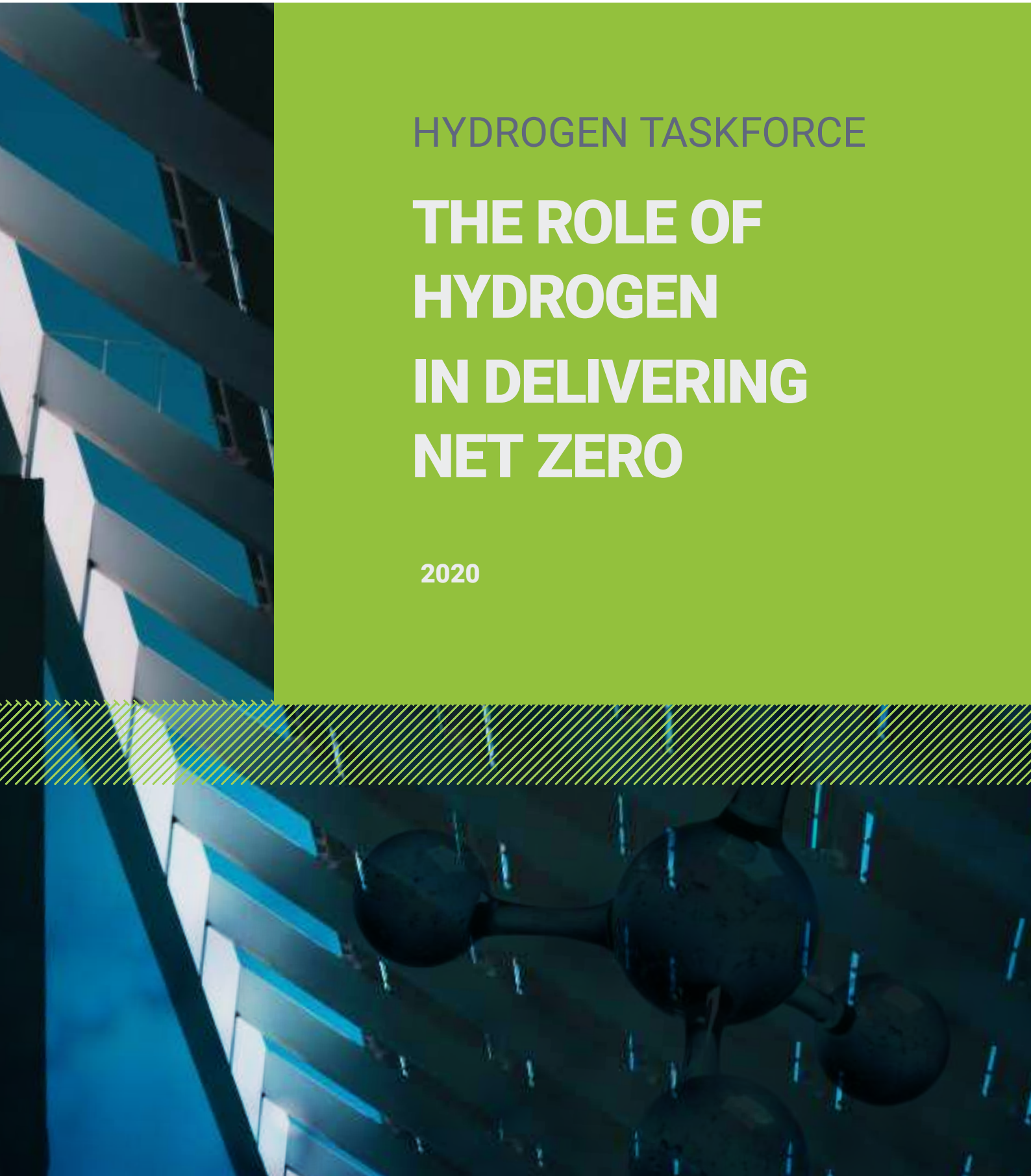

HYDROGEN TASKFORCE

THE ROLE OF HYDROGEN IN DELIVERING NET ZERO

2020

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Executive Summary

Hydrogen is essential to the UK meeting its net zero emissions target. We must act now to scale hydrogen solutions and achieve cost effective deep decarbonisation. With the support of Government, UK industry is ready to deliver.

The potential to deploy hydrogen at scale as an energy vector has risen rapidly in the political and industrial consciousness in recent years as the benefits and opportunities have become better understood. Early stage projects across the globe have demonstrated the potential of hydrogen to deliver deep decarbonisation, reduce the cost of renewable power and balance energy supply and demand. Governments and major industrial and commercial organisations across the world have set out their ambition to deploy hydrogen technologies at scale. This has created a growing confidence that hydrogen will present both a viable decarbonisation pathway and a global market opportunity. Hydrogen will have an important role to play in meeting the global climate goals set out in the Paris Climate Agreement and due to be discussed later this year at COP26.

The UK's commitment to a net zero greenhouse gas emissions target has sharpened the conversation around hydrogen. Most experts agree that net zero by 2050 cannot be achieved through electrification alone and as such, there is a need for a clean molecule to complement the electron. Hydrogen has properties which lend themselves to the decarbonisation of parts of the energy system which are less well suited to electrification such as industrial processes, heating and heavy and highly utilised vehicles. Hydrogen solutions can be scaled, meaning that the contribution of hydrogen to meeting net zero could be substantial.

A steady start has been made to exploring the hydrogen opportunity. Partnerships between policymakers and industry exist on several projects which are spread out right across the country, from London to many industrial areas in the north east and north west. Existing projects include the early stage roll out of transport infrastructure and vehicles, feasibility studies focused on large scale hydrogen production technologies, projects exploring the decarbonisation of the gas grid and the development of hydrogen appliances.

The Government recently announced new funding for hydrogen through the Hydrogen Supply Programme and Industrial Fuel Switching Competition. These programmes are excellent examples of collaboration between Government and industry in driving UK leadership in hydrogen and developing solutions that will be critical for meeting net zero.

If the UK is going to meet net zero and capitalise on the economic growth opportunities presented by domestic and global markets for hydrogen solutions and expertise, it is critical that the 2020s deliver a step change in hydrogen activity, building on the unique strengths and expertise developed during early stage technology development.

The Hydrogen Taskforce brings together leading companies pushing hydrogen into the mainstream in the UK to offer a shared view of the opportunity and a collective position on the next steps that must be taken to ensure that the UK capitalises on this opportunity. There are questions to be answered and challenges that must be overcome as hydrogen technologies develop, yet by focusing on what can be done today, the benefits of hydrogen can be immediately realised whilst industry expertise and knowledge is built.

Industry and Government have important roles and must work in partnership to ensure that hydrogen technologies are sufficiently developed and deployed to meet the challenge presented by net zero. This will ensure the UK is positioned to capitalise on the global opportunity presented by hydrogen.

The Hydrogen Taskforce proposes that industry and Government come together on the following activities over the current parliament to enable hydrogen to scale and be deployed on a commercial basis moving forwards:

DEVELOPMENT OF A CROSS-DEPARTMENTAL UK HYDROGEN STRATEGY

The Prime Minister has recognised a need for cross departmental working on climate issues through the formation of the Cabinet Committee on Climate Change. Hydrogen is an energy carrier that has a role to play across the energy system. Its application sits across sectors whose remit lies with multiple different Government departments including Business, Energy and Industrial Strategy (BEIS), Department for Transport (DfT), Ministry for Housing, Communities and Local Government (MHCLG), Department for Environment, Food and Rural Affairs (DEFRA) and HM Treasury. This has contributed to a more fragmented approach to policy and regulatory development for hydrogen. Given hydrogen's cross sector application, there is value in a more joined up approach, which would ensure that hydrogen's role in the future energy system emerges in a strategically coordinated manner.

Many other economies have recognised the value in cross departmental coordination and the development of a Hydrogen Strategy or Hydrogen Roadmap including Japan, Germany, Korea and China. 2019 has seen the publication of many of these strategies, which have been developed with strong input from industry. These strategy documents give industry and the investment community confidence in the ambition and commitment of countries to hydrogen and allows them to invest. In the global race to emerge as a leading nation in the development of hydrogen technologies, a UK Hydrogen Strategy is a glaring omission.

