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Your Gas Network

Key Insights from Imperial College's work on the impact of hydrogen for heating and resilience

Introduction

In the evolving energy landscape, hydrogen will be a crucial complement to renewable energy sources, enhancing the resilience of the energy system.

In 2023, Imperial College published their latest whole energy analysis. The purpose of the study was to understand the contribution hydrogen for heating would make to the economics and resilience of a net zero energy system. The study compares the Heat Electrification pathway with the Hydrogen pathway and used a significant number of sensitivities to test the results.

This report demonstrated that the hydrogen heating pathway was £5.4bn per year lower cost overall to deliver than an electrically heated future. This is interesting given the commonly held view that heat pumps are more efficient and therefore cheaper. The difference in cost comes when you look at the whole of the system that is required to support an electrically heated future. It simply requires more investment in infrastructure and more complex and costly changes within homes. It therefore demonstrates the importance of looking at the whole energy system when making infrastructure decisions.

Given the importance of this work, we wanted to summarise the key findings here and include some recommendations on what decisions should be made about new energy infrastructure, especially by the newly forming National Energy System Operator (NESO).

The analytical work completed by Imperial College explores two pathways. A Heat Electrification pathway where heat in buildings is supplied by electricity with hydrogen playing a role in industrial and power sector decarbonisation, and a Hydrogen pathway where hydrogen heats the majority of homes currently on the gas grid. The cost analysis is useful in that it includes network infrastructure, production and generation - the infrastructure needed to manage resilience as well as determining the cost to consumers to heat their homes.

The Role and Value of Hydrogen in Future Zero-Carbon Great Britain's Energy System

Key Findings

from the Imperial College report:

The scale of infrastructure required is huge in both pathways and potentially more challenging where all heat is electrified:

1. The Hydrogen pathway is £5.4bn less costly overall than Heat Electrification and lowest cost in every sensitivity applied.

2. Hydrogen production will need to scale rapidly to 50GW where heat is electrified or up to 80GW by 2050 with hydrogen heating - up to eight times the current 2030 10GW ambition.

3. In the Heat Electrification pathway, 84GW of dispatchable generation from low-carbon gases, hydrogen and natural gas with CCS (carbon capture and storage), will be needed to meet periods of prolonged wind drought.

4. The Heat Electrification pathway requires a more extensive distribution network, incurring an additional £3billion yearly compared to the Hydrogen approach.

5. Hydrogen storage of 6TWh is needed in both pathways; driving energy system resilience in different ways.

6. The gas (or hydrogen) network can provide £1m/day of 'free flexibility' through 'linepack in the gas network"' - supporting the whole energy system.

7. Despite heat pumps being 3-4 times as efficient as hydrogen boilers, primary energy use is only ~20% greater in the Hydrogen pathway.

These insights are helpful in demonstrating how a whole system analysis can deliver a lower cost net zero pathway when energy vectors are considered together. The way they interact enables optimised solutions to be developed.

