Gi
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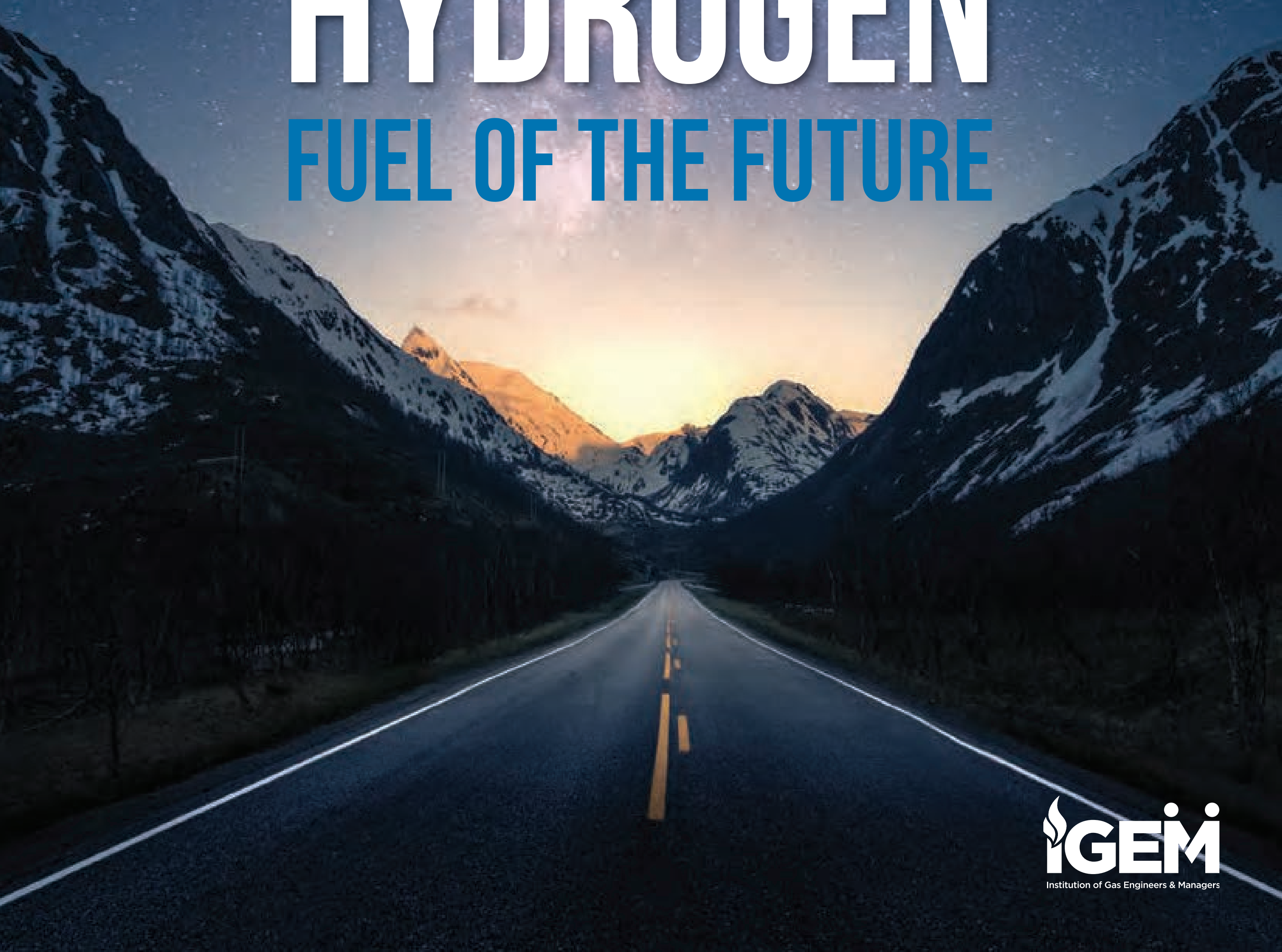
NEWS

- NEW REPORT OUTLINING HYDROGEN'S KEY ROLE IN UK ENERGY TRANSITION
- SSE, EQUINOR PLAN TO STORE HYDROGEN AT UK GAS STORAGE SITE
- UK'S FIRST HYDROGEN-POWERED HOMES OPEN TO THE PUBLIC

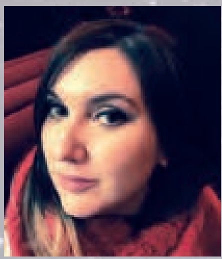
THE DAWN OF HYDROGEN

FUEL OF THE FUTURE



IGEM
Institution of Gas Engineers & Managers

WELCOME TO THE HYDROGEN EDITION



WELCOME TO THIS SPECIAL publication exploring and celebrating all things hydrogen.

This is a time of enormous change for the gas industry as the UK and the world at large attempts to meet the challenges of decarbonisation in the face of climate change.

Hydrogen is expected to play a vital role in achieving the government's commitment of eliminating the UK's contribution to climate change by 2050, with the industry creating up to 8,000 jobs by 2030 and potentially unlocking up to 100,000 jobs by the middle of the century.

But despite the UK government's huge ambitions, hydrogen is just one piece of the puzzle, and it will be necessary to seek solutions that bring the whole energy system together – including not just heat for buildings, but hard-to-decarbonise areas such as manufacturing, road transport, aviation and shipping.

Here, we bring you just a taste of some of the amazing work taking place across the energy sector to understand this fuel more clearly, to comprehend its strengths and limitations and to integrate it into our current energy infrastructure.

We hope you enjoy this special publication,

SHARON BAKER-HALLAM

EDITOR

BA (HONS) AIGEM

INSTITUTION OF GAS ENGINEERS AND MANAGERS (IGEM)

DISCOVER IGEM'S HYDROGEN KNOWLEDGE CENTRE

IGEM'S HYDROGEN KNOWLEDGE CENTRE is a digital resource hub for everything related to hydrogen energy. A searchable repository of hydrogen records from a wide range of sources including public agencies, gas network companies, academic and research institutions, supply chain organisations and energy and engineering experts.

IGEM is passionate about supporting the transition to a net zero carbon emissions future – and this is one of the ways in which we're playing our part.

Our goal is to capture existing and newly published hydrogen learning, consolidating knowledge into one searchable library, making hydrogen information and research quick and easy to find.

IGEM members automatically have access to the Hydrogen Knowledge Centre, but anyone can join the institution to access its content quickly and easily.

The Hydrogen Knowledge Centre can be accessed at www.h2knowledgecentre.com

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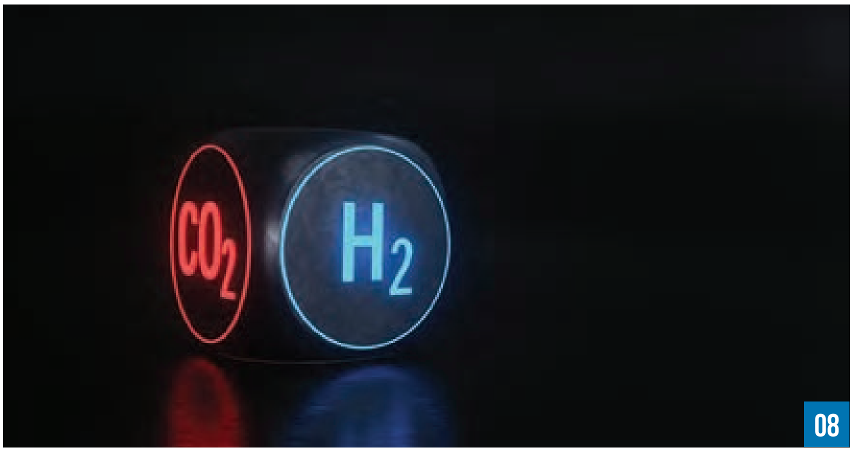


NEW REPORT OUTLINING HYDROGEN'S KEY ROLE IN UK ENERGY TRANSITION

CADENT HAS SET OUT BOLD NEW PLANS FOR THE TRANSITION AWAY FROM FOSSIL FUELS

CADENT HAS UNVEILED a new report that draws together considerations to create a pioneering plan to transition 22 million UK homes to low carbon heat by 2050 with hydrogen included.

The report underlines the scale of the challenge ahead, acknowledging that a mosaic of low carbon heating solutions will be required to meet the needs of individual communities, and setting out 12 key steps that can be taken now to get us there.

For instance, demonstrating that hydrogen is safe is a key aspect to explore with necessary steps needed to be completed to ensure that all the safety evidence for hydrogen in the gas network is completed, reports *H2 View.*

As well as this, enabling the development of a hydrogen economy is crucial and should set production targets, develop production and carbon capture and storage business models, support industrial cluster development, accelerate hydrogen blending and mandate hydrogen-ready appliances.

Necessary upgrades should also be made to the gas network for hydrogen, according to the report.

Innovation should be prioritised by fostering and incentivising innovation in both the technology and in the regulatory framework.

Injecting pace into the building of infrastructure that is known to be needed is key and groups should start planning now whilst building supply chains and skills in parallel.

This could help identify ways to accelerate the planning and development processes as well as enabling 'learning by doing'.

Another key area regarding hydrogen is deepening the understanding of the critical factors in the economics that will determine the energy mix with a need to refine analysis on the role of hydrogen as new information emerges.

This could be on energy efficiency deployment rates and the pace at which the price of hydrogen falls.

Dr Tony Ballance, Chief Strategy and Regulation Officer at Cadent, said, "Reports and studies have so far largely focused the economic and technical aspects of the transition, leaving most consumers with little understanding of the impact of such changes on their current heating systems, or the options available to them.

"We believe this must change. Consumer needs will be best met when they are central to decisions, understanding their views on heating and beginning engagement early, being upfront on how much the transition will cost and ending unnecessary 'format' wars over which technology will win.

"The installation of all low carbon technologies will create some disruption for many. All solutions are likely to cost more. But if we fail to get this right, we will fail to gain public support – and that means we will risk failing to make the transition away from fossil gas.

"This will require engagement from customers, industry and government and a willingness to move beyond an 'us' versus 'them' debate between the gas and electricity industry."

SSE, EQUINOR PLAN TO STORE HYDROGEN AT UK GAS STORAGE SITE

SSE THERMAL, part of SSE and Norwegian oil and gas company Equinor have announced plans to store hydrogen at their existing gas storage site on the East Yorkshire coast.

The site, called Aldbrough, consists of nine underground salt caverns which would be converted to store hydrogen, reports Reuters.

The project, due to be completed by 2028 with an expected capacity of at least 320 gigawatt hours, might require additional caverns to be built, the firms said.

Gaseous hydrogen produced from fossil fuels has been stored underground in caverns for many years.

The site would be used to store hydrogen from the Humber region, where a low carbon, hydrogen hub is being developed. The hydrogen would be used for the heat, industry and transport markets from the late 2020s onwards.

The companies said that while the Aldbrough facility would initially store hydrogen produced to fuel the Keadby Hydrogen Power Station, it would enable growing hydrogen ambitions, including supplying an expanding offtaker market including heat, industry and transport from the late 2020s.


PLANS FOR ONE OF THE WORLD'S LARGEST HYDROGEN STORAGE FACILITIES

NATIONAL GRID COULD BE REPLACED BY NEW FUTURE SYSTEM OPERATOR UNDER BEIS AND OFGEM PLANS


THE GRID OPERATOR HAS WELCOMED THE CONSULTATION

THE UK GOVERNMENT and energy regulator Ofgem have outlined their initial views on replacing National Grid with a new independent system operator for electricity and gas, as part of a string of policy updates designed to accelerate the low carbon transition.

Ofgem and the Department for Business, Energy and Industrial Strategy (BEIS) have launched a consultation on the management of energy systems operations in England, Scotland and Wales (Northern Ireland has devolved responsibilities). They are proposing that the National Grid, which has balanced supply and demand to ensure electricity access for more than 30 years, is replaced with an independent "future system operator" (FSO), according to sustainability website *edie*.

This move, the organisations claim, could help accelerate the transition of the UK's energy systems to net zero at the lowest possible cost to domestic and commercial energy users. Ofgem stated earlier this year that National Grid would face a "conflict of interest" in advising on the future of the energy system because it is a FTSE100 firm that also owns and operates networks.

The consultation document proposes that the FSO should take on strategic network planning, long-term forecasting and market strategy functions for gas. It also outlines "new or enhanced roles and functions" including overseeing the UK's hydrogen and carbon capture and storage (CCS) sectors, which are set to grow rapidly in the coming decades.

Five high-level characteristics for the FSO are then detailed: "It will need to be technically expert; operationally excellent; accountable to consumers and able to support the delivery of net zero on behalf of the public; independently minded; and operationally and financially resilient."

National Grid has stated that it "welcomes" the consultation and will "work closely" with BEIS and Ofgem throughout. As the consultation concludes in late September, a phased introduction of the FSO is expected.

UK'S FIRST HYDROGEN-POWERED HOMES OPEN TO THE PUBLIC

DIFFERENT MANUFACTURERS WILL SHOWCASE THEIR INNOVATIONS

THE UK'S FIRST homes with household appliances powered entirely using hydrogen have officially been opened by Energy and Climate Change Minister Anne-Marie Trevelyan.

Located at Northern Gas Networks' (NGN) innovation site in Low Thornley, Gateshead, the two semi-detached homes have been built to provide the public with the opportunity to experience a zero-emission hydrogen gas-fuelled "home of the future".

