Written Evidence Submitted by Imperial College London

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1. Nigel Brandon OBE FREng is Dean of the Faculty of Engineering at Imperial College London. His research is focused on electrochemical devices for energy applications, with a particular focus on fuel cells, electrolysers, and batteries. Nigel is a Director of the Hydrogen and Fuel Cells SUPERGEN Hub, a founder of Ceres Power, a UK AIM listed fuel cell company spun out from Imperial College in 2000, chair of the Sustainable Gas Institute at Imperial College, and a founder of RFC Power, a flow battery company spun out from Imperial College in 2018. He was awarded the Royal Academy of Engineering Silver Medal in 2007, the Inst Civil Engineers Baker Medal in 2011, and the ASME Francis Bacon Medal in 2014, for his contribution to fuel cell science and engineering.

Introduction

2. Hydrogen and fuel cell technologies are a growing focus in many countries, with the aim of achieving a low-carbon energy system in the future. The emergence of these sectors presents a demonstrably significant economic opportunity to the UK.

3. The carbon credentials of hydrogen depend on its production route – fossil derived hydrogen retains a carbon footprint unless carbon abatement is used. Zero carbon hydrogen can be produced via electrolysis using zero carbon electricity, such as from renewables.

4. Hydrogen can also be carried in other forms, such as ammonia, which offers potential benefit when transporting over long distances.

5. The UK is well-placed to develop and secure some of the economic opportunities associated with this market both in the UK and abroad, as part of the UK government's focus on clean growth.

6. Hydrogen is important because it is one very the few available zero-carbon vectors for decarbonising economies. The UK Government's Clean Growth Strategy and the UK Committee on Climate Change have identified hydrogen as the most cost-effective option for decarbonising several parts of the UK energy system, alongside increased electrification using low carbon electricity.

7. The government's investment in projects thus far will be helpful in promoting the public perception of new hydrogen technologies by demonstrating the technical feasibility of technologies. However, new policy framework and financial incentives are required in order to enhance the competitiveness of hydrogen technologies in the energy sector, and to encourage private investment in technology scale-up and supply chain development, along with government investment in underpinning science and skills provision to support the sector as it grows.

Potential future markets

8. We have identified a number of potential future markets for hydrogen and for fuel cells:

- Fuel cells are well-suited to heavy-duty trucks and buses and could power cars and trains.
- The gas networks could be converted to deliver hydrogen instead of natural gas to homes and businesses for low or zero carbon heating.
- Iron and steel, chemical feedstocks, and high-temperature processes could mostly be altered to use hydrogen rather than current carbon based feedstocks.
- Hydrogen could help integrate renewables, such as offshore wind, and provide energy storage and flexible peak generation. [1]

The current situation within the UK

9. The UK has globally leading companies in the sector, manufacturing (small volumes) of product and attracting investment from both the financial markets and leading international companies. The UK also has a strong underpinning science base in the sector. There is an opportunity to grow this area and to develop an export-focused hydrogen industry over the next few decades, creating value and jobs within the UK, as well as supporting our own de-carbonisation ambitions.

10. A weak future UK market for H2FC (hydrogen/fuel cell) technologies is a key issue. Many H2FC technologies are on the cusp of commercialisation, but costs are still higher than for incumbent technologies, and will only decrease with scale, supported by continued innovation. Virtually all UK companies operate in the UK market, but near-term markets are currently seen as most likely to grow outside the UK. UK policy support for the development of domestic H2FC markets is considered poorer than in the European Union, North America and East Asia. Other countries have provided grants to bridge the cost difference or have used public procurement to grow a market, with the aim of building domestic industries as future export industries. The lack of a domestic market might be one underlying reason why many companies struggle to access finance for growth. [1]

The role of universities in the innovation system[2]

11. The UK has substantial academic expertise across all H2FC research areas and produces world-leading research when measured by average citations. UK academics are globally-connected, with 60% of publications including international authors, but relatively few publications have industrial co-authors compared with competitors such as Japan. The relative focus of the UK on H2FC, relative to other energy technologies, is as strong as its principal competitors. However, academic research funding has declined to a low level, and current UK Government hydrogen energy programmes have little academic involvement. There is a lack of availability of labour with appropriate skills in the UK, which is considered worse than in competitor countries.

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[1] Opportunities for hydrogen and fuel cell technologies to contribute to clean growth in the UK – H2FC White Paper

[2] The Economic Impact of Hydrogen and Fuel Cells in the UK – H2FC White Paper

UK universities have the expertise to support innovation both through research and training, but can only carry out this role if appropriate funding is available.[1]

12. We recommend that a national Hydrogen Research Institute or similar is established to bring together academia and industry with other stakeholders to undertake the integrated research and development, and skills development, needed to progress hydrogen and its carriers.