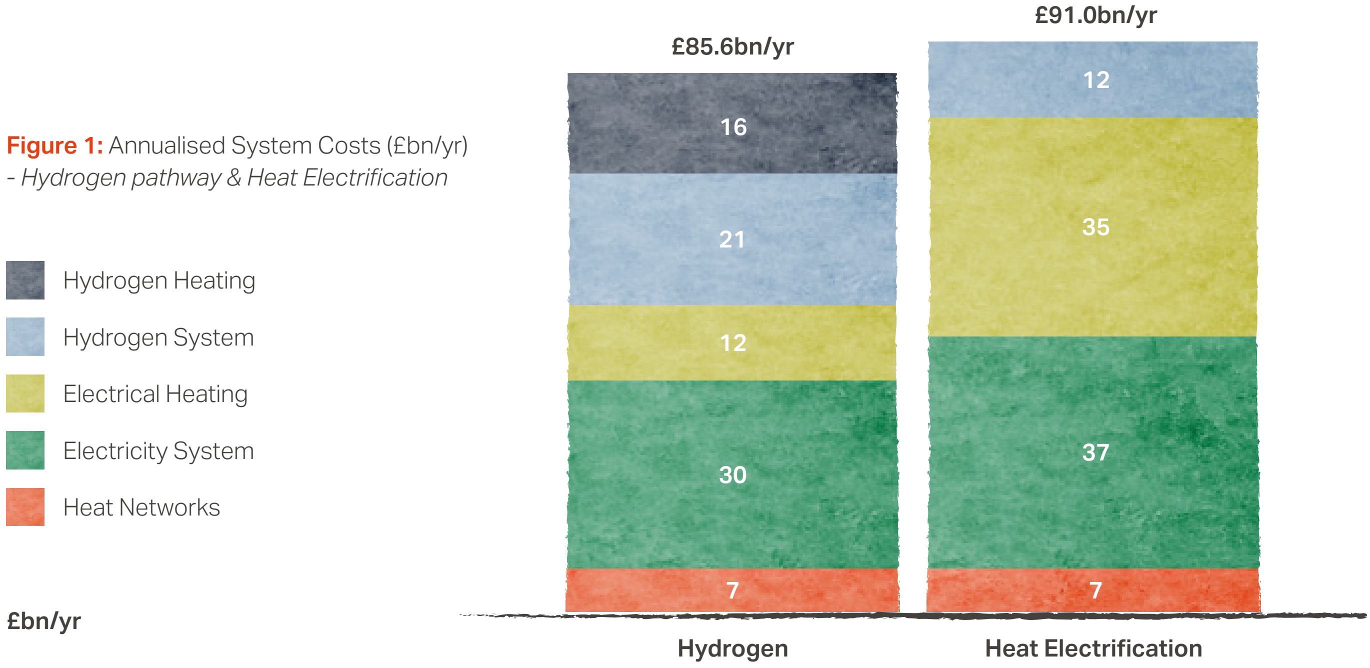
[1] Imperial College Report: The Role and Value of Hydrogen in Future Zero-Carbon Great Britain's Energy System

Finding 1

The Hydrogen pathway is £5.4bn/year less costly overall than the Heat Electrification pathway and lowest cost in every sensitivity applied.

The Hydrogen pathway (**£85.6bn/year**) is **£5.4bn/year lower** than the cost of the Heat Electrification pathway (**£91bn/year**). The cost of the overall energy system is minimised through the improved synergy across primary fuels, infrastructure and sectors of demand.

Figure 1: Annualised System Costs (£bn/yr) *- Hydrogen pathway & Heat Electrification*



In the evolving energy landscape, hydrogen will act as a crucial complement to renewable energy sources (RES) driving whole system cost-effectiveness through:

- **Enhanced Demand Matching:** Through storage of excess RES generation, hydrogen bridges the gap between supply and demand fluctuations, maximising RES utilisation and minimising curtailment.
- **Long-Term Energy Storage:** Hydrogen offers a versatile and long-duration energy storage solution, enabling efficient management of energy demand over extended periods.
- **Resilient and Dispatchable Supply:** Hydrogen power generation offers firm and dispatchable capacity, bolstering the overall reliability and responsiveness of the energy system.
- **Efficient Infrastructure Utilisation:** Integrating hydrogen heating unlocks synergies across the energy chain, optimising utilisation of generation, production, storage, and transportation infrastructure, thereby minimising system-wide costs.
- **Cost-Effective Operations:** Cross-vector flexibility, enabled by hydrogen integration, paves the way for cost-effective investment and operational strategies within the future energy system.

Imperial conducted a range of sensitivities to test the robustness of their findings. The Hydrogen pathway was the most cost effective with all sensitivities applied, including where assumed gas prices were three times higher than the base case. These sensitivity studies showed potential cost savings for the Hydrogen pathway of £2-7.3 billion/year.

Recommendation:

