Briefing on the Energy Bill

By: Hydrogen Science Coalition 28/8/2022

Introduction

This briefing on the Energy Bill is provided by members of the Hydrogen Science Coalition https://h2sciencecoalition.com/, which is a group of independent academics, scientists and engineers who are working to bring an evidence-based viewpoint to the heart of the hydrogen discussion.

We stand for supporting what the scientific evidence indicates, putting facts at the centre of any justification for using hydrogen in the energy transition.

Our aim is to ensure that any public investments in hydrogen reflect the most effective path forward in the journey towards net-zero emissions by 2050.

Our time dedicated to the Hydrogen Science Coalition is entirely voluntary and we have no public or private vested interests in our position.

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Energy Efficiency

The Bill is unclear about energy efficiency. It has a few clauses and two mechanisms that refer to energy efficiency:

(i) Powers to replace the EU 'Energy Performance of Buildings' (EPB) regime with a UK-specific version, along with powers for the Secretary of State to require *energy usage or efficiency of premises* to be assessed, certified, published and for efficiency improvements to be identified and recommended[1].
(ii) A duty on the Independent System Operator and Planner (ISOP) to promote a coordinated electricity and gas system that operates *efficiently and economically*[2]

These measures are not sufficient. Energy efficiency should be at the heart of this bill, with strong mechanisms to ensure that the most efficient energy vectors are used in the high consumption sectors, particularly home heating and transportation. The Bill should include a basket of measures to minimise energy consumption and waste in all parts of the supply chain: from generation through storage to end-use.

Energy efficiency simply means 'using less energy to perform the same task – that is, eliminating energy waste' [1]. Energy efficiency comes in many forms: insulating houses, reducing the energy consumption, reducing energy losses due to energy transformations and reducing energy losses in vehicles and appliances. Energy efficiency does **not** have to come at the expense of a reduction in utility or comfort. It is not a soft option. It is an essential part of minimising energy consumption and achieving a successful energy transition.

[1] Energy Bill Clause 198
[2] Energy Bill Clause 112

Improving energy efficiency will:

(iii) Directly reduce carbon emissions from the UK's economy;
(iv) Reduce the amount of renewable electricity generation needed to decarbonize the country, thereby speeding-up the energy transition;
(v) Reduce consumption of gas and the resulting fugitive methane and combustion CO2 emissions.
(vi) Improve the country's energy security by reducing the need to import energy;
(vii) Improve the UK's economy: Improving energy-efficiency will lower costs on both the household and economy-wide levels. This will improve the economy by increasing the financial headroom available for generating tax revenue from energy users.

Hydrogen vs electricity for heating

The **single most important area** in which to focus energy efficiency effort is in **specifying the core mechanism for heating the UK's housing stock**. If this is not done correctly, all subsequent efficiency gains in buildings and appliances will simply be 'sticking plasters' over a gaping financial wound in the economy caused by profligate waste of energy.

One of **the least energy efficient** processes possible is to convert electricity into hydrogen via electrolysis and use this to heat houses. This is shown in Figure 1, which compares two ways of heating the UK's housing stock, using renewable electricity as the starting point: green hydrogen boilers and heat pumps. The widths of the pink arrows pointing upwards in the two figures show the amount of energy waste (the opposite of efficiency) in each case.

The UK's gas consumption for domestic purposes in 2019 was 310 TWh [2]. This equates to an average national requirement for about 70GW of heat through the winter months. Both pathways modelled in the figure deliver this same amount of heat into homes at the right side of the figure. (Note that demand peaks are significantly higher than this, meaning that measures are needed to balance supply and demand. These can include: (i) demand management; (ii) overbuilding and curtailing renewables and (iii) electricity storage systems.)

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

(i) during electrolysis, which is about 75% efficient;
(ii) in compression and transmitting the hydrogen to end-use customers, which is particularly energy intensive for hydrogen [3]; and
(iii) 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: 0.95x0.75x0.9x0.8x0.9 = 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[3].

[3] This large installed capacity (385GW) would be needed because offshore wind power generation in the North Sea has a 'power factor' of approximately 39%, due to intermittency… 385GW x 0.39 = 150GW.

