COUNCIL FOR SCIENCE AND TECHNOLOGY

MEETING NOTE: PRIME MINISTER'S COUNCIL FOR SCIENCE AND TECHNOLOGY - MINISTERIAL BRIEFING ON HYDROGEN

Timing: 18th June 2020, 14:30 – 16:30

Attendees:

Name	Role	Organisation
Minister Kwasi Kwarteng	Minister of State for Business, Energy and Clean Growth	Department for Business, Energy, and Industrial Strategy (BEIS)
Professor John Loughhead	Chief Scientific Adviser	BEIS
Professor Alan Penn	Chief Scientific Adviser	Ministry of Housing, Communities, and Local Government (MHCLG)
Professor Andrew Curran	Chief Scientific Adviser	Health and Safety Executive (HSE)
CST Members		
Professor Muffy Calder	Vice Principal & Head of College of Science & Engineering	University of Glasgow
Dervilla Mitchell	Executive chair of the UK, India, Middle East and Africa region	Arup
Professor Paul Newman	Director	Oxford Robotics Institute

Professor Dame Nancy Rothwell	President and Vice-Chancellor	The University of Manchester
Paul Stein (Chair)	Chief Technology Officer	Rolls-Royce
External Experts		
Jo Bamford	CEO	Ryse Hydrogen
Professor Nigel Brandon	Dean of the Faculty of Engineering	Imperial College London
Professor Peter Bruce	Vice-President	The Royal Society
Chris Gibson	Engineering Manager of CCUS, Hydrogen and Environmental Technologies	BP
Professor Dame Lynn Gladden	Professor of Chemical Engineering	University of Cambridge
Antony Green	Project Director of Hydrogen Gas Transmission	National Grid
Baroness Brown of Cambridge, Julia King	Deputy Chair	Committee on Climate Change
Professor Sir Chris Llewellyn Smith	Emeritus Professor	University of Oxford
Mark Neller	Project Management Director	Arup

Professor Nilay Shah	Head of the Department of Chemical Engineering	Imperial College London
Professor Benjamin Sovacool	Professor of Energy Policy	University of Sussex
The Royal Academy of Engineering		
Keyne Walker	Policy Officer	The Royal Academy of Engineering
Philippa Westbury	Senior Policy Adviser	The Royal Academy of Engineering
The Royal Society		
Daniel Callaghan	Senior Public Affairs Advisor	The Royal Society
Paul Davies	Senior Policy Advisor	The Royal Society
Elizabeth Surkovic	Head of Policy in Resilient Futures	The Royal Society
Policy officials		
Damitha Adikaari	Science & Innovation for Climate and Energy	BEIS
Matthew Billson	Science & Innovation for Climate and Energy	BEIS
James Crosby	Private Office for Minister of State for Business, Energy and Clean Growth	BEIS

Stuart Hawksworth	Centre for Energy and Major Hazards	HSE
Paul Henderson	Hydrogen Supply	BEIS
Alex Lochead	Clean Heat Directorate	BEIS
Richard Leyland	Heat and Business Energy	BEIS
Stewart McEwen	Energy Division	HSE
Rita Wadey	Industrial Energy	BEIS
Matt Williams	Clean Growth	BEIS
CST Secretariat		
Evie Ackery	Project Research Officer	Government Office for Science
Rita Haddad	Head of Secretariat	Government Office for Science
Charley Lenton-Lyons	Project Research Officer	Government Office for Science

Introduction

1. Paul Stein opened the meeting by welcoming Minister Kwasi Kwarteng, Minister of State for Business, Energy and Clean Growth, alongside the invited speakers and policy officials. He outlined the purpose of the session as follow up to advice from the Prime Minister's Council for Science and Technology on a systems approach to achieving net zero emissions by 2050.

2. The Minister had requested a more detailed discussion of the latest scientific, engineering, and technological thinking on retrofitting of homes and the development of a hydrogen economy, including key challenges, opportunities, and prospects for success. This session focused on the production of hydrogen at scale. The Minister noted a specific interest in encouraging industry investment in hydrogen.

Low carbon hydrogen production and use at scale

3. Professor Peter Bruce commenced by highlighting the different means of hydrogen production and some advantages and disadvantages of each.
    a. Grey hydrogen is well established and widely used, with costs largely linked to the price of methane. To be compatible with a net-zero system, this method would have to be combined with carbon capture and storage (CCS) to make blue hydrogen. It is helpful to look at blue hydrogen as a systems issue.
    b. Green hydrogen is also an established technology though is currently used less than blue hydrogen. The costs of producing green hydrogen are primarily linked to the cost of electricity, making it increasingly viable as the cost of renewable energy comes down.

