UK HFCA

The role for Nuclear-Enabled Hydrogen in delivering Net Zero

Key messages

Nuclear-Enabled Hydrogen (NEH) is zero emission at the point of production.

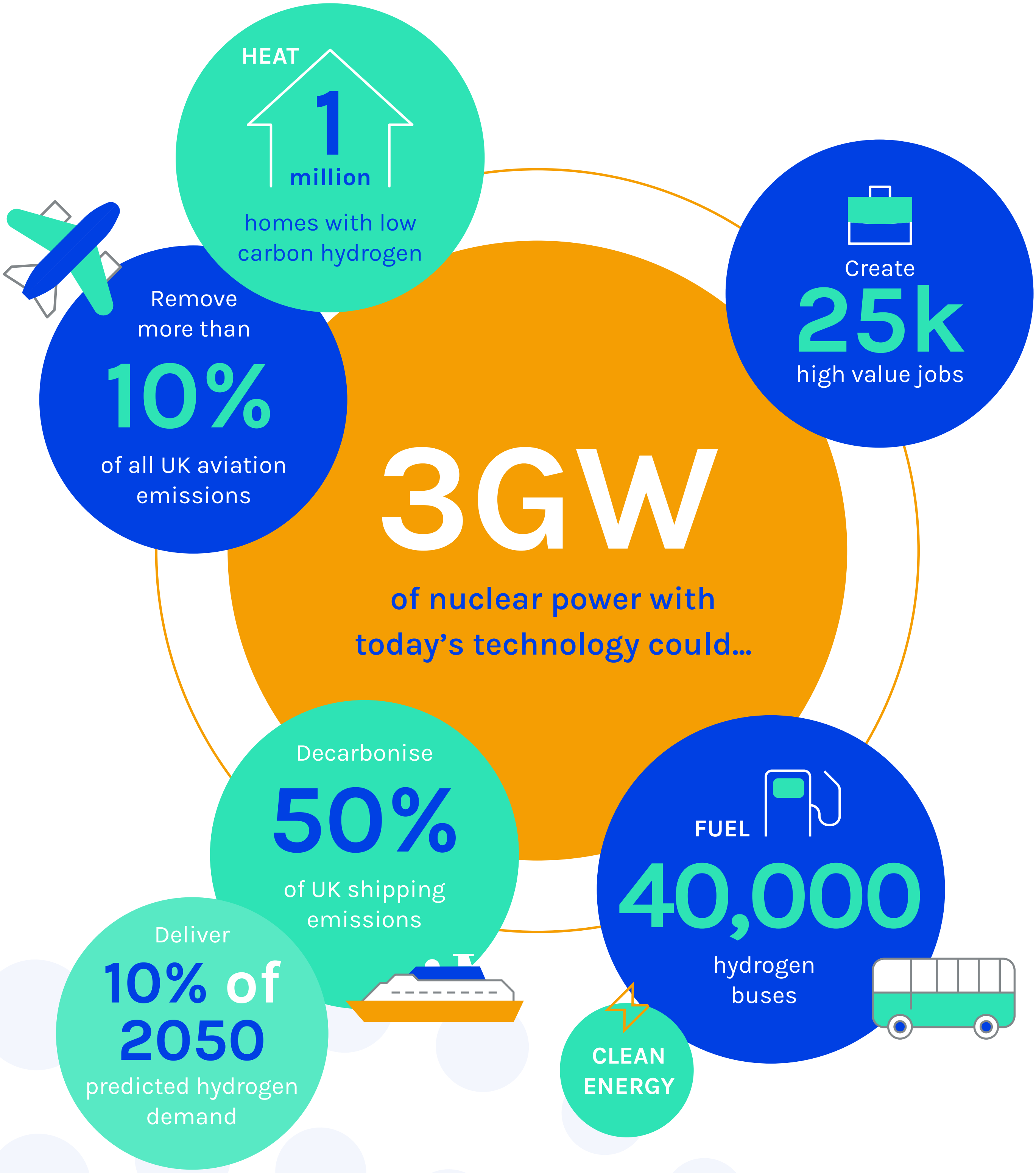
NEH offers the potential for mass-scale hydrogen production and could make a nationally significant contribution to future demands for hydrogen.

