THE ROYAL SOCIETY

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Commons Science and Technology Committee inquiry into the role of hydrogen in achieving net zero

Key Points

- Time is tight to deliver net zero. Reducing carbon emissions and adapting to climate change will require research, development and deployment of low carbon technologies and nature-based solutions serving biodiversity. Science drives research and development and creates deployable solutions for our low carbon future.

- Low carbon hydrogen (hydrogen produced from sources other than fossil fuels) has the potential to play a major role in achieving net zero. Increased R&D investment is needed to enable the development of the technologies needed to do this.

- However green hydrogen production should not be viewed in isolation – the production of hydrogen from sustainable electricity offers the potential to produce low carbon electro-fuels and ammonia, which in turn may offer solutions for trading renewable energy, fuelling aviation and shipping and decarbonising the production of agricultural fertilisers. These should be considered in the round.

- There will be no single technology that enables the UK to transition to net-zero, rather a mix of technologies will be needed. The UK should establish a body which can create and maintain an evidence based, living and investible technology roadmap to net zero to deliver carbon reduction and adaptation. This needs to sit outside short political cycles and draw on independent expertise from scientists, engineers, economists and others, across academia and industry for technology assessment. This type of roadmap could, for example, draw up the decision points on hydrogen investment, where is it sensible and where are there risks where other technologies would be better.

- Adequate funding that is long-term and locked-in will be critical to leveraging the scale of private sector investment that will be required for success.

1. **Introduction**

1.1. The Royal Society is the national academy of science for the UK. Its Fellows include many of the world's most distinguished scientists working across a broad range of disciplines in academia, industry, charities and the public sector. The Society draws on the expertise of the Fellowship to provide independent and authoritative advice to UK, European and international decision makers.

1.2. The Society's fundamental purpose, reflected in its founding Charters of the 1660s, is to recognise, promote, and support excellence in science and to encourage the development and use of science for the benefit of humanity. Our strategic priorities therefore are to promote excellence in science; to support international collaboration; and to demonstrate the importance of science to everyone.

1.3. The Society welcomes the opportunity to respond to the Committee's inquiry into hydrogen. There will be no single technology that enables the UK to transition to net-zero, rather a mix of technologies will be needed. This submission provides an overview of hydrogen as one of the possible pathways that together can lead to a low carbon energy future. It also provides detail on associated technologies such as ammonia and outlines the need for a technology roadmap to net zero to deliver carbon reduction and adaptation.

1.4. To avoid confusion, it should be noted that throughout this submission, the description of hydrogen or ammonia by colour (brown, blue, green etc.) refers only to the production method. The hydrogen or ammonia produced have the same properties.

2. Hydrogen

2.1. Hydrogen is the most abundant element in the Universe. On Earth, it is found in many chemical compounds, but as a gas it rarely occurs naturally. When generated as a gas it can be used as an energy carrier or vector, which at the point of use produces no carbon dioxide.

2.2. This means that the large-scale production of low-carbon hydrogen has the potential to play a significant role in decarbonising multiple parts of the energy system and ultimately the UK's target of achieving net zero by 2050. Increased R&D investment is needed to enable the development of the technologies needed to do this. But, like all low carbon technologies, it is not a cure all and should be seen as one of the many technologies that together can help move us towards net zero.

2.3. The production of low-carbon hydrogen requires the input of energy. There are two ways in which hydrogen is currently produced at scale:

- **Steam methane reforming with carbon capture and storage.** This process has been used to produce hydrogen from natural gas (and other fossil fuels) and steam for decades. The technology is well understood and is operated on an industrial scale around the world. Carbon capture and storage is an essential prerequisite if this method is to be used to produce low-carbon hydrogen, as production methods emit carbon dioxide either from the energy input or as a by-product. However, carbon capture is not 100% efficient and other methods of hydrogen production should be considered if net zero is important.

- **Electrolysis of water.** This process separates hydrogen from water using electricity in an electrolysis cell. Electrolysis produces pure hydrogen which is ideal for fuel cell electric vehicles. It has a high efficiency though many current facilities are small. This technology shows great potential to be scaled up and used as a way of converting excess electrical energy produced by renewables into hydrogen, which enables energy storage flexibility. Economic viability relies in part on the availability of sources of low-carbon, low-cost electricity. Electrolysis has the potential to be deployed to produce low-carbon hydrogen in the near to mid-term alongside steam methane reforming, provided the renewable power is available.

2.4. The hydrogen produced by these processes can then be stored and transported to where it will be used. At each stage, energy is lost in the transformation, for example the electrolysis of water might be 70% efficient, the burning of hydrogen to make electricity in a fuel cell might be 50% efficient, so the overall "loss" of energy can be large (65% in the above example). Minimising these losses is therefore an important R&D focus.

2.5. As an energy source, hydrogen can be burnt with air in an engine/turbine to generate power or fed into a fuel cell to produce electricity.

2.6. The cost of making low-carbon hydrogen depends upon the method used and the energy source. With steam methane reforming with carbon capture and storage ("blue" hydrogen) the price of methane is key. With the electrolysis of water using sustainable electricity ("green hydrogen") the price of electricity is key.

2.7. Benefits of hydrogen:

- Hydrogen can be stored in bulk, for example in underground caverns, for use later. It can also be produced and traded around the world, in a similar way as oil and gas.