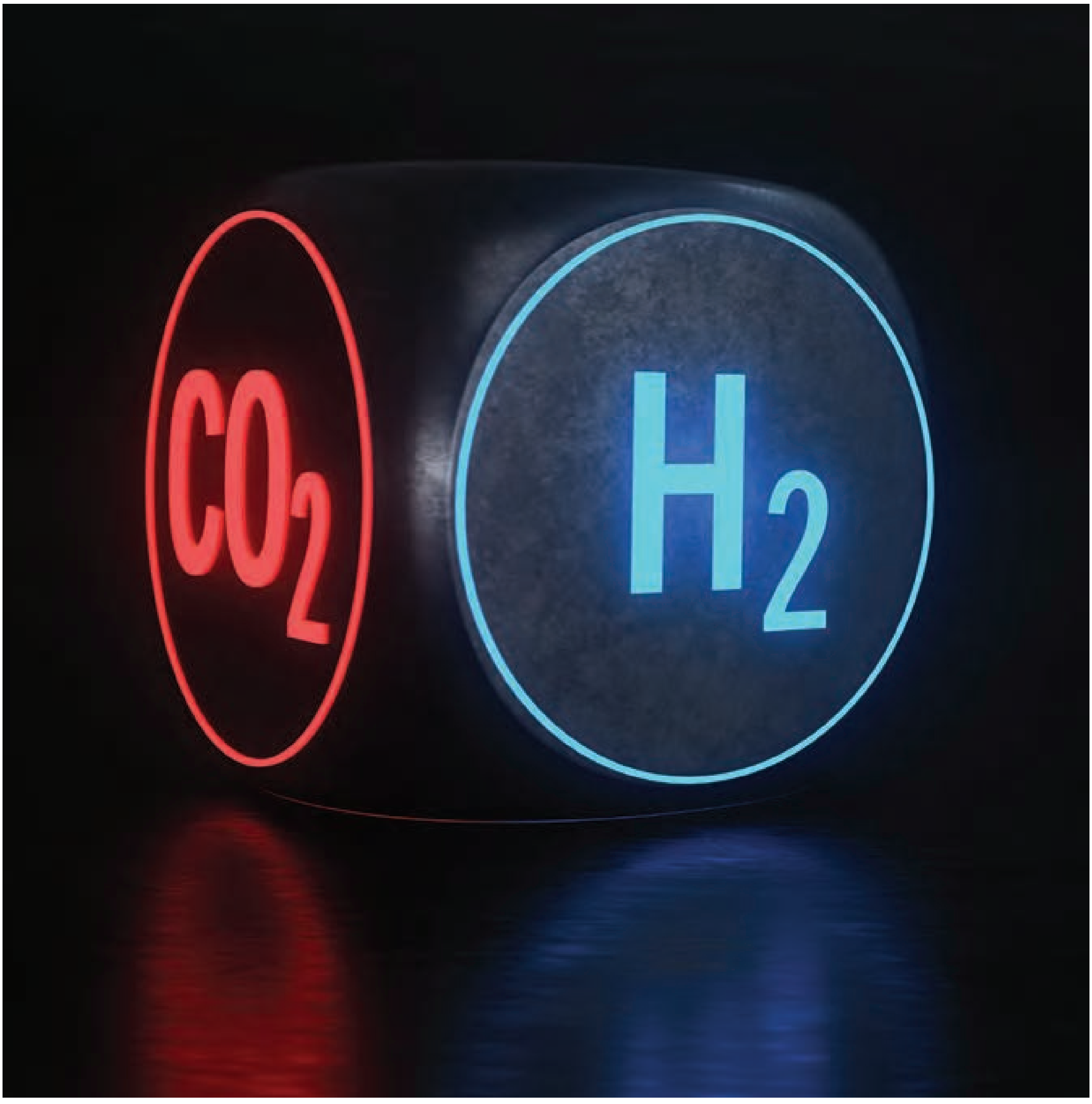
The public will be able to interact with a range of hydrogen-fed appliances such as hobs, cookers, boilers, fires and a barbecue, which will be rotated so different manufacturers will be able to showcase their innovations and get feedback from users.

The homes have been built in partnership between gas distributors Cadent and NGN and the government's Department for Business, Energy and Industrial Strategy (BEIS), reports *Energy Live News*.

According to the developers, the hydrogen homes will have a three-year lifespan – but potentially longer of up to 10 years.

They are not intended to be habitual but to showcase the use of hydrogen-fuelled applications in a real-world domestic setting.

HEADING FOR HYDROGEN



The hydrogen economy, a past victim of its own hype, has surged up the priority list of many oil and gas organisations. A new report from DNV GL reveals that hydrogen has taken a primary position in the sector's decarbonisation efforts, shaking off the hype it fell victim to in previous years. Liv A Hovem, CEO of Accelerator at DNV, explores some of the findings and shares her thoughts on the future of the embryonic fuel widely expected to power the energy transition

Societies globally are aligning on the need to act faster to fight climate change, with several nations already committing to net zero targets for CO_2 emissions. Many oil and gas majors have also committed to reducing or eliminating their emissions. DNV GL's recently-launched report, *Heading for Hydrogen*, based on a survey of more than 1,000 senior oil and gas industry professionals – suggests a more certain future for hydrogen and that the time is right to begin scaling the hydrogen economy, despite recent oil market shocks.

Our report reveals that half (52 per cent) of senior oil and gas professionals expect hydrogen to be a significant part of the energy mix by 2030 and a fifth (21 per cent) say their organisation is already actively entering the hydrogen market. The proportion intending to invest in the hydrogen economy doubled from 20 per cent to 42 per cent in the year leading up to the coronavirus-induced oil price crash. The global picture reveals more than half of respondents to DNV GL's research in the Asia-Pacific region (56 per cent), the Middle East & North Africa (54 per cent) and Europe (53 per cent) agree that hydrogen will be a significant part of the energy mix within 10 years. North America (40 per cent) and Latin America (37 per cent) are only a little behind.

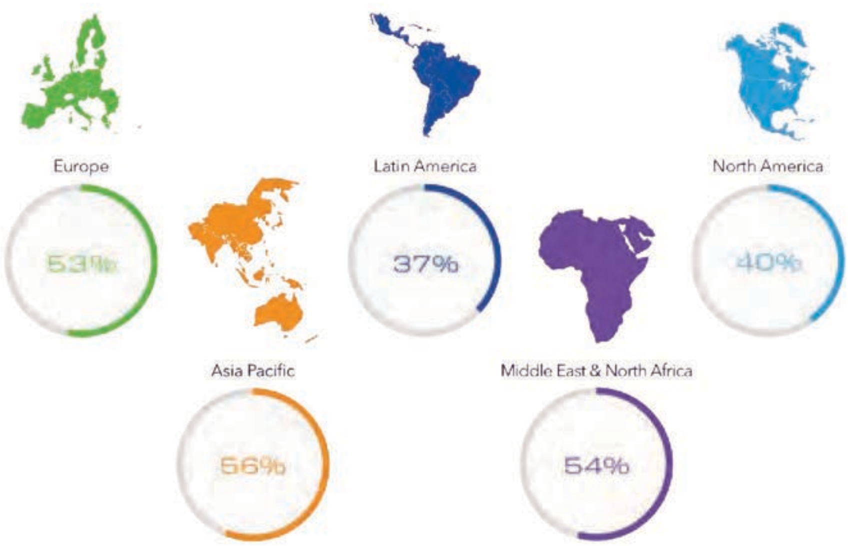
The report suggests that recent shifts in the industry's investment priorities are unlikely to affect the sector's long-term efforts to reduce carbon emissions.

DNV GL found a significant rise in those reporting that their organisation is actively adapting to a less carbon-intensive energy mix – up from 44 per cent for 2018 to 60 per cent for 2020. Carbon-free hydrogen production, transmission and distribution is now widely recognised as a central component to the oil and gas industry's decarbonisation efforts.

A LONG-TERM PROJECT

Hydrogen is rightly in the spotlight as the transition gathers pace. However, to realise its potential, both governments and industry will need to make bold decisions. The challenge now is not in the ambition, but in changing the timeline; from hydrogen on the horizon, to hydrogen in our homes, businesses, and transport systems.

EXTENT TO WHICH RESPONDENTS AGREED THAT HYDROGEN WILL BE A SIGNIFICANT PART OF THE ENERGY MIX WITHIN 10 YEARS



The success of a hydrogen energy economy is closely aligned with the future of natural gas, renewable energy, and carbon capture and storage (CCS) technology, according to *Heading for Hydrogen*.

Hydrogen can be produced in several ways, but if it is going to help in the battle with climate change the process will have to be decarbonised. While hydrogen gas produced from renewable energy (green hydrogen) is the industry's ultimate destination, analysis shows that the sector can only realistically scale up to large volumes and infrastructure with carbon-free hydrogen produced from fossil fuels combined with CCS technology (blue hydrogen).

DNV GL's 2019 *Energy Transition Outlook*, a forecast of world energy demand and supply, predicts that natural gas will become the world's largest energy source in the mid-2020s, accounting for nearly 30 per cent of the global energy supply in 2050. Natural gas and hydrogen can play similar roles within the global energy system, and the synergies between them – in application and infrastructure – will drive the hydrogen economy.

Exploiting the synergies with natural gas is just one of the ways to make the hydrogen economy a reality. To get to the stage where societies and industry can enjoy the benefits of hydrogen at scale, all stakeholders will need to focus on four hydrogen 'enablers': safety, infrastructure, CCS and policy.

THE FOUR HYDROGEN ENABLERS

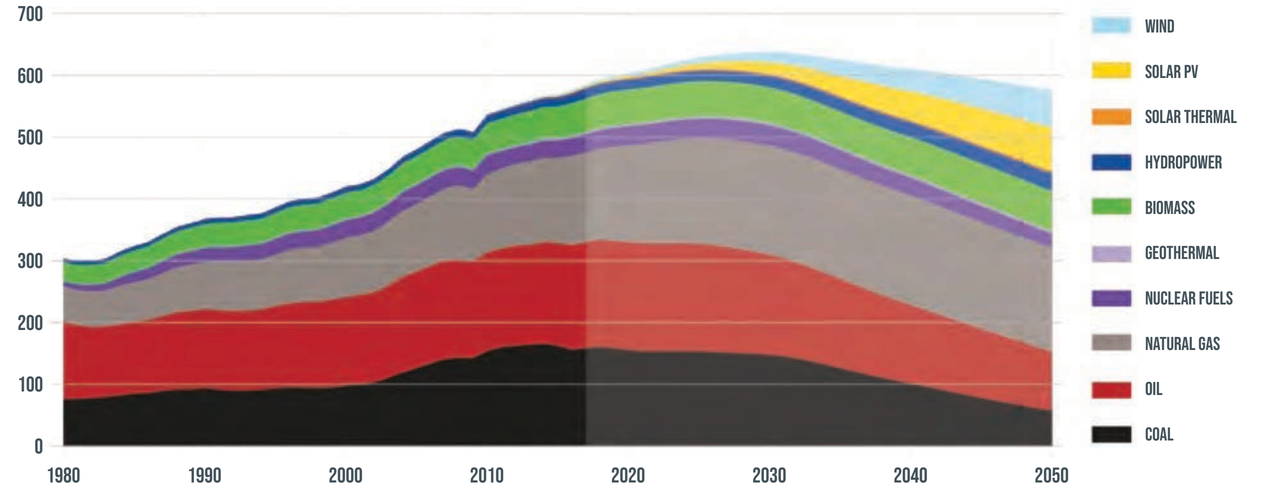
The first is to prove the safety case for hydrogen. For hydrogen to gain broad acceptance and adoption – in domestic settings and for new applications beyond current industrial uses – industry and regulators will need to establish robust safety standards for each specific use case. The public perception must be addressed, and stakeholders must take steps to ensure people are confident of hydrogen being safe for use in domestic and other settings.

DNV GL is helping governments and gas operators to demonstrate safe hydrogen production, transmission and consumption. One example is the Hy4Heat programme in the UK, which aims to establish whether it is technically possible, safe, and convenient to replace methane with hydrogen in residential and commercial areas. Tests on three specially constructed houses are proving the safety case for a switch from natural gas to hydrogen in a domestic setting at DNV GL's Spadeadam Testing and Research

WORLD PRIMARY ENERGY SUPPLY BY SOURCE

HISTORICAL DATA SOURCE: IEA WEB (2018)

UNITS: EXAJOULES PER YEAR (EJ/YR)



site – the world's first comprehensive hydrogen testing facility.

The second area is to develop efficient hydrogen infrastructure. Countries with natural gas transmission and delivery systems in place can continue to use those assets in a hydrogen economy. Even where existing infrastructure can be reused or repurposed, there will still be issues to resolve. Our experts are helping companies across the global oil and gas value chain to develop hydrogen-fit infrastructure. One operational constraint to overcome includes the fact that hydrogen pipeline networks may need to be operated at different pressures (or velocity) than natural gas/biogas.

Further research may be needed into whether hydrogen could have an adverse effect on materials (e.g., in pipes and valves) and finally, various appliances would need to be converted or replaced (e.g., water heaters, compressors, pumps and sensors). An interesting example is the project DNV GL has been undertaking in the Netherlands – the Power2Gas programme being led by Stedin, a Dutch gas and power grid operator. We have been managing and providing expert support to test that homes can be heated by 100 per cent hydrogen replacing natural gas in an existing pipeline for the first time in the country.

Third is the need to scale CCS technology. All major routes to successfully decarbonise gas rely on the large-scale uptake of CCS. More than half of those we surveyed (55 per cent) said that the oil and gas industry could not decarbonise without greater uptake of CCS. CCS struggles to gain traction because there is a cheaper option for industry; emitting carbon into the atmosphere costs virtually nothing. Our 2019 *Energy Transition Outlook* finds that CCS will not scale until the 2040s without changes to government policy.

However, if policymakers make bold decisions – the types of bold decisions that stimulated other clean technologies like solar and wind – large-scale uptake can happen.

Industry can also play a role by finding ways to reduce the cost of implementing CCS. Some 62 per cent of senior oil and gas industry professionals think the sector should drive adoption forward immediately, and not wait for government policies/incentives.

The final enabler for the growth of hydrogen relates to the need to incentivise value chains through policy. The quicker that government incentivises industry to adopt technology, the quicker the technology goes down the cost-learning curve and becomes independently financially viable. Use cases will create demand for hydrogen, and demand will lead to further investment, lower costs, greater acceptance, and the momentum needed to build sustainable supply chains. But to make use cases a reality, governments and inter-governmental organisations have to make more long-term policy commitments.

IMPORTANCE OF COLLABORATION

Collaboration is vital for hydrogen to reach its true potential. To progress to the stage where societies and industry can enjoy the benefits of hydrogen at scale, governments and industry will need to make bold decisions and balance short- and long-term priorities to address the key enablers I mentioned above. In Norway, for example, DNV GL supported the government with technical and market analysis to provide a knowledge base for decisions regarding national strategy and policy measures. It's also about collaboration between organisations and companies to bring together the best technical expertise and experience that will drive this forward.

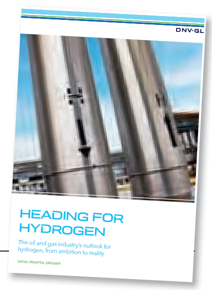
If policymakers make bold decisions – the types of bold decisions that stimulated other clean technologies like solar and wind – large-scale uptake can happen

In the UK, Antony Green, Project Director for Hydrogen at National Grid, said in the report: "The UK's net zero targets have put a massive impetus on utility networks to find the right path. As a result, we've seen collaboration like never before over this last 12 months."

SHIFTING THE TIMELINE

The challenge now is not in the ambition, but in changing the timeline. This is a challenge of adaptability, laid bare in 2020 as the world is blindsided by a dramatic black swan event. But our research suggests that once the recovery gains momentum, the oil and gas industry will continue – or even accelerate – its diversification, with an ever-increasing focus on the most abundant element in the universe.

Download the DNV GL report Heading for Hydrogen at www.dnvgl.com/oilgas/hydrogen/heading-for-hydrogen.html



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Challenging today.
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To create a more connected, sustainable world.

Jacobs is fully committed to delivering the global energy transition – the large scale and pace of change required to provide a smart, decarbonised energy system.

SHARED WISDOM

THE HYDROGEN KNOWLEDGE CENTRE

In March, IGEM officially launched the world class Hydrogen Knowledge Centre, a new digital library offering a searchable database of hydrogen research, reports, data, presentations and videos. Here, we look at what this new service has to offer and how it can improve knowledge sharing of hydrogen globally

Last month, IGEM was proud to announce the launch of the UK's first Hydrogen Knowledge Centre - a world class digital repository dedicated to sharing hydrogen resources around the world.

The Hydrogen Knowledge Centre was developed with support from the Department for Business, Energy & Industrial Strategy (BEIS) through its Energy Innovation Programme and will lead the advancement of hydrogen knowledge globally.

IGEM's Hydrogen Knowledge Centre currently holds over 1,300 resources on everything from hydrogen production, transmission, distribution and storage to applications, safety and hydrogen blending.