Co-locating the production of NEH within industrial clusters could bring strong synergies between the nuclear electricity and heat generation and the industries served by the cluster.

NEH can offer several levels of energy security through strong supplier relations, domestic processing capability and the long- term storage of fuel thus contributing to wider energy security.

Government support via both legislation and financial incentives will be important to ensure that NEH can realise its potential.

Figure 1: Nuclear-Enabled Hydrogen's Potential[1]



1 https://www.nnl.co.uk/wp-content/uploads/2021/07/Hydrogen-Round-Table-FINAL-v2.pdf

Background and context

Nuclear power has provided safe and clean electricity to the grid for over 60 years in the UK. Both nuclear energy and hydrogen have come increasingly to the fore as the UK seeks to both deliver its Net Zero targets and enhance energy security. The Government's recently published British Energy Security Strategy[2] includes increased ambitions across nuclear and hydrogen, highlighting their growing importance in the UK's energy system.

Nuclear-Enabled Hydrogen (NEH) is the term for hydrogen that is produced using heat and electricity derived from nuclear power. Using technology available today, such as electrolysers, hydrogen can be produced with zero emissions at the point of generation.

The combination of nuclear power and hydrogen through NEH offers the potential of mass-scale hydrogen production, which can be used to help decarbonise some of the UK's hardest to abate sectors. This Paper highlights the role and potential for NEH and calls for action from Government to enable its deployment.

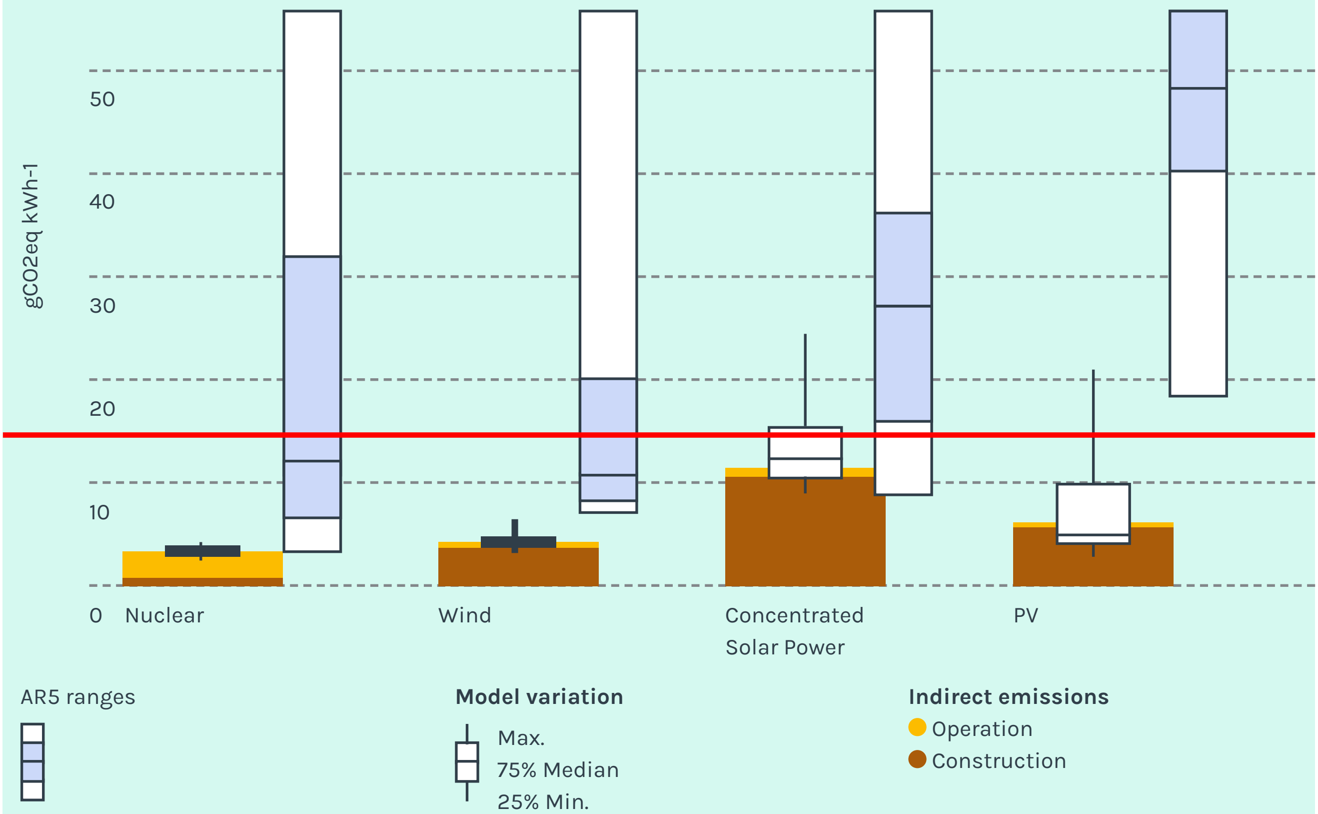
2 https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy

The NEH opportunity

There are a number of areas where NEH can contribute to the UK's goal of Net Zero by 2050 within the context of established use cases for hydrogen. Underpinning this contribution to Net Zero are a series of valuable attributes that NEH possesses: zero carbon; low-cost energy input; large scale; co-location synergy; and beneficial roles accross the energy system.

Zero carbon: Nuclear plant operations do not emit any CO_2 and, when coupled with electrolytic hydrogen production the result is zero carbon hydrogen production. Figure 2 below shows how the life cycle emissions from nuclear power are comparable to Solar PV, and Wind.

Figure 2: Lifecycle Emissions From Power Technologies Deployed In The UK[3]



3 https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-footprints/

NEH does emit some CO_2 in three stages of its production process: the construction and decommissioning of the nuclear plant; the mining of the minerals used as a feedstock for the plant; and the construction and decommissioning of the electrolyser. Yet the scale of these emissions is vastly outweighed by the volume of clean energy generated by just one plant across its 60+ year lifespan.

Low-cost electricity input: NEH has the bulk of its costs held in the infrastructure required for generating nuclear power and, once operational, will see low-cost hydrogen production throughout the lifetime of the asset. Furthermore, nuclear power offers operational efficiencies through being a steady source of electricity for electrolysis. Unlike Solar-PV and wind, the clean energy provided by nuclear is steady year-round, meaning that the annual load factor of an electrolyser will be higher and produce more hydrogen per MW installed. Furthermore, as thermal technology, nuclear power stations can provide heat at a variety of temperatures to enable higher efficiency production of hydrogen and subsequent products such as Ammonia and Synthetic Aviation Fuel (SAF) – further detail on each product is given below.

Approximately 70% of the cost of hydrogen from wind energy in 2030 will be the electrical input to electrolysers[4]. Evidence from the National Nuclear Laboratory[5] shows that forecast cost reductions for nuclear energy rapidly make NEH cost competitive with renewables enabled hydrogen. Securing another low-cost energy input for low carbon hydrogen ensures that not only the 2030 10GW target for low carbon hydrogen production is reached, but is done so affordably.

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Large Scale: One 3GW nuclear power plant has the potential to generate enough hydrogen to decarbonise the heating of 1 million homes or 40,000 hydrogen buses (the UK has 32,000 operational buses today) from a site no more than a few square miles in size, with technology available today. Generating power on a predictable basis, with operating cycles of more than a year for a modern nuclear plant, provides valuable scale and capacity to the wider hydrogen energy system, helping reduce the need for inter-seasonal storage.

40,000
hydrogen buses could potentially powered by one 3GW nuclear

Co-location synergies: Co-location of NEH with industrial clusters could bring strong synergies between the nuclear electricity generation and the industries served by the cluster. Nuclear power generates large amounts of heat which can be used in nearby industrial or district heating facilities. Within these clusters, shipping – served by GW scale ammonia production - is also a potential off-take option for NEH. Furthermore, NEH has the scope to form important regional hubs in current industrial or domestic clusters, capable of offering mass volumes of hydrogen to these regions – see below.

Beneficial roles across the energy system: NEH offers benefits and roles across the energy system, as shown in Figure 3 below. However, these are not currently recognised in the key energy system models used by the UK Government and other stakeholders to predict the nature of our future energy system. The Energy System Catapult has demonstrated through its Nuclear for Net Zero modelling that the technologies both de-risk Net Zero and expand the role of hydrogen in a future energy system.