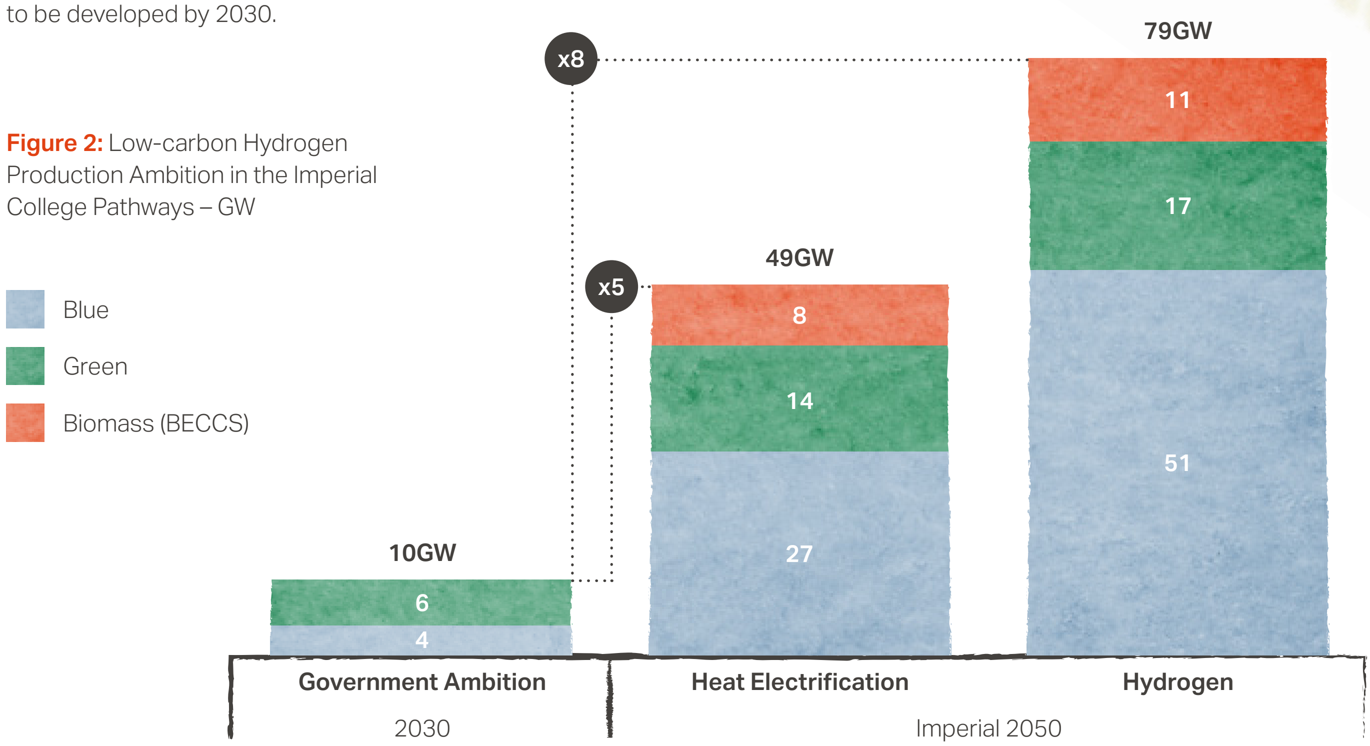
The option of hydrogen for heat should be retained whilst the UK pursues heat electrification in the short term and the hydrogen economy is established in the next ten years.

Finding 2

Hydrogen production will need to scale rapidly to 50GW where heat is electrified or up to 80GW by 2050 with hydrogen heating - up to eight times the current 2030 10GW ambition.

By 2050, 27-51GW of blue hydrogen will be needed to provide dispatchable low-carbon hydrogen. Green hydrogen (14-17GW) will facilitate energy balancing across the electricity and hydrogen systems. Up to 11GW of BECCS (bio-energy carbon capture & storage) hydrogen production is needed to contribute to the negative emissions that are critical to achieve net zero. The government has set out an ambition for 10GW of low-carbon hydrogen production to be developed by 2030.

Figure 2: Low-carbon Hydrogen Production Ambition in the Imperial College Pathways – GW



Different hydrogen production technologies can contribute different roles across the pathways. Autothermal Reformers (ATR) with Carbon Capture and Storage (CCS) produce blue hydrogen with residual carbon emissions of less than 5%. Electrolysers produce green hydrogen and enable renewable energy sources (RES) system integration by introducing flexibility at across the hydrogen and electricity systems. Electrolysis allows RES output to be converted to hydrogen and stored efficiently over long durations to supply peak hydrogen demand – for power generation, industrial demand and heat. BECCS - bioenergy with Carbon Capture and Storage, is important as a negative emissions production technology for hydrogen as well as power generation. Up to 11GW of biomass (BECCS) hydrogen production contributes to the negative emissions that are critical to achieve net zero.

The 'Business models' established by government to support hydrogen investment do not currently reflect the full role that hydrogen will play in the future energy system, focusing largely on on-site production for industrial demand. Hydrogen producers are funded based on planned production volume related to capacity. In future, hydrogen production will be a function of the need for flexibility, the availability of storage capacity and the extent of hydrogen and electricity system integration. Funding models will need to be developed that reflect the wider system cost-benefits of having flexible capacity. Importantly, investment in low-carbon hydrogen production will need to accelerate - regardless of decisions on how home heating is to be decarbonised.