Hydrogen and Fuel Cells in Energy Systems [3]

13. The long-term penetration of hydrogen and fuel cell technologies could vary from a few small niches to providing virtually all transport and heat demands, as well as supporting a low-carbon electricity system. Hydrogen offers a low-carbon, business-as-usual approach for consumers that alternative low-carbon technologies cannot currently match. Hydrogen and particularly fuel cell technologies have long been touted as revolutionary, but are now reaching maturity in many markets. The transition to hydrogen could be led by heat or transport, taking a decentralised or centralised approach. Any large-scale infrastructure would require government support and forward planning to cope with the scale and uncertainties involved. Transmission pipelines and distribution networks are natural monopolies and so would likely be heavily regulated. In contrast, several hydrogen refuelling stations are already in operation in the UK with distributed on-site electrolysers.

14. Fuel cell CHP has been deployed for commercial and district heat-scale technologies for several decades, and fuel cell micro-CHP is now being widely deployed with little or no subsidy in homes in Japan, South Korea and several other countries.

15. One of the UK's most valuable cleantech companies, Ceres Power, founded to commercialise Imperial research, plans to collaborate with the Bosch Group to prepare for mass production of solid oxide fuel cell (SOFC) technology. This will help drive forward the creation of sustainable and resilient electricity systems by enabling highly efficient power stations to be built and distributed throughout the grid in a decentralised fashion. Ceres takes a decentralised approach, using a licensing business model to accelerate technological advances in hydrogen through the scale and expertise of its industry partners. It is estimated that the market for decentralised power generation will be €20 billion by 2030.

Opportunities for the UK within different sectors

16. Heavy-duty vehicles, buses and taxis are better suited to fuel cells than batteries currently. The UK is already developing fuel cell buses. Public procurement of fleets of fuel cell vehicles might be justified by including the costs of environmental externalities and future cost reductions in business cases. This could underpin the development of fuel cell markets. The creation of a basic national hydrogen refuelling station network would enable the public to use fuel cell vehicles.[1]

17. The UK is at the cutting edge of understanding the opportunities and challenges of using hydrogen for heating and industry in the longer term. Minimising the cost of producing bulk hydrogen is crucial for these applications. One UK company has a leading autothermal reformer technology to produce "blue" hydrogen from natural

[3] The role of Hydrogen and Fuel Cells in Future Energy Systems H2FC White Paper

gas, with most CO2 emissions captured by carbon capture and storage (CCS). Another company has a leading electrolyser technology to produce “green” hydrogen from renewables, which is highly flexible and can facilitate the use of hydrogen storage by capturing excess generation. Creating an early market could enable the UK to develop a new export industry for both bulk hydrogen and related technologies.[1]

Focus on road transport hydrogen fuel[2]

18. Road transport fuel may offer the greatest value proposition – it is a driver for large scale implementation that can lead the way for other hydrogen and fuel cell markets. Early mass implementation will focus on the applications that offer the highest returns before seeking to supply lower margin mass applications and markets. A significant move away from current UK use of refined fuels towards hydrogen can be expected to yield a valuable increase in GDP and employment. The likely gains will come not only from the production and distribution of hydrogen in the UK but also from the range of service sector activities, including finance, involved in a potentially strong domestic supply chain.

19. There is already a strong foundation in the UK economy. The bulk of the H2FC supply chain comprises components already common to the existing electricity and gas sectors. The UK already possesses a significant element of the H2FC supply chain in terms of both manufacturing and services activity.

20. We propose that the UK builds up its H2FC transport sector to take advantage of the potential for wider economic expansion through strong UK supply chain opportunities. It will be crucial to avoid being left behind by other vehicle manufacturing countries in developing a strategy that builds on a basis of ‘make not buy’ in the introduction of new technologies.

Focus on energy storage[2]

21. Hydrogen is a key enabler for energy storage thanks to its ability to time-shift when renewables are available to when there is demand for electricity. Hydrogen can also be stored in underground caverns (a mature technology) to offer truly large scale and long term energy storage[4]. The value proposition for hydrogen and fuel cell regeneration would be much stronger if energy storage in the UK was better valued generally. Energy storage will become increasingly important as more and more intermittent primary generation facilities come online and will enable further renewables. We need to move swiftly to properly incentivise investment in energy storage generally.

Barriers to innovation and recommendations[1]

22. The UK has an opportunity to take the lead in developing a low-carbon hydrogen economy as an export industry. However there are currently barriers to innovation and a supportive policy environment will be imperative to achieve this. The weak UK market relative to other countries is a barrier to UK companies scaling-up production and reducing costs through innovation. Funding processes for companies are considered slow and excessively bureaucratic. Academic funding has been reduced

[4] British Geological Survey – Underground Storage in the UK

to a low level, despite some parts of the H2FC sector experiencing difficulties accessing skilled labour.
If UK companies do not have an opportunity to innovate, then they will not be competitive with imports as markets for hydrogen energy develop, in the UK and elsewhere, over the coming decades.