4 https://energycentral.com/system/files/ece/nodes/440406/solving-the-integration-challenge-ore-catapult.pdf
5 https://www.nnl.co.uk/wp-content/uploads/2022/03/Preliminary-Economic-Assessment-of-Nuclear-Enabled-Hydrogen-Production-Final-Approved.pdf

Figure 3: NEH – A role across the energy system

FUEL CELLS FOR SURFACE TRANSPORT

Large scale nuclear power stations could be coupled with electrolysers today to generate the high purity hydrogen required for fuel cell vehicles. With many of the identified sites for nuclear new build being in or near to industrial clusters, generated hydrogen would be usable locally to decarbonise heavy transport.

DECARBONISING THE GAS GRID

Over 300 TWh of natural gas is used each year for the heating of homes and offices across the UK. This forms one part of the circa 900 TWh of natural gas distributed in the networks each year, all of which could benefit from the scale and predictable supply of NEH from current generation reactors and next generation Small Modular Reactors (SMRs).

NUCLEAR ENABLED HYDROGEN

A role across the energy system

AMMONIA FOR SHIPPING

Decarbonisation of marine transport with ammonia is a growing area of interest globally. The UK could be at the forefront of shipping decarbonisation through the generation of ammonia using hydrogen and heat generated from nuclear power; the heat can uniquely benefit many of the production processes required for ammonia production and be co-located with demand at ports using next generation SMRs and Advanced Modular Reactors (AMRs).

SYNTHETIC AVIATION FUELS

One of the most challenging sectors to decarbonise is flight, where heavy batteries fundamentally limit the range of electric aircraft. Hydrogen generated from nuclear could be co-located with Direct Air Capture and synthetic fuel production processes to generate carbon neutral or carbon negative synthetic fuels for aviation. With predictable costs and production schedules, it would provide the stable supply of fuel needed to enable global flight operations.

Today and tomorrow

Following the recent increase in the UK's production target for low carbon hydrogen from 5GW to 10GW by 2030, 3GW of nuclear power with today's technology could meet 22.5% of this new target. Deploying electrolysis alongside nuclear power plants can provide additional flexibility to the grid while contributing to the governments 10GW target for low carbon hydrogen. In light of the recently updated targets for UK Nuclear power – with plans now for 24GW to be online by 2050 - decisive early action is key. And with projects reaching FID each year until 2030, the role of NEH in these proposed plant operations must be considered today and decided on in the near future.

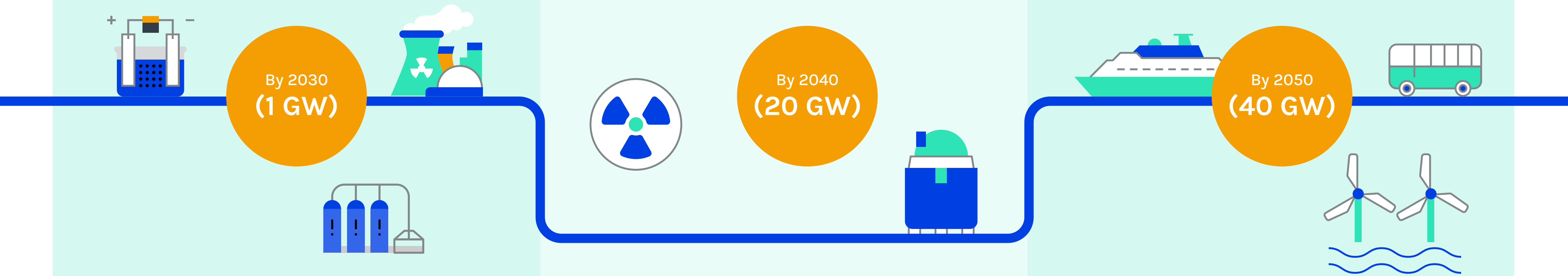
The current lack of storage for hydrogen means that producers which can offer a constant rate of production will be at an advantage for off-takers that require constant supply. If the off-takers have an interruption to their requirements, the hydrogen could likely be safely diverted into the natural gas grid at 10% or 20%, subject to Government decisions on blending. NEH could be used to fill the UK strategic reserve to protect the future renewable electric grid from times when the wind does not blow. Thus, NEH is well placed to meet steady and year-round hydrogen demands, directly enabling the build out of hydrogen infrastructure.