Recommendation:

Hydrogen production 'business models' will require reform to reflect the value from hydrogen capacity in providing energy system flexibility.

Finding 3

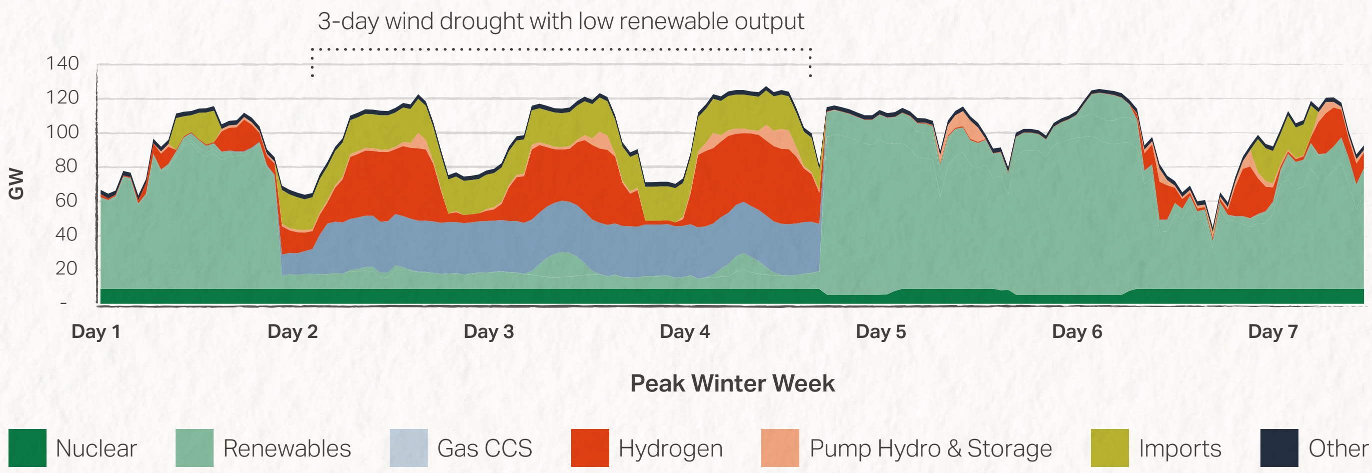
In the Heat Electrification pathway, 84GW of dispatchable generation from low-carbon gases, hydrogen and natural gas with CCS, will be needed to meet periods of prolonged wind drought.

The future energy system must be able to cope with extreme weather events. Of particular interest is the circumstance where high pressure sits across the UK in winter – this can result in the coincidence of low wind and cold weather with the consequences of low renewables output and high heat demand – sometimes called a 'dunkelflaute' or 'wind drought'.

Analysis by the MET office suggests the potential for 10-17 days of wind drought in future. Imperial's analysis includes modelling of this type of event for a 3-day period in the core pathways with the cost impact of longer duration weather events set out in the sensitivities.

During the peak demand wind drought, hydrogen-based gas turbines will generate approximately 21% of total electricity supplied to make up for the renewable deficit with additional capacity being provided by nuclear and natural gas with CCS. 84GW of dispatchable supply of low-carbon gases, hydrogen and natural gas with CCS, meet the need for flexible electricity generation. Hydrogen storage will be pivotal in both pathways to ensure supply to generation assets, industry and homes. 'In the hydrogen pathway, 56GW of dispatchable hydrogen and gas CCS generation utilises dispatchable gas and blue hydrogen supply as well as storage flexibility to meet peak electricity demand. The data shows that in the Heat Electrification pathway, a period of cold windless days will require significant flexibility including electricity storage and interconnector supply. Hydrogen provides resilience by providing a long-term energy store.

Figure 5: Peak winter electricity supply & demand, incl. a 3-day wind drought: Heat Electrification pathway



Recommendation:

The NESO should plan for integrated energy infrastructure to deliver an optimal future energy system incorporating gas, electricity and hydrogen (and CO2), enabling balancing of intermittent renewable power generation. This should include establishing an investment strategy with a security of supply standard for the electricity system that recognises the impact of heat demand under system stress conditions.

