insular context, electrically and topographically. There is a strategic choice to be made between developing this electrical renewable energy potential for export [interconnections], valorizing it on the domestic electricity market or valorizing it by facilitating its integration into the power system through a multi-sectoral and integrated approach to the energy transition for the UK."

Furthermore, the UK government is investing in CCS through its GBP60 million international CCS program, which has been running since 2012.

Offshore wind & hydrogen for seasonal storage

According to IRENA, successfully integrating huge amounts of new wind and solar capacity into electricity grids will produce a substantial requirement for energy storage by 2050[11] . But, this storage does not necessarily need to be provided by lithium-ion batteries as is common today as the additional renewable generation can be used to produce hydrogen, which is of course an energy storage medium. Doing this can also provide longer time shifts in energy consumption than batteries are generally capable of: on a seasonal scale rather than in response to hourly or daily fluctuations within the system. Hydrogen storage can be done in different ways, from storage of compressed or liquified hydrogen, to being mixed into liquid fuels, solids or blended with natural gas in gas grids[12].

IRENA predicts that using hydrogen as a storage medium for renewable electricity will only occur on a large-scale after 2030. Until then, other flexibility options will be pursued, like demand-side response, battery storage, or supply-side interventions, but planning for hydrogen to enter this space should be – and is being – started now.

The sort of infrastructure plan the UK needs to start putting in place is illustrated by a 440MW hydrogen retrofit of a gas power plant in the Netherlands, due to come online in 2023. It will sources its hydrogen from local production and will use CCS and send carbon to be stored at a site in Norway.

11 IRENA's analysis, 2019b

12 "Compendium of Hydrogen Energy (pp. 165-192)"; Chapter: Hydrogen admixture to the natural gas. Judd and Pinchbeck, 2016; Stetson et al., 2016

But the UK will need to create a stable and viable framework if dedicated renewable hydrogen production is to appear in a meaningful way before 2030. To that end, the country could adapt existing successful support schemes, such as the Contracts for Difference process for incentivizing new renewables generation, to accommodate hydrogen-focussed developments in a specific allocation pot. Alternatively, bespoke frameworks could be created for the purpose.

Excess offshore generation

With increased offshore wind ambitions recently announced which have lifted 2030 installation targets up to 40GW from a previous 30GW figure, excess electricity produced by these new plants could be put to meaningful use by generating hydrogen, which could provide greater stability for power prices with its implicit time shift of energy delivery offered by using hydrogen as a storage medium.

There are two ways to convey the energy produced ashore: the constriction of transmission infrastructure to connect to electricity grids onshore, or the production of hydrogen using the energy produced by the wind farm, and then convey the hydrogen ashore.

In April 2020 researchers at the UPV/EHU 's Faculty of Engineering[13]-Vitoria-Gasteiz in Basque Country, Spain explore how offshore wind farms could produce hydrogen in situ instead of conveying their energy ashore by cable. Their research has confirmed that adding this functionality can improve the efficiency of a wind farm without the need for major capex.

The Spanish research suggests that of the two options greater energy efficiency is achieved if the hydrogen is generated offshore and then transported by boat, as that allows for greater energy flexibility of supply (which makes it easier to meet fluctuating demand). Tests conducted on a 5MW turbine during the research showed a 2.5% increase in annual production when power generation was no longer required to match demand, and that 130,000Nm3 of hydrogen could be produced using this extra energy. Given the UK's abundant offshore resource, this presents an attractive model for hydrogen in the UK as it seeks to maximize efficiency of production.

For North Sea developments, Aberdeen in northeast Scotland has been selected as the site the first floating wind project in the world to produce hydrogen in the manner advocated by the UPV/EUH research.

The pioneering Dolphyn project plans to deploy a 2MW system to produce green hydrogen at Kincardine site, 15km off Aberdeen from 2024. The Dolphyn project, sited at the Kincardine offshore wind farm, will initially be a 2MW demonstration project, before growing by another 10MW by 2027.