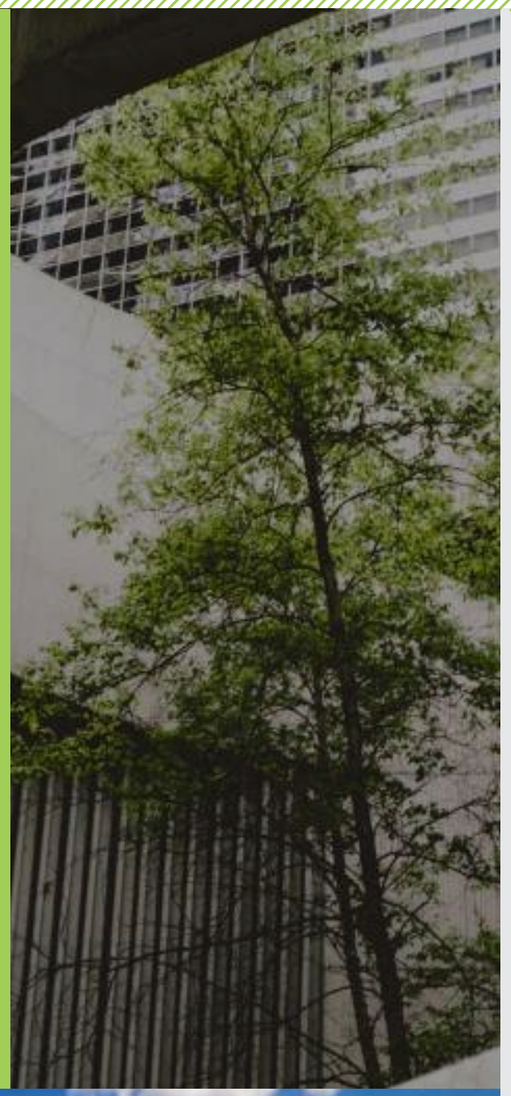
The Taskforce is committed to supporting the Government to develop this strategy over 2020. This strategy should address the role of hydrogen across the energy system and the steps that must be taken to unlock the benefits of the energy carrier. The Taskforce suggests that this strategy includes policies that will enable hydrogen to scale up over the next decade. These could include the following policies:

COMMITMENT BY GOVERNMENT OF £1BN OVER THE NEXT SPENDING REVIEW PERIOD TO HYDROGEN PRODUCTION, STORAGE AND DISTRIBUTION PROJECTS

The UK Government has recognised that developing low cost bulk hydrogen production, storage and distribution solutions will be essential to the realisation of the benefits offered by hydrogen. This can be seen in the Government's Hydrogen Supply Competition, Industrial Fuel Switching and the commitment to a new £100m Hydrogen Production Competition. The Hydrogen Taskforce welcomes these programmes but also proposes that this funding level is insufficient to develop the technology at the scale and speed that is required and does not reflect the scale of the opportunity presented by hydrogen.

The UK is well placed to lead on the development of hydrogen production, storage and distribution technologies. However, Government and industry should together invest now to ensure that the technology development and commercialisation takes place in the UK. A strong investment signal by Government would unlock significant investment from industry in the UK and lead to a step change in technology development. Hydrogen has significant cost down potential of up to 50% over the next decade[1]. The introduction of low-cost clean hydrogen onto the UK market would be a game changer across multiple end use applications where the economics of hydrogen supply are currently a constraining factor.

The Taskforce calls on the Government to commit £1bn of capex funding over the next Spending Review period to hydrogen production, storage and distribution projects. The industry is ready to invest in large scale hydrogen production, storage and distribution projects to decarbonise critical areas of the UK energy system with Government support.



DEVELOPMENT OF FINANCIAL SUPPORT FOR THE PRODUCTION OF HYDROGEN FOR BLENDING INTO THE GAS GRID, INDUSTRIAL USE, POWER GENERATION AND TRANSPORT

Uncertainty of future revenue streams and higher production costs are issues common to almost all early stage energy technology. The UK has significant experience in delivering cost-down in low carbon energy through the implementation of schemes such as Contracts for Difference, Capacity Market, Renewable Heat Incentive and the Heat Networks Investment Project. These schemes were designed to promote the deployment of low carbon generation technologies, allowing them to achieve cost down and mass market deployment. Hydrogen technologies are still in early stages of deployment and as such face operational cost challenges, particularly when competing with low cost high carbon alternatives such as natural gas.

The development of a financial support scheme will enable investment across the supply chain, including those areas which are less mature, enabling hydrogen technologies to achieve cost down and mass market deployment.

AMENDMENT OF GAS SAFETY MANAGEMENT REGULATIONS (GSMR) TO ENABLE HYDROGEN BLENDING INTO THE UK GAS GRID AND TAKE THE NEXT STEPS TOWARDS 100% HYDROGEN HEATING THROUGH SUPPORTING PUBLIC TRIALS AND MANDATING HYDROGEN-READY BOILERS BY 2025

The Government and industry are currently working on establishing the health and safety case for hydrogen and the tolerance of the network and appliances to a hydrogen blend under the HyDeploy project. This work is progressing well, and the first stages are complete. The Taskforce calls on the Government to prioritise the work of HyDeploy to establish the safety case and then to amend the GSMR and introduce policies to enable hydrogen blending to commence before the end of 2022.

In addition to supporting HyDeploy, the next phase in the UK's development of 100% hydrogen heating must take place over the next five years. This will enable the Government to take a decision as to the future of the gas grid. Industry and Government must collaborate on public trials in occupied buildings of 100% hydrogen heating both in the domestic and commercial settings. Given the current UK domestic gas boiler market is around 1.6m units per year, a mandate that all boiler installations from 2025 are hydrogen ready would mean that a significant proportion of the existing housing stock is prepared for a future changeover.

Industry is committed to working with the Government to ensure that the next phases of HyDeploy are completed as quickly as possible with a target of amending the GSMR to enable hydrogen blending by the end of 2022. The Taskforce is also committed to working with the Government to deliver 100% hydrogen heating public trials.

COLLABORATION TO ESTABLISH 100 HYDROGEN REFUELLING STATIONS (HRS) BY 2025 TO SUPPORT THE ROLL-OUT OF HYDROGEN TRANSPORT.

The UK Government has made a start in supporting hydrogen transport and we are beginning to see a fledgling network emerge, however this must now be stepped up and consolidated over the next five years. The UK competes for vehicles with the likes of Japan, Korea, California and Germany, all of which have clear infrastructure strategies. If the UK is to establish itself as Europe's hydrogen transport leader, then it must have an ambitious but realistic infrastructure strategy. As the UK looks to protect its automotive manufacturing sector, establishing a leading position in an emerging but important future technology will be important as OEMs decide where to base manufacturing.

Activity must be scaled over the next 5 years, building on the learnings of early stage roll out, to develop a nationwide network that leverages local gas and electricity grid capabilities, and anchored around lead users such as back to base fleet operators and at key network points. In order to achieve this, the current gap in vehicle capex and opex costs will need to be addressed.

The Taskforce considers that this target of 100 stations by 2025 could be achieved through a per vehicle subsidy scheme which incentivises early adoption coupled with a hydrogen incentive scheme. The proposed vehicle subsidy scheme has been developed by UKH2Mobility. The approximate subsidy request up to 2025 is around £130 million and would support the deployment of over 6,000 vehicles.

Industry is ready to support the roll out of hydrogen mobility in the UK.

Policy Recommendations

— The Hydrogen Taskforce is calling on the Government to nurture the policy environment that will drive the next stage in scaling hydrogen solutions and enable industry to invest in hydrogen technologies in the UK

1

Development of a cross-departmental Hydrogen Strategy within UK Government

2

Commitment by Government of £1bn over the next Spending Review Period to hydrogen production, storage and distribution projects

3

Development of financial support for the production of hydrogen for blending into the gas grid, industrial use, power generation and transport

4

Amendment of Gas Safety Management Regulations (GSMR) to enable hydrogen blending into the UK Gas Grid and take the next steps towards 100% hydrogen heating through supporting public trials and mandating hydrogen-ready boilers by 2025

5

Collaboration to establish 100 hydrogen refuelling stations (HRS) by 2025 to support the roll-out of hydrogen transport

Introduction

The Hydrogen Opportunity

In 2019 the UK became the first major global economy to commit to a net zero emissions target by 2050. This target presents one of the greatest challenges the UK has ever faced and sits in the context of a global effort to limit climate change and its impact. There is a growing consensus that hydrogen has a key role to play in achieving full decarbonisation of the economy by offering a complementary decarbonisation pathway, alongside electrification, for the UK energy system. This recognition is shared by many other nations and as such the global market for hydrogen technologies is expected to grow rapidly over the coming years. The Hydrogen Council estimates that this value could be as much as $2.5tn by 2050[3].