The institution, which represents gas professionals around the world, will expand the repository with the latest

WHAT THE INDUSTRY IS SAYING ABOUT THE HYDROGEN KNOWLEDGE CENTRE

Ian Bagworth, Senior Engineer - Gas at Ofgem, said: *"The only way to a net zero future is to have a reliable, independent source of information."*

Dr Angela Needle, Director of Strategy at Cadent Gas Limited, said: *"This is the news we have been waiting for. A great resource to accelerate learning."*

David Hodgson, MD TFP Hydrogen Products, said: *"An excellent idea to communicate how hydrogen can play a role in the energy system."*

research as it emerges, supported by hydrogen projects currently underway across the UK and internationally.

Neil Atkinson, Chief Executive Officer at IGEM, said: "It is widely recognised that hydrogen will play an important role in our future energy mix if we are to stand any realistic chance of meeting our net zero carbon emissions target by 2050.

"For a healthy hydrogen economy to take shape with the urgency required, it is essential that the industry works collaboratively and is able to access and share knowledge across all sectors.

"At IGEM, we are passionate about our leadership role to enable the UK transition to a low carbon gas network. One of the ways we are playing our part is through the development of the Hydrogen Knowledge Centre.

"With the backing of BEIS, we've created a growing and carefully curated database of resources from a wide range of sources including gas network companies, academic institutions, research bodies, supply chain organisations and industry experts, accessible by anyone.

"The development of a Hydrogen Knowledge Centre is an exciting next step in bringing the industry's learning into a central space for the advancement of the profession and to support the UK's transition to a net zero carbon emissions future."

On 17 March, scores of delegates joined IGEM online for a special launch event, which included presentations from:

- Dr Mark Taylor FIMA, Deputy Director for Energy Innovation, Department of Business, Energy and Industrial Strategy (BEIS)
- Dr Stuart Hawksworth, Head of the Centre for Energy & Major Hazards at the HSE, and President of the International Association for Hydrogen Safety
- Keith Owen, Head of Systems Development and Energy Strategy at Northern Gas Networks

Virtual attendees were among the first to see the new Hydrogen Knowledge Centre, receiving a unique preview of its capabilities and how it can support the sector towards a greener future.

At IGEM, we are passionate about our leadership role to enable the UK transition to a low carbon gas network

Content includes journal articles, conference papers, data sets, policy reports, project documents, research papers presentations and videos.

IGEM is at the forefront of the gas transition and the Hydrogen Knowledge Centre is just one aspect of its work to support the country's net zero ambitions. In addition to developing the UK's first hydrogen technical standards from transmission to domestic utilisation, IGEM is working in partnership with industry and government to support the feasibility and safety evidence base for scaling up low carbon gases and hydrogen into the existing UK gas network.

IGEM members automatically have access to the Hydrogen Knowledge Centre, but anyone can join IGEM as an Associate Member to access its content quickly and easily.

The Hydrogen Knowledge Centre can be accessed at www.h2knowledgecentre.com. If you wish to contribute content to the Hydrogen Knowledge Centre, please contact us at hydrogen@igem.org.uk.

HUNDREDS OF RESOURCES TO EXPAND YOUR KNOWLEDGE

HERE ARE JUST some of the latest reports you can discover through the Hydrogen Knowledge Centre

SGN PROJECT REPORT: FLAME VISIBILITY RISK ASSESSMENT

By DNV, Margaret Caulfield, Sarah Kimpton and Andrew Phillips

This report contains information on the relative risks of natural gas and hydrogen fires, particularly regarding their visibility. The fires considered are those that could occur on the H100 Fife trial network. The H100 Fife project will connect a number of residential houses to 100 per cent hydrogen gas supply and includes hydrogen production, storage and a new distribution network. From a review of large and small-scale tests and incidents, it is concluded that hydrogen flames are likely to be clearly visible for releases above 2bar, particularly for larger release rates. At lower pressures, hydrogen flame visibility will be affected by ambient lighting, background colour and release orientation, although this is also the case for natural gas.

GAS GOES GREEN: BRITAIN'S HYDROGEN NETWORK PLAN REPORT

By Energy Networks Association

Britain stands on the cusp of a world-leading hydrogen revolution, one the UK gas industry is uniquely positioned to take advantage of. With an extensive, world-leading gas grid, huge amounts of offshore wind resource and liquid energy markets, there are few other places as well-positioned as the UK to lead the international race to build a hydrogen economy. Published as part of Energy Networks Association's Gas Goes Green programme, Britain's Hydrogen Network Plan will play a vital role in delivering the UK's ambitions for hydrogen, as set out in the Prime Minister's 10-point plan for a green industrial revolution.

The plan sets out how Britain's gas network companies will enable 100 per cent hydrogen to be transported for use in different sectors of the UK economy. It also identifies the wider actions needed to provide hydrogen production and storage, showing how transitioning the gas networks to hydrogen will allow hydrogen to play a full role in achieving net zero in the hard-to-decarbonise sectors such as industry, heavy transport and domestic heating, saving an estimated 40 million tonnes of CO_2 emissions every year.

HYDROGEN COUNCIL REPORT: DECARBONISATION PATHWAYS

This report shows that low carbon hydrogen supply at scale is economically and environmentally feasible and will have significant societal benefits if the right localised approach and best practices for production are used. The report also demonstrates that there is not one single hydrogen production pathway to achieve low lifecycle greenhouse gas (GHG) emissions, but rather the need for a fact-based approach that leverages regional resources and includes a combination of different production pathways. This will achieve both emission and cost reductions, ultimately helping to decarbonise the energy system and limit global warming.

The report outlines that there are many ways of producing hydrogen and although GHG emissions vary widely, very high CO_2 savings can be achieved across a broad range of different hydrogen production pathways and end uses. For example, while 'green' hydrogen produced through water electrolysis with renewable power achieves the lowest emissions, 'blue' hydrogen produced from natural gas with high CO_2 capture rate and storage can also achieve low emissions if best technologies are used and best practices are followed.

HY4HEAT PROGRESS REPORT

Hy4Heat's mission is to establish if it is technically possible, safe, and convenient to replace natural gas with hydrogen in residential and commercial buildings and gas appliances. This will enable the government to determine whether to proceed to a community trial.

There is growing international consensus that hydrogen will be essential to successfully tackling climate change. So BEIS is working to develop hydrogen as a strategic decarbonised energy carrier for the UK, which will be an essential element of the UK's efforts to transform and decarbonise our energy system in line with our legally binding 2050 net zero commitment. Hydrogen can be used across multiple end-use sectors, including industry, transport, heat, and power. BEIS is looking to support and develop low carbon hydrogen production methods, which will position hydrogen as a highly effective decarbonisation option, particularly in hard-to electrify sectors and processes.

At the end of 2017 BEIS appointed Arup to be the programme manager for the Hy4Heat programme. Arup partnered with technical and industry specialists: Kiwa Gastec, Progressive Energy, Embers and Yo Energy, and together the team oversees the programme and technical management of all the work packages. For the past three years Hy4Heat has been exploring whether replacing natural gas (methane) with hydrogen for domestic heating and cooking is feasible and could be part of a plausible potential pathway to help meet heat decarbonisation targets. To do this the programme has been seeking to provide the technical, performance, usability and safety evidence to demonstrate whether hydrogen can be used for heat in buildings.

THE HEAT IS ON

As the UK explores ways to reach net zero emissions by 2050, the question of how to decarbonise heat – responsible for 40 per cent of the country's emissions – will be essential to delivering the promise made by Theresa May on behalf of the UK government in 2019. With 85 per cent of UK homes currently connected to the gas network, making use of this existing asset to transport clean hydrogen, which is zero carbon at the point of use, offers one such pathway, according to the folks at Northern Gas Networks (NGN)

Hydrogen has seen a surge in support over the last 12 months and a much-awaited government hydrogen strategy is expected in early 2021.

As government drafts its plans, industry continues to build up the picture of evidence on which policy can be built, with different hydrogen programmes exploring different parts of the heat challenge.

H21 – THE SAFETY EVIDENCE

Led by Northern Gas Networks (NGN), H21 is a suite of pioneering gas industry projects, aimed at proving that the existing UK gas network can be converted to transport 100 per cent hydrogen, in order to support UK Climate Change Act obligations.

From blueprints setting out the infrastructure requirements for hydrogen production, storage and CCUS (H21 North of England), to demonstrating the critical safety evidence needed for policy (H21 NIC), the H21 programme is building understanding about the network technology needed to ensure clean energy for customers, delivered as safely and reliably as the natural gas of today.

In the four years since the H21 Leeds City Gate study proved that hydrogen conversion was technically possible and economically viable, H21 is now on the cusp of delivering critical evidence evaluating the risks of a hydrogen network compared to those of a natural gas network.

A collaborative partnership between NGN, Cadent, SGN and Wales & West Utilities along with the Health and Safety Executive Science Division (HSE-SD) and DNV GL, the Phase 1 research is backed by £9 million of Ofgem Network Innovation Competition (NIC) funding, with two major testing programmes carried out at the HSE-SD in Buxton, and at DNV-GL's Spadeadam base in Cumbria.

These focused on testing a huge range of distribution network assets, including the consequences of leakage under hydrogen conditions, plus testing at Spadeadam to inform the Quantitative Risk Assessment, with a full report expected in the new year.

National Grid Gas Transmission joined as project partners for H21 NIC Phase 2, which was awarded a further £6.8 million funding in 2019.

The H21 Phase 2 project will examine existing network operations and procedures, to understand any adaptations which may need to be made under 100 per cent hydrogen conditions.

In another strand of the H21 NIC work, Leeds Beckett University carried out social sciences research to explore perceptions of a hydrogen gas network. Delivered via a national survey and several customer focus groups, the research is the first real insight into how gas customers feel about the prospect of using hydrogen in their homes.

The findings showed the UK public is receptive to the concept of a hydrogen-fuelled network and that safety was not a major concern. Customers were interested in the environmental impact of the gas they use today, but cautious of the costs associated with replacing appliances.

CURRENT PROGRESS

H21 NIC - REVIEWING ALL DISTRIBUTION WORK PROCEDURES FOR PHASE 2

Through an appraisal of network components, procedures, network modelling and testing, H21 Phase 2a is now demonstrating how gas distribution network companies would manage the network and the conversion to 100 per cent hydrogen process safely.

NGN has more than 650 individual operational practices documented in its procedural library. Of these around half were found to have the potential to be impacted by a switch from natural gas to hydrogen. The HSE-SD is now reviewing and assessing impacted procedures to understand which may need further investigation to ensure a hydrogen network is as safe and reliable as today's gas network.

DNV GL's test and research facility at RAF Spadeadam, in Cumbria, is the location for a hydrogen micro-grid which is being purpose-built to represent a typical UK distribution network.

The H21 project team will take the HSE-SD's findings and use the microgrid to review, test and make recommendations to amend the operational and maintenance procedures required to operate a network on 100 per cent hydrogen.

It is critical that the likelihood and consequences of gas leakage and the way hydrogen behaves in the current gas network (and when it escapes) are understood so the gas can be safely handled.

Russ Oxley, Northern Gas Networks' H21 Project Manager, said: "Only by meticulously deep diving into every procedure and understanding the tiniest minutiae of detail can we aspire to learn the impact of hydrogen.

"We are creating a whole new area of expertise and this will have an impact on our supply chain. Some equipment may

become obsolete and new solutions are likely to be needed. There will be some great opportunities for innovation in everything from PPE to tools."

THE NEXT STEP: UNOCCUPIED TRIAL ON A NETWORK

The next part of Phase 2 of the H21 project will see trials on an unused section of the gas network in the South Bank area of Middlesbrough. NGN has secured the lease of the site from Redcar and Cleveland Council and will carry out several months of rigorous testing on an isolated part of the network, once planning consent is secured.

The site, incorporating Pym Street and part of Cromwell Road, formally housed around 70 terraced homes and was deemed ideal for its likeness to a typical UK residential area. The houses were demolished around a decade ago but, as the underground network has since been untouched, the gas infrastructure and other utilities, along with the carriageways and footpaths remain intact.

The trials will provide further vital evidence about the compatibility of the existing gas network to distribute hydrogen. Every operation reviewed by the HSE-SD and tested at Spadeadam will be replicated at the South Bank site.

NGN will initially spend three months modifying the site by isolating existing pipework and laying new pipework to create a loop. The pipes currently run from the front to the back of the site but, by laying additional mains to form a loop, flows can be measured as hydrogen returns to the network.

Tests will be carried out jointly by NGN engineers, who will be seconded from their work on the gas network, closely supervised by a team of four experts from DNV GL and with technical input from HSE-SD.

"We have support from the local MP and Mayor, as they recognise the potential of hydrogen and we hope to educate local schools about the benefits of a hydrogen future and the potential role it has to play in supporting the transition to a low carbon energy future"

Natural gas will be decommissioned from the pipes and replaced with hydrogen. Key procedures will then be interrogated including venting and purging, under pressure drilling, live repairs, dead and live insertions, new connections, flow stops and network modelling.

A hydrogen boiler will be onsite and fed by the network to demonstrate that a clean gas boiler can perform as well as a natural gas boiler, while replicating the look and feel of the boilers already installed in 85 per cent of UK homes connected to the gas network.

NGN Project Manager Neil Travers explains more about the trial: "Previous phases of work have involved taking our assets to a facility to be tested with hydrogen. The South Bank project brings hydrogen to a live gas network for the first time.

"The location of the site at the heart of Teesside's industrial cluster will galvanise the region as the perfect location for a growing hydrogen economy and the resulting prosperity and employment opportunities this could generate.

"We have support from the local MP and Mayor, as they recognise the potential of hydrogen and we hope to educate local schools about the benefits of a hydrogen future and the potential role it has to play in supporting the transition to a low carbon energy future."

OUTCOMES

Every conclusion and piece of evidence drawn from the H21 project moves the UK closer to realising the vision of a 100 per cent zero carbon hydrogen network. Plans are now being developed for H21 Phase 3, a small-scale demonstration to take place in 2022. This would involve supplying 100 per cent hydrogen to around 100 homes on a public gas network.

The H21 co-ordinated work programme brings together the very best brains and engineers in the gas industry. The collaborative nature of the project is avoiding a replication in research by different gas distribution networks and minimising the investment and resulting cost to the customer.

Ultimately the project's numerous findings will be fed into government to influence a policy decision about the future of hydrogen.

For more information about the H21 programme, visit www.h21.green

DOMESTIC HYDROGEN SMART METERING

HYDROGEN SMART METER

THE DIVERSE, UNBUNDLED gas supply chain will provide many challenges for the transition to hydrogen. BEIS tendered in 2019 to ensure all domestic products would be ready for hydrogen. Pietro Fiorentini was awarded the meter, regulator and ancillary (ECV) pipework. This amazing opportunity has produced the most accurate domestic SMETS2 ultrasonic meter available. It is capable of measuring hydrogen or natural gas, and any blend of these two gases.

This incredible advancement in technology will allow the energy providers to install this meter now, in preparation for the transition to hydrogen throughout this decade. The new meter will be installed at the Spadeadam 'Hy Street' and also in the 'Hydrogen Home'. The new house, pictured above and built by Northern Gas Networks, will be completed in the coming months. It will demonstrate to the public how appliances will migrate to hydrogen, safety and securely for the net zero carbon free future.

