Written Evidence Submitted by the Dalton Nuclear Institute, University of Manchester (HNZ0071)

The Government's "Ten Point Plan for a Green Industrial Revolution" document, released in November 2020 incorporated a section on "Driving the Growth of Low Carbon Hydrogen" [1, pp. 10–11]. On 4 December 2019, the House of Commons Science and Technology Committee launched an inquiry into the role of hydrogen in achieving Net Zero in the UK.

The 2050 target of achieving Net Zero nationally is an admirable, but very ambitious target, which will require a huge undertaking to achieve. However, the strategies outlined in the Ten Point Plan document [1], and subsequent Energy White Paper [2] are an excellent early step towards reaching this target. We agree with the aims and ambitions of both documents.

As a nuclear institute, our interest is understandably focused primarily on the potential roles (plural) of nuclear energy in the energy mix of the future, which are mentioned elsewhere in the Ten Point Plan [1, pp. 12–13]. There is very clearly a continuing role for nuclear power generation in providing base-load electricity generation for businesses and homes, as evidenced by the progress made on Hinkley Point C, and hopefully Sizewell C. However, the extent to which nuclear is able to contribute to decarbonisation is contingent on the specifics of secondary energy sources (i.e. energy sources such as hydrogen and electricity [3, pp. 9–10]) within the UK.

To date, the role of nuclear energy has been narrowly confined to providing base-load electricity generation, as it is economically ill-placed to accommodate the peaks in demand from the grid over a 24-hour cycle (see Figure 1). Nuclear plant have very large upfront capital costs [4, p. 30], and only become economically competitive with other generation methods over time, because of their relatively cheap fuelling costs. This is in direct contrast with gas generation, which are cheap to build, with more expensive fuel. It is therefore economically imprudent for nuclear stations to operate at anything other than maximum capacity.

This changes entirely with the government's future energy strategy regarding heating and locomotion. Not only will a shift away from oil and gas towards electrical vehicles and heating vastly raise the demand for electricity overall, it will flatten the demand curve as consumers are encouraged to charge vehicles overnight. Nuclear energy will have an alternative to costly idleness during periods of low electricity demand in the form of charging vehicles.