[3] MET Office: Characterising Adverse Weather

Finding 4

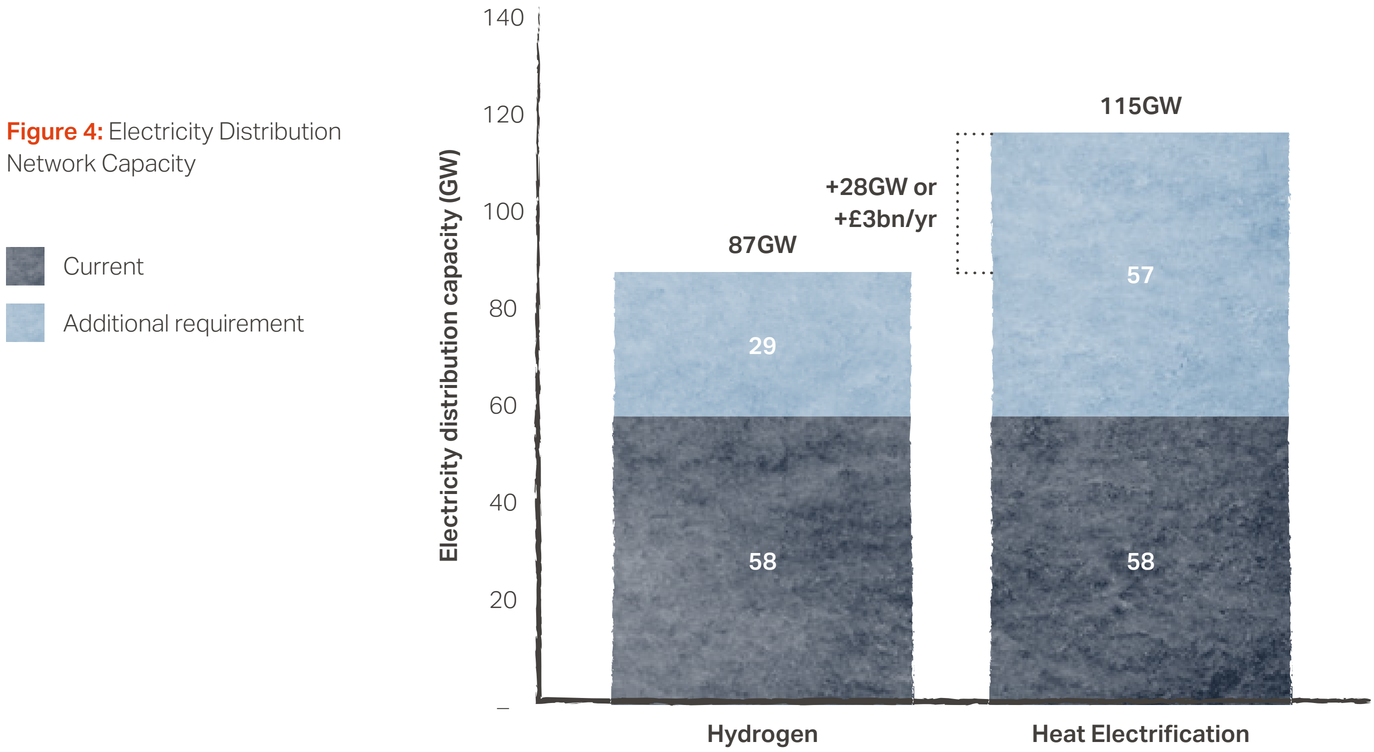
The Heat Electrification pathway requires a more extensive electricity distribution network, incurring an additional £3billion yearly compared to the Hydrogen approach.

Electricity distribution capacity will need to grow from 58GW to 87– 115GW to supply peak heat.

Growth in electricity demand for heat will necessitate major investments in network capacity. Government analysis outlines the reality: the current grid, operating at 50-60 GW, must expand to handle peak heat demand, reaching 130-190 GW by 2050. This upgrade will cost £100-£240 billion and encompass laying 210,000-460,000 km of additional cabling, both overhead and underground, potentially impacting 25-50% of local communities. Furthermore, offshore infrastructure demands an additional £110 billion, pushing the total potential investment towards £350 billion.

The Hydrogen pathway minimises electricity dependence for heating, reducing electricity infrastructure costs. Conversely, the Heat Electrification pathway requires a more extensivedistribution network, incurring an additional £3billion yearly compared to the Hydrogen approach.