The UK is well placed to emerge amongst the global winners of the hydrogen transition through high-value jobs, export benefits and cost-effective decarbonisation in key sectors of its economy including heavy transport, heavy industry and domestic heat. This is because it is starting from an advantageous position with UK firms leading on hydrogen sector niches, widespread R&D and university expertise, transferable skills from the oil and gas sectors and leading services firms developing services tailored to hydrogen. Additionally, the UK's large domestic renewable resources – particularly wind – mean it has an advantageous position for the production and eventual export of green hydrogen.

The Hydrogen Taskforce is founded by UK based companies of different sizes and specialisation – BP, Shell, ITM, BOC, Arup, Cadent, DBD, Baxi, Storengy, and BNP Paribas – that are active across the entire value chain and are at the forefront of hydrogen innovation, globally. The Taskforce's aim is to convey a coordinated voice which is essential to securing tangible policy support and recognition from the UK Government and the Devolved Assemblies that will culminate in a collaborative and ambitious programme to enable the UK to become world leading in the hydrogen sector.

> *Moving beyond an 80% target changes hydrogen from being an option to an integral part of the strategy.*
>
> *By 2050, a new low-carbon industry is needed with UK hydrogen production capacity of comparable size to the UK's current fleet of gas-fired power stations.[2]*

We see the hydrogen sector in the UK as essential because of the economic opportunity for the UK but also due to the very nature of the hydrogen proposition. The biggest benefits of hydrogen applications are only seen when the whole energy system is considered, and when short-term needs and long-term benefits are taken into account. Hydrogen infrastructure requires a holistic view to transition from initial fragmented, stand-alone hydrogen applications to integrated regional hydrogen clusters that offer a compelling pathway to green, secure energy within the next investment cycle for the energy sector.

The level of ambition and collective scale of Taskforce supporters ensures that the proposed partnership between the Government and the industry will be mutually beneficial towards delivering the benefits of hydrogen. As industry players we have invested significantly in developing unrivalled expertise and skills related to hydrogen; we stand prepared to match Government contribution in driving UK hydrogen investment forward through corresponding investment.

With hydrogen emerging as a major market within the global energy transition, the UK should stand ready to benefit and exploit its competitive advantages. A joined-up approach between industry and Government to develop a partnership can ensure that the UK responds to the competitive challenge, starting with investment here in the UK.

A brief introduction to Hydrogen

Hydrogen is an energy carrier that is primarily used today as an industrial feedstock. It has specific characteristics that make it well suited for use within the energy system.

CHARACTERISTICS

— Abundant:

Hydrogen is the most abundant element on the planet and can be produced from any primary energy source including hydrocarbons and renewables. There are two mechanisms for creating clean hydrogen:

- Green Hydrogen can be created by splitting water into hydrogen and oxygen using electrolysers.
- Blue Hydrogen can be produced through steam-methane reforming or autothermal reforming coupled with Carbon Capture Usage and Storage (CCUS).

— Clean:

Hydrogen has zero carbon emissions at the point of use

— High energy density by mass:

Hydrogen has one of the highest energy density values by mass of any fuel; its energy density is between 120 and 142 MJ/kg.

BENEFITS

— Flexible:

Hydrogen can be utilised across the energy system in power, heat, industry and transport applications. It can be burnt or used to generate power and heat in a fuel cell. It can also be used as an industrial feedstock.

— Storable:

Hydrogen can be stored efficiently at scale in a variety of forms for long periods of time. The ability to store hydrogen in salt caverns and other geological stores makes it uniquely well suited for achieving seasonal storage for heat applications. It can be converted to other carriers such as ammonia and Liquid Organic Hydrogen Carriers (LOHC) to facilitate more compact storage

— Transportable:

Hydrogen can be transported via pipelines, as compressed or liquified gas or converted to other carriers such as ammonia and LOHC to facilitate transportation over long-distance (similar to LNG).

— Safe:

As with any chemical carrier, hydrogen is low risk under the right safety management regulations and protocols. Hydrogen has been safely used for industrial applications over many decades.

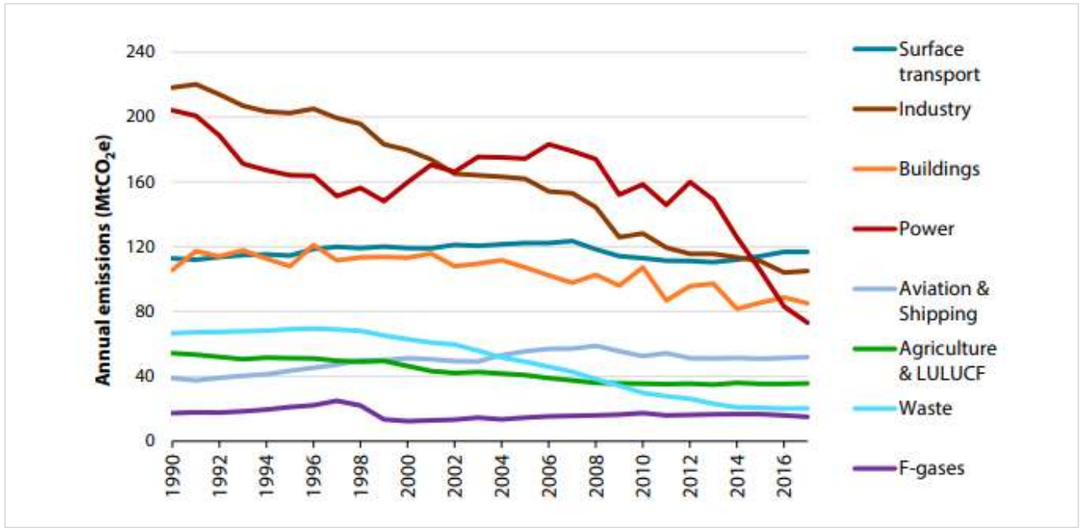
The Challenge in Meeting Net Zero

In June 2019, the UK Government amended the 2008 Climate Change Act to include a net zero target by 2050, and in doing so became the world's first major economy to make full decarbonisation a legal requirement. Previously the world's largest consumer of coal and the leader of the industrial revolution, the UK is now well-placed to again lead the paradigm shift that will change the way we generate and consume energy. By drawing on domestic resource and existing expertise, the UK can act early and proactively to address its own decarbonisation objectives. There are however significant challenges that must be overcome if the UK is to meet its net zero target.

DECARBONISATION OF "HARD TO ABATE" SECTORS

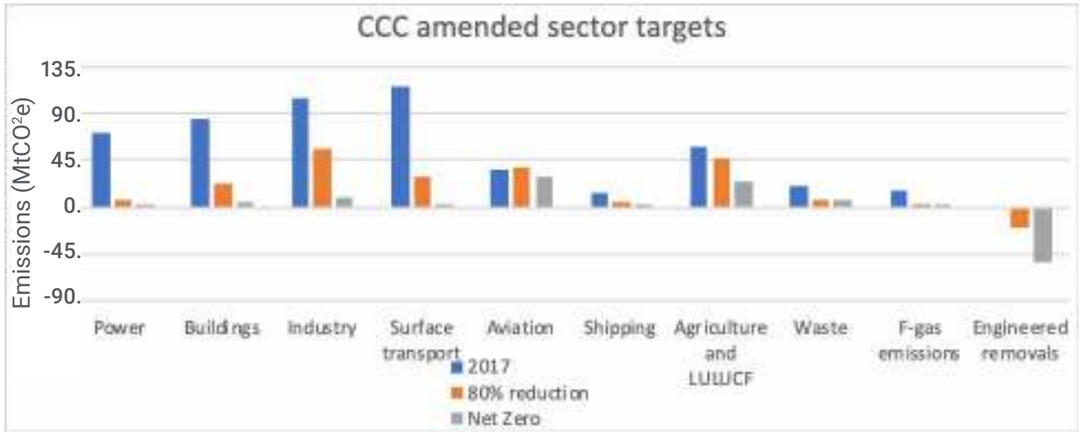
Significant progress has been made since 2008, with emissions having fallen 40%[4] against a 1990 baseline, however most of this progress has been made in the power sector, achieved through the phase out of coal, switch to gas and the increase of renewable generation. Conversely, the last 5 years has seen minimal progress in decarbonisation of heat in buildings, industry and shipping, and surface transport emissions have increased. Solutions for these 'hard to abate' sectors must be developed and deployed rapidly over the next decade if the UK is to meet its net zero target.

