Hydrogen for heating? A comparison with heat pumps (Part 1)

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This two-part article compares the effectiveness of the options available using these methods on the basis of energy efficiency and carbon emissions (Part 1), and technology readiness and infrastructure requirements (Part 2).

Energy efficiency

Green hydrogen boilers vs heat pumps

The UK's gas consumption for domestic heating in 2021 was 318 TWh. This equates to an average national requirement for about 70GW of heat through the winter months. Two ways to deliver this heat in a low-carbon future are shown on the right side of Figure 1.

The top half of Figure 1 shows that for a green hydrogen pathway, a large amount of energy is lost as waste heat (purple arrows):

- during electrolysis, which is about 75% efficient;
- in compression and transmitting the hydrogen to end-use customers, which is particularly energy intensive for hydrogen; and
- inefficiency of the condensing boilers that burn the hydrogen to produce heat.

The overall efficiency of the process can be determined by multiplying the individual process efficiencies: 0.95×0.75×0.9×0.8×0.9 = 0.46, ie 46%. This means that to generate the 70GW of heat required on average by the UK's housing stock, 70/0.46 = 150GW of renewable electricity would be needed to power the process.

To generate 150GW of renewable electricity, approximately 385GW of installed offshore wind generating capacity would be needed. This would require a sea area of approx. 52,000 km^2, shown to scale as the blue squares on the maps in figure 1, with 32,000 of the largest (12MW) wind turbines.

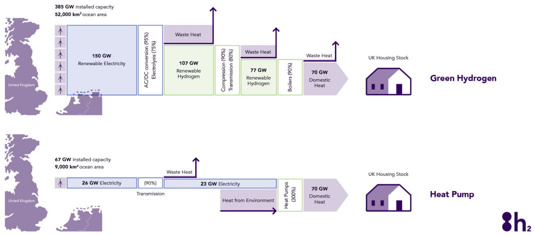

Figure 1: Providing domestic heating in the UK using either Green Hydrogen or Heat Pumps. The colours of the arrows indicate the type of energy: electricity, green hydrogen or heat. The widths of the arrows are proportional to the power flows (in units of GW). The blue boxes show scaled areas of wind turbine farms on the maps.

The bottom half of Figure 1 shows the more energy-efficient route of using the electricity directly to power heat pumps, located in consumer's houses.

Heat pumps use electricity to transfer heat from the environment into buildings. This is measured by a 'Coefficient of Performance' (COP) which is typically around 3: ie '300% efficiency'. Including 10% losses in electricity transmission, the overall efficiency of the process is approximately 270%.

So, to provide the same 70GW of heat to consumers' homes, only 70/2.7=26GW of renewable electricity would be required. This implies an installed offshore wind capacity of approximately 67 GW, requiring a sea area of 9, 000 km^2 with 5,600 x 12MW turbines.

This is still a very large amount of renewable electricity generation, but is only 1/6 of the generating capacity needed by the green hydrogen pathway. The heat pump solution will not only use 1/6 of the quantity of energy, but it will be 1/6 of the cost to run, will require 1/6 of the capital to build the generating capacity, and will generate 1/6 of the carbon emissions in-use of a green hydrogen solution.

Looking at this another way, the heat pump route is nearly six times more energy efficient than heating with green hydrogen.

What are the implications of this heat pump factor of 6?

- Consumers pay six times the price for the energy to heat their homes.
- Or, the government subsidises the cost of hydrogen heating, causing a significant drain on the economy.
- Significant environmental impact from building and operating the very large amount of electricity generation needed to produce the hydrogen.

Carbon emissions

It is commonly thought that using green or blue hydrogen for heating is zero-carbon and therefore 'clean'. This is not correct.

Even if sufficient electrolyser capacity was available to generate the hydrogen, it would be necessary to use grid-mix electricity because, as explained above, there will not be sufficient renewable electricity for decades. In the remainder of this article, we refer to hydrogen made from *grid-mix electricity* as 'green' hydrogen, though it is more strictly named 'yellow' hydrogen.

According to UK government statistics, in 2020, the carbon 'emissions intensity' of the UK grid was 136 gCO2/kWh. (Every kWh of electricity generated resulted in 136 g of CO2 emissions.) This intensity is gradually reducing as coal-fired power stations are phased out and renewable generation increases, making electricity 'cleaner' with time.

Projected future carbon emissions from heating the UK's buildings can be roughly estimated on this basis (see Figure 2). For example, in 2020:

- A heat pump delivering heat using UK grid electricity generated carbon emissions of 50g of CO2 per kWh of heat delivered.
- The figure for a green hydrogen boiler was 300g of CO2 per kWh of heat. (Again, the ratio of carbon emissions of a green hydrogen boiler to a heat pump is 300/50, i.e. the same factor of 6.)

As a further comparison, a modern condensing boiler burning natural gas generates approximately 200g of CO2 per kWh of heat delivered, which is constant with time, and an electric space heater generates about 160 gCO2/kWh.

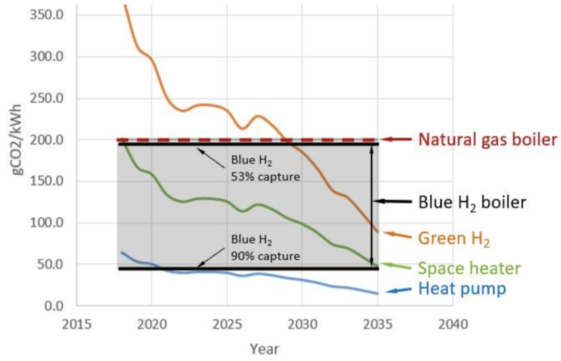

Figure 2: CO2 emissions from various heat sources.

Figure 2 shows that **in 2020, carbon emissions of green hydrogen boilers would be about 50% greater than existing natural gas boilers, with projections showing they would not start to deliver emissions lower than conventional gas boilers until nearly 2030.**

Conversely, in 2020 a heat pump would generate just 25% of the CO2 emissions of a natural gas boiler. This is expected to decrease to just 15g of CO2 per kWh by 2035.

The process of manufacturing 'blue' hydrogen, which involves CCS (carbon capture and storage), is not zero-emission, as carbon capture is not a perfect process. The most effective CCS process available results in 90% of carbon capture but has an energy efficiency of only 69%. Processes with higher energy efficiencies tend to have lower capture rates (as low as 53%). This range is shown as a shaded band on Figure 3. Manufacture of blue hydrogen also generates fugitive methane emissions which would make it impossible to reach the net-zero carbon commitments of the UK government.

Conclusions

Heat pumps use one-sixth the amount of electricity to deliver the same amount of heat to a building as a green hydrogen boiler. Consequently, the energy costs of heat pumps are one-sixth of those of hydrogen boilers. Heat pumps can deliver immediate, deep cuts in carbon emissions – they reduce carbon emissions by 75% compared to existing natural gas boilers, while green hydrogen boilers won't reach the emissions performance of a natural gas boiler until 2029 or the performance of a 2020 heat pump until around 2040.

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