4. Professor Bruce summarised the four main applications for hydrogen in a net-zero energy system.
    a. Transport: hydrogen is particularly promising in HGVs. It is possible to convert hydrogen to ammonia, which may have applications in shipping and aviation.
    b. Storing electricity: there is large seasonal variation in energy demand in the UK; being able to store electricity for use during peak times is thus important. Energy is required to convert hydrogen into a liquid, where it can then be stored in tanks for transport at a pressure of 350-700atm. Alternatively, hydrogen gas can be compressed and stored in underground caverns at a pressure of 70-250 bar. The round-trip efficiency of hydrogen storage (electricity to hydrogen to electricity) is ~33% of the initial energy. An alternative storage option is to convert hydrogen into ammonia, which has the benefit of being a liquid at room temperature when stored at 10atm pressure. This makes it easier to

store but more expensive to make currently. The round-trip efficiency of ammonia storage is ~25% of the initial energy.

c. Heating: hydrogen has potential application in domestic boilers, hybrid heat pumps and fuel cell combined heat and power systems.
d. Industry: one of the hardest sectors to decarbonise, hydrogen has the potential to replace carbon when converting metal ores to metals.

5. Professor Bruce detailed some of the core challenges for hydrogen production at scale, such as reducing costs and alternative production methods for blue and green hydrogen. It will also be important to investigate 'whole system' considerations, including the role and costs of CCS, the availability of materials and the circular economy, storage methods, and the development of the hydrogen transmission and distribution network.

6. Suggested industries for continued R&D support include manufacture of catalysts, electrodes, electrolysers, fuel cells, clean zero fossil chemicals and exporting energy.

7. Professor Andrew Curran described HSE's work linked to maximising the safety of hydrogen, noting an international collaborative approach to avoid issues that have previously occurred. The importance of building confidence in the community around safety was highlighted, with high costs associated with a failure in the hydrogen system. A collaborative space between researchers, industry, and regulators is necessary to determine R&D priorities. Issues around the use of methane and leakage (GHG) in blue hydrogen production must be considered.

8. Participants discussed how to make hydrogen viable at scale:
    a. As a fuel for transport, hydrogen is comparable to diesel in cost (~£6.30/kg) and capable of longer-range travel than electrical vehicles. Hydrogen buses are already in deployment and the first fleet of hydrogen trains and ferries are expected within the next five years. By building on the success of hydrogen-based transport, hydrogen could become a viable heating source in the 2030s. Construction facilities can take around two years to build and are thus a key factor to consider for timescales. A cohesive national plan remains integral in this area.
    b. CCS is expected to come into wide use in the production of blue hydrogen around 2025. Steam methane reforming is the most common method for producing grey hydrogen, though there are other reformers available that have higher scaling ability, achieve higher levels of carbon capture, and have potential to be more cost-effective for blue hydrogen such as autothermal reformers.

c. Producing hydrogen at scale will require a de-risking of the technology for investors. It is important that the UK government considers how it can achieve this, in part through guarantees (e.g. the UK's efforts on offshore wind).
d. Cost curves suggest that, whilst blue hydrogen production with CCS at scale is currently around half the price of green hydrogen, green hydrogen may become the more cost-efficient option by 2050. This is partly due to the additional costs of scaling up CCS, a potential levy on carbon production, and decreasing costs of offshore wind and electrolyser costs. Alongside cost, it will be important to factor in other considerations of blue vs green hydrogen, such as safety, public acceptability of risk and pace of deployment.

Electrolysers as a means of producing green hydrogen at scale

9. Baroness Brown began the session by highlighting the benefits of electrolyser technology:
    a. The technology produces zero-emission hydrogen, is grid friendly, can provide increased UK energy security, and generates high purity hydrogen that can be directly utilised in highly efficient fuel cells. In addition, the technology is ready to be deployed now.
    b. The 2050 energy grid will have a high proportion of renewables; modelling has shown that 40% of the time generators will be producing electricity at times when prices are very low. Storing this electricity as hydrogen improves its business case and investment appeal.