Figure 1 – UK Greenhouse Gas Emissions[5]



The Committee on Climate Change (CCC), in its Net Zero report, amended its previous emissions targets for each sector to meet the new net zero target. Significantly, it is amongst the "hard to abate" sectors that the CCC are recommending that additional decarbonisation must bridge the gap between an 80% reduction and net zero. CCC analysis shows that 71% of the additional emissions reductions that must be made under the net zero scenario come from buildings, industry, shipping and surface transport.[6] This presents a sizable challenge.

Figure 2 – Additional decarbonisation required under net zero[7]



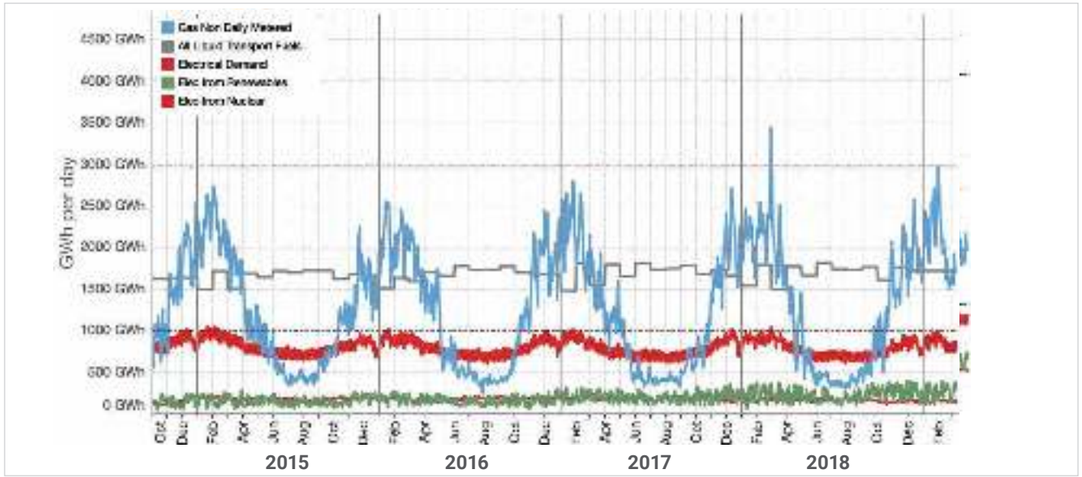
The use of hydrogen opens new decarbonisation solutions within these hard to abate sectors which can support and complement existing solutions.

DEMAND VARIATION AND ENERGY STORAGE

A number of the applications within the "hard to abate" sectors have characteristics and demand profiles which make them well suited to chemical energy carriers. For example, the demand profile of domestic and commercial heat in the UK, with its large intra-seasonal variation, has been well served by natural gas, which, with its high energy density, is relatively cheap and easy to store during the summer when demand is low. Hydrogen shares many of the properties which make natural gas well suited to meet heat demand, whilst not containing carbon.

Hydrogen offers a viable mechanism for managing demand variation by providing a large scale, long term energy storage solution.

Figure 3 – UK daily energy demand[8]



[7] Ecuity analysis based on CCC Net Zero (2019)

PRESSURE ON ELECTRICITY DISTRIBUTION NETWORKS

The UK's electricity distribution network has been designed and sized to match the UK power supply and demand profile. The heat and transport sectors are currently supported by alternative infrastructures; the natural gas network and the vehicle refuelling network respectively. The size of these energy domains is greater than that of the power domain with annual demands of 352TWh for power, 733TWh for heat and 663TWh for transport in 2018[9]. In 2018 gas hourly demand peaked at 214GW whilst electricity peaked simultaneously at 53GW. The electricity distribution network is currently not designed to manage the demands of the heat and transport sectors and, whilst the electricity distribution network will inevitably need to be upgraded to support the roll out of battery electric vehicles, there would be significant challenges in attempting to use the electricity network to support the entire transport and heat domains.

Hydrogen offers a complementary energy vector that could utilise an alternative existing distribution network. Initial studies[10] conducted in the UK indicate that hydrogen could be distributed by repurposing the existing gas distribution network, relieving pressure on the electricity grid which is typically expensive to upgrade.

FURTHER INTEGRATION OF LOW-COST RENEWABLES THROUGH SMART SECTOR INTEGRATION

Renewable power generation technologies are currently the UK's most mature and cost effective decarbonisation solutions, having been deployed in volume over the past decade. The UK has more installed capacity of offshore wind than any other country in the world, with costs of new offshore wind falling by 50% since 2015[11] . It also has a large offshore wind potential of approximately 6000TWh via a potential capacity of 1300GW, which is nearly three times the UK's current consumption of all forms of energy[12]. Similarly, solar PV has seen unprecedented rates of growth in the UK with installed capacity rising to 13.3GW[13] from a near standing start at the beginning of the last decade, while economies of scale have resulted in global PV panel prices falling by over 70% during this period[14].

Deployment of renewables in the UK has now reached high enough penetration levels that at times of peak supply and low demand, renewables are being curtailed. In order to minimise curtailment and enable the expansion of new low-cost renewables to continue, there is an imperative for smarter use of power which could occur by utilising hydrogen as a mechanism for storing energy. This is known as energy sector coupling or smart sectoral integration. This will enable the UK to utilise its low-cost renewable assets to decarbonise sectors which are more suited to chemical energy carriers whilst reducing pressure on the electricity distribution network.

01

— DECARBONISATION OF “HARD TO ABATE” SECTORS

The UK must address the sectors that have made little progress in decarbonisation to date. Hydrogen opens new decarbonisation solutions within these hard to abate sectors which can support and complement existing solutions.

02

— DEMAND VARIATION AND ENERGY STORAGE

Energy domains with large demand variation and energy storage requirements require chemical energy carriers. Hydrogen offers a viable mechanism for managing demand variation by providing a large scale, long term energy storage solution. .

03

— PRESSURE ON DISTRIBUTION NETWORKS

The electricity distribution network is not designed to support the heat and transport domains in addition to the power domain and is expensive to upgrade. The deployment of battery electric vehicles will put pressure on the electricity grid. Hydrogen offers an alternative energy carrier that utilises different available infrastructure and technologies that could relieve some of this pressure.

04

— FURTHER INTEGRATION OF RENEWABLES

Renewables present the UK with a mature, low cost decarbonisation solution; however, their intermittent nature means that storage is required to enable greater levels of deployment. Hydrogen provides storage and sector coupling capability, maximising the impact of renewables in the UK.

Challenges that must be addressed to decarbonise the UK’s energy system

The role of hydrogen across the energy system

For applications where there are no other viable decarbonisation pathways, meeting net zero is not possible without hydrogen and therefore investment in the development and demonstration of hydrogen solutions must be an immediate priority.

The scale and demand profile of domestic and commercial heat means that, although other technologies such as heat pumps and district heating have a key role to play, decarbonisation at the scale required in a net zero scenario will require hydrogen to make a significant contribution to decarbonising on grid buildings. Similarly, the scale and complexity of the power domain mean that hydrogen will have a key role to play in balancing the grid, providing generation capacity and enabling the deployment of renewables.