HIGH PRESSURE STATION

FUTURE PROOF NETWORK STATION

Partnering with the UK gas networks to 'future proof' their assets, PF-UK has redesigned the standard network station. 3D has been utilised by our group for more than two decades designing infrastructure around the globe. The latest design takes into consideration IGEM/TD/13 Supplement 2 *Hydrogen installations <7bar* and GIS E:34. The station features hydrogen compliant components, flow and pressure monitoring (FIO2- RTU) and wireless (GSM) real-time (Modbus/Scada) data. Site telemetry is powered by our new innovation, the Atex-approved microturbine. It utilises the flow of gas through the station to generate free green energy. This negates the need for permanent and expensive electrical supplies or solar panels, which are subject to vandalism and UK weather changes. This is designed to assist in network station replacement to prepare the networks for the hydrogen transition.

WINLATON – HYDROGEN DISTRICT NETWORK INJECTION STUDY

PF-UK supplied the gas network station at Winlaton. This installation has been chosen to study the injection of 20 per cent hydrogen (station inlet) to a live district network. This station supplies 600 domestic homes. Critical material analysis was conducted by our R&D department to demonstrate to the HSL and HSE that our station was compliant for hydrogen injection. The network results will be monitored and published throughout the coming year.

HIGH PRESSURE STATIONS

PF-UK was last year commissioned by a network to supply a 100 per cent hydrogen high pressure station for the testing facility at Spadeadam. This innovative project will see a hydrogen network test all the components in the supply chain over the coming years. It is a collaboration between three major network operators.

The station was delivered and installed at site, in February 2021 after six months of design and manufacturing. It was recently featured on Sky News' *Daily Climate Show.*

THE MICROTURBINE

This great piece of technology generates electricity onsite by using the gas flow on through station, turning the turbine to generate power. PF UK now has the ability to generate 150W up to 40bar pressure. This is perfect to connect to the station where there is no power onsite but also, for telemetry, giving you real time data to carefully manage the efficiency of your site.

MICROTURBINE

Pietro Fiorentini

HYDROGEN BLENDING

WHAT IS IT AND WHY DOES IT MATTER?

The government should set a target for when the first large-scale hydrogen production plants will be connected to Britain's gas grid, says a new report commissioned by gas distribution company Cadent and published by Energy Network Association's (ENA) Gas Goes Green programme. **Dr Angie Needle**, Director of Strategy at Cadent, explains why this report's recommendations could help kickstart the growth of a world-leading hydrogen economy here in the UK

The latest Frontier Economics report, commissioned by Cadent, sets out what Britain needs to do to start introducing large quantities of hydrogen into its network of 284,000km of gas pipelines. That's important because it's exactly what we need to do to get going with the process of replacing the carbon-emitting 'natural' or fossil gas that most of us use at the moment. The report sets out the detail of what can be done and what needs to be done for three key stakeholders: government, gas network companies and hydrogen producers.

But why does that matter? Here in the UK we've got a world-leading gas network and we're hugely reliant on it. Eighty-five per cent of homes and businesses use the fossil gas it provides for heating, cooking and hot water – often at the times when we need them the most.

But we need to get rid of fossil gas to tackle the climate emergency. Household carbon emissions from our heating alone need to drop from almost three tonnes a year today to just 138kg by 2050. Blending up to 20 per cent hydrogen into the gas grid with existing natural gas could save around six million tonnes of carbon dioxide emissions every year, the equivalent of taking 2.5 million cars off the road.

According to the independent Committee on Climate Change, for hydrogen to be an option for reducing emissions, early projects need to get off the ground in the 2020s. At the moment, there is no large-scale production of low carbon hydrogen in the UK and blending hydrogen into the gas grid will help stimulate that by providing a secure demand base.

Of course, customers will naturally ask about safety and how any change will affect them – will hydrogen have an impact on the way people use their cookers, heating and hot water?

We've been running a world-leading live demonstration of hydrogen blending at Keele University, partnering with Northern Gas Networks and with the approval of the Health and Safety Executive. This project is called HyDeploy. That trial has consisted of up to 20 per cent hydrogen blended with fossil gas and used for heating and cooking in 100 homes on the Keele University campus, via a private gas network. Customer response has been overwhelmingly positive, particularly since they hardly had to do anything during the changeover.

The theory that we can blend hydrogen safely with natural gas is well-established. However, this first phase has proven that theory works safely in practice, with no impact on the way people use their gas boilers or cookers.

The second phase will follow the same approach used at Keele, but on a public network near Gateshead in the north-east of England. It will use the same technology that has been tested and approved in the first phase, with the same rigorous approach to safety and the same Gas Safe checks for customers' appliances.

The main difference with this demonstration is that we will be using the hydrogen with a wider variety of customers and appliances to make the trial more representative of the UK as a whole. So, around 670 households and several businesses will be using the hydrogen blend from December 2020, following Health and Safety Executive approval.

PIC CAPTION L-R: RICHARD WALSH, HEAD OF EXTERNAL AFFAIRS, CADENT; JACOB YOUNG MP, CHAIR OF THE ALL PARTY PARLIAMENTARY GROUP (APPG) FOR HYDROGEN; ARNIE CRAVEN, EXTERNAL AFFAIRS MANAGER, CADENT

On top of these demonstrations, there's a lot of work that needs to be done behind the scenes to get hydrogen blending and production off the ground. For example, the regulators need to focus on the non-technical aspects to ensure that networks are ready and able to accept hydrogen as soon as production is available. The report details what is needed in this area, such as the commercial regime, and metering arrangements.

At the moment, only 0.1 per cent of the gas in Britain's network of gas pipelines is allowed to be hydrogen, by law. We think the time is now right to start looking at how we change that law so that a 20 per cent blend is allowed.

Once innovation and safety trials have progressed to the next stage, that will allow gas networks to start blending far larger amounts of hydrogen into the grid – creating the demand for hydrogen that will help get the industry we need to produce it off to a flying start. The report sets out the details of how gas networks can work with hydrogen producers to do that.

To do that, and to ensure that we've got enough hydrogen, we need the government to play more of a proactive role in co-ordinating industry and the various different regulatory organisations. One of the easiest ways it can do that is to set a target date for when the first hydrogen production plant will be connected to the gas grid. This will give everyone involved the confidence to move forward so that we can begin to realise the green benefits of using hydrogen as part of our daily lives.

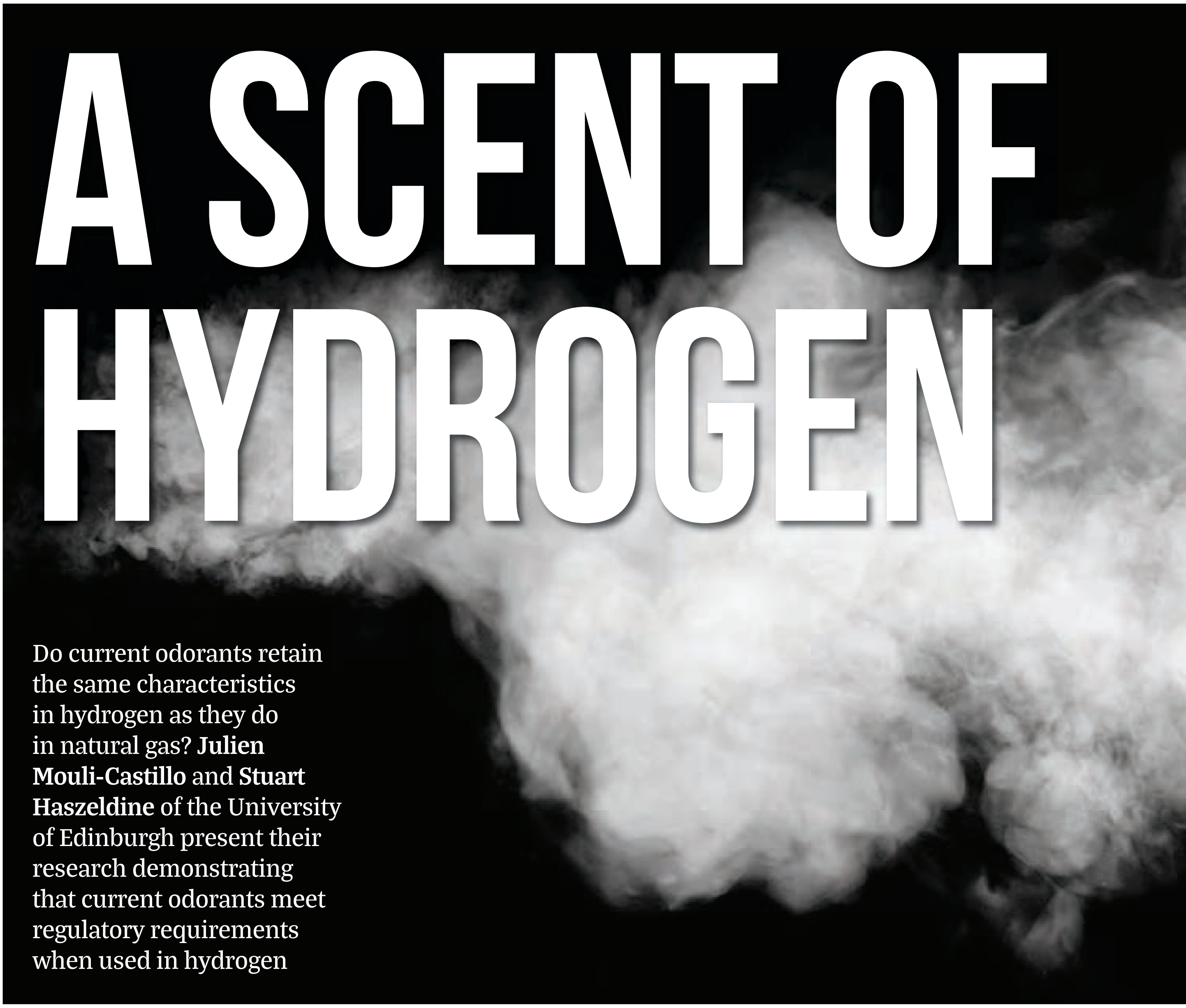
We need to get rid of fossil gas to tackle the climate emergency. Household carbon emissions from our heating alone need to drop from almost three tonnes a year today to just 138kg by 2050

We were delighted that the report received the support of Jacob Young MP, Chair of the All-Party Parliamentary Group for Hydrogen, on the day of its launch. He said: "Hydrogen has the potential to play a major role in the UK's economic recovery from Covid-19, and offers a compelling pathway towards supporting the decarbonisation of heating, transport and industrial processes. However, to play that role, it is now more important than ever for hydrogen production to be ramped up – and the commercial framework for hydrogen blending outlined in Cadent's report offers a really good way to achieve that.

"Building a world-leading hydrogen economy will have massive positive benefits, creating high-skilled jobs, driving economic growth and improving the environment. Cadent's report is another step on the journey towards that hydrogen economy, and I am happy to support it."

We will continue to work hard with our peers across the gas industry to persuade the government to include hydrogen in its forthcoming energy strategy, so that it can work alongside renewables and other sources of energy to enable the UK to meet its net zero target by 2050.

You can read more about Cadent's hydrogen work at www.hydeploy.com



A SCENT OF HYDROGEN

Do current odorants retain the same characteristics in hydrogen as they do in natural gas? **Julien Mouli-Castillo** and **Stuart Haszeldine** of the University of Edinburgh present their research demonstrating that current odorants meet regulatory requirements when used in hydrogen

The Paris international agreement of 2015 on climate action, combined with the UK Climate Act of 2008 means that the UK is legally mandated to reduce greenhouse gas emissions.

For the UK that means reducing these emissions from fossil fuel use by at least 100 per cent from the 1990 levels on a pathway to 2050[1].

The reduction of greenhouse gas emissions may become even more stringent, following the recommendations of the Committee on Climate Change, for the UK to aim for net zero emissions by 2050[2].

The demand for heat in the UK in 2019 is mostly met by using natural gas, where combustion results in a significant release of greenhouse gas emissions from residential properties, commercial properties, power stations, and industry.

The emissions from residential combustion alone resulted in $65.2MtCO_2$ equivalent in 2017, according to the UK government statistics[3]. This represents a reduction of only 16 per cent since 1990, which means that considerably more needs to be done to tackle the decarbonisation of domestic heat.

Regarding industrial heat and particularly demand from electricity generation by power plants, the UK has increased its reliance on natural gas since 1990. Consequently, the current emissions from gas fuels, all sectors considered, are 25 per cent higher than in 1990[4]. Consequently, reducing emissions from natural gas is paramount to meeting the UK targets.

Hydrogen gas could play a major role in meeting the required decarbonisation objectives. Extensive research is currently being carried out by the UK gas industry into the gas engineering, network logistics and safety issues linked to a hydrogen economy.

A shift to hydrogen could help leverage additional value from the significant investment made into the gas distribution network over the past decades as part of the mains replacement programme, the aim of which is to shift from metal mains to safer polyethylene ones[5,6].

Fuel switching from natural gas to hydrogen would also enable the gas industry, its millions of customers and the thousands of jobs that depend on it, to have its place in a low carbon economy.

As part of the shift to hydrogen gas networks there are still elements that require further research and development. Accordingly, a significant amount of research with laboratory, design and field testing work is being invested to prove the viability of hydrogen as a low carbon heat solution

and to provide evidence to assess safety at specified sites.

Among those research investors is SGN, one of the UK's gas distribution networks, transporting gas to nearly 5.9 million homes and businesses across Scotland, the south of England and Northern Ireland. SGN is currently undertaking a project which aims to bring the world's first 100 per cent hydrogen domestic gas distribution network to fruition. Funded by Ofgem, the H100 project is investigating and evidencing all aspects to deliver the first 100 per cent hydrogen domestic network as a safe and reliable demonstration. This will serve around 300 properties and be a significant stepping stone in demonstrating the resilience and safety of 100 per cent hydrogen networks with minimal disruption to the end user.

One justified pre-requisite of this project is to demonstrate that hydrogen can be distributed by a system which is as safe as the current natural gas distribution network. Referring to natural gas, one of the key safety measures is the use of distinctive odorants to trigger an early warning detection response in the event of a leak. The public perception of natural gas odorant is intrinsically linked to danger and elicits an emergency response. Therefore, identifying an odorant suitable for hydrogen networks is essential.

Odorant offers a reliable, efficient and cost-effective way of providing an early warning in case of a leak, inside or outside of a property. Due to its characteristic 'natural gas' odour, it allows anyone to detect leaks as an automatic response without any formal training. The odorant must be detected by the human olfactory system at less than 20 per cent of the lower flammability limit, providing enough time for proper detection, reporting and management of the leak.

Hydrogen can burn when its concentration in air is between four per cent and 74 per cent of the volume, hence four per cent is its lower flammability limit. This means that the odorant should make any leak detectable before the hydrogen concentration reaches 0.8 per cent of the volume.

Hydrogen is odourless when produced by conventional means such as the reforming of methane gas using steam, or electrolysis of water using electricity. Therefore, the odorant must be added to the gas before it enters the gas distribution network.

Odorant offers a reliable, efficient and cost-effective way of providing an early warning in case of a leak, inside or outside of a property. Due to its characteristic 'natural gas' odour, it allows anyone to detect leaks as an automatic response without any formal training

An odorant must be non-toxic to humans, animals and the environment at the concentration found in the distribution network. It also must be stable and remain within the hydrogen during transportation and storage and must be suitable for the intended end uses.

Although SGN's H100 project is targeting an end use currently dominated by combustion in boilers and cookers, in order to expand the future resilience of hydrogen applications in a wider low carbon economy, it would be good practise to investigate additional uses, such as feedstock to fuel cells.