10. Professor Nigel Brandon detailed why hydrogen production at scale is beneficial for the UK, noting:
    a. An opportunity to create jobs across a variety of sectors and regions
    b. Hydrogen can make energy transport easier
    c. The UK has a well-established industry base, rapidly growing UK technology-based companies with global reach, and many emerging businesses linked to hydrogen
    d. The UK's world-class academic base, which is furthering the underpinning science and engineering for hydrogen technology
    e. Opportunities for export and inward investment

11. Cost is a significant consideration for using electrolyser technology as opposed to blue hydrogen alternatives. Data from the Offshore Renewable Energy Catapult demonstrates that costs are primarily linked to the cost of electricity and electrolyser efficiency. Continuing to develop a global supply chain will allow attractive price points for green hydrogen.

12. Baroness Brown detailed some of the global market considerations:
    a. Modelling estimates suggest a global hydrogen market worth $2.5 trillion in 2050 (~25% of which would be green hydrogen), creating 30 million jobs in the process.
    b. Germany recently committed to invest €9bn in hydrogen capability, with the aim of having 5GW worth of electrolyser capacity by 2030. Other countries with notable hydrogen strategies include China, Japan, South Korea, Australia, and the Netherlands.
    c. Estimates produced by the Offshore Renewable Energy Catapult place the potential value of UK hydrogen production in 2050 at £150bn GVA, with electrolyser exports worth an additional £100bn GVA.

13. The following were suggested as necessary for electrolyser technology to be a success in the UK:
    a. Industry supply and demand, which could be achieved through a Hydrogen Sector Deal.
    b. Confidence for private investors. This will require mechanisms for early price support and could include a national investment bank.
    c. Other key factors include major demonstrations of success, innovation support, an academic programme that supports the technology and skills needed, and an integrated strategy.

14. Discussion covered the roles of blue and green hydrogen in the future UK energy grid.
    a. It was noted that both blue and green hydrogen will have a key role, with the UK needing significant hydrogen production to meet future needs.
    b. The UK has a strength in autothermal reforming technologies, with opportunities to make clean energy by combining hydrogen with CCS. CCS through its direct links with blue hydrogen also offers the opportunity to encourage post combustion decarbonisation and also facilitate negative emission technologies such as bio energy with carbon capture and storage (BECCS) and direct air capture (DAC).
    c. Electrolysis typically produces a higher purity product than blue hydrogen. This is useful for specific applications, such as transport, but not necessary for other uses, such as heating homes. Research programmes are currently underway to develop strategies for dealing with impurities.
    d. Various electrolyser technologies are available and in different stages of development. For example, high-temperature electrolysis can provide hydrogen at a high efficiency of over 90% but technology is still early in development. Current electrolyser efficiencies are typically in the range 60-70%.

e. Some of the deployable technologies (e.g. storage options) are applicable to both blue and green hydrogen.

15. Participants covered the importance of developing market pull for hydrogen technologies:
    a. To generate market pull, the government will need to establish a sustainable economy. Mechanisms could include something like the Contracts for Difference system used by the successful Green Investment Bank and regulation reform.
    b. Once market pull has been achieved, focus can be shifted to improving aspects of the supply chain, with UK industries set up to benefit from this approach. International investment could also be expected to increase once UK companies can demonstrate potential in other areas.
    c. The Department for Transport have attempted to create demand in renewable fuels by pledging £3 billion for 4,000 zero-emission buses. If funding such as this is invested specifically in hydrogen, it could help build support from industry and increase competition. Further policy levers that could be used to increase industry investment include developing the renewable fuels obligation and reforming the Bus Services Operators Grants to increase subsides for hydrogen.

16. The UK missed out on the opportunity to be an original equipment manufacturer with offshore wind. The UK still has potential to be a global leader in hydrogen technology and own intellectual property rights for both blue and green, but the next 12 months will be crucial if the UK is to achieve this. There are also opportunities for the wider contractor and supply chain to gain experience and know how in executing these projects which will be transferable on a global scale.

Social science and industry insights on increasing hydrogen uptake

17. Professor Benjamin Sovacool detailed the importance of viewing hydrogen as a socio-technical system, considering non-technological aspects, such as market and user practices, regulations, and mass media perceptions.

18. There are different pathways we can take to transition to a hydrogen economy, which depend on a range of factors, such as the level of resource committed to its implementation. The best available hydrogen technologies should be deployed now.

19. The UK's transition from town gas to natural gas in the 60's and 70's was used as a good example of demand-side transition.