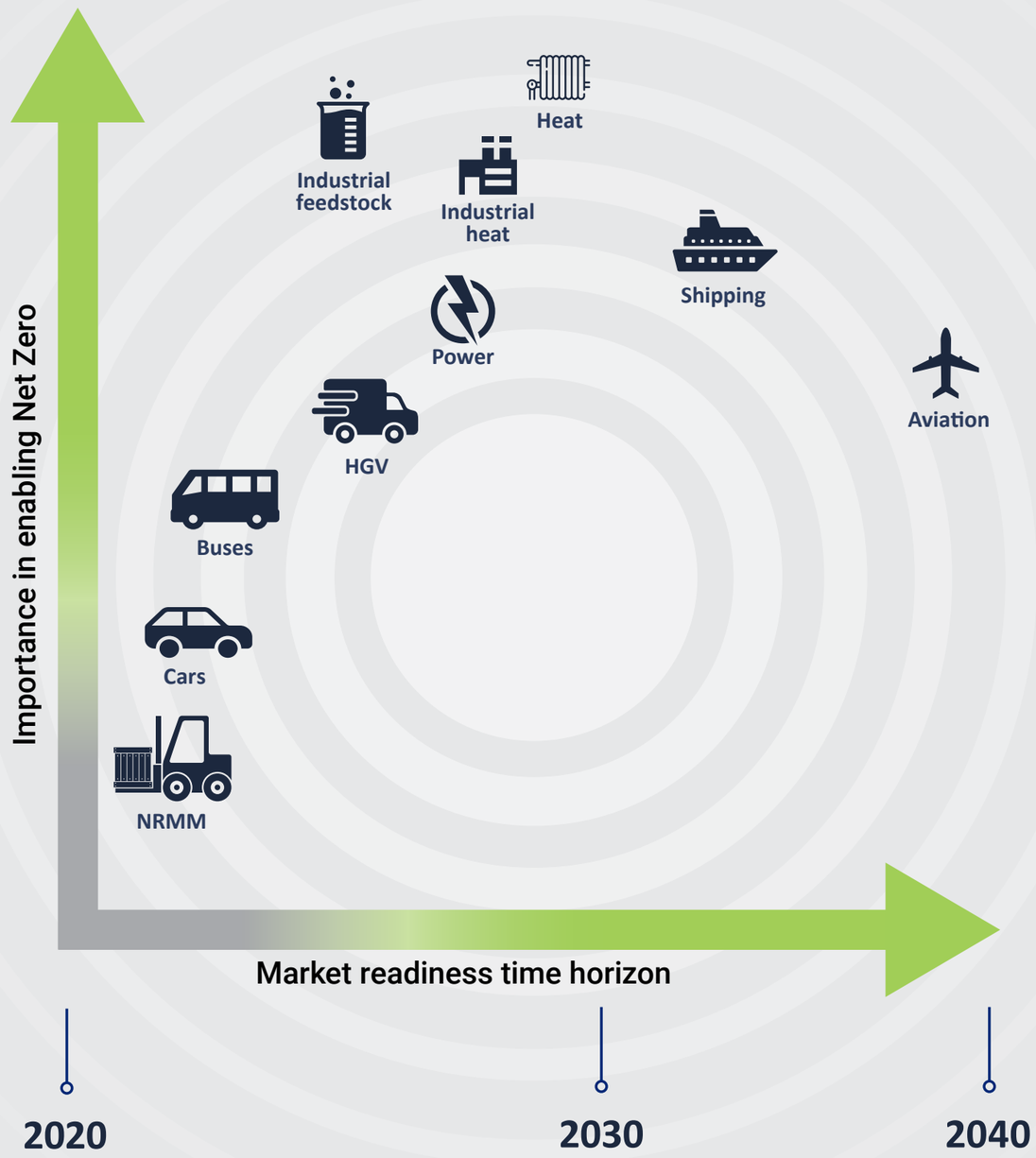
Industrial heat and feedstock, regional rail, HGVs, shipping, aviation

There are a range of hydrogen solutions that are currently being commercialised. These technologies can be deployed now or in the near future, providing early markets for hydrogen, developing infrastructure and allowing the upstream supply chain to mature whilst making an immediate contribution to decarbonisation.

domestic and commercial heat, power generation and balancing

The timeline for hydrogen becoming cost-competitive in each of these end-use applications is dependent on several factors including industry investment in R&D, the development of supportive policy frameworks and the cost and availability of clean hydrogen. For technologies that have reached higher levels of maturity, such as cars and buses, there is an opportunity to ramp up deployment over the next decade as costs decrease and technology is more readily available. Those areas where there is currently less certainty on future costs due to a longer projected timeline for technology development, a 'learning by doing' approach should be taken as solutions are scaled up.

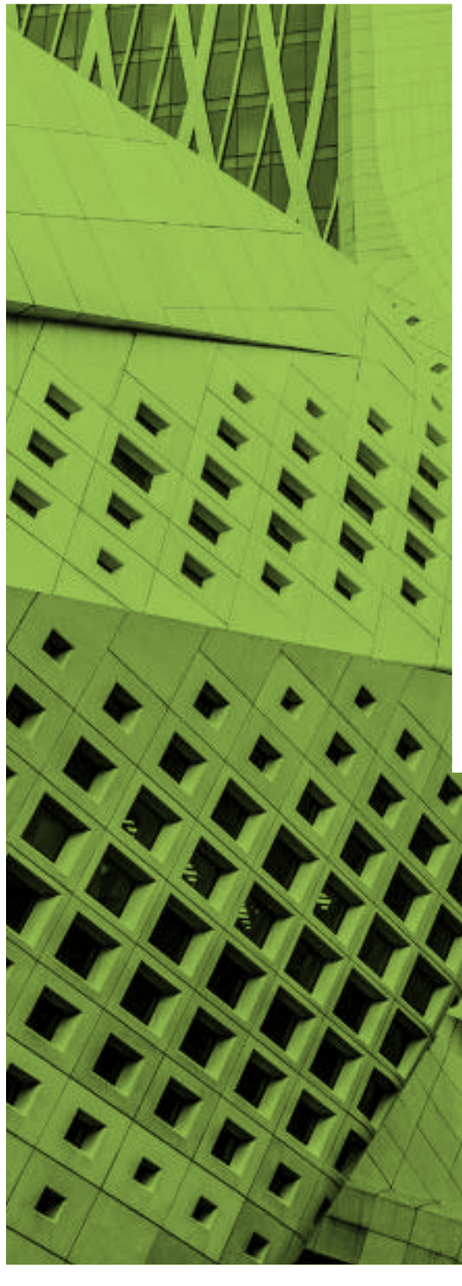
NRMM, cars, buses, blending



UK leadership in hydrogen

The Government set out its ambition in the Industrial Strategy to be the world's most innovative economy, delivering high value jobs and prosperous communities through the development of sustainable infrastructure. UK industry, with the support of Government, has made a steady start in its development of hydrogen and is well positioned to emerge as a global leader. It is now time to accelerate hydrogen development programmes, leveraging existing knowledge and assets and enabling the UK to develop exportable technology and expertise.

The Hydrogen Council estimates a future hydrogen and equipment market worth $2.5 trillion globally by 2050 supporting 30 million new jobs. In Europe, the Fuel Cell and Hydrogen Joint Undertaking (FCHJU) forecasts that total hydrogen demand could increase from about 325 TWh in 2015, to 2,250 TWh by 2050 given credible assumptions on the role of hydrogen in European economies[15]. Several national governments have identified the opportunity presented by hydrogen, not just as a decarbonisation solution but also as an economic growth opportunity and are investing heavily in capability and capacity building as a result. The race to emerge as a global leader in hydrogen has already begun, and the UK must be focused and ambitious, building upon past successes and leveraging existing areas of global leadership. Not acting now will increase the cost of entry for industry and Government in the future and will mean the UK has less control over technology, standards, protocols and materials developed outside the UK.



The Government has, to date, invested over £90m in hydrogen projects which has, in conjunction with EU funding, enabled industry to develop and deploy hydrogen technologies. In addition, the Government has announced £70m of investment in new hydrogen supply and industrial fuel switching projects. These investments have created unique expertise and knowhow within UK industry that must now be leveraged to enable decarbonisation at scale and create exportable products and expertise. Examples of effective collaboration between industry and Government include:

01

— THE UK HYDROGEN MOBILITY PROGRAMME

The UK hydrogen mobility programme has been in operation since 2012 and is an effective collaboration between Government and industry, the programme has resulted in the deployment of 15 stations and over 200 vehicles. There have been significant learnings from the programme including deployment models, user experiences and maximising infrastructure reliability. Government support has enabled the industry to move through the early demonstration phase and focus must now be on mass deployment.

02

— HY4HEAT, HYDEPLOY, H21 AND H100

BEIS and OFGEM have supported several projects focused on the use of hydrogen to decarbonise domestic and commercial heat by decarbonising the gas grid. These projects have included feasibility studies which have demonstrated the technical and economic viability of this pathway as well as the development of appliances that use 100% hydrogen. As a result of these programmes, the UK is now considered to be a global leader in the development of hydrogen for heating. Industry and Government must continue to collaborate to build on this area of strength.

03

— 3. HYDROGEN SUPPLY PROGRAMME

The Hydrogen Supply Programme committed £33 million to exploring the feasibility of producing low cost clean hydrogen at scale. The technologies developed through this programme include both blue and green hydrogen as well as storage and distribution solutions. The supply of low-cost clean hydrogen will be critical to the feasibility of hydrogen for large scale decarbonisation and, as such, investment in these activities must be scaled over the next five years.