Fuel cells allow electricity to be produced from hydrogen, yet for that reaction to occur the hydrogen has to be extremely pure, and the sulphur-based odorant 'new blend' (NB) used in the current UK gas distribution network is unsatisfactory and would degrade the fuel cell, halting its electricity production.

Here, we will present the initial findings from work undertaken during the H100 project to identify a suitable odorant for a 100 per cent hydrogen gas network. The work was conducted by National Physical Laboratory and Air Spectrum.

TABLE 1 SELECTED ODORANTS FOR FURTHER TESTING. NB STANDS FOR NEW BLEND, TBM FOR TERTIARY BUTYL MERCAPTAN, DMS FOR DIMETHYL SULPHIDE, THT FOR TETRAHYDROTHIOPHENE, MA FOR METHYL ACRYLATE, EA FOR ETHYL ACRYLATE, EMP FOR 2-ETHYL-3-METHYLPYRAZINE.

	COMPOUND	RATIONALE	SCENT
1	ODORANT NB (78 PER CENT TBM, 22 PER CENT DMS)	PRIMARY ODORANT USED BY SGN AND OTHER UK GAS NETWORKS	STRONG, OFFENSIVE, CABBAGE-LIKE
2	STANDBY ODORANT 2 (34 PER CENT ODORANT NB, 64 PER CENT HEXANE)	DILUTED FORM OF ODORANT NB USED BY SGN IF SUPPLY OF ODORANT NB IS COMPROMISED	LIKE ABOVE, WITH A GASOLINE-LIKE ODOUR
3	ODORANT THT (100 PER CENT THT)	MOST COMMONLY USED ODORANT WITHIN EUROPEAN GAS NETWORKS	ONION AND GARLIC-LIKE
4	GASODOR-S-FREE (37.4 PER CENT MA, 60.1 PER CENT EA, 2.5 PER CENT EMP)	SULPHUR-FREE GAS ODORANT IN USE WITHIN SOME GERMAN GAS NETWORKS, AND COMPATIBLE WITH FUEL CELLS ACCORDING TO THE MANUFACTURER	ACRID HOT PLASTIC ODOUR
5	5-ETHYLIDENE-2NORBORNENE	ODORANT WITH AN UNPLEASANT ODOUR THAT IS SUITABLE FOR FUEL CELL APPLICATIONS	COAL GAS, TURPENTINE-LIKE

TABLE 2 RISK ASSESSMENT SUMMARY FOR THE SELECTED ODORANTS.

	COMPOUND	RISK ASSESSMENT
1	ODORANT NB (78 PER CENT TBM), 22 PER CENT DMS)	THIS ODORANT DOES NOT QUALIFY AS TOXIC.
2	STANDBY ODORANT 2 (34 PER CENT ODORANT NB, 64 PER CENT HEXANE)	THIS ODORANT DOES NOT QUALIFY AS TOXIC.
3	ODORANT THT (100 PER CENT THT)	WHEN PURE, THIS ODORANT IS CONSIDERED TOXIC AND ADEQUATE MEASURES SHOULD BE TAKEN WHEN IT IS ADDED TO THE GAS STREAM. AT CONCENTRATIONS AND CONDITIONS WITHIN THE GAS NETWORK, THE TOXICITY LEVEL IS NOT REACHED, AND THEREFORE CONSIDERED SAFE.
4	GASODOR-S-FREE (37.4 PER CENT MA, 60.1 PER CENT EA, 2.5 PER CENT EMP)	WHEN PURE, THIS ODORANT IS CONSIDERED TOXIC AND ADEQUATE MEASURES SHOULD BE TAKEN WHEN IT IS ADDED TO THE GAS STREAM. AT CONCENTRATIONS AND CONDITIONS WITHIN THE GAS NETWORK, THE TOXICITY LEVEL IS NOT REACHED, AND THEREFORE CONSIDERED SAFE.
5	5-ETHYLIDENE-2-NORBORNENE	THIS ODORANT DOES NOT QUALIFY AS TOXIC.

Selecting candidate odorants for testing was carried out by forming a suite of criteria focusing on the characteristics of the odour, the physical and chemical properties of the odorant and its quality. The criteria were based on existing regulations likely to be applied to a hydrogen gas network.

In addition, commercial factors and end uses, such as testing the currently used UK natural gas odorant, and a chemically similar sulphur-free additive suitable for fuel-cells, were also considered in the candidate selection process.

In terms of odour characteristics, a suitable odorant should have a strong odour at very low concentrations. Under gas mains conditions, the odour should be unpleasant and distinctive enough as to not be confused with other common odours (such as sewers).

The physical properties of the odorant should be such that it remains homogenous within the hydrogen gas, both during transport inside the pipes but also during storage. In practice, this would mean that the odorant should not condense under typical transport or storage conditions.

Similar odour tone tests are performed in the wine, whisky and perfume industries. The test resulted in all the selected odorants having a suitable strength and odour intensity to be easily detected

The odorant should not leave significant residues after evaporation or combustion. The chemical properties of the odorant are also important. The odorant should be at least 95 per cent pure, to prevent contamination of the gas supply with impurities which could clog boiler burners for example.

The odorant also must remain stable within the low pressure transport distribution system to the end user. Typically, gas will retain an odour, within an acceptable range, for up to eight hours following cessation of odorant injection.

The final gas quality after the addition of the odorant should follow applicable standards. Although adjustments are still needed for hydrogen networks, the British Standard ISO 14687-1 from 1999 offers an indication of the gas quality required for boilers and cookers.

The ISO 14687-2 and ISO 14687-3 offer guidance as to the gas quality required for vehicle and fixed fuel cells. The main constraint here being a low level of sulphur compounds of less than 0.004µmol/mol.

Overall, thirteen odorants were considered following a review of the

existing literature, including international standards, peer-reviewed publications and patents. The ones selected for further investigation, along with the rationale for their selection, are indicated in Table 1. Among the shortlisted odorants which passed the screening criteria, the current odorant used by SGN and other UK gas distribution networks was shortlisted for further testing. This should help reduce costs and maintain the same odour as methane gas if the odorant is found to be suitable for domestic use in cookers and boilers.

To ensure the selected odorants are safe to use, a risk assessment was performed. Its findings are reported in Table 2. All the selected odorants presented an acceptably low level of risk for humans and the environment at the recommended concentrations for hydrogen distribution. Two of those odorants, THT[7] and GASODOR-S-FREE[8, 9, 10], were found to require safety measures when handled as pure undiluted substances. However, dilution measures can be easily implemented to reduce the risk to an acceptable level. The risk from those substances to the environment and people can be managed using standard industry practices.

Following on from the risk assessment, a set of olfactory tests[11] were performed using human volunteers to determine the suitability of odorants in terms of their odour characteristics. These tests determined the threshold concentration at which the odour becomes detectable and the odour intensity profile, which is how strong the odour is perceived for different concentrations over and above the threshold value. A hedonic tone testing was also performed to identify the pleasantness of the odour, as well as its characteristics (what does it smell like).

The testing was carried out in accordance with BS EN 13725:2003 at an Air Spectrum laboratory accredited by the United Kingdom Accreditation Service (UKAS). Samples of odorised gas were presented to a panel of experts to assess the pleasantness of the experience and identify what the odour reminds them of.

Similar odour tone tests are performed in the wine, whisky and perfume industries. The test resulted in all the selected odorants having a suitable strength and odour intensity to be easily detected.

However, the 5-ethylidene-norbornene odorant, which is most suitable for fuel cells, failed to obtain an 'unpleasant' rating and so is less-preferred. The GASODOR-S-FREE sulphur free odorant used in Germany, however, has an unpleasant odour and could hence prove an attractive option as it is compatible with fuel cells.

This however highlights the need for further investigations into odorants compatible with hydrogen fuel cells as they are currently limited. Alternative methods may need to be investigated, such as the removal of the odorant from the hydrogen before it is fed into the fuel cell.

These promising results indicate that current odorants used in the natural gas networks do have suitable characteristics to be applied to a 100 per cent hydrogen gas distribution network. Physical and chemical tests are currently underway to investigate the other key aspects of odorant selection (e.g., whether the gas will retain an odour, within an acceptable range, for up to eight hours following cessation of odorant injection).

In addition, testing to investigate fuel cell degradation and pipeline and boiler corrosion will also be undertaken. It is essential that fuel cells can be operated using gas distributed from the network. To this end, even if Odorant NB was chosen to ensure consistency with the current natural gas supply, sulphur scrubbers could be installed immediately upstream of fuel cells, rather like domestic water filters. At present, it looks like hydrogen could find a scent suitable for its ascent.

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PIPELINES FOR A HYDROGEN FUTURE

Andrew Stevenson, **Doug Everard** and **Mebs Bobat**, of Sustainable Pipeline Systems, discuss the latest hydrogen-compliant automated pipeline systems with built-in digital pipeline integrity technology

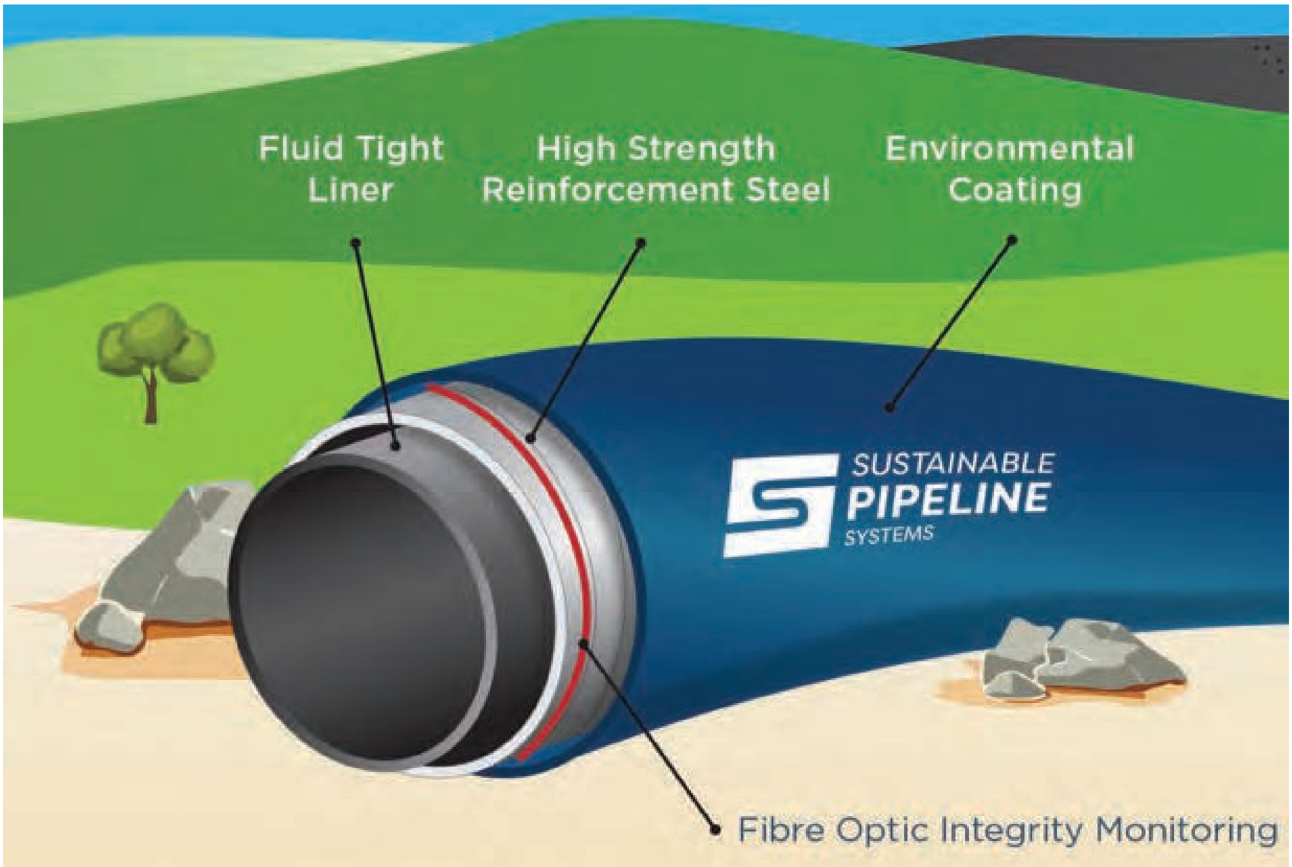
There is growing interest in the introduction of hydrogen into gas grids for energy transmission and distribution in the UK and elsewhere. It is important to be able to transport hydrogen at high pressure as part of the energy infrastructure. A new automated pipeline system is being developed, one that is intrinsically hydrogen-compliant as well as having several other benefits for rapid low-cost pipeline construction.

The key benefits include reduced time schedule, total installed cost and carbon footprint, plus enhanced flexibility with in-built digital integrity monitoring, enabling proactive inspection and maintenance.

The Mobile Automated Spiral Interlocking Pipe (MASiP) incorporates spiral wound optical fibre to provide an enhanced level of real-time information about stress-strain patterns in the pipe, together with pipeline integrity issues as a result of internal and external inputs. The pipe structure consists of a polymer liner and reinforcing layers of high strength steel strip with a patented interlock. The whole pipe is then coated for environmental protection. This type of pipe structure is inherently more flexible and more responsive than conventional steel pipe structures.

The system is designed to be manufactured in the field with advanced quality control systems ensuring good information about the initial status of the pipe. Twelve inch (300mm) diameter pipe has been fabricated and tested at pressures up to 100barg with water media and with hydrogen-rich natural gas mixtures. Pressure fluctuations in

FIGURE 1 SCHEMATIC SHOWING THE STRUCTURE OF MASIP WITH LOCATION OF OPTICAL FIBRE WITHIN THE PIPE WALL



the range of 30 to 40barg have been used to calibrate the system.

Outputs from the spiral wound optical fibre windings have been analysed using distributed acoustic sensor (DAS) electronics. These outputs enable a healthy pipe pattern to be characterised to a resolution of about six inches along the pipeline length and then continuously monitored. The methodology under development aims to go beyond leak detection and use the information within a comprehensive life prediction methodology.

MASiP is designed to be a sustainable pipeline system with an intrinsically digital infrastructure for pipeline integrity management. Durability trials in a hydrogen-rich gas mix have now been completed successfully alongside standard X52 pipe, with sponsorship from National Grid

HYDROGEN COMPLIANT STRUCTURE

The MASiP system consists of four layers. The innermost layer is a liner pipe – usually a polymer, usually HDPE to – provide fluid tightness and chemical resistance to the fluid transported by the pipe.

Unlike carbon steel, where there are some published effects of hydrogen accelerating weld fatigue life, hydrogen has no effect on polymers such as HDPE or PVDF.

The next layer is the reinforcement layer, which provides mechanical pressure containment and consists of a high strength steel strip incorporating a patented interlocking rib. Hydrogen can only reach the reinforcement layer by permeation through the polymer liner and so will be at low pressure and low concentration. The reinforcement structure also provides a venting mechanism.

The next layer is a distributed sensing layer consisting of optical fibre bundles. The function of this layer is to respond to the state of the reinforcement layer of the pipe.

The outer layer is an environmental protection layer; a two-part system, one to adhere to the reinforcement surface and encapsulate the fibre optic cables, and the other to provide outer resistance to moisture and minor mechanical impacts such as scuffs, etc.