- The existing gas network can be converted to be used to transport hydrogen for heating homes, which means cost savings and minimal street disruption.
- Steam methane with CCS production uses an energy source not dependent upon renewable electricity.

2.8. Issues and limitations of hydrogen**:**

- Because of its physical properties, the bulk storage and transfer of hydrogen requires the input of energy to either compress it to between 350 and 700 atmospheres pressure or to liquify it at –253C.
- Questions exist over the leakage of methane - a greenhouse gas – emitted in the steam methane reforming process.
- High integrity carbon capture and storage (CCS) is required as a prerequisite when using steam methane reforming as production methods emit carbon dioxide either from the energy input or as a by-product.
- The conversion of the gas transmission/distribution network and/or replacement of domestic appliances will be required.
- Cost - the costs of steam methane reforming hydrogen production are primarily influenced by the cost of natural gas and the costs and method of carbon capture and storage. Production costs (i.e. not including transportation through pipes, billing costs, taxes and levies) have been estimated to be in the order of 2 to 5 pence per kWh. The cost of production by electrolysis is dependent upon the cost and availability of electricity from renewable sources and is estimated to be between 4 and 9 pence per kWh. Whole system modelling will be necessary to comprehend the value of electrolysers for grid balancing and energy storage. R&D is needed to reduce the capital and operational costs, increase the lifetime of materials used and accommodate the variability of renewable electricity supply.
- The safe, efficient, effective supply and affordable storage of hydrogen.

2.9. More detailed information on hydrogen production can be found in the following Royal Society policy briefing: Options for producing low-carbon hydrogen at scale (2018). In addition, the Royal Society policy briefing Nuclear Cogeneration: civil nuclear in a low-carbon future highlights how nuclear energy (heat) could be used to produce low carbon hydrogen more efficiently.

3. **Associated technologies**

3.1. Whilst the production and use of low carbon hydrogen (blue or green) has the potential to decarbonise domestic heating and heavy transport, it is also an important stage in the production of low carbon ammonia (NH_3) and sustainable synthetic fuels and in the decarbonisation of many chemical and industrial processes, for example steelmaking. As highlighted in the previous section, there are also a number of associated technologies that are critical to its success such as energy storage. In the following paragraphs we briefly outline these technologies associated with hydrogen production. Given their close association, these should be viewed alongside any review of the potential contribution of hydrogen to delivering net zero.

3.2. Ammonia is commercially produced through the reaction of hydrogen with nitrogen in the Haber Bosch process. This has been used for many years to produce a range of chemicals, most notably agricultural fertilisers. The same process can be used to produce low carbon “green” ammonia using green hydrogen and nitrogen from the air. Ammonia is currently stored and transported in quantity as a liquid at much lower pressures (around 10 atmospheres) and temperatures (around –33C) than hydrogen. It can be burnt in air in engines to produce power (e.g., in ships) or used in fuel cells to generate electricity. The main disadvantage of ammonia is the energy lost in the production process. Care is also needed to ensure the safe handling and use of ammonia. More details can be found in the following Royal Society Policy Briefing: Ammonia: zero-carbon fertiliser, fuel and energy store

3.3. Sustainable synthetic fuels such as electro fuels (efuels) can be made by combining green hydrogen with carbon dioxide. The advantage of such fuels is that existing infrastructure and engines can be used, for example for aviation. In addition to the energy inefficiencies inherent in their production, the main disadvantage of efuels is the production of CO_2 when they are burnt. This can at least be partly offset using direct air capture technology to capture CO_2 from the air. More details can be found in the following Royal Society Policy Briefing: Sustainable synthetic carbon based fuels for transport

3.4. Alternative "direct" methods of producing ammonia and synthetic fuels, that negate the need to first produce hydrogen are being researched, however none of these are currently at a high technology readiness level.

3.5. Long term, terawatt hour scale clean energy storage will be essential to ensuring a reliable and continuous supply of electricity as more intermittent sources of electricity, wind and solar, are deployed. Whilst batteries are an excellent short-term energy storage medium, their costs and energy density currently preclude them from long term, terawatt hour storage. It is likely that bulk green hydrogen or green ammonia storage will be the most practical and cost-effective solutions, particularly if a market in the international trading of renewable energy develops.

3.6. In addition to hydrogen and the technologies directly associated with its production, there are a number of further technologies that will be crucial to successful roll-out of these to deliver net zero. These include digital technologies, from smart meters to supercomputers, weather modelling and AI, which if used effectively could deliver nearly one third of the carbon emission reductions required by 2030. Capitalising on this will require a cross-Government approach. More details can be found in the following Royal Society report: Digital technology and the planet

4. A technology roadmap to net zero to deliver carbon reduction and adaptation

4.1. As described above, there will be no single technology that enables the UK to transition to net-zero, rather a mix of technologies will be needed within the energy system. The UK should establish a body which can create and maintain an evidence based, living and investible technology roadmap to net zero to deliver carbon reduction and adaptation. This needs to sit outside short political cycles and draw on independent expertise from scientists, engineers, economists and others, across academia and industry for technology assessment (similar to the NICE process in medicine). Adequate funding that is long-term and locked-in will be critical to leveraging the scale of private sector investment that will be required for success.

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