Hydrogen Roadmap Europe, FCHJU (2019)

Case Studies

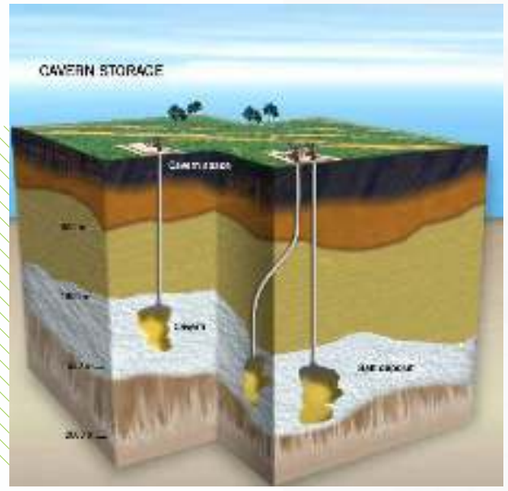
HyNet

HyNet has received a £13m boost funding the Hydrogen Supply and Industrial Fuel Switching competitions. The project is delivering a clean hydrogen production facility for deployment within the hydrogen cluster in the north west. The technologies being developed under the programme would enable CCUS whilst reducing the cost of clean hydrogen. Additionally, the project will demonstrate the feasibility of switching several key industrial processes from natural gas to clean hydrogen as part of the wider HyNet project. Practical demonstration and experimental development of direct-firing, boiler, and refinery technologies will be delivered at NSG Pilkington's Greengate Works (glass manufacturer), Unilever's Port Sunlight plant (personal care, home care, and beauty products), and Essar Oil's Stanlow Refinery.

Gigastack

The Gigastack project has received £7.5m funding from the Hydrogen Supply Competition. Gigastack will demonstrate the delivery of bulk, low-cost and zero-carbon hydrogen at a refinery in Humberside through ITM Power's gigawatt scale polymer electrolyte membrane (PEM) electrolysers, manufactured in the UK.

The project aims to dramatically reduce the cost of green hydrogen, as a key enabler for scaling up the deployment of renewable generation assets. The Phase 1 feasibility study showed that the Gigastack project could reduce the cost of green hydrogen by more than 50% compared to today's costs.



Centurion and HySecure

Centurion, funded by Innovate UK and project partners Storengy, Ineos and Cadent and Hysecure funded by the Hydrogen Supply programme have paved the way to safely store hydrogen in salt caverns. The studies have shown that repurposing existing salt caverns is a relatively quick and cost-effective method of providing bulk storage of hydrogen and have also demonstrated the technical feasibility of building new purpose-built caverns. Conversion could take place in as little as 1.5 years whilst a new cavern could be built in 3.5 years.

Capital costs of hydrogen storage in caverns are expected to fall by 50% to £600/MWh. This is very competitive with the cost of battery storage, currently £160,000/MWh. The large storage volumes provided by salt caverns are also key to providing the intra-seasonal storage required to meet winter energy demand.

100% Hydrogen Boiler

Funded through the Government's Hy4Heat programme, heating appliance manufacturers are developing domestic hydrogen appliances to demonstrate the safe use of hydrogen as a fuel in providing domestic heating, hot water and cooking requirements. The programme aims to provide critical evidence of end use application, safety, in-use emissions, and functionality.

Heating manufacturer Baxi Heating UK is among the companies developing an 100% hydrogen fuelled appliances for demonstration testing during 2020. They have developed a ''hydrogen ready boiler'' which can be initially installed to operate on natural gas then converted to hydrogen with a simple intervention at a future date. The appliance will use the same outer case dimensions and pipe connection points as a current natural gas boiler in order to facilitate as far as possible a "like for like" changeover.

Crucially, this means that installation of 'hydrogen ready' boilers could begin long before 100% hydrogen is available within a locality by utilising the existing natural gas network. Once hydrogen is available, the hydrogen ready boilers can be simply and easily converted to hydrogen without the need for a new heating system.

Baxi's 100% hydrogen ready boiler

HyDeploy

Hydrogen gas injection at Keele University

HyDeploy is a pioneering energy demonstration project to establish the potential for blending hydrogen, up to 20%, into the normal gas supply by using an ITM Power electrolyser. A 10-month live demonstration of blended gas is taking place on part of the Keele gas network and will finish in August 2020. HyDeploy will help to determine the level of hydrogen which can be used by customers safely and with no changes to their existing domestic appliances.

HyDeploy will unlock hydrogen injection into the grid, which, coupled with policy support, will create an early market for hydrogen. This will be important for investors and developers of hydrogen production technologies.

Aberdeen Bus Project

The Aberdeen Bus Project launched in 2015 was a ground-breaking scheme that delivered 10 hydrogen buses, at the time the largest fleet in Europe. The buses, operated by First Aberdeen and Stagecoach, have driven more miles in commercial operation than any other hydrogen fuel cell bus project to date. The refuelling station, operated by BOC, supported both the buses and a fleet of cars, demonstrating the benefits of multi modal infrastructure. The £19m project was funded jointly by the EU's Fuel Cell and Hydrogen Joint Undertaking (FCHJU), Innovate UK, Aberdeen Council, Stagecoach and First, Scottish Government, Scottish Enterprise, Scottish Hydro Electric Power Distribution and Scottish Gas Network. Phase 2 of this project will commence in 2020 with the introduction of 15 next generation double decker buses.

Aberdeen's ground breaking bus fleet

The initial UK capability must now be built upon. Investment should scale rapidly in line with both the role that hydrogen must play in enabling the UK to achieve net zero and the global opportunity presented by hydrogen. Emphasis should be placed on markets where the potential for hydrogen is the greatest and where the UK stands to benefit from being a first mover rather than waiting for cost down to be achieved elsewhere. In order to build a globally significant hydrogen industry the UK must focus on the following approaches

1. **Taking advantage of existing infrastructure and assets**
2. **Leveraging industrial expertise**
3. **Supporting the UK's hydrogen champions**

1. Taking advantage of the existing infrastructure and assets

The UK has high levels of natural wind resource, enabling significant domestic wind generation, the UK has more offshore wind capacity than anywhere else in the world, currently over 8GW[16]. In addition, the UK is looking to expand its nuclear capacity – the efficient and cost-effective use of these resources can be maximised using hydrogen to enable sector coupling and matching supply and demand. Investment in electrolyser technology development would allow the UK to maximise the value from its world leading offshore wind capability.

Over 80% of UK homes and businesses in the UK are connected to the gas network giving the UK a world-leading level of gas grid coverage. In addition, the network has a high level of performance achieving 99.9% reliability[17]. The gas grid also performs a valuable role in the energy system, providing storage capacity and supporting system flexibility. The gas grid is an asset of considerable value, however, without decarbonisation, the UK risks being left with a significant stranded asset that cannot be utilised under a net zero scenario. Instead the UK should be looking to leverage this asset, using hydrogen, to decarbonise heat and to support the decarbonisation of transport and industrial processes through delivery of clean hydrogen.

UK CO_2 storage potential is significant, estimated to be around 78GT[18], with no major technical hurdles to storing industrial scale CO_2 offshore. The top 15% of this potential storage capacity would last the UK around 100 years. Investment in Carbon Capture Use and Storage (CCUS) technologies would allow the UK to exploit this natural asset and develop a world leading blue hydrogen production sector.

2. Leveraging industrial expertise

Existing areas of industrial expertise located across the UK could be built upon to create a world leading hydrogen cluster with high value jobs and exportable knowledge and technologies. The oil and gas industry currently supports over 300,000 jobs. Over decades, the industry has supported the development of a skilled workforce and supply chain that is experienced in producing and distributing gas to customers. This expertise can be leveraged to support the development of hydrogen solutions and the transition away from dependence on fossil fuels whilst protecting high value jobs within the sector. For example, experience within the sector could be used produce blue hydrogen via CCUS, convert and maintain hydrogen pipelines and safely handle and distribute hydrogen.

The industry and adjacent research bodies have a strong track record of building on existing expertise to create innovative solutions to new challenges. For example, the industry has leveraged its knowledge of subsea exploration and maintenance of offshore machinery to enable the UK to become the world leader in offshore wind technology. This growth in the offshore wind sector has been supported by Government policy, through the Offshore Wind Sector Deal, demonstrating how government and industry can work together to reduce costs and build a world leading industry. There is now an opportunity to use that same expertise to develop a world leading hydrogen production industry.

The UK is currently the largest gas boiler market in Europe and the industry has a strong track record of developing and manufacturing global leading products. In addition, there is an extensive installer network with unrivalled expertise in installation and maintenance of gas boilers and gas central heating systems. This industry is well positioned to support the transition towards hydrogen heating and is currently leading on the development of 100% hydrogen boilers.