Overall, the offshore wind legislative framework is heavily focused on competitiveness, with onshore links funded by each individual project developer and later auctioned off to financial investors under Ofgem's Offshore Transmission Owners (OFTO) tender process – which is beneficial for bill payers – but meaning there is no sharing of infrastructure and each wind farm has an individual connection to transmit power. This raises three main concerns: it has a negative environmental impact, it is financially inefficient, and it may have an impact on coastal communities.

Given the potential of offshore wind, it is important to look at creating a regulatory framework that supports the development of offshore wind in hand with renewable-based hydrogen production. It is to this end that the UK is looking to overhaul its current procurement processes for offshore transmission infrastructure, with concrete plans due to be published

13 Aitor Saenz-Aguirre, Unai Fernandez-Gamiz, Ekaitz Zulueta, Iñigo Aramendia, Daniel Teso-Fz-Betono. "Flow control based 5 MW wind turbine enhanced energy production for hydrogen generation cost reduction", International Journal of Hydrogen Energy DOI: 10.1016/j.ijhydene.2020.01.022

in the near future. Initial indications suggest that multiple future offshore developments will share links to single points on the mainland, creating efficiencies and assuaging environmental concerns in some coastal communities, with floating wind farms located further out to sea piggybacking on the transmission lines of fixed-bottom facilities nearer shore.

As part of this, the OFTO process itself will face an overhaul to accommodate the new expected physical characteristics of the lines themselves. A consultation was carried out in 2020, and a decision will be taken on a new process in due course.

The UK Hydrogen 2050 Pathway

To explore the opportunities for the UK to 2050, in 2017 BEIS proposed a model it developed with University College London (UCL) where hydrogen would be used in heating through the construction of a new distribution network.

The Hydrogen 2050 Pathway plots a way to decarbonize buildings with green or blue hydrogen, with most – but not all – buildings expected to use a hydrogen grid by the mid-point of the century. The remaining buildings would benefit from heat pumps or district heating schemes. "Beyond industry and low-carbon mobility targets, the analysis of large projects under development in the UK shows an appetite for the use of hydrogen for district heating," says *Etienne Briere*.

The role of CCS in this pathway is greater than for others, but green hydrogen from renewables is likely to become cost competitive with reformed hydrogen over the next 10 to 15 years, and may at that point play a more prominent role.

Despite the UK's ambitions to build a hydrogen economy to help achieve its decarbonization goals, these efforts have created a certain bittersweet feeling in the sector. "The UK has not been great at energy policy, and leadership has come from the EU. The UK government needs to listen to the advice from all over EU and its own Commission for Climate Change," says *Dr. Graham Cooley*, CEO of ITM Power.

Dr. Graham Cooley also points to the UK's sometimes uneven approach to clean energy technologies: "In the UK, the government has put 30 times more money into plug-in EV infrastructure than hydrogen infrastructure; they are supposed to be technology agnostic but it is not the case."

On the other hand, on the transport front, *David Macartney*, Commercial Manager at Energia Group, shares his thoughts about how the UK government is introducing renewable energy-based fuels through the Renewable Transport Fuel Obligation (RTFO). The policy aims to reduce greenhouse gases (GHG) produced by road transport. "The existing policy incentivizes electrolyzers to be commissioned at a renewable site and for the renewable site to satisfy additionality thresholds. If the UK is to become a global leader in the hydrogen economy it should also consider options that expedite the deployment of hydrogen solutions and transition to hydrogen facilities using new renewable assets, given the development timeline of renewable electricity generation projects," says *Macartney*.

So, the hydrogen pathway has laid some of the groundwork for the UK's hydrogen energy transitions towards the middle of the century but, as illustrated above, a lot more support and detail is required to push the market in the right direction. That, coupled with a patchy track record on policy leadership, is creating some tension around whether the country can follow through on its broad ambitions specified to date.

Like many of its European counterparts, the UK is thus now at a point where it needs a clearly defined hydrogen strategy that then feeds into specific policy and regulation to ensure its targets are realized successfully and in an efficient manner. The government is understood to be looking at publishing such a strategy in Spring 2021, and the market eagerly awaits that development.

2.2. Germany

As the largest economy in Europe, Germany is often key to the success of regional investment projects and a financial powerhouse for investment in emerging energy technologies. In the push for the development of a new hydrogen economy based on zero-carbon technologies, this is certainly the case.