MOBILE MANUFACTURING SYSTEM

MASiP is a holistic approach to new pipeline installation and includes fabrication of pipe in-field using mobile automated equipment.

Effectively, raw materials are delivered to the site and mobile automated equipment modules move along the right of way, fabricating and installing pipe continuously, directly into a trench or onto supports. This includes automated quality control systems to measure and record every inch of pipe key parameters as laid with 100 per cent traceability. Optical fibre is installed automatically as part of the pipe fabrication process.

With this approach it is no longer necessary to manufacture pipe in a dedicated steel mill or to manually weld pipe sections on site, etc. Compared to conventional construction methods, pipe stringing, lifting and lowering are also eliminated. The need for large amounts of semi-skilled labour in locations is eliminated with reduced risk of HSE incidents.

FIGURE 2 MOBILE PIPE FABRICATION AT THE FIELD TRIAL SITE

FIGURE 3 FLOW LOOP TRIAL IN HYDROGEN-RICH GAS MIX AT DNV GL SPADEADAM

HYDROGEN DURABILITY TRIALS

A gas mix including 30 per cent hydrogen and 70 per cent methane has been used in a flow loop setup at DNV GL Spadeadam, with pressure cycling over an eight-month period designed to simulate the operational gas pressures of National Grid Gas Transmission in the UK. This programme is ongoing but has so far been successful in proving hydrogen durability alongside standard X52 pipe.

ADVANTAGES OF SPIRAL WOUND OPTICAL FIBRE

Optical fibre systems are a powerful source of accurate data, but generally the fibre is laid in a straight line in a separate trench next to the pipeline. The advantages of spirally winding the fibre around the pipe are that the 360° data collection offers a complete view of the whole pipe and the intimate contact enhances the data that can be collected. Additionally, the optical fibre can be incorporated into the structure of the pipe at fabrication and the two-layer environmental coating provides protection to the fibre.

Tests were carried out using test pipe sections with strain gauges to calibrate the stress/strain outputs from the fibre optic system.

The physical tests consisted of applying a series of pressure cycles to 12-inch diameter MASiP test pipe.

When there is a pressure cycle, there is a clear change on the pattern of hoop and axial stress/strain distributions, which allow a healthy pipe profile to be recorded and used as a benchmark for data analysis.

The optical fibre cable provides complete connectivity along the pipe. Data gathering and pre-processing was carried out using Optasense advanced system, which uses interference fringes created when light pulses are fired down the fibre to construct baseline data on hoop strain as well as temperature change and acoustic transients. This is an advanced system already in service with linear optic fibre systems.

It was found that there was a good correlation between the strain gauge outputs and the fibre optic outputs for stress strain along the pipe.

The ability of a closely wound optical fibre to generate a large amount of data and for this data to offer resolution to every six inches of pipe length in real time offers a ground-breaking approach to pipeline integrity management. Spare fibres in the cable allow dedicated fibres for specific parameters of interest and also for general communications. All these benefits in one fibre cable provide a real advantage over conventional systems.

FIGURE 4 TEST PIPE WITHOUT ENVIRONMENTAL OUTER LAYER SHOWING STRAIN GAUGES AND OPTICAL FIBRE CABLE

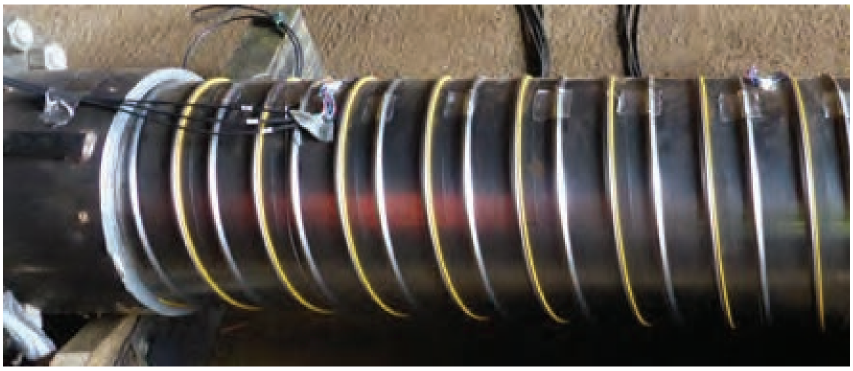


FIGURE 5 WATERFALL OUTPUT FROM CHANNELS ALONG THE TEST PIPE

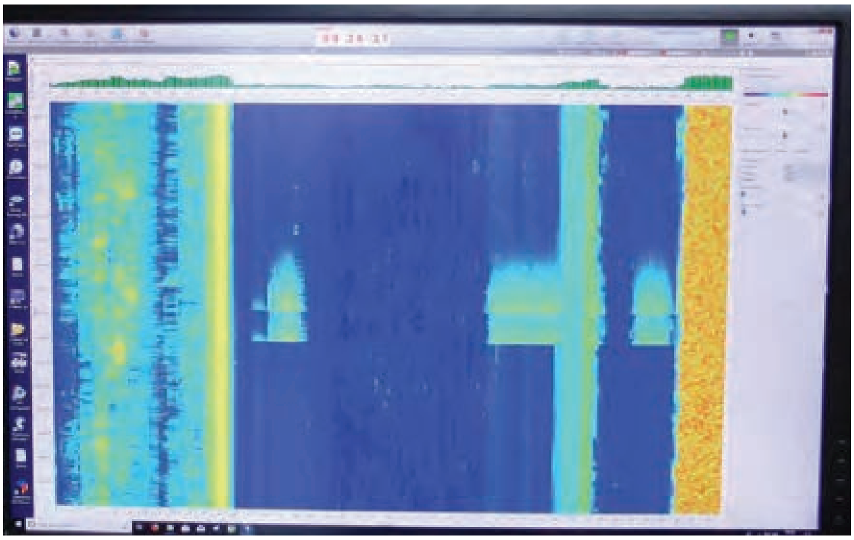
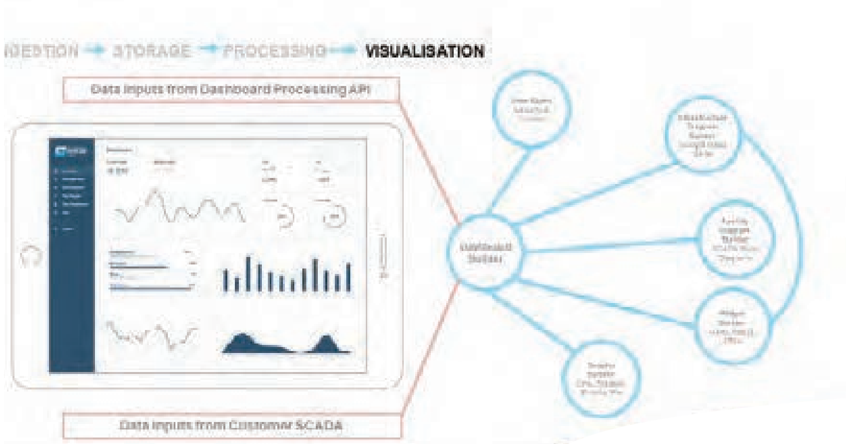


FIGURE 6 INDICATIVE FRONT END VISUALISATION



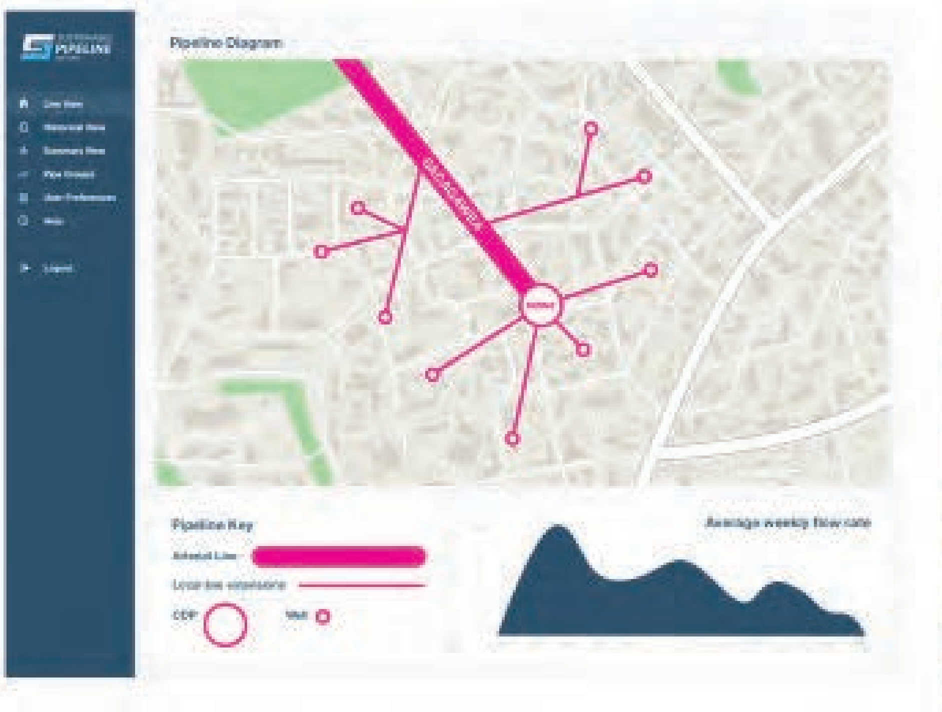
DATA MANAGEMENT

This system generates a huge amount of data on a daily basis so it is important to have an organised data management system.

The processing system comprises seven areas:

- DAS is the field equipment on the pipe referred to above
- Comms node passes pre-processed data onto the main computing system using spare fibres
- Data aggregator is the first level of processing at the main servers, formulating data for bulk storage
- Storage is a large volume data store for long term access to data
- Data analysis is where the main

FIGURE 7 **INDIVIDUAL PIPELINE INTEGRITY MAP**



processing is carried out
- Visualisation is the software module that provides screen views of insights needed by different users
- Identity management portal identifies the user and views that they need

Neural networks can be used and have advantages over the conventional type of statistical processing with such methods as linear regression. These can also be fed into a neural network system which, once trained, offers a more robust approach.

Visualisation dashboards can be configured to specific pipeline and operator needs so that the optimum insights are presented for the role of the viewer. This can also be integrated with other sources such as existing SCADA systems.

Individual pipelines can be portrayed, and sections colour coded with the risk level to aid appropriate planned responses.

LEAK PREVENTION STRATEGY

Our strategy for leak prevention is to first identify every potential failure mode of a pipeline and then develop the healthy pipe profile that would enable the early stages of any of these events to be monitored automatically before they reach the level at which failure would occur.

This is a well-established process for deep water production platforms in the North Sea and elsewhere and was successful in eliminating structural failure events that did occur prior to its introduction.

The real time monitoring parameters available from this system are:
- Pressure
- Temperature
- Stress/strain
- External vibrations (e.g., interference)
- Leak detection (internal and external)
- Location identification of issues

These monitoring parameters give rise to the following leak prevention benefits:
- Continuous prediction/updating based on algorithms of healthy pipe
- Proactive inspection and maintenance as required, rather than time-based as is done currently
- Analysis done by exception
- Fatigue life prediction in real time based on the above inputs

CONCLUSIONS

A new pipeline system has been developed and tested with hydrogen gas that incorporates spiral wound optical fibre as an intrinsic part of the pipe wall structure and offers several advantages to pipeline operators:
- Intrinsic compatibility with hydrogen gas at high pressures
- Real time digital integrity monitoring with an instant alert system against identified threats to reduce inspection costs
- Reduce risk of leakage with genuinely preventative and proactive approach
- Ability for pipeline engineers and operational managers to understand pipeline life expectancy at any given moment in time.
- Ease of using surplus fibres in the bundle for general purpose communications either at the outset or in the future
- Reduced risk of HSE incidents due to decrease in manpower requirements
- Automated construction process with 100 per cent traceability and automated quality control data collection
- Potential to halve the cost of pipeline construction
- Improved logistics for larger diameter pipelines above eight inch diameter
- A more flexible pipe structure better able to follow terrain without bend stations
- Reduced carbon footprint and reduced overall environmental impact

Sustainable Pipeline Systems (SPS) provides solutions for the mobile construction of onshore pipelines for oil gas, CO_2 and water. For more information visit www.sustainable-pipelines.com

ACKNOWLEDGEMENTS

SPS would like to acknowledge the contribution of National Grid Gas Transmission for sponsoring the hydrogen gas trials, Optasense Ltd for supplying the trial data analysis equipment, Dashboard for developing front end visualisation and DNV GL at Spadeadam for setting up and conducting the pipe and flow loop tests. SPS would also like to acknowledge funding from Research and Innovation UK.

THE EUROPEAN HYDROGEN STRATEGY

Dr F Maximilian Boemke and **Dr Christian Bauer**, partners at Watson Farley & Williams, discuss the EU's ambitions for hydrogen and some of the obstacles it may meet along the way

According to the European Union (EU), green hydrogen "is a key priority to achieve the European Green Deal and Europe's clean energy transition." It is seen as a technology which can bridge the gap between electricity production from renewable energy and the goal of decarbonising a large share of the EU's energy consumption by 2050. In order to set the path for how hydrogen can be used in this way, and to make a first step towards setting the regulatory framework for a European hydrogen market, on 8 July 2020 the EU issued its "hydrogen strategy for a climate-neutral Europe", known as the EU Hydrogen Strategy.

The aim of the EU Hydrogen Strategy is to decarbonise hydrogen production and expand its use in sectors where it can replace fossil fuels.

The EU Hydrogen Strategy focuses on hydrogen produced from renewable energy sources (so called "green hydrogen"). The EU Hydrogen Strategy provides the following definition of green hydrogen: "hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources. The full life-cycle greenhouse gas emissions of the production of renewable hydrogen are close to zero. Renewable hydrogen may also be produced through the reforming of biogas (instead of natural gas) or biochemical conversion of biomass, if in compliance with sustainability requirements."

Although the main focus lies on green hydrogen, the EU Hydrogen Strategy recognises the role of other low carbon hydrogen in the transition phase in the short to medium term.

FIRST HYDROGEN TRAIN IN HOLLAND

The path set by the EU Hydrogen Strategy is divided into three phases. Each phase sets a specific objective to be achieved within the relevant phase. The EU summarises the objectives for each phase as follows:

PHASE 1 (2020-24): The objective is to decarbonise existing hydrogen production for current uses such as the chemical sector and promote it for new applications. This phase relies on the installation of at least 6GW of renewable hydrogen electrolysers in the EU by 2024 and producing up to one million tonnes of renewable hydrogen. For comparison, only approximately 1GW of electrolysers have been installed in the EU at the time of writing this article.

PHASE 2 (2024-30): Hydrogen needs to become an intrinsic part of an integrated energy system with a strategic objective to install at least 40GW of renewable hydrogen electrolysers by 2030 and the production of up to 10 million tonnes of renewable hydrogen in the EU. Hydrogen use will then gradually expand into new sectors, including steelmaking, trucks, rail and some maritime transport applications. It will still mainly be produced close to the user or the renewable energy sources, in local ecosystems.

PHASE 2 (FROM 2030 ONWARDS AND TOWARDS 2050): Renewable hydrogen technologies should reach maturity and be deployed at large scale to reach all hard-to-decarbonise sectors where other alternatives might not be feasible or have higher costs.