23. To encourage H2FC innovation, we will need to:

- Remove barriers and grow UK markets
- Create a strategic national UK vision for hydrogen and fuel cells
- Nurture a vibrant innovation ecosystem in the UK
- Continue to invest in innovation and manufacturing in UK companies, and in growing the supporting academic base to enable skills development and long term innovation

24. We recommend:

- Use of public procurement and subsidies if appropriate to create a market for fleets of hydrogen fuel cell vehicles
- Creation of a national refuelling station network for public and private use. It is difficult to justify the use of fuel cell vehicles if refuelling infrastructure is not available
- Examination of opportunities to use low-carbon hydrogen in oil refining, ammonia and methanol production, steelmaking, and elsewhere, as part of the new Industrial Strategy Challenge Fund (ISCF) industrial decarbonisation challenge
- Creation of a green hydrogen standard scheme for the UK to enable the value of green and blue hydrogen to be recognised by the market
- Development of a hydrogen strategy to plan for a UK hydrogen economy, and to identify opportunities to export both hydrogen technologies and green hydrogen fuel
- Development of an electrochemical strategy covering domestic and export opportunities for battery, fuel cell and electrolyser innovations
- Coordination of innovation funding from UK Research and Innovation (UKRI) and the UK Government, and how it is best invested between industry and academia, accounting for skills needs in the sector
- Creation of a “Hydrogen Partnership” to accelerate a shift to hydrogen energy systems in the UK and to stimulate opportunities for UK businesses
- Consideration of investment to create a critical mass in the hydrogen and fuel cell sectors in terms of industry/academic capacity and skills/knowledge base
- Creation of a national “Hydrogen Institute” focusing on innovations in the production, distribution and use of hydrogen (and its carriers, such as ammonia) in the energy system
- Mechanisms for UK researchers and companies to build on existing collaborations with European counterparts, and access European markets

Coordination/clustering [2]

25. Visibility of clustering provides a strong focus for investors and financial services interest and provides the type of 'anchor' business activity for domestic UK supply chain development. Geographically the UK offers a number of relatively obvious areas in which clustering may be successful and employed to nucleate the growth of a H2FC sector. UK coordination and support for an emergent H2FC sector is somewhat scattered between a number of relevant agencies, including transport, business, energy and academia.

26. Germany has chosen to adopt a single national agency – Nationale Organisation Wasserstoff und Brennstoffzelle (NOW) to coordinate and support its emerging H2FC sector. This is better suited for dealing with the cross-cutting issues that H2FC presents and the formation of a UK agency similar to that in Germany is strongly recommended.

27. Acceleration of H2FC clusters will accelerate the UK's ability to develop a valuable domestic H2FC market that cannot readily be relocated off-shore. Two linked clusters would work well, one focusing on densely populated urban deployment and a natural gas energy base, the other focusing on exploiting renewables opportunities in less densely populated areas. There is potential for the devolved governments to partner with the UK government on the latter.

Our place in the world[2]

28. It is vital that the UK continues to take part in EU H2FC development programmes in some fashion following our exit from the EU, perhaps in the manner of Norway or Switzerland. Patterns of production and wealth creation are currently being established and the UK could suffer if its indigenous players are at a disadvantage to their EU counterparts who will retain the ease of collaboration and market access.

29. No longer being part of the EU offers potential advantages: the relaxation of state aid rules under the future relationship agreement offers potential to direct and invest in the establishment of a strong domestic market. There are wider opportunities for potential UK exports in Japan, SE Asia and the US where relationships already exist.

30. We recommend that the UK Government considers boosting support to UK H2FC businesses to levels the EU-State Aid regulations would have prevented. The sector is facing strongly entrenched encumbency in the existing energy markets and often extremely high development costs. UK core H2FC companies are largely still SMEs and they will struggle in the face of competition from Japanese and other SE Asian conglomerates which have immense market power and exceptional internal R&D capabilities as well as a capacity to raise R&D finance. Many are also closely linked to state-funded research facilities. Additional tax and investment instruments would also help to bolster the probability of UK H2FC businesses growing beyond SME scale.

31. We recommend that the UK automotive sector is strongly encouraged to ensure it stays abreast of developments in H2FC vehicle manufacture and does not become left behind by Japanese and German manufacturers in particular. The UK has invested heavily in the automotive manufacturing sector and it is essential that this public investment is protected by the speedy evolution of the UK sector into H2FC vehicles. The UK government can drive this by inputting to the existing investment and support structure. There could be substantial merit in linking an H2FC industrial cluster directly to that state investment.

32. Countries such as the US, Japan, Australia, S. Korea, China, Germany and the Netherlands have ambitious plans for scaling up hydrogen technologies and developing supply chains at a national and international level - with hydrogen providing the opportunity to trade renewable energy across regions and seasons. These plans are backed up by major national investment programmes, including €9 billion investment by Germany as part of the national economic stimulus program, up to $100 million investment by the U.S. Department of Energy in two new DOE National Laboratory-led consortia to advance hydrogen and fuel cell technologies research and development (R&D) and $4.1 billion investment in hydrogen infrastructure announced by South Korea.

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