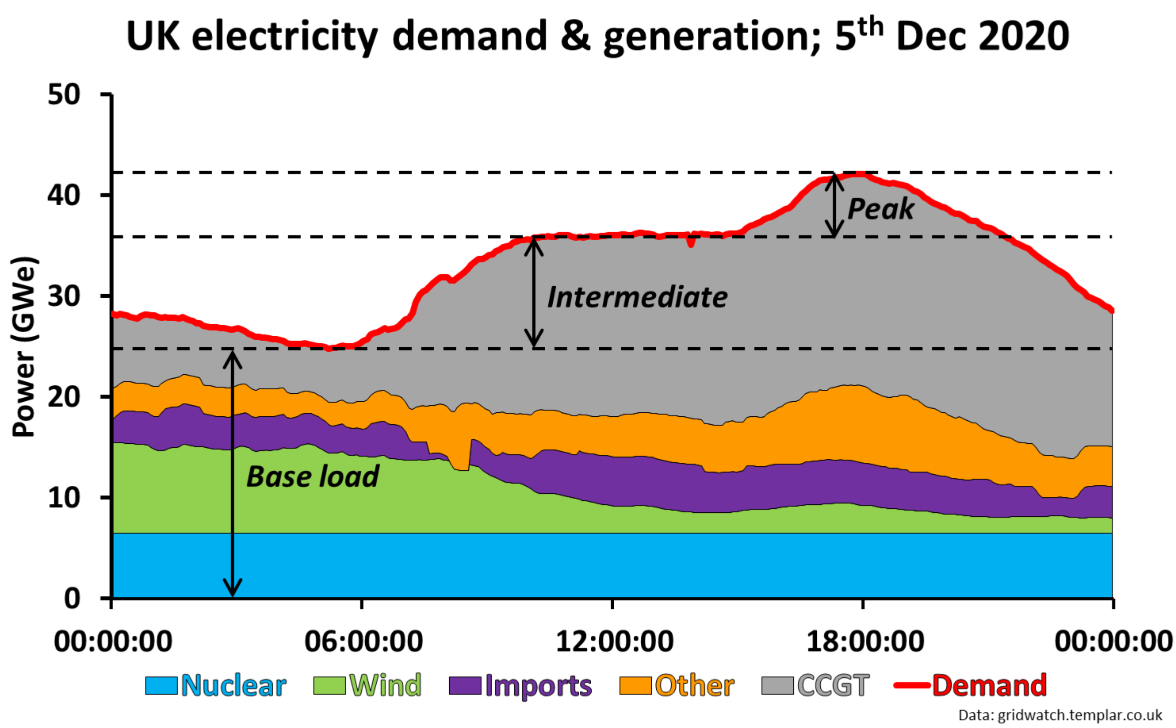

Figure 1. *An electricity demand profile from one day last month. Things to note from this plot:*
1. The base, intermediate and peak regions of electricity demand, which repeat diurnally.
2. The intermittent generation profile of wind. During peak demand on this day, wind was generating 1.5 GW from over 24 GW of installed capacity [5] *(~6% capacity).*
3. Gas (CCGT) fills the shortfall in periods of higher demand.
4. The invariant nuclear generation. Nuclear's capacity factor is at its lowest for a decade (~63% [6, p. 93]*) due to prolonged outages at two ageing stations.*
5. "Other" comprises Coal, Solar, Biomass, Hydro, OCGT and Pumped Storage.

This potential obviously also exists if hydrogen were to succeed as a secondary energy source, with nuclear plants generating hydrogen by electrolysis during periods of low electricity demand. However when considering hydrogen production more generally; nuclear energy, as a low-carbon method of producing high temperature heat, is in a position to make a unique contribution.

Figure 2 is from The Royal Society's recent report on nuclear cogeneration [7], and helps to illustrate the utility from reactors operating at high temperatures. As shown in the figure, thermochemical methods of producing hydrogen have the potential for increased efficiency, however require high temperatures (in excess of 500°C) in order to carry out. This raises two points: Firstly, the specific utility of nuclear energy to generate hydrogen efficiently; secondly, that the specific reactor system is of importance. Reactors such as Sizewell B and Hinkley Point C (under construction) are Light Water Reactors (LWRs), and operate at around 300°C, below what is needed for thermochemical hydrogen production. This highlights the importance of a holistic, coordinated energy strategy.

As stated, the reactors currently under construction are LWRs. The next development in reactor technology are Small Modular Reactors (SMRs), which operate in a similar temperature region as LWRs. Beyond this, the specific Advanced Modular Reactor (AMR) system is still undecided; having a clear national strategy regarding hydrogen will naturally inform the reactor selection process. One serious contender for an AMR demonstrator in the UK is the High Temperature Gas Reactor (HTGR) [8, pp. 135–191], which has the benefit of a high operating temperature suitable for thermochemical hydrogen production. The Japanese Atomic Energy Agency have experience with the design, largely from their work with their High Temperature Test Reactor, and have an R&D programme on conditions for production of high temperature hydrogen [9, pp. 155–173]; the IAEA provide a comprehensive overview of the field more broadly [10].