Figure 4: Electricity Distribution Network Capacity



Ensuring winter warmth in Great Britain involves navigating investment options, complex technological considerations and potential community disruptions. Selecting the optimal pathway demands a balanced and meticulous assessment of cost, complexity, and local impact. The implications of critical infrastructure decisions will undoubtedly hold significant weight for years to come and be an important component of the NESO responsibilities.

Recommendation:

Detailed electricity network investment plans are urgently needed to establish cost and scale of disruption that will result from electricity network upgrades and mitigate the impact on local communities of the implied £2-3bn/yr of investment needed between now and 2050.

[2] Appendix I: Electricity Networks Modelling (August 2022) - BEIS

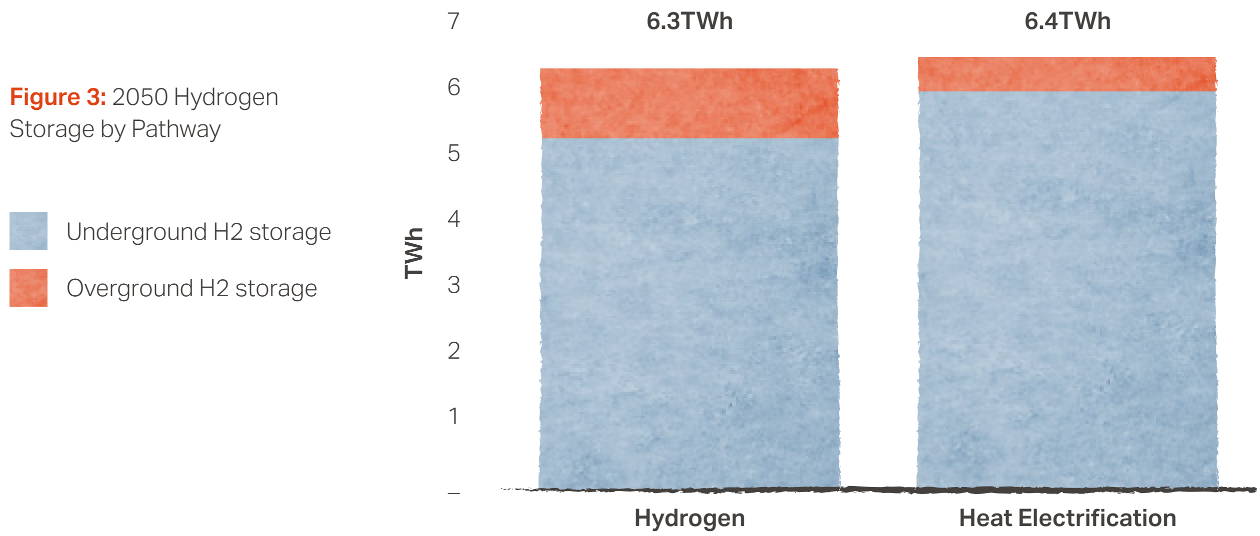
Finding 5

Hydrogen storage of 6TWh is needed in both pathways; driving energy system resilience in different ways

Storage provides long duration flexibility crucial for balancing the hydrogen system and supply for hydrogen-fired electricity generation. The main sources of hydrogen storage are set out as underground purpose-built salt caverns - which provide cost-effective storage at scale, and distributed overground hydrogen storage with pressurised vessels that help manage the variability of hydrogen pipeline operating pressure. Capacity at scale is critical to manage supply across both the hydrogen and electricity systems.

The same volume of hydrogen storage is needed regardless of the pathway for heat decarbonisation. In the Hydrogen pathway, 6.3TWh of storage is needed to shift production from summer to winter to meet heat demand for hydrogen and provide flexibility across the energy system. Whilst in the Heat Electrification pathway, 6.4TWh of storage enables intermittent renewables to generate when demand is low and provides fuel for electricity generation during winter demand peaks.

Figure 3: 2050 Hydrogen Storage by Pathway



Despite the natural advantages of favourable geology that the UK enjoys, storage development will not be straightforward. Timescales for storage development are seen as 3-5 years for pre-construction, including permitting, engineering design and contracting and 5-10 years to develop a series of caverns which are needed to achieve terawatt hour scale. This means that a strategic perspective on deployment is required from the UK government to establish a credible delivery trajectory. In the next ten years the storage required to support a net zero electricity system must be developed.

Recommendation:

The criticality of hydrogen storage should be recognised with designation as nationally significant infrastructure projects.