20. A recent study on the social acceptance of hydrogen in the UK showed that it was viewed less favourably than most other renewable options. This is in part due to the public having a poor understanding of different energy options.

21. Chris Gibson described the role of industrial clusters in increasing hydrogen production and infrastructure in the UK. He noted that blue hydrogen is usually produced at scale through joint ventures and the technology is mature today for large scale delivery. With CCS, blue hydrogen can be implemented at scale today with infrastructure also able to facilitate green hydrogen in the future and through these clusters other low carbon industries and new technologies will be encouraged.

22. Factors needed to move blue hydrogen projects forward to implementation include a UK roadmap for hydrogen that demonstrates UK energy transition, published business models for both CCS and blue hydrogen and new measures to stimulate end-user demand. It is crucial these factors are in place for these large projects to progress into the front-end engineering design (FEED) stage of development and then into execution.

23. Discussion covered the role of information campaigns in improving public perceptions of hydrogen. Education campaigns can be used to shape different energy transmission processes. However, to accelerate the transition, top-down coordination is required from the UK government. Smart Energy GB's smart meter roll-out is an example of where information campaigns have been insufficient on their own.

Hydrogen deployment milestones to consider on the road to net-zero 2050

24. Professor Nilay Shah noted that an important consideration with hydrogen is finding niches where the UK can excel and grow rather than tackling the most difficult issues first. To achieve this, we will need to think about whole-value chains, including hydrogen supply, transport, storage and end-use.

25. It is not conducive to focus on either green or blue hydrogen as the sole solution, but instead important to focus on implementing hydrogen at scale. Blue hydrogen production can help to build a market now, which green hydrogen will increasingly feed into as it develops. Hydrogen hubs can be established through industrial clusters. These will in turn encourage interest from other end-users and enable growth. This approach suggests that hydrogen is better deployed at a regional level and then connected nationally.

26. Producing blue hydrogen alongside CCS allows for greater reduction of CO_2 emissions and is more cost effective than CCS alone. Research has shown

that by increasing the cost of CO_2, further industry investment would be seen in hydrogen with CCS, resulting in an overall decrease in CO_2 intensity.

27. By investing in large-scale geological storage, such as salt caverns, the total system cost can be reduced by 15%. Additional resources can be saved by re-purposing existing assets, primarily the national gas network.

28. Tony Green detailed how we might re-purpose existing assets and connect industrial clusters:
    a. Plastic distribution networks are the primary focus of several existing projects, including H21 and HyDeploy. These are producing positive results with their ability to carry hydrogen. The UK's current transmission network is primarily steel, which brings challenges (e.g. embrittlement) but current results were also looking positive. In a review of hydrogen compatible assets, National Grid noted the majority of suppliers reported their assets were compatible with hydrogen with only suppliers of heat exchangers and gas turbines doubting compatibility.
    b. The UK industry is collaborating with other parts of Europe in this area. Some countries have gas transmission companies that are further ahead than the UK, including Snam in Italy, who have completed trials running hydrogen in their transmission network, and Gasunie in Holland, who have converted a feeder and have been running on hydrogen for the past 18 months.
    c. As part of a national innovation competition with Ofgem, National Grid have submitted a proposal to decommission assets and perform an offline trial using hydrogen to prove compatibility. The second phase of the project would be in deblending hydrogen from the natural gas network. This technology would allow a phased rollout of hydrogen by facilitating gas consumers using different blends of gas. For example, a power station could stay on 100% methane while a distribution network could take up to a 20% blend of hydrogen to start decarbonising heat.

29. It was noted that better visibility of advances both upstream (e.g. where hydrogen production is going to occur in the UK) and downstream processes (e.g. should we focus decarbonisation efforts on powering heat, industry or transport) in hydrogen is needed. To develop accurate modelling, there needs to be a clear end goal for hydrogen in the UK. Financial investment or a statement of intent from the UK government will encourage business models. The Energy Networks Association (ENA) have already put forward their Gas Goes Green plan to accelerate delivery of hydrogen in a net zero energy system.[i]

30. Attendees noted that Imperial College London's modelling estimates for hydrogen growth in the UK have been driven by unbiased economic analysis and systems engineering considerations. Another modelling scenario is currently being developed, which is skewed based on current hydrogen developments and likely decisions.

31. Two areas that are ready for immediate deployment include the use of fleet-based transport, which could use central refuelling facilities, and industrial clusters, which could share hydrogen infrastructure. Once these technologies meet the needs of participants, there will be an opportunity to scale up. Transport is better suited for green hydrogen as it requires a higher purity and there is lower demand. Meanwhile, industrial clusters are better suited to blue hydrogen as there is higher demand.