"The EU Hydrogen Strategy highlights that support schemes are likely to be required for some time to enable renewable hydrogen to become cost-effective on the scale envisaged."

SCALE UP OF HYDROGEN CAPACITY

The most relevant goal of the EU Hydrogen Strategy is the build-up of additional hydrogen production capacity (i.e., building electrolysers). The EU Hydrogen Strategy provides targets of installing (i) in phase 1, at least 6GW of renewable hydrogen electrolysers in the EU by 2024 and (ii) in phase 2, 40GW of renewable hydrogen electrolysers in the EU, along with an additional 40GW electrolyser capacity target in the eastern and southern 'neighbourhoods' of Europe, e.g., Ukraine, as the priority partners for cross-border trade in hydrogen.

Considering the fact that current electrolyser production capacity in Europe is under 1GW per year, these goals have caused raised eyebrows throughout the EU. The Oxford Institute for Energy Studies (OEIS) comments: "Achieving 40GW by 2030 (even without the further 40GW to supply the EU from neighbouring countries) will require a very rapid scale-up in electrolyser production capacity and/or strong reliance on imported electrolysers, most likely from China."

The aim of the EU Hydrogen Strategy is to decarbonise hydrogen production and expand its use in sectors where it can replace fossil fuels

Naturally, such a massive and rapid scale-up will require considerable investment. Consequently, the EU Hydrogen Strategy foresees the establishment of a European Clean Hydrogen Alliance, with the key aim of identifying and building up a clear pipeline of viable investment projects by bringing together public and private stakeholders. Many EU financial instruments are also noted, in particular the EU ETS Innovation Fund, which will pool together around €10 billion to support low carbon technologies over the period 2020-2030 and, as part of the Commission's recovery plan, the Strategic European Investment Window of InvestEU.

While the EU Hydrogen Strategy is mostly and predominantly looking at green hydrogen, it also considers and acknowledges the usefulness of other forms of low carbon hydrogen (for example blue hydrogen). The report envisages a cumulative investment of €3-€18 billion for low carbon fossil-derived hydrogen compared with €180-€470 billion for renewable hydrogen (produced using mainly solar and wind).

SUPPORT SCHEMES

In addition to the European Clean Hydrogen Alliance, the EU Hydrogen Strategy highlights that support schemes are likely to be required for some time to enable renewable hydrogen to become cost effective on the scale envisaged.

In this regard, the EU Hydrogen Strategy envisaged an amendment of the EU Emissions Trading System (ETS). In the next revision of the ETS, the Commission may consider how to incentivise the production of renewable and low carbon hydrogen while considering the risk of carbon leakage. If differences in climate targets around the world continue, the Commission will propose a Carbon Border Adjustment Mechanism in 2021.

According to the EU Hydrogen Strategy, Carbon Contracts for Differences (CCfD) could be another valuable support mechanism. The strategy document envisages CCfDs where the public counterpart would remunerate the investor by paying the difference between the carbon strike price and the actual strike price in the ETS.

The OEIS comments on the introduction of a CCfD support scheme by stating that "the strategy does contemplate the use of Carbon Contracts for Differences (CCfDs), presumably awarded by auction to guarantee a carbon price to a project developer irrespective of the actual price of carbon prevailing under the ETS. CCfDs appear to be a very logical, market-based mechanism to promote decarbonisation in an economically efficient way. Given the significantly lower cost of blue hydrogen production today, it is to be expected that any auction for CCfDs would be won by blue hydrogen projects initially,

ENERGY COMMISSIONER KADRI SIMSON

EU COMMISSIONER FRANS TIMMERMANS

ZEPPELIN FLYING OVER LAKE CONSTANCE

with green hydrogen having to rely on more direct support schemes until costs have reduced sufficiently. Therefore, we envisage that successful implementation of the strategy will require several government-backed auctions, both (a) for CCfDs and (b) to promote green hydrogen projects specifically over the next 12 months".

Finally, the EU Hydrogen Strategy foresees (i) a common low carbon threshold/standard which would be defined relative to the existing ETS benchmark for hydrogen production and (ii) comprehensive terminology and certification for renewable and low carbon hydrogen; thus, introducing a certificate of origin for hydrogen and enabling trading of green hydrogen.

However, the EU Hydrogen Strategy does not introduce a new support scheme in the form of a feed-in tariff, which was criticised. The OEIS commented on the need for member states to arrange competitive tenders: "While the strategy document contemplates several possible support schemes, the detailed implementation plan is far from clear. If the 6GW target by 2024 is to have any hope of being achieved, several EU governments will need to arrange competitive tenders for such projects in the next 12 months. Such tenders would need to provide direct support to a renewable hydrogen project, either by underwriting the costs or by providing a bankable revenue stream to create a business case for a private investor". The latter is currently the most relevant issue for the EU Hydrogen Strategy.

WHAT DOES THIS MEAN FOR THE ENERGY SECTOR?

The increase in green hydrogen capacity will need to be matched by a similar scale-up in renewable energy deployment, which are likely to be large wind and solar plants. The strategy notes that from now until 2030 "€220-€340 billion would be required to scale up and directly connect 80-120GW of solar and wind energy production capacity to the electrolysers to provide the necessary electricity".

Wind and solar farm operators may therefore find potential for bankable business models through concluding long-term PPAs with the operators of hydrogen facilities. This model may be of particular relevance for facilities which are nearing the end of their feed-in tariff period and are looking for a business model following its expiry.

In Phase 2, the EU Hydrogen Strategy also sees hydrogen playing an increasing role as a form of energy storage to negate the intermittency of increasingly renewable systems. OEIS notes that while the strategy document mentions both daily and seasonal storage it does not recognise that "hydrogen's real advantage is over longer periods beyond the capability of batteries". This brings up new possibilities for project developers who could combine electrolysers and hydrogen storage facilities with large scale renewable energy plants. First project ideas pointing in this direction are already discussed in the market, which involve offshore wind farms, hydrogen plants at sea and loading facilities for tank ships (comparable to LNG offshore terminals). However, since for the time being batteries will be much easier to handle and install (hydrogen is still a highly flammable substance) it will take a while until hydrogen can play out its full advantage in terms of long-term energy storage.

The increase in green hydrogen capacity will need to be matched by a similar scale-up in renewable energy deployment, which are likely to be large wind and solar plants

But the impact of the EU Hydrogen Strategy goes beyond the renewables sector. In order to achieve a European market for hydrogen, energy infrastructure will become more and more important. In this regard, the EU Hydrogen Strategy contemplates hydrogen networks based on the conversion of existing natural gas pipelines combined with (relatively limited) newly-built hydrogen-dedicated infrastructure. For example, it expects that the hydrogen network in Germany and the Netherlands may consist of up to 90 per cent repurposed gas infrastructure. However, the EU Hydrogen Strategy is vague on how this European hydrogen grid will be regulated. OEIS comments: "the strategy appears to downplay some of the complexity of converting natural gas pipelines to hydrogen service, but it does recognise that significant investments will be required and that regulatory changes will be required to enable that" and also: "while not stated explicitly, the strategy appears to be supportive of the concept that in the longer term a pan-European hydrogen network will develop and co-exist with a methane network, which will increasingly carry bio- or synthetic methane".

SUMMARY

With the EU Hydrogen Strategy, the EU sets the framework for the development of the hydrogen sector into one of the backbones of the European energy industry. It will be interesting to see if and when the EU manages to transfer this strategy into directives and regulations. Nevertheless, a first step is made, hopefully others will follow soon.

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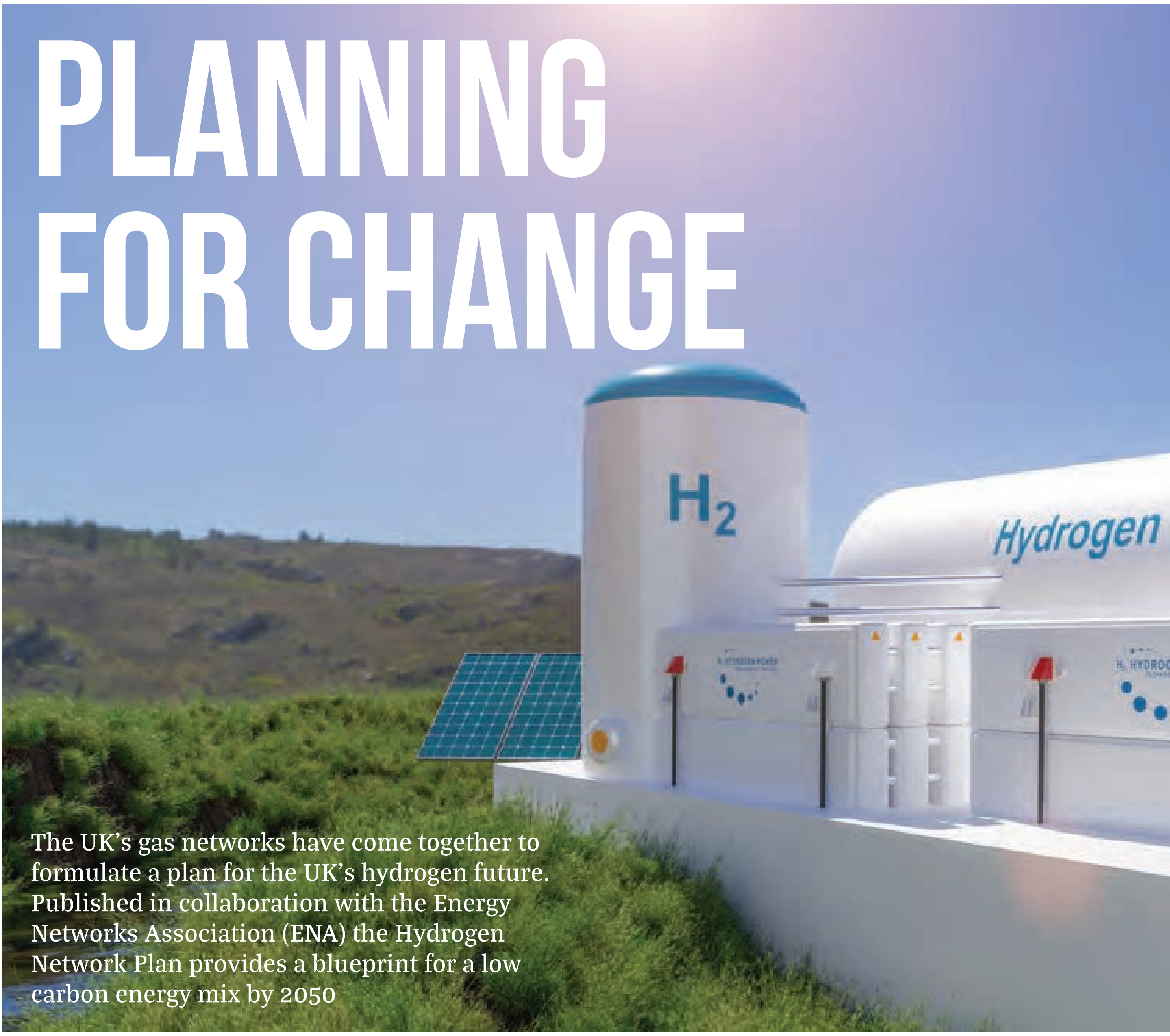
PLANNING FOR CHANGE



The UK's gas networks have come together to formulate a plan for the UK's hydrogen future. Published in collaboration with the Energy Networks Association (ENA) the Hydrogen Network Plan provides a blueprint for a low carbon energy mix by 2050

Published as part of Energy Networks Association's Gas Goes Green programme, Britain's Hydrogen Network Plan sets out the detail of the activity that all five of Britain's gas network companies (Cadent, National Grid, Northern Gas Networks, SGN & Wales & West Utilities) will undertake to turn Britain's hydrogen ambitions into reality, as set out in the Prime Minister's November 2020 10-point plan for a green industrial revolution.

This includes plans to deliver the UK's first hydrogen town by 2030, in a major new blueprint for building the UK's hydrogen economy.

Between them, the companies are responsible for owning and operating the pipelines and other infrastructure that currently deliver gas to 85 per cent of homes in Great Britain.

Britain's Hydrogen Network Plan also sets out the work gas network companies will undertake to meet the UK's other hydrogen objectives, including being ready by 2023 to blend up to 20 per cent hydrogen into local gas grids and to help the UK meet its hydrogen production target of 1GW by 2025 and 5GW by 2030.

It sets out how they will help deliver a network of refuelling facilities for zero emissions heavy good vehicles, and connect the renewables production, carbon capture and storage and hydrogen use for industrial SuperPlaces, helping deliver two clusters by the mid-2020s and two more by 2030.

Specifically, the plan provides explains how the companies, responsible for owning and operating £24 billion of energy infrastructure, will:

- Ensure the safe delivery of hydrogen through innovation projects. This includes work being undertaken by the Hy4Heat programme (led by BEIS), to test different household appliances such as boilers, heaters and cookers in variety of different settings, and the world-leading H21, H100 Fife and HyNTS Future Grid projects, which are testing different parts of the gas network.
- Maintain security of energy supply, to ensure gas networks have enough capacity to meet Britain's energy demands using hydrogen. This includes modelling how gas networks will behave, to ensure that capacity is put in place in the right places and how much hydrogen will be needed.

communities. And it's about ensuring that the economic benefits of hydrogen are spread around the country, to take advantage of the breadth and scale of that transformation.

"Britain's Hydrogen Network Plan sets out how our gas network companies will do all of that in the years ahead."

The detailed and practical plan sets out how Britain's gas networks will enable the decarbonisation of hard-to-reach sectors such as industry, heavy transport and domestic heating, integrating higher volumes of renewable electricity generation and saving an estimated 41 million tonnes of CO_2 a year – eliminating around 12 per cent of the UK's total CO_2 emissions as we move towards net zero.

It sets out the projects that gas networks will, with regulatory approval, carry out to enable 100 per cent hydrogen to be transported for use in different sectors, identifies the wider actions needed to provide sufficient hydrogen production and storage, and highlights the remaining policy gaps that need to be filled.

The detailed and practical plan sets out how Britain's gas networks will enable the decarbonisation of hard-to-reach sectors such as industry, heavy transport and domestic heating, integrating higher volumes of renewable electricity generation and saving an estimated 41 million tonnes of CO_2 a year – eliminating around 12 per cent of the UK's total CO_2 emissions as we move towards net zero

Projects such as Project Cavendish, on the Isle of Grain, will pioneer the connection of hydrogen production facilities to Britain's gas networks.

- Work with people's needs, to help reduce carbon emissions while ensuring that people and businesses have a choice of different low carbon technologies – in homes, offices and factories, as well as on the roads. This includes delivering hydrogen neighbourhood trials of different domestic appliances, through the world-leading H100 Fife project and hydrogen village trials through the HyNet Homes project. The Future Billing Methodology and Real-Time Networks projects will help ensure consumers continue to receive accurate gas bills, as more hydrogen is introduced to the gas grid.
- Deliver jobs and investment, including through the replacement of old iron mains gas pipes around the country with new, hydrogen-ready pipes instead. By 2032, the companies are planning to have invested £28 billion in doing so, in projects around the country. The plan shows that gas network companies are playing a role in delivering £1.5 billion of funding in industrial decarbonisation projects around the country.