Hydrogen strategy

As of June 10, 2020, the German government officially approved its National Hydrogen Strategy, aimed in particular at improving the framework requirements for the development of the technology. The initiative is also intended to lay the foundation for private investments in the economic and sustainable generation, transport and use of hydrogen. At the same time, it unlocks EUR7 billion in domestic funding for zero-carbon hydrogen investment (including transitional reliance on carbon-neutral technologies such as "blue" carbon technologies that include CCS), with an additional EUR2 billion allocated for international partnerships to develop zero-carbon projects. It is that receptive environment that gives rise to high hopes for hydrogen and more specifically green hydrogen as part of Germany's energy transition.

Aligned with moves at European level, the highly anticipated German National Hydrogen Strategy focuses on green hydrogen at the expense of support for using CCS to produce hydrogen from natural gas.

The approved German strategy states that only hydrogen produced based on renewable energy is sustainable in the long term. Hydrogen made with natural gas using CCS, which is highly controversial in Germany, is only to be used on a transitional basis.

The German hydrogen strategy intends to increase green hydrogen to 5GW by 2030 and an additional 5GW for the period until 2035.

In the short term, industrial applications are the core target of Germany's hydrogen strategy. The refinery sector is already taking the lead in adopting green hydrogen, looking to the substitution of hydrogen produced from fossil fuels by SMR by green hydrogen from electrolyzers. For instance, the Get H2 Nukleus project in northwest Germany is the first publicly accessible hydrogen network allowing wide-ranging CO2 reductions. It will use a 100MW electrolyzer owned by RWE Generation to generate green hydrogen, which will be connected by a pipeline to two BP refineries in Lingen, Lower Saxony and Gelsenkirchen.

In the chemical sector, the same is potentially feasible, and Evonik is also tapping into the Lingen hydrogen pipeline. Production of green hydrogen and supply to customers is expected to start by the end of 2022.

Earlier in 2020, the German Association of Gas Transmission System Operators (FNB Gas: a collection of national gas transport companies in the country) presented a plan to build a 1,200km grid, the H2 Startnetz project, by 2030 to transport green and blue hydrogen, becoming the world's largest hydrogen grid. The EUR660 million scheme would link centers in North Rhine Westphalia (NRW) and Lower Saxony to 31 green hydrogen projects. The grid would also link to the Netherlands where several offshore wind-powered hydrogen production projects are in the implementation stage. Where the plans of the gas network operators are implemented, about 1,100km of the 1,200km hydrogen grid will be converted former gas pipelines, while some 100km will be newly constructed. This new energy grid will make it possible for the steel and chemical industries in the Rhur region, industries with significant carbon emissions, to become net-zero emission industries. In terms of financing, grid fees are expected to be increased by less than 1% by 2031 in order to provide the funds to facilitate the transition.

However, according to the German Association of Gas Transmission System Operators, a prerequisite for the implementation of the H2 starter network is that amendments to the regulatory legal framework expanding the existing gas network regulation also to hydrogen grids – as proposed by a broad alliance of industry and energy industry associations – are initiated shortly.

"We do see companies from various industries developing new business models and especially market participants trying to expand their position in related sectors also to the hydrogen sector." says *Michael Cieslarczyk*, Partner at DLA Piper. "The industry shows the possibilities attached to the use of hydrogen in production processes, provided that the necessary infrastructure is available. The operators of gas network infrastructure are in the starting blocks, to provide the necessary pipeline infrastructure either by new erection or rededication of existing gas infrastructure. Still, the German government seems not to be ready to simply extend existing gas market regulation to the hydrogen industry. Although they are willing to promote the development of the hydrogen economy, they want to first monitor developments in the industrial space and may consider a more flexible approach to regulation to stimulate investment and provide hydrogen with the unregulated room which it needs to grow at the pace which is required if climate goals are to be met. At the same time it can be expected that the German government will bear in mind that the costs for establishing and expanding the infrastructure could ultimately be passed on to end consumers (including the German industry)."