The nuclear industry, supported by Government programmes such as the Nuclear Sector Deal, the Advanced Modular Reactor programmes and the UKAEA's £220m STEP programme, provides tens of thousands of jobs in the UK. There is scope for hydrogen to be integrated with nuclear using electrolysers, providing storage and low-cost transport fuel.

Industry in the UK is supported by world leading research institutions, such as Imperial College London, the University of Birmingham and St Andrews who all contribute valuable research and develop intellectual property. Alongside research institutions, professional service firms provide valuable engineering, design and project management services. These professional service firms are rapidly building capability and expertise in hydrogen and there is scope for this know-how to be exported. In addition, the UK is also playing a leading role in the provision of finance for decarbonisation projects, a position that has been strengthened by the UK Government's Green Finance Strategy. Access to finance will be key to unlocking large scale hydrogen projects and integrating the finance sector into early discussions will be beneficial moving forwards.

3. Supporting the UK's Hydrogen Champions

The UK is home to several organisations that have been pioneering hydrogen solutions for many years, developing world leading technologies. A strong domestic market for hydrogen would drive growth and innovation, providing valuable support for the UK's hydrogen champions and helping them to compete on the world stage.

ITM Power is a globally recognised expert in hydrogen technologies, designing and manufacturing electrolysers for the mobility, power to gas and industrial markets. The product has the capability of being scaled to 100MW+ in size and has been deployed across multiple applications. ITM Power has been instrumental in the development of the UK's fledgling hydrogen refuelling network. BOC is the UK's largest gas company and currently produces hydrogen for use in industrial processes and refuelling stations. BOC has over 120 years' experience providing gases to UK businesses and has pioneered some of the early applications of green hydrogen for mobility.

Shell and BP have a long history of meeting energy needs of businesses and consumers in the UK using fossil fuels. However more recently, the organisations have been developing and supporting clean sustainable energy solutions such as hydrogen. Shell has a growing network of hydrogen stations in Europe and North America and is part of several initiatives to encourage the adoption of hydrogen in transport. In 2018, BP's Lingen refinery in Germany became the world's first refinery to use green hydrogen from water electrolysis to meet a portion of its hydrogen demand, helping to lower the carbon footprint of its products.

The UK is also home to some of the global leaders in fuel cell technology development, both the catalysts and componentry as well as the integration and design of the fuel cells themselves. With organisations that have been pioneering these technologies for nearly 20 years, substantial multi-million-pound investment R&D has resulted in a market leading position for UK companies.

UK organisations are also pioneering the use of hydrogen to decarbonise heat. The UK gas network operators, such as Cadent and SGN, have invested in early stage R&D exploring the conversion of the gas grid to use hydrogen. In tandem, boiler manufacturers, such as Baxi, have developed 100% hydrogen boilers that will enable the UK to utilise its existing infrastructure, manufacturing and installation assets to deliver low carbon heating for the UK housing stock.

Barriers and Enablers

There are various challenges that must be overcome for hydrogen to fulfil its potential and reach the technological maturity required for large scale deployment.

UNDERSTANDING OF THE IMPORTANCE OF HYDROGEN IN THE ENERGY TRANSITION WITHIN INDUSTRY, GOVERNMENT AND THE GENERAL PUBLIC

Awareness is increasing and hydrogen has been recognised in key papers such as the Committee on Climate Change's Net Zero report, National Grid's Future Energy Scenarios and BEIS' Clean Growth Strategy. However, there is still a low level of awareness across wider government stakeholders, politicians and industry players of the role of hydrogen as a key solution for meeting net zero.

The potential applications for hydrogen are broad and diverse and subsequently there are a great many stakeholders that must be engaged. Although there are certain applications where hydrogen has clear advantages over other decarbonisation pathways, hydrogen is most compelling when considered at an energy system level, incorporating several different applications. The complex and diverse nature of the case for hydrogen necessitates a coordinated approach in communicating the economic, environmental and energy system benefits of hydrogen.

A LONG-TERM REGULATORY FRAMEWORK THAT RECOGNISES THE IMPORTANT ROLE OF HYDROGEN IN THE ENERGY TRANSITION

In the past, emerging technologies have benefited from long term policy support mechanisms coupled with corresponding deployment forecasting. This approach was successful in the deployment of solar PV in the UK, where the Feed-in tariffs (FITs) and Renewables Obligation (RO) resulted in over 13GW installed capacity across 1 million installations in less than a decade.[19] Similarly since November 2011, the Renewable Heat Incentive (RHI) has resulted in over 5GW of installed capacity of renewable heating technologies in the UK.[20] The UK's Contracts for Difference (CfDs) demonstrate how policy support has aided the reduction in the cost of renewables, with offshore wind power costs falling from a high of £119.89/MWh in the first Allocation Round (2015) to £39.95/MWh in the third Allocation Round (2019)[21]

Currently there is no roadmap, UK hydrogen strategy or incentives for clean hydrogen production and no regulatory framework that considers hydrogen in an integrated manner, reflecting the value of the energy carrier to the UK energy system. Investment in hydrogen often requires a long-term horizon of several years, if not decades. Government must be prepared to share risk with industry or risk the UK being left behind. The UK has legally binding emission reduction targets in place, which gives stakeholders confidence when investing in low carbon technology however, greater clarity and granularity is required on how the UK Government views the role of hydrogen to encourage investment. This has been successful in other countries, such as Japan, where government and industry have jointly developed a long-term roadmap for creating the "hydrogen society" which has driven investment in hydrogen technologies.

As an emerging set of technologies, existing market mechanisms and regulatory frameworks, designed for mature technologies, are unsuitable for hydrogen and without further intervention would result in limited deployment. Policy that encourages scaling-up, for example adjusting previously successful models such as CfDs or Regulated Asset Base (RAB) model or designing novel policy mechanisms that encourages innovation should be pursued.

CROSS-SECTOR COORDINATION WITH GOVERNMENT SUPPORT

Whether industry is looking to deliver large scale hydrogen production projects, decarbonise heat or roll out hydrogen mobility, there is a diversity of organisations that will need to play critical roles. Collaboration will be key to the efficient development of hydrogen solutions and the development of new business models and value chains. For example, in the mobility sector, hydrogen infrastructure providers and OEMs must coordinate to ensure that supply and demand are matched. In California, the California Fuel Cell Partnership has brought together auto OEMs, energy companies, fuel cell companies and Government to deploy over 8,000 FCEVs and 43 refuelling stations across the state with a further 19 in development.[22] In Europe, both Germany and France have ambitious roll out plans for hydrogen mobility infrastructure, with Germany aiming to ramp up from 100 stations that are currently deployed to 400 by 2023. This is being delivered through a government industry coalition which will invest €350 million by 2023.[23]

Similarly, it will be important as hydrogen heating solutions are developed that there is strong coordination between appliance developers, the network operators and hydrogen producers to ensure that there is consistency in specification and standards.

A collaboration culture is required across industries investing in hydrogen in different sectors to maximise cost effectiveness and efficiency. Although different applications are at different stages of development and commercialisation, economies of scale would suggest that clustering multiple applications in "Hubs" where infrastructure and generation assets can be shared will improve economics at early stages.

INDUSTRY STANDARDS MUST BE DEVELOPED ACROSS THE BOTH HYDROGEN AND ITS APPLICATIONS

Codes and standards provide the information needed to safely build, maintain and operate equipment and facilities – ensuring uniformity of standards within the domestic market will allow the scaling of technologies nationally. Setting world-leading standards can also enable export to international markets and ensure that the UK has a competitive advantage in exploiting trade opportunities with hydrogen. Setting and upholding standards is in keeping with the UK's commitment to set, align and uphold international regulatory standards for the environment, climate change and consumer protection.

Policy Recommendations

— In order to meet net zero, hydrogen solutions must be deployed at scale on a commercial basis. In order to achieve this Government and industry must work together.

1

Development of a cross-departmental Hydrogen Strategy within UK Government

2

Commitment by Government of £1bn over the next Spending Review period to hydrogen production, storage and distribution projects

3

Development of financial support for the production of hydrogen for blending into the gas grid, industrial use, power generation and transport

4

Amendment of Gas Safety Management Regulations (GSMR) to enable hydrogen blending into the UK Gas Grid and take the next steps towards 100% hydrogen heating through supporting public trials and mandating hydrogen-ready boilers by 2025

5

Collaboration to establish 100 hydrogen refuelling stations (HRS) by 2025 to support the roll-out of hydrogen transport

1. Development of a cross-departmental Hydrogen Strategy within UK Government

Hydrogen is an energy carrier that has a role to play across the energy system and its application sits across sectors whose remit lies with multiple different Government departments including Business, Energy and Industrial Strategy (BEIS), Department for Transport (DfT), Ministry for Housing, Communities and Local Government (MHCLG), Department for Environment, Food and Rural Affairs (DEFRA) and HM Treasury. This has contributed to a more fragmented approach to policy and regulatory development for hydrogen. Given hydrogen's cross sector application, there is value in a more joined up approach which would ensure that hydrogen's role in the future energy system emerges in a strategically coordinated manner.