As mentioned above, another area that NEH could serve in the short term is co-location with industrial clusters, tying into the hydrogen networks being built in these locations, while providing base-load clean hydrogen production capacity. Implementing a plan in the short-term for GW scale production of hydrogen in these clusters provides a strong foundation for ammonia and SAF production. Figure 4 shows a vision of how nuclear-enabled hydrogen could develop in the UK.

22.5%

of the UK's production target for low carbon hydrogen could be reached with 3GW of nuclear power

Figure 4: A Vision For Nuclear-Enabled Hydrogen Roll-out In The UK



- Deployment of electrolysis at scale alongside existing nuclear power plants in the UK could contribute to the Government's 10 GW target, providing additional flexibility to the electricity grid from 4 GW of nuclear capacity.
- Demonstration of heat assisted electrolysis has been delivered in the UK and is close to at scale commercial deployment alongside the new build nuclear fleet.

- With tens of GWs of nuclear new build on stream, the majority is operating with flexible generating capacity producing hydrogen and electricity dependant on the demands of the integrated system operator.
- Small modular reactors are being deployed off electricity grid, generating hydrogen, ammonia, and other products for a range of market demands.
- Advanced modular reactors have been demonstrated in the UK and are used to generate a range of products, including synthetic hydrocarbons. A fleet rollout is underway to deliver the capacity of synthetic products required to meet UK and global demands.

- The UK is a global leader in production of synthetic hydrocarbons from nuclear and hydrogen, enabling a buoyant export market and increasing global energy security.
- A fleet of large-scale reactors, small modular reactors and advanced modular reactors operating alongside a range of hydrogen production technologies is producing a range of products to meeting UK and global needs.
- Capacity is assured for decades to come as a result of the long lifetime of nuclear reactors.

NEH's Role in Energy Security

Energy security has come increasingly under the spotlight in recent months and is becoming a key consideration for the UK's energy future. NEH can offer numerous levels of energy security through its diversity of supply.

The feedstock for the process, uranium, is mined in a few key regions with whom the UK has strong relations. Currently, the UK's major suppliers operate in Australia, Canada and Kazakhstan. The UK has well established capability in processing uranium to create a fuel which can be stored for long periods until needed in the nuclear power plant, where normally multiple years' worth of fuel are already stored on site. As such, it is possible to maintain a buffer of months or even years of processed uranium throughout the supply chain to combat potential supply side issues. These three aspects - strong supplier relations, domestic processing capability and long- term storage of fuel - result in high energy security.

NEH provides predictable hydrogen production, reducing the need for inter-seasonal storage of hydrogen and hydrogen-based products. These energy security attributes of the UK's nuclear supply chain mean that NEH offers a route to clean hydrogen that can weather global energy supply issues.

NEH provides predictable hydrogen production, reducing the need for inter-seasonal storage of hydrogen and hydrogen-based products

Beyond security of supply, the scale of NEH and variety of products that can be made affords the opportunities to develop future export markets, where the UK can be a global leader in the development and deployment of the technology.

Ammonia: NEH is well situated to provide large scale ammonia production due to the high temperatures that are required for ammonia production and which are a feature of the nuclear energy generation process. Whilst ammonia has been identified as a promising energy carrier for decarbonising marine shipping, its adoption would currently be constrained by an ability to scale up. Switching just 30% of shipping to ammonia as a fuel would require a doubling of global production capacity[6].

NEH produced ammonia can also be utilised in the production of fertilisers to help decarbonise both domestic and foreign agriculture. Additionally, NEH produced ammonia can be exported, for use directly in power stations replacing coal, oil or natural gas, with transport to countries which lack indigenous energy production (e.g. Japan).

Synthetic Aviation Fuel (SAF): Low-carbon heat from nuclear energy can drive direct air capture with high efficiency (and as AMRs will operate at higher temperatures than other nuclear reactors, further efficiencies are likely to be realised). The captured carbon can then be combined with hydrogen to create SAF using globally proven processes at a scale of production required to decarbonise aviation.