International collaboration

While specifically looking into the framework requirements for the development of the technology in Germany, the German government is, however, also placing its National Hydrogen Strategy in an international context. It emphasizes the importance of the market ramp-up of hydrogen technologies as a joint European project, the necessity of developing international markets and of expanding the transport and distribution infrastructure at home and abroad, and shows the export potential of German initiatives and research activities in connection with hydrogen technologies. This accords with the European hydrogen strategy, which emphasizes the international dimension of the hydrogen economy and at the same time aims to strengthen the EU's leading role in hydrogen technology worldwide.

In practice, following the creation of new partnerships to develop a cross-border hydrogen network, grid operators GRTgaz and Creos Deutschland are already collaborating on a project, MosaHYc, to create a 100% pure hydrogen pipeline connecting Saar (Germany), Lorraine (France), and the Luxembourg border. The project will focus on the conversion of two existing pipelines into a 70km pipeline for pure hydrogen, capable of transporting up to 20,000m3/h (60MW) of hydrogen. GRTgaz and Creos will cooperate with the respective national authorities on technical and regulatory aspects before a final investment decision is made by 2022.

The State of North Rhine-Westphalia and the Netherlands have started a joint research initiative for the creation of transnational value chains for green hydrogen that would span from the Dutch North Sea to NRW. On top of that, the Ministry of Economic Affairs of the Netherlands, the State of North Rhine-Westphalia and the German federal government are conducting a joint study on the feasibility of transnational green hydrogen.

The study includes the production of hydrogen from offshore wind farms in the North Sea, off the coasts of Germany and the Netherlands, which will be transported to major German industrial clusters through existing pipelines. This operation would be possible with the availability of the Dutch Gasunie's gas transport infrastructure, which is available due to the closure of the Groningen gas field. Moreover, both countries have salt caverns in which hydrogen can be stored safely and used with a large-scale electrolyzer.

Summary

As with the initial renewable energy boom of the first two decades of the 21st century, which Germany pioneered with its Renewable Energy Sources Act (EEG) in 2000, Germany is in many ways leading once again on hydrogen.

Aside from its key position at the heart of Europe – both geographically and politically within the EU – many countries are following Germany's lead when it comes to planning their own energy transitions with hydrogen as a key component.

Additionally, there are many areas within Germany's economy that lend themselves towards hydrogen production and consumption. From strong industrial and manufacturing sectors, a robust financial sector and a history of community engagement in renewable technologies, to a large and expanding offshore wind sector. All of these elements can contribute to significant hydrogen development.

When this is coupled with a clear strategy from the highest levels of government, it sends a clear signal to the investment, development, supply chain, and contracting communities, that hydrogen in Germany has the potential to be a safe bet for them over decades long time-scales.

3. The Middle East

Due to the scarcity of freshwater in the Arabian Gulf, Middle Eastern countries are looking to sea water to produce hydrogen, which first needs to be desalinated using reverse osmosis (RO). This is a costly proposition, but it has not hampered interest in the possibility of producing clean hydrogen in the region.

A number of factors are in the favor of the Middle East when it comes to its prospects in the low-carbon hydrogen space. There is, of course, a world-leading oil and gas industry which could be retooled towards hydrogen production, but also there is vast potential for enormous solar generation which could similarly be employed to make hydrogen. Lastly, the region sits on a crucial junction within international trade routes and so it could tap into hydrogen export markets where they begin to develop.

The availability of hydrocarbons in the six economies of the Gulf Cooperation Council (GCC) has also led to the emergence of heavy industry, including aluminum smelters, chemical industry, refineries and steelmaking, and several of these have provided demand for hydrogen for many years.

The Middle East is home to a string of solar projects, in Dubai, Abu Dhabi and Saudi Arabia, that have established new benchmarks for the low cost of energy. Early in 2020, Abu Dhabi Power Corp in the United Arab Emirates (UAE) secured the world's lowest tariff for a solar power plant – a 2GW solar PV plant in Al Dhafra – with a winning bid of 1.35US¢/kWh from EDF and China's Jinko Power. The Al Dhafra project continues a trend for breaking new ground in terms of how low bids for solar capacity can go, which is a particularly pronounced trend in the Middle East due to its advantageous natural solar resources, extremely low cost of capital enjoyed by many state-backed companies, and economies of scale on offer from the size of the projects themselves.