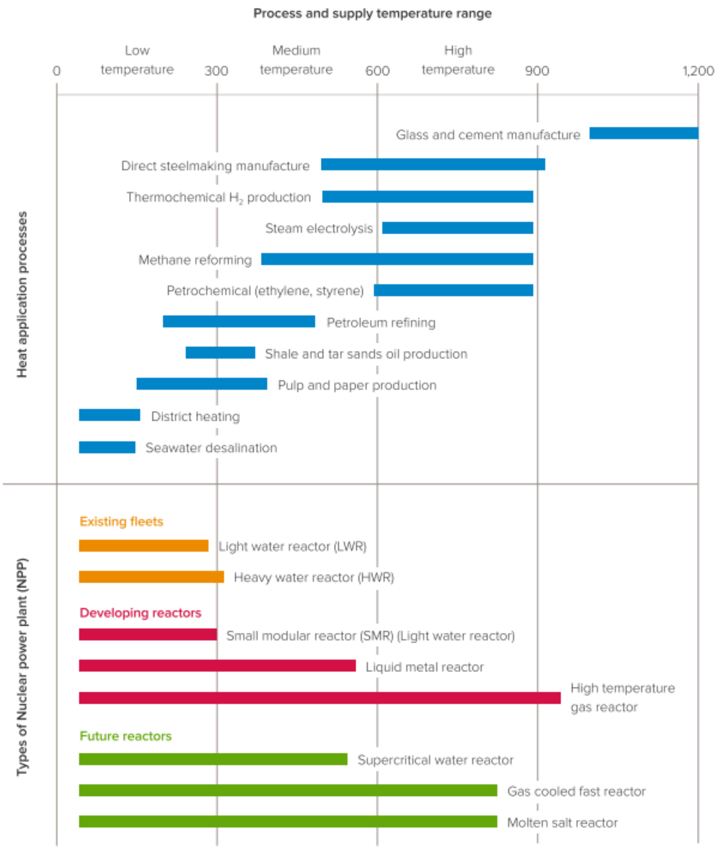

Figure 2. Temperature ranges of heat application processes and types of nuclear power plant [7, Fig. 6].

Last year's report from the Nuclear Innovation and Research Advisory Board (NIRAB) includes direct recommendations for government regarding hydrogen [11, Sec. 3.4]:

> *"Government should enable nuclear contribution to wider energy decarbonisation, by:*
>
> - *Developing a more detailed technical and commercial understanding of the role that advanced reactors can play in an evolving market for competitive low-cost heat, hydrogen and synthetic fuels;*
> - *Investing in the development of reactor systems that give access to more efficient high temperature outputs."*

…and:

> *"Government should facilitate actions to ensure that nuclear energy is fully recognised and underpinned as a credible and cost competitive route to the production of clean hydrogen."*

We strongly support the recommendations detailed from NIRAB in their report and encourage the development of a national R&D programme to facilitate the development of a demonstrator reactor; properly supported, a demonstrator reactor system could be in place by 2030. Attention should also be given to ensuring appropriate nuclear systems are pursued so as to reap the benefits high temperature nuclear can offer regarding high temperature hydrogen production.

Table 1 and Table 2 provide some estimates on efficiencies of various methods of hydrogen production, and equivalent hydrogen yields for various reactor systems. It is not immediately obvious how to compare hydrogen production from renewables with that from a thermal source such as nuclear energy. Here it is done with two steps:

1. Comparing renewables and nuclear PWRs at an arbitrary value of 100 MWe is suitable for their comparison.

2. Comparing PWRs to higher temperature reactor systems is best done with an equivalent thermal power.

This way, estimates of the equivalent production of hydrogen by different methods have been determined and are shown in the right column of Table 2.

Table 1. Candidate hydrogen production technologies

Method	Temp (°C)	Efficiency (%)	Comments
Classic electrolysis	20	40-50	***Important:*** Efficiency is <50% of the *electrical* input, which is itself <50% efficient if generated from thermal means.
Alkaline electrolysis	60-90	50-70, target >82	Already well developed; the above caveat applies.
PEM electrolysis	50-80	45-60, target 86, limit 94	High current densities possible; the above caveat applies.
Solid oxide electrolysis of steam	700-1000	75-85, target >95 (partly thermal)	No noble metal catalysts. Still at low readiness level for large scale.
Thermochemical	500-1000	40-50 (thermal)	For processes without an electrolysis step, efficiency is thermal.
Thermolysis of water	~2500	100 (thermal)	How to do it and separate O_2 and H_2?