32. Attendees noted the importance of international collaboration, with work underway across Europe to share research on hydrogen. There is an international focus on larger range deployment of hydrogen infrastructure.

33. Discussion covered potential safety concerns around hydrogen storage and transport.
    a. It was suggested that hydrogen embrittlement is not likely to be an issue should steps be taken to mitigate risks (e.g. reducing the number of pressure cycles). The world's longest hydrogen gas pipe along the Gulf Coast, which has been active for 30 years, is run in a similar way to the UK gas system and was highlighted as an example of the safety of hydrogen.
    b. Seismic activity in storage was also deemed to be a low risk, as the UK would be expected to use offshore storage away from populations and key infrastructure.
    c. These safety issues did not exist in the UK's previous town gas system as the pressure was much lower due to a lack of national transmission system and no added pressure cycles.

Open floor discussion

34. In developing a UK hydrogen roadmap, it will be important to identify the barriers and challenges of hydrogen production at scale. For example, the supply of cobalt in batteries and precious metals in some fuel cells. A disciplined systems approach will be needed.

35. Covid-19 has made the public more aware of air quality issues. This should increase the appeal of zero-emission hydrogen-based transport, as the public experience the benefits first-hand.

36. Discussion covered how the UK might transition from incumbent to novel technology. The International Institute for Applied Systems Analysis produced a model that suggests progression is more about units of scale and market scaling than novel versus incumbent technologies. It was also noted that new technologies take on average 50-70 years to fully replace old technologies. Fast changes often occur when there is a clear benefit over previous methods. Should hydrogen transition occur quickly, critical wider factors such as skills diffusion will need to be a priority.

37. Arup have been working with industry, academia, and government to understand what is needed to develop a hydrogen economy by 2035. This work concurs that the best approach would be to start with public transport and local use, with supply systems centred on industrial clusters. This could then build out onto a national scale. Demand for hydrogen should be expected to increase in the late 2020’s as production scales up, with a shift back to green hydrogen in the 2040’s.

38. Once a market for hydrogen has been established production and distribution facilities can be improved. Whichever country can establish the market for hydrogen first will have a price advantage and have benefits in exporting. Government funding will play an important role in encouraging further investment in hydrogen, with a suggestion that current government subsidies for non-renewable fuels should be diverted to renewables such as hydrogen to increase competition in the area.

Closing thoughts from CSAs and Minister Kwarteng

39. Professor John Loughhead provided the following thoughts on points raised in the session:
    a. Starting with niches makes sense to build public and private sector acceptability of hydrogen, though some niches have existed for decades and not developed, so it is important to understand the causes of this.
    b. International collaboration will be important as the UK would find it difficult to develop all aspects of a hydrogen economy on its own. Regulations, standards, and norms will also be important factors in establishing hydrogen.
    c. There are currently enough viable technology options to focus on deployment. Blue and green hydrogen are optimally suited to different applications and will both have important roles. Linking green hydrogen with offshore wind raises potential implications for existing electricity infrastructure and the resilience of the UK energy system. Despite

sufficient technology options there is still potential for disruption, with an advance in the area such as solar to hydrogen in a single step process having the potential to transform the global landscape.

40. Professor Alan Penn reinforced the importance of receiving private sector investment, noting that more must be done to level the playing field with established fuels including the removal of hidden subsides on incumbent technologies.

41. Professor Andrew Curran agreed on the importance of international collaboration and promoting an environment where countries can share achievements and failures to learn in a systematic way. He also emphasised the need for an end-to-end funding stream with opportunities for discovery and deployment elements of hydrogen. Finally, he stressed the role of HSE in enabling new technologies and encouraged early engagement from the rest of government.

42. Minister Kwarteng thanked speakers and attendees for an informative targeted session. He brought the session to close with the following points:
    a. The transition to hydrogen can occur quickly with the right support. This is inherently a supply and demand issue with multiple avenues by which to achieve this including transportation and industrial clusters. Incentivising the supply side remains a priority, with the role of a national investment bank and Contracts for Difference system noted.
    b. The government expects to make announcements soon regarding its strategic approach to hydrogen and on funding models, linking ambitions to COP26 in November 2021.

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[i] https://www.energynetworks.org/assets/files/GGG_Launch_Doc_FINAL.pdf