There should be a commitment to 2TWh by 2030 or as early as possible and at least 6-12TWh by 2040 to create supply chain confidence in investment needed for enabling development in these timeframes.

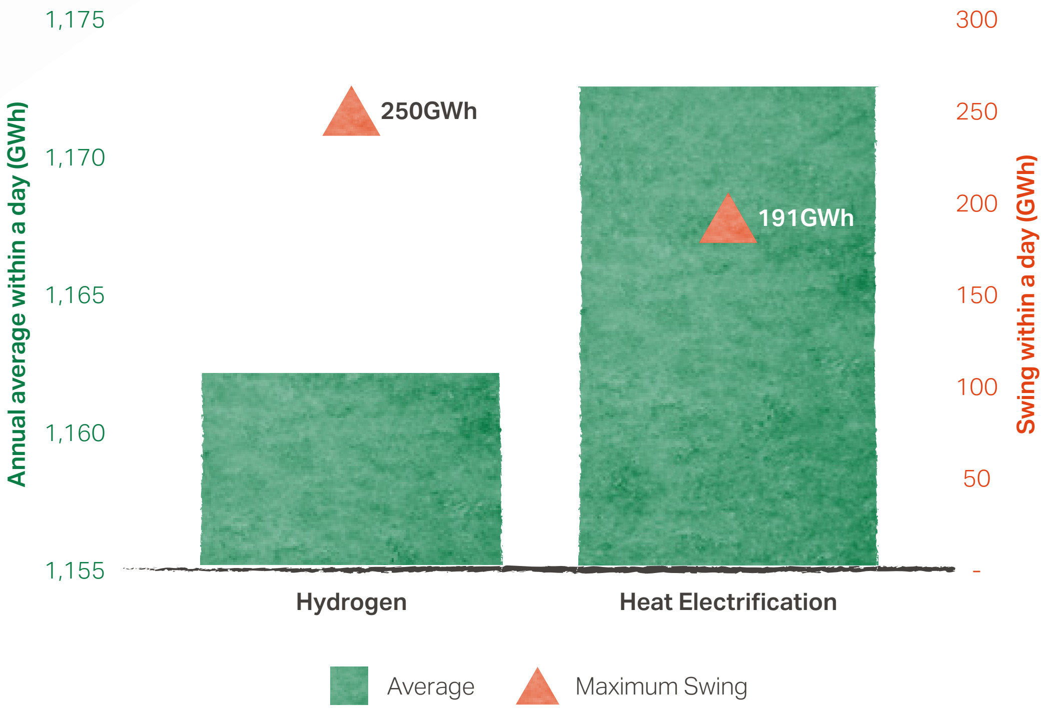
Finding 6

The gas (or hydrogen) network can provide £1m/day of 'free flexibility' through 'linepack' - supporting the whole energy system.

Hydrogen networks can unlock valuable flexibility. Network operations provide substantial energy storage in pipelines. This 'linepack' provides flexibility through varying the pressure and volume of the gas. Hydrogen's energy density is a third of natural gas and so a third of the energy can be stored in the same pipeline. This free flexibility, already available in today's gas system, complements other short-duration solutions like batteries, boosting overall system flexibility. Modelling demonstrates that a larger hydrogen network can provide even more free flexibility. By operating with lower typical linepack in the Hydrogen pathway, costs decrease while delivering 30% more flexibility –250GWh/day compared to 190GWh under Heat Electrification. To replicate 250GWh/day of flexibility with grid-scale batteries would cost £15-30bn.

Linepack will be valuable in managing diurnal swings in supply and demand and offsetting the intermittency of renewables. Linepack value is present in the Heat Electrification pathway but is markedly higher in the Hydrogen pathway.