Table 2. Potential high temperature efficiencies with reactors of different temperatures

Type		Electrical efficiency	Thermal power (MWth)	Electrical power (MWe)	Hydrogen equiv. (MWth)
Renewables		-	-	100	80
PWRs (300°C)	Electrolysis	35%	286	100	80
FR (550°C)	Electrolysis	40%	286	114	92
	Solid oxide			106	103
	Thermochemical			-	114
HTGR (750°C)	Electrolysis	45%	286	129	103
	Solid oxide			116	126
	Thermochemical			-	129
VHTR (1000°C)	Electrolysis	50%	286	143	114
	Solid oxide			122	155
	Thermochemical			-	143

If hydrogen is to make a significant contribution to achieving Net Zero, a large amount of it will be needed (of the order of tens of millions of tonnes per year to replace the UK's vehicle fuel, aviation fuel and natural gas). With such a large demand requirement, all available avenues of production must be considered, including nuclear energy.

In summary:

- Nuclear is as well-placed for electrolysis as any other technology, with its high energy density being of benefit.
- While nuclear is not mentioned within Point 2 (Hydrogen) of the Ten Point Plan, the potential for hydrogen production from advanced nuclear technology *is* mentioned in Point 3 (Nuclear Power). We must continue to acknowledge the potential of nuclear in hydrogen production.
- The emergence of hydrogen into the energy landscape would enable nuclear energy to fulfil a much wider role than simply providing baseload power; the futures of nuclear energy and of hydrogen production should therefore be considered together, not in isolation.
- Nuclear energy offers opportunities for hydrogen generation using high temperature methods which are more efficient than processes at low temperatures. These are not yet widely applied, and efforts should be made to research the feasibility of these techniques at scale.
- A wide range of Advanced Modular Reactors are proposed (from 2030) with a broad variety of applications. Attention should be paid to the utility and feasibility of the potential reactor systems available in the approach to 2050. Some specifications on the amounts of hydrogen anticipated will facilitate the development of an appropriate reactor design to fit the task of producing hydrogen.
- The government's direction as evidenced by the Ten Point Plan and the Energy White Paper are wholly sensible; the next step is to ensure this sensible direction is successfully put into practice. Continued use of expertise from bodies such as NIRAB will be invaluable in drawing up such an R&D programme.

References

[1] BEIS (Department for Business Energy and Industrial Strategy), "The Ten Point Plan for a Green Industrial Revolution," 2020.

[2] BEIS (Department for Business Energy and Industrial Strategy), “Energy White Paper: Powering our Net Zero Future,” 2020.

[3] UN (United Nations), “Concepts and methods in energy statistics, with special reference to energy accounts and balances: A technical report,” 1982.

[4] NEA (Nuclear Energy Agency) and OECD (Organisation for Economic Co-operation and Development), “Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders,” 2020.

[5] RenewableUK, “Wind Energy Statistics,” 2020. https://www.renewableuk.com/page/UKWEDhome.

[6] BEIS (Department for Business Energy and Industrial Strategy), “Digest of United Kingdom energy statistics 2020,” 2020. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/924591/DUKES_2020_MASTER.pdf.

[7] Royal Society, “Nuclear cogeneration: Civil nuclear energy in a low-carbon future,” 2020. [Online]. Available: royalsociety.org/nuclear-cogeneration.

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[9] Japan Atomic Energy Agency (JAEA) *et al.*, “Excellent Feature of Japanese HTGR Technologies,” 2018. doi: 10.11484/jaea-technology-2018-004.

[10] IAEA (International Atomic Energy Agency), “Hydrogen production using nuclear energy,” 2013. doi: 10.3327/jaesj.43.1117.

[11] NIRAB (Nuclear Innovation & Research Advisory Board), “Achieving Net Zero: The role of Nuclear Energy in Decarbonisation,” 2020.

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