Using solar energy as an analogy, *Filip Smeet*, Senior Vice President at Nel Hydrogen Electrolyzer Division, comments on the hydrogen situation: "15 to 20 years ago there were hardly any funds to invest in PV panels or wind turbines because there was no business case for them, so the technology was still too expensive. When policymakers decided to support the business cases with market pull measures, we could see that solar and wind markets developed rapidly and delivered power prices below fossil parity in some parts of the world. I believe electrolytic hydrogen will follow the same path."

Complementing daytime solar PV and concentrated solar power (CSP) with electrolysis to create clean hydrogen storage infrastructure means that intermittent daytime solar resources can be effectively stored, and potentially distributed over long distances, for use during the evening or when solar energy is limited, using combined heat and power (CHP) and grid balancing infrastructure.

The domestic oil and gas, and steel sectors, can also benefit from the development of hydrogen capacities, potentially providing them with a low-carbon alternative in a world which is rapidly moving towards the post-fossil fuels age. If the UAE is taken as an example, the vast desertscape which makes up much of the country's topography could be repurposed to install sufficient solar generation to be able to create a hydrogen industry that could match its current oil and gas wealth, and much of the same conditions exist in other Middle Eastern countries.

Oman is developing bold strategies to reach the renewable energy podium in the Middle East. The Port of Rotterdam in the Netherlands owns a 50% stake of the Port of Sohar and Freezone in Oman. Thus, the sultanate is exhibiting great interest in producing solar, wind and hydrogen energy to ship to Rotterdam. Oman aims to play a crucial role in the energy supply chain, including the production of solar and wind-powered hydrogen production and shipping. For instance, Belgian engineer DEME Concessions is working with Omani partners to start a 500MW solar and wind-powered hydrogen production in the Port of Duqm in Oman.

David Macartney, Commercial Manager at Energia Group, comments on the logic behind hydrogen infrastructure: "The best economics for a hydrogen plant is to run at high utilization. If you are using an electrolyzer only on daylight hours or when the wind is blowing, the economics of the electrolyzer become more challenging. There are some considerations with hydrogen projects such as route to market and demand, efficient transportation of the hydrogen to the end user and safety. Many electricity companies have operational experience of managing hydrogen as it has been used in power stations for many years."

Following the same concern, *Taichi Katayama*, Business Development at Eurus Energy Europe, agrees with the difficulties of hydrogen logistics: "Hydrogen transportation would be an issue – especially for wind energy. Wind farms are typically developed at remote and windy locations, where you cannot always expect large demand for hydrogen. I believe hydrogen pipelines could be a solution in the future."

Development of hydrogen production in the region is also assisted by the geographical proximity to Asian growth markets means. Companies like Shell and Kawasaki are currently exploring ways to safely export hydrogen, with the element in its liquid state being seen as the best way to do so.

That may give the Middle East a material strategic advantage in terms of the prospects of hydrogen in the region. As an illustration, Japan is planning to deploy hydrogen as a clean energy source on a large-scale by 2030. As one of the largest importers of energy from the Middle East, Japan's hunger for energy and its poor natural resources could replace the Silk Road with a hydrogen equivalent which would pair Asian markets with supply from the Middle East.

Additionally, there is opportunity to produce green hydrogen-based ammonia to replace the carbon-emitting manufacturing processes currently in Saudi Arabia's northwestern region. A joint venture project between Air Products, developer ACWA Power and smart-city mega-project NEOM, is planning to build in Saudi Arabia what the groups claim will be the "world's largest green hydrogen plant".

With the first section of NEOM aimed to be complete by 2025, the US$500 billion green hydrogen-based ammonia production plant will be built in the Tabuk Province of northwestern Saudi Arabia and planned to produce 650 tonnes of hydrogen for global export.

4. North Africa

North Africa has recently drawn attention as a potential partner for European companies looking at clean hydrogen sector opportunities to accelerate an ambitious green deal, which is speeding up its targets for the next decade. The region, (and in particular Morocco), lays claim to a significant mix of renewable energy resources necessary for clean hydrogen production – i.e. water, sun, biomass and wind. Indeed, the vast coastline presents attractive opportunities to develop impressive wind energy capacities (which can be a key component of hydrogen sector development) in the coming years.