Liquid Hydrogen: Liquefication of hydrogen to enable global distribution will require large amounts of additional energy, yet could provide a valuable export market analogous to current LNG supply chains, although it is likely that much of this opportunity could be achieved via NEH produced ammonia. NEH would be uniquely placed to support this through co-location at shipping terminals and being able to offer direct heat integration for compressors and associated components in a system, improving overall system performance.

6 https://www.lr.org/en/insights/articles/decarbonising-shipping-ammonia/

The Role for Public / Private partnerships

The key role for Government lies in enabling actions for NEH. Key recommendations for bringing NEH into the energy mix by 2030 and enabling future growth of the energy vector encompass accelerators for NEH, industrial Clusters and NEH, and Incentives for NEH.

Accelerators for NEH: The UK HFCA calls for Government to facilitate the scale up of NEH, including making more sites available for nuclear, and allowing more operator organisations in the UK to meet this need. Sites previously identified as having potential for nuclear could provide up to 90% of 2050 zero carbon hydrogen demand[7], but this may be challenging with just one operator. Steps should be taken to ensure the UK has domestic organisations that can operate NEH facilities.

90%

of 2050 zero carbon hydrogen demand could me met through sites previously identified for nuclear power

The Government has provided a £100 million of funding to support the continued development of the Sizewell C project in Suffolk[8] and has established a partnership for SMR's with a consortium led by Rolls Royce. Through match funding, the Government is offering £210 million towards this project, which will be met with £280m million from private partners. This forms part of a commitment laid out in the Prime Minister's 10-point plan, where the UK announced £385 million of match funding for SMRs along with up to £170 million for R&D for AMRs - which offer considerable efficiencies for NEH. Along with match funding, there should be a mechanism in place to support the early stages of projects to develop NEH such as feasibility and FEED studies.

£210m

towards the Rolls-Royce SMR project

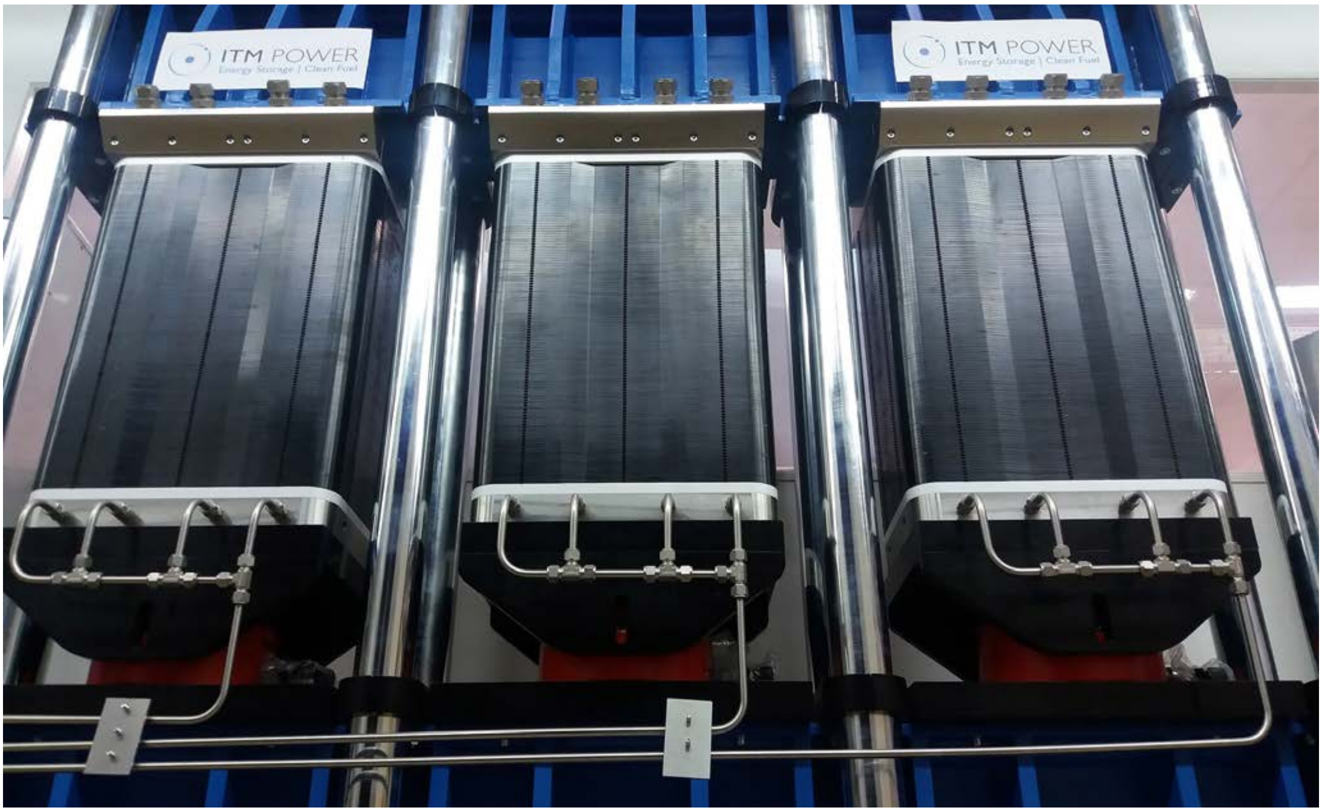
Industrial Clusters and NEH: NEH in industrial clusters brings unique synergies to the UK's hydrogen plans in this area. BEIS should work to promote the use of NEH in industrial clusters, establishing which sites in these clusters are suitable for NEH. Special attention should be paid here to ensure that the UK can reap the benefits of co-located NEH with industrial clusters in the long-term decarbonisation of industry and maritime shipping.