Commenting on the plan, Chris Train, ENA's Gas Goes Green champion, said: "Building the UK's first hydrogen town is not just about replacing the natural gas that most of our homes rely on today; it's about reducing our carbon emissions in a safe and secure way. It's about delivering meaningful choice for households, businesses and

A TRANSITION FOR A POST-COVID UK

Conversion of much of the overall gas network is the best way to allow hydrogen to reach all the users who will need it. A full role for hydrogen in decarbonisation is estimated to create 195,000 jobs overall, of which 75,000 jobs and £18 billion of economic value added would be created by 2035, supporting the UK's post-Covid recovery.

The plan meets the need for hydrogen set out in ENA's previous *Pathways to Net Zero* report. It has been developed following extensive stakeholder consultation, including workshops and interviews, to understand the key barriers and opportunities for different sectors, and the role for gas networks.

The task is major, but achievable. But there is no time to waste – ambition must be turned into action at all levels.

The Hydrogen Network Plan will be delivered in four broad stages:

- Over the next five years, the gas networks will be preparing for transition, including continuing the Iron Mains Risk Reduction Programme, completing the safety case, trialling 100 per cent hydrogen in homes, and carrying out network modelling to ensure that security of supply can be maintained. This first stage will give government the information required to make policy decisions on the conversion of networks.
- From 2025-30, networks will be carrying out solution pilots, including larger 100 per cent hydrogen domestic pilots, 20 per cent blending in parts of the network, and billing based on energy content rather than volume. The iron mains replacement programme will also continue.
- In the 2030s, they will scale up, building new hydrogen pipelines between industrial clusters and connecting with storage facilities; connecting hydrogen production to the networks; and, with the iron mains replacement programme completed, rolling out 100 per cent hydrogen conversion for use in homes, dispersed industry and transport.
- In the 2040s, the full transition will occur, with a national hydrogen network in place and hydrogen a normal part of training for Gas Safe engineers.

THE FOUR TENETS

To deliver a 100 per cent hydrogen network, the plan has four key tenets:

1.Ensuring people's safety: Working closely with the Health & Safety Executive, UK innovation projects are making great progress and results have shown that using hydrogen in the natural gas grid is fundamentally safe. Current safety work is developing the right technology and procedures across the GB system, including: end-user appliances, such as domestic boilers and industrial burners, the low-pressure distribution network, and the high-pressure transmission network.

2. Maintaining security of supply: The networks will deliver a hydrogen system that meets the same high levels of supply security as today, with very rare unplanned interruptions. This means ensuring: sufficient physical network capacity and resilience to meet demand peaks; effective system

operation; linkages to sufficient hydrogen production and storage capacity; and flexibility to connect new sources at more entry points.

3. Focusing on people's needs: The hydrogen network will have a strong customer focus, supporting consumers to decarbonise in a convenient and cost-effective way, including through interim steps to enable rapid decarbonisation. This covers: domestic convenience and utility; transport sector convenience and utility; industrial sector convenience and utility; interim steps to reduce emissions rapidly and early, including blending and hybrid heating systems; and energy-content billing.

4. Delivering jobs and investment: The UK's gas networks will deliver the supply chain to construct and convert the network needed to allow 100 per cent hydrogen to be introduced on time, which includes: equipment, including appliances and long-lead items, and skilled people.

The plan sets out to achieve the hydrogen transformation of the network according to these principles, with the networks having projects planned and underway across the country to deliver this.

WIDER ACTIONS NEEDED

Alongside the preparation of gas networks for hydrogen conversion, a set of wider actions are needed for hydrogen to be adopted at scale. These are outside of the networks' control, although projects are being supported by the gas network operators. Building on the ten-point plan, the government's Hydrogen Strategy needs to support work in several areas to enable Britain's hydrogen network. The key areas include: hydrogen production, hydrogen storage and ensuring that CCS is developed at scale in several clusters by 2030.

Policy actions needed to deliver this plan

Policy support and decisions from government are required for hydrogen development in all sectors. Significant progress is being made, including ongoing work to develop business models for low carbon hydrogen production, but there are several gaps in policy. These gaps need to be addressed in the forthcoming Hydrogen Strategy to deliver on the commitments made in the ten-point plan and to deliver the Hydrogen Network Plan.

These include:

- **Hydrogen-ready appliances:** There is no timetable for mandating hydrogen-ready appliances, which are necessary to facilitate a network conversion. The earlier hydrogen-ready appliances are rolled out, the smoother the conversion will be. A mandate needs to be in force by no later than 2025, which would mean that most homes would have hydrogen-ready appliances by 2040.
- **Hybrids:** Hybrid heating systems should be supported now, for roll-out at scale.
- **Hydrogen production volumes:** The main risk is that insufficient volumes of hydrogen production are supported. GW-scale production capacity needs to be added each year, and business models need to support this scale. While the ten-point plan targets 5GW of low carbon hydrogen production capacity by 2030, this needs to be increased to 10GW to enable this plan.
- **Storage and conversion support:** There are no business models for hydrogen storage or for network conversion, both of which could be funded through the regulated asset base (RAB) framework. A RAB for hydrogen storage should be in place from 2025, and for domestic conversion from 2030.
- **Flexibility:** The RIIO2 framework needs to be managed in a sufficiently supportive and flexible way to enable the range of innovation projects and trials to be carried out in a timely way.
- **Planning:** The planning system will need to be able to accommodate a large volume of applications for hydrogen production, storage, pipeline and other facilities. It is not clear whether the planning system will be able to manage this in a timely manner. Planning applications should be prioritised and decisions expedited.
- **Delivery:** Delivering the Hydrogen Network Plan requires action on the part of networks, government, regulators and others over the coming years.

Published as part of Energy Networks Association's Gas Goes Green programme, Britain's the full Hydrogen Network Plan can be found at www.energynetworks.org

THE RACE TOWARDS A LIGHTER-THAN-AIR ECONOMY

A new report from Edison's **Anne Margaret Crow**, Director of TMT/ Industrials and **Dan Gardiner**, Director of Energy & Resource, examines some of the prerequisites for the development of a thriving hydrogen economy in Europe and globally

Climate change remains at the top of the global political agenda. However, the net zero targets committed to by numerous governments cannot be achieved without the use of renewable hydrogen. This is because while cheap renewable power combined with battery storage looks set to address sections of the transport and power sectors, important gaps remain that hydrogen is well suited to fill.

Sectors ripe for hydrogen decarbonisation

Hard to reach sectors such as steelmaking, residential and commercial heating, long-distance road freight, shipping and aviation, have no obvious, low-cost, convenient alternatives to fossil fuels, and collectively account for approximately 34 per cent of global energy consumption. Hydrogen's high energy-to-mass ratio and low losses during storage and transportation make it an ideal fit across these sectors. There is also scope for fuels cells to be used in off-grid generation, distributed generation, and back-up power. However, an understanding of the key market dynamics is critical for those wishing to invest in the sector.

The tech behind green hydrogen

The key technology underpinning the transition is the fuel cell, which generates electricity from hydrogen. Working in reverse, electrolysers use electricity to generate hydrogen from water. Currently, 99 per cent of the hydrogen produced globally is done so through techniques based on fossil fuels, so the widespread deployment of electrolysers running off surplus wind and solar power is needed to ensure enough 'green' or renewable hydrogen.

Costs for renewable hydrogen are going down quickly. Electrolyser costs have reduced by 60 per cent in the last ten years. For regions where renewable electricity is cheap, electrolysers are expected to be able to compete with fossil-based hydrogen by 2030.

Enabling the transition – pushing down costs of fuel cells and renewable hydrogen

At present, neither renewable hydrogen nor fossil-based hydrogen with carbon capture are cost-competitive with fossil-based hydrogen. However, costs for renewable hydrogen are going down quickly. Electrolyser costs have reduced by 60 per cent in the last ten years. For regions where renewable electricity is cheap, electrolysers are expected to be able to compete with fossil-based hydrogen by 2030. The cost of fuel cells is also expected to fall.

Virtuous circle required – government funding and regulatory frameworks are key

These cost reductions are predicated on the creation of a virtuous circle that drives hydrogen adoption and triggers the economies of scale required. This requires government investment in infrastructure, R&D, as well as an enabling regulatory framework. Although it is impossible to say how successful investment and policy initiatives will be, the level of support is likely to be the major determinant of how rapidly the market grows.

The hydrogen economy – decarbonising the final 20 per cent

At least 20 countries, collectively representing around 70 per cent of global GDP, are proposing hydrogen strategies or roadmaps as key elements of their decarbonisation plans. We have identified the sectors where we see the biggest opportunities for hydrogen: industrial processes, heating, fuel cell buses and trucks (not passenger cars), grid and back-up power generation in areas with strict restrictions on emissions and materials-handling equipment.

HYDROGEN ESSENTIAL TO ACHIEVING 'NET ZERO' TARGETS

Net zero targets cannot be achieved, in our view, without green hydrogen. Recently published forecasts from the EU, the Hydrogen Council and Bloomberg New Energy Finance (BNEF) suggest hydrogen could grow significantly by 2050.

Decarbonising the hard-to-reach sectors

Hydrogen is critical for replacing coal and gas in fossil-fuel intensive industrial processes such as steelmaking. By storing the excess energy generated by renewables until it is needed, hydrogen can help address intermittency in the power sector and provide a potential path for decarbonising heating. Hydrogen's high energy-to-mass ratio makes it particularly suitable for heavy-duty, long-distance road freight, maritime and aviation applications.

Adoption still dependent on government initiatives

Investment in hydrogen technology and capacity has accelerated in the last year, analysts have lifted long-term forecasts and share prices have soared. Yet hydrogen has a long history of not delivering on its potential. Historically, its role has been limited by high production costs and the need for new and adapted infrastructure to support distribution and storage. Falling renewable costs are addressing the price premium for green hydrogen, but governments will also need to provide investment and implement policies that explicitly encourage hydrogen adoption and deliver the scale required to drive down costs.

Converting ambition into reality: Policy and economics

The EU's recently published report, *A hydrogen strategy for a climate-neutral Europe*, suggested hydrogen's share of Europe's energy mix could grow from two per cent in 2018 to 13–14 per cent by 2050. The Hydrogen Council (a global CEO-led initiative of over 90 leading energy, transport, industry and investment companies) thinks it could reach 18 per cent by 2050, BNEF predicts 24 per cent globally. Estimates vary but it is difficult to imagine net zero being achieved without significant growth in hydrogen, in our view.

To meet these ambitious environmental targets, governments will need to put supportive policies in place. Scale, as the experience of falling renewable energy and battery prices highlights, is the key to sustained falls in production costs. Yet it is difficult to justify the investment in either the R&D or capacity needed to scale-up hydrogen production without greater visibility of demand.

Widespread adoption of hydrogen will require co-ordinated investment across the energy industry in new or adapted infrastructure. To reduce the need for additional infrastructure and improve the economics, industrial sectors such as steelmaking, chemicals, oil and gas should look to collaborate and co-locate in hubs. Governments will need to play a role in facilitating this co-ordination and establishing sufficient demand certainty in the initial development phase.

HYDROGEN PRODUCTION AND DISTRIBUTION

The infrastructure needed to create, store and distribute hydrogen is also essential for the development of the market. In the initial phase of the EU's roadmap, hydrogen will be generated close to where it is used by multiple clients on industrial parks or hubs. Such clusters are already forming, for example in Fukushima in Japan, Ulsan in South Korea, San Pedro Bay Ports in California, Pilbara in Western Australia and Hebei, Hunan and Shandong in China.

Ports around the North Sea appear particularly active with projects such as Humber Zero and the Tees Valley in the UK and H-Vision Rotterdam and NortH2 in the Netherlands. These sites could potentially expand to form hubs where electricity from wind farms in the North Sea could generate hydrogen to use in local petrochemical and steel industries.

The IEA estimates that North Sea generation capacity is expected to exceed 50GW by 2030, roughly two-thirds the current total electricity generation capacity in the UK. Beyond these hubs, the economics of hydrogen distribution get more challenging. Hydrogen flows faster than natural gas, making it potentially suitable for distribution through pipelines, but its smaller molecules make it much leakier. Upgrades to pipeline networks will be needed.

The European Hydrogen Backbone Report, published in July 2020, estimates a total investment of €27–64 billion would be required by 2040 to create a 23,000km-long network across western Europe. Three-quarters of this network

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would use existing natural gas pipelines that have been converted to transporting hydrogen, the remainder would require new stretches of pipeline.

The report estimates that this if this network was created, transport of hydrogen would account for only a small part of total hydrogen costs for end users with an estimated levelised cost of between €0.09-0.17 per kg of hydrogen per $1000km^2$ compared with future production costs of €1-2/kg for green and blue hydrogen.

The report notes that the capital cost of a newly-built dedicated hydrogen pipeline is likely to be 10-50 per cent more expensive than its natural gas counterparts and that existing natural gas pipelines need relatively little modification to transport pure hydrogen, such that the capital cost of repurposing existing pipelines is likely to be 10-25 that of building new dedicated hydrogen pipelines. Hydrogen's low density also makes it expensive to store. BNEF estimates that for hydrogen to displace natural gas entirely would require three to four times the existing storage infrastructure at a cost of over $600 billion. While hydrogen can be compressed, the costs of this can exceed production costs and the availability of geological storage options such as salt caverns, which are cheaper, is limited by geography.

HYDROGEN'S PLACE IN THE MARKET

The EU hydrogen roadmap sets out how it intends to stimulate the market. It estimates that between 2020 and 2030 investment in electrolysers could range from €24 billion to €42 billion and investments of up to €65 billion will be needed for hydrogen transport, distribution and storage and hydrogen refuelling stations.

The report also calls for an enabling regulatory framework (requiring legislation at both a national and European level) plus sustained research into breakthrough technologies and a large-scale infrastructure network. It envisages establishing a series of hydrogen clusters that will become increasingly interconnected.

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The immediate (Phase 1, 2020-2024) focus of legislation will be technology funding. This will be provided through bodies such as the InvestEU programme and the ETS Innovation Fund and will be directed by bodies such as the European Clean Hydrogen Alliance which includes companies 2G Energy, Ballard, ENGIE EPS, FuelCell Energy, McPhy, Nel Hydrogen, PowerCell and Proton Motor Fuel Cell. The subsequent focus will be the creation of a framework for an open and competitive hydrogen market.

Other governments have also announced their own hydrogen roadmaps. For South Korea, the environmental advantages of hydrogen are complemented by a desire for energy security and support for its export economy. The government is heavily subsidising fuel cell deployment to reach its target of obtaining 11 per cent of the nation's primary energy from 'new' (which includes fuel cells) and renewable sources by 2035.

It hopes this investment will also create a national fuel cell industry worth US$98 billion, employ 175,000 people by 2040 and support Hyundai, which launched its first fuel cell car last year. In the US, while the Trump administration was overtly hostile to investment in green energy and US government-backed R&D funding of hydrogen has halved in the last decade, individual states, primarily California, have adopted more favourable policies and President Biden has a much more positive stance on renewable energy. The UK has yet to announce a co-ordinated plan for hydrogen but is supporting investment in the technology. Construction of ITM Power's 1GW recently completed electrolyser factory, which is the world's largest, was partially funded by grants from the EU and InnovateUK.

Edison is an investment research, investor relations and consulting firm, with offices in North America, Europe, the Middle East and Asia Pacific. The full report, Hydrogen - rising fast in the global energy mix can be found at www.edisongroup.com

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