According to the World Bank, with 3,500 km of coastline, Morocco's wind speed can reach up to 10m/s, which could potentially translate into 135GW of wind power (offshore included). Morocco also has one of the highest rates of solar insolation in the world, with between 3,000-3,600 hours in the Sahara Desert. At the end of 2019, Morocco's renewable energy capacity reached 3,685MW, including 700MW of solar energy, 1,215MW of wind power, and 1,770MW of hydroelectricity. The country's objective is to reach 6,000MW of renewable energy production before the end of 2020 – an attainable goal, according to the Moroccan Agency for Sustainable Energy (MASEN).

Since 2016, P2X has begun to take hold within the minds of policymakers and industry in Morocco and the country is now shooting to be a world-leader in the field, with hydrogen naturally being a key part of the equation.

As *Dr. Mathias Bimberg*, Head of Infrastructure at Prime Capital, points out, there are commercial advantages to jumping into the hydrogen space from different angles, "We want to use the energy intelligently, invest into electrolysis facilities to produce green compressed hydrogen and later produce derivatives such as ammonia, ethanol and methanol." The potential development of the hydrogen industry in Morocco will also lead to the production of hydrogen derivatives like green ammonia to be used by Moroccan players like OCP in order to reinforce its position as leading international player in the fertilizers sector.

In 2018, the Moroccan Institut de Recherche en Energie Solaire et Energies Nouvelles (IRESEN), in partnership with the German Corporation for International Cooperation and the German Moroccan Energy partnership (GIZ-PAREMA), assessed that Morocco could account for nearly 4% of the global P2X market by 2030, which illustrates its potential as a significant market player.

To that end, Morocco embarked on an ambitious renewables program which set a target of 42% of electricity supply coming from renewable by 2020, moving onto 52% by 2030. To achieve that it plans to add up to 11GW of solar, wind and hydropower capacity by 2030.

As an example of the work already underway to achieve its goals, Morocco has built the Noor solar complex in Ouarzazate. It consists of CSP and PV projects that will ultimately total 582MW of capacity. The scale of these projects have particularly helped to reduce the cost of CSP, which now rivals thermal generation in the country on a costs basis.

IRESEN has succeeded in moving P2X up the agenda of the Moroccan government, while also encouraging the investigation of green hydrogen as a decarbonization solution for the country.

According to the Netherlands Association for the United Nations (NVVN), by aggregating solar and wind project output in Morocco a high load factor for hydrogen electrolysis can be achieved. In 2019, Morocco was host to bids of EUR28/MWh for an 850MW wind farm, demonstrating the low renewable generation costs achievable in the market. The NVVN predicts that tariffs will further reduce to EUR10-20/MWh in the next decade. An agreement was signed between Morocco and Germany on June 2020 for the development of the hydrogen production sector and to set-up related

research and investment projects. Following this agreement, MASEN announced the implementation of the first industrial green hydrogen plant in Africa.

If electrolyzer efficiencies of 80% can be coupled with reduced capex requirements of EUR300/kW, which should be within reach over coming years, hydrogen could be produced in Morocco for around EUR1 per kg, beating expected costs in Europe and cost-competitive with high-carbon emitting hydrogen production via SMR without CCS. This is a further illustration of the opportunity for Morocco to be a major hydrogen player.

Wind power is a key technology with benefits for the MENA region, with the Global Wind Energy Council data indicating an increase of 894MW of wind power in the region in 2019. Despite allowing cost-effective and sustainable energy, wind power still faces challenges in power market frameworks, transmission infrastructure bottlenecks and policy.

What is more than evident from recent studies, and from current and planned projects, is that natural resources in North Africa, an in Morocco in particular, present a huge opportunity for the region to be a key player in the development of the hydrogen sector.

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We work with a broad scope of clients ranging from the world's largest oil and gas companies to investment banks active in energy and commodities trading and venture-backed alternative energy entrepreneurs. Our lawyers provide strategic advice on planning, development, financing and permitting matters, as well as legislative, political and regulatory issues.

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