Incentives for NEH: Whilst the development of NEH facilities will take time, actions should be taken now to ensure that NEH is fully considered for low carbon hydrogen production. In order to signal to industry that NEH will be a future energy vector, there should be extensions to all

7 https://d2umxnkyjne36n.cloudfront.net/insightReports/PPSS-Summary-Report-with-Peer-Review.pdf?mtime=20160908160324
8 https://www.gov.uk/government/news/government-readies-sizewell-c-nuclear-project-for-future-investment

incentives associated with low carbon hydrogen to include NEH in its scope. This should include the RTFO, Hydrogen Business Model, and the Net Zero Hydrogen Fund.

Contracts for difference (CfDs) have been a key enabler for the UK's offshore wind sector and have helped drive costs down over the past decade. This approach was also successfully applied in the biomass sector[9]. More recently, Hinkley Point C has received a CfD to guarantee a strike price for a 35 year period[10]. Government should recognise the differences associated with large-scale, long-term capital build projects like nuclear and make use of a range of financing support mechanisms as appropriate. This should include application of the Regulated Asset Base model, which shares risks between developers, government and energy users, to enable lower cost buildout of nuclear power. The application of different financing mechanisms should be considered on a case-by-case basis for nuclear technology generations as the rollout of SMRs and AMRs progresses in the UK.



9 https://renewablesnow.com/news/ec-to-assess-cfd-for-645-mw-drax-biomass-plant-in-uk-508208/#:~:text=Drax%20is%20working%20to%20convert%20to%20biomass%20three,of%20electricity%20falls%20below%20a%20pre-determined%20strike%20price.

10 https://www.nuclearinst.com/Events/Branch-events/london/Hinkley-Point-C-the-Contract-for-Differences-agreement-/44862#:~:text=The%20Contract%20for%20Differences%20was%20perhaps%20the%20most,output%20of%20Hinkley%20Point%20C%20for%2035%20years.

About the UK HFCA

The UK HFCA is the leading pan-UK hydrogen association, dedicated to supporting stakeholders across the entire value chain of both the Hydrogen sector and the Fuel Cell industry. Our 80+ members represent over 200,000 employees globally, with combined revenues over £400 billion, and cover the entire value chain from raw material sourcing, to supply chain and components, financing, professional services, B2B and consumer facing solutions. With over 15 years of experience, the UK HFCA is a leader in advocating for and accelerating the transition to Net Zero in the UK through the deployment of hydrogen and fuel cell solutions. Our mission is to help grow the industry and our members' activities in the UK and beyond, and achieve the best policy outcomes for the industry across the full range of applications and opportunities.

Executive members

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