Figure 6: Hydrogen Linepack across Pathways



Recommendation:

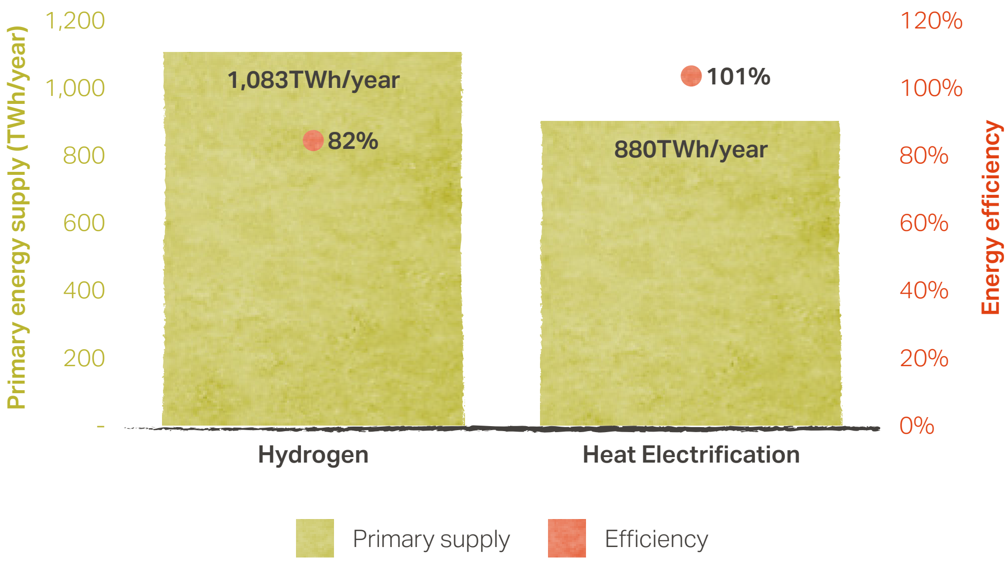
The value of storage flexibility provided by gas networks should be recognised alongside a review of whole system funding and regulation to reflect the overall system value of the gas network.

Finding 7

Despite heat pumps being 3-4 times more efficient than hydrogen boilers, primary energy use is only ~20% greater in the Hydrogen pathway.

Despite its lower primary energy consumption (880 TWh/year vs. 1,083 TWh/year, system-wide costs outstrip the Hydrogen pathway due to several other factors. Infrastructure operates with low utilisation, which inflates the capital cost of back-up generation, hydrogen production capacity, and peak electricity distribution infrastructure. Heat pumps have higher upfront costs relative to gas or hydrogen boilers. Although Heat Electrification exhibits higher primary energy efficiency (101% vs. 82%), the Hydrogen pathway achieves greater system-wide cost efficiency. This underscores the importance of whole system analysis when comparing the costs of different heat decarbonisation pathways.

Figure 7: Primary Energy Use and Whole System Efficiency



So, although heat electrification is more efficient in primary energy use, overall costs are higher. We therefore urge government to consider all aspects of a fully functioning energy system. This work by Imperial College has clearly showed that efficiency of heat pumps is not a proxy for 'lowest cost'. This is an argument often used by advocates of this technology. We would therefore expect that the evaluation of hydrogen and electrification from a Heat Policy perspective covers all aspects of efficiency, cost effectiveness, resilience, and deliverability to come to a full economic decision.

Recommendation:

In support of a future decision on heat decarbonisation, the government should assess in detail the logistics and deliverability of electricity system transformation alongside the ongoing government programme to analyse the transition of the gas network to hydrogen.

Summary of Recommendations

1. The option of hydrogen for heat should be retained whilst the UK pursues heat electrification in the short term and the hydrogen economy is established in the next ten years.

2. Hydrogen production ‘business models’ will require reform to reflect the value from hydrogen capacity in providing energy system flexibility.

3. The National Energy System Operator (NESO) should plan for integrated energy infrastructure to deliver an optimal future energy system incorporating gas, electricity and hydrogen (and CO2), enabling balancing of intermittent renewable power generation. This should include establishing an investment strategy with a security of supply standard for the electricity system recognising the impact of heat demand under system stress conditions.

4. Detailed electricity network investment plans are urgently needed to establish cost and scale of disruption that will result from electricity network upgrades and mitigate the impact on local communities of the implied £2-3bn/yr of investment needed between now and 2050.

5. The criticality of hydrogen storage should be recognised with designation as nationally significant infrastructure projects.

   There should be a commitment to 2TWh by 2030 or as early as possible and at least 6-12TWh by 2040 to create supply chain confidence in investment needed for enabling development in these timeframes.

6. The value of storage flexibility provided by gas networks should be recognised alongside a review of whole system funding and regulation to reflect the overall system value of the gas network.

7. In support of a future decision on heat decarbonisation, the government should assess in detail the logistics and deliverability of electricity system transformation alongside the ongoing government programme to analyse the transition of the gas network to hydrogen.

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