Many other economies have recognised the value in cross departmental coordination and the development of a Hydrogen Strategy or Hydrogen Roadmap including Japan, Germany, Korea and China. 2019 has seen the publication of many of these strategies which have been developed with strong input from industry. These strategy documents give industry and the investment community confidence in the ambition and commitment of countries to hydrogen and allows them to invest. In the global race to emerge as a leading nation in the development of hydrogen technologies, a UK Hydrogen Strategy is a glaring omission.

The Taskforce is committed to supporting the Government to develop this strategy over 2020. The Taskforce suggests that this strategy includes policies that will enable hydrogen to scale up over the next decade. These could include the following policies:

2. Commitment by Government of £1bn over the next Spending Review period to hydrogen production, storage and distribution projects

Hydrogen is an emerging technology with huge potential to decarbonise hard to reach areas of our energy system. The UK Government has recognised that developing low cost bulk hydrogen production, storage and distribution solutions will be essential to the realisation of the benefits offered by hydrogen. This can be seen in the Government's Hydrogen Supply Competition, Industrial Fuel Switching and the commitment to a new £100m Hydrogen Production Competition. The Hydrogen Taskforce welcomes these programmes but also proposes that this funding level is insufficient to develop the technology at the scale and speed that is required and does not reflect the scale of the opportunity presented by hydrogen.

The UK is well placed to lead on the development of hydrogen production, storage and distribution technologies. However, Government and industry should together invest now to ensure that the technology development and commercialisation takes place in the UK. A strong investment signal by Government would unlock significant investment from industry in the UK and lead to a step change in technology development. Hydrogen has significant cost down potential of up to 50% over the next decade.[24] The introduction of low-cost clean hydrogen onto the UK market would be a game changer across multiple end use applications where the economics of hydrogen supply are currently a constraining factor.

The Taskforce calls on the Government to commit £1bn of capex funding over the next Spending Review period to hydrogen production, storage and distribution projects. This funding could be used to fund the following activities:

- **Hydrogen Industrial Cluster competition**
- **Development of HyDeploy to demonstrate technical and safety case for hydrogen blending**
- **Public trials of hydrogen heating in occupied buildings**
- **Power to Gas competition**
- **Hydrogen mobility infrastructure**

The industry is ready to invest in large scale hydrogen production, storage and distribution projects to decarbonise critical areas of the UK energy system with Government support.

3. Development of financial support for the production of hydrogen for blending into the gas grid, industrial use, power generation and transport

Uncertainty of future revenue streams and higher production costs are issues common to almost all early stage energy technology. The UK has significant experience in delivering cost-down in low carbon energy through the implementation of schemes such as Contracts for Difference, Capacity Market, Renewable Heat Incentive and the Heat Networks Investment Project. These schemes were designed to promote the deployment of low carbon generation technologies, allowing them to achieve cost down and mass market deployment. Hydrogen technologies are still in early stages of deployment and as such face operational cost challenges, particularly when competing with low cost high carbon alternatives such as natural gas.

The development of a financial support scheme will enable investment across the supply chain, including those areas which are less mature, enabling hydrogen technologies to achieve cost down and mass market deployment.

4. Amendment of Gas Safety Management Regulations (GSMR) to enable hydrogen blending into the UK Gas Grid and take the next steps towards 100% hydrogen heating through supporting public trials and mandating hydrogen-ready boilers by 2025

Establishing early markets for hydrogen is essential for the roll out of the technology. The gas grid offers a great opportunity to decarbonise heat whilst providing a reliable early market for hydrogen. At this early stage, hydrogen would provide a very small percentage of the gas delivered to homes, meaning that the impact of the higher cost of hydrogen compared to natural gas on the consumer would be negligible, of the order of £10 per year for the average household.

The Government and industry are currently working on establishing the health and safety case for hydrogen and the tolerance of the network and appliances to a hydrogen blend under the HyDeploy project. This work is progressing well, and the first stages are complete. The Taskforce calls on the Government to prioritise the work of HyDeploy to establish the safety case and then to amend the GSMR and introduce policies to enable hydrogen blending to commence before the end of 2022.

In addition to supporting HyDeploy, the next phase in the UK's development of 100% hydrogen heating must take place over the next five years. This will enable the Government to take a decision as to the future of the gas grid. Industry and Government must collaborate on public trials in occupied buildings of 100% hydrogen heating both in the domestic and commercial settings. Given the current UK domestic gas boiler market is around 1.6m units per year, a mandate that all boiler installations from 2025 are hydrogen ready would mean that a significant proportion of the existing housing stock is prepared for a future changeover.

Industry is committed to working with the Government to ensure that the next phases of HyDeploy are completed as quickly as possible with a target of amending the GSMR to enable hydrogen blending by the end of 2022. The Taskforce is also committed to working with the Government to deliver 100% hydrogen heating public trials.

5. Collaboration to establish 100 hydrogen refuelling stations (HRS) by 2025 to support the roll-out of hydrogen transport

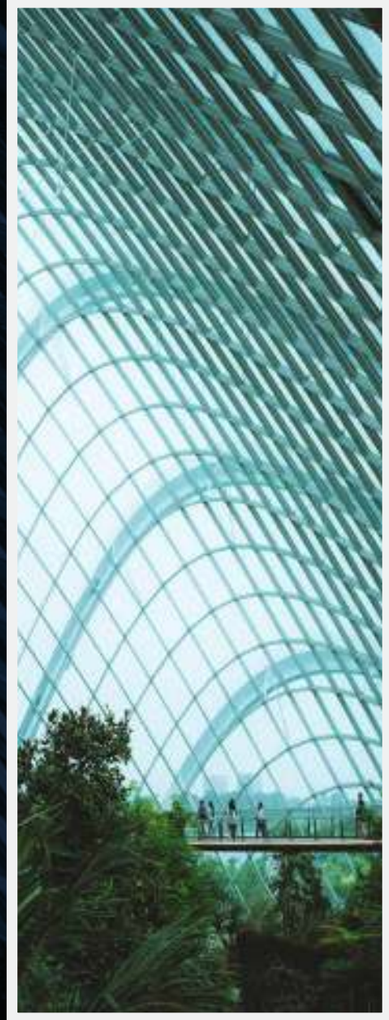
Hydrogen has a key role to play in the decarbonisation of transport in the UK, offering a technically and economically viable pathway to zero emissions across multiple transport applications. With larger vehicles where batteries are unviable, hydrogen offers the only viable solution; with smaller vehicles hydrogen offers the only rapid refuelling long range solution. Moving away from fossil fuels, consumers, both private and commercial, require a range of technology choices that can meet their varying transport needs. Hydrogen is an important technology that will be required if we are to meet net zero.

The UK Government has made a start in supporting hydrogen transport and we are beginning to see a fledgling network emerge however, this must now be stepped up and consolidated over the next five years. The UK competes for vehicles with the likes of Japan, Korea, California and Germany, all of which have clear infrastructure strategies. If the UK is to establish itself as Europe's hydrogen transport leader, then it must have an ambitious but realistic infrastructure strategy. As the UK looks to protect its automotive manufacturing sector, establishing a leading position in an emerging but important future technology will be important as OEMs decide where to base manufacturing.

Activity must be scaled over the next 5 years, building on the learnings of early stage roll out, to develop a nationwide network that leverages local gas and electricity grid capabilities, and anchored around lead users such as back to base fleet operators and at key network points. In order to achieve this, the current gap in vehicle capex and opex costs will need to be addressed.

The Taskforce considers that this target of 100 stations by 2025 could be achieved through per vehicle subsidy scheme which incentivises early adoption coupled with a hydrogen incentive scheme. The proposed vehicle subsidy scheme has been developed by UKH2Mobility. The approximate subsidy request up to 2025 is £130 million and would support the deployment of over 6,000 vehicles.

Industry is ready to support the roll out of hydrogen mobility in the UK.



HYDROGEN TASKFORCE www.hydrogentaskforce.co.uk

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