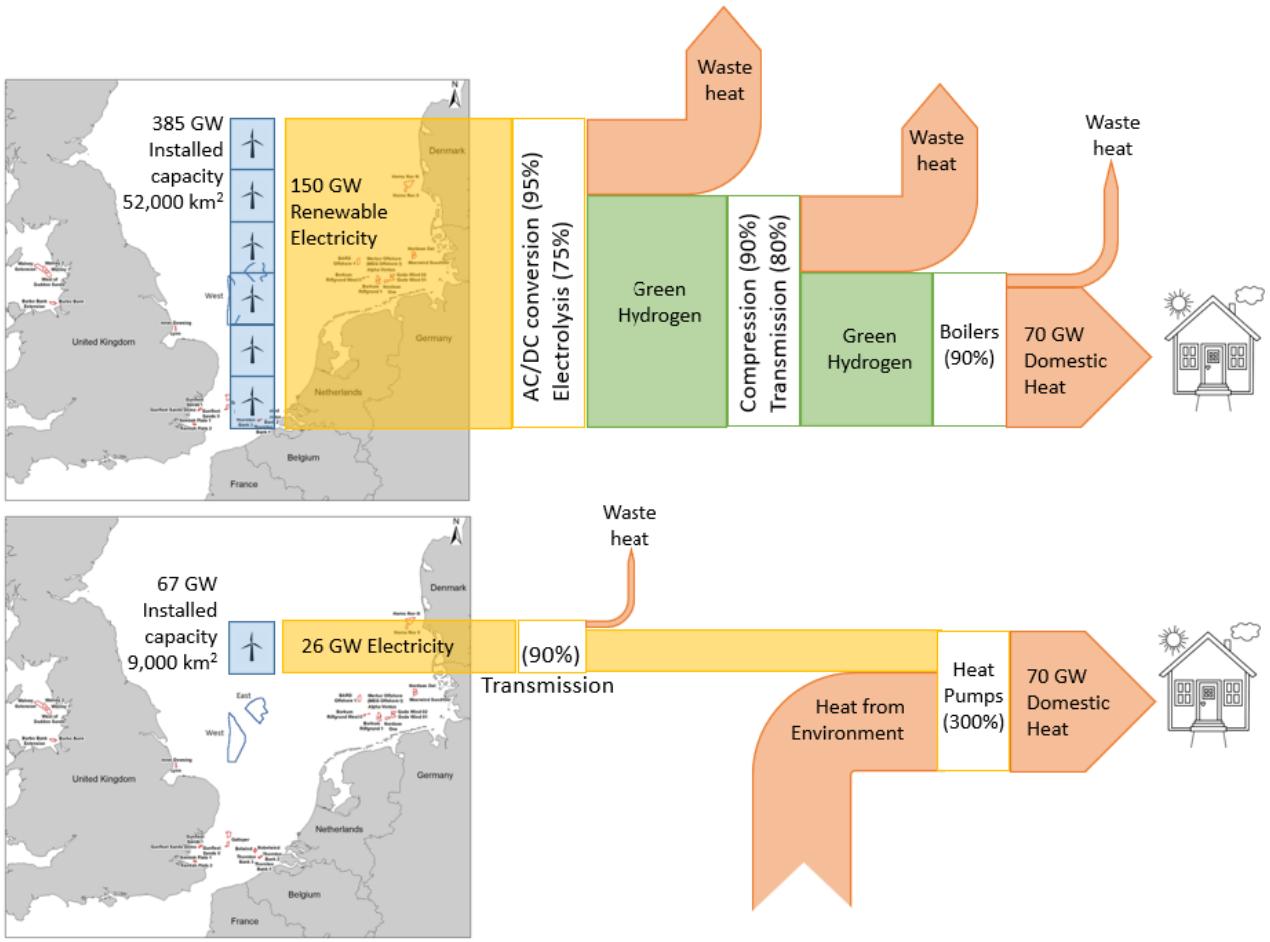


Fig. 1 Providing domestic heating in the UK using either Green Hydrogen or Heat Pumps. The colours of the arrows indicate the type of energy: electricity, green hydrogen or heat. The widths of the arrows are proportional to the power flows (in units of GW). The blue boxes show scaled areas of wind turbine farms on the maps. Red polygons on the maps are existing offshore wind turbine installations, which currently total approx. 10 GW.

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.

Conclusion: Promoting heat pumps is undoubtedly **the single most important measure that could be implemented to improve the energy efficiency of the UK. It would reduce the energy cost to the economy of heating the UK's housing stock by a factor of 6.** Choosing a hydrogen heating route would be a serious mistake for the UK economy.

Renewable electricity capacity

It is highly doubtful that 385GW of offshore wind capacity could be installed by 2050. A simple comparison of the areas of wind turbines shown to scale in Figure 1 confirms this. The current installed base of offshore wind is just 10GW, located across 38 sites (shown as red polygons in the figure). The UK's overall power consumption averaged across a year is approximately 35GW. So 385GW is more than 10 times the average annual power consumption. This is not a plausible amount of offshore wind generation under any foreseeable circumstances.

Conclusion: It is unlikely that the UK could ever build a heating system based on green hydrogen. The amount of renewable electricity required is completely impractical and the economic costs would be insurmountable.

Hydrogen safety

Risk of Explosions

Hydrogen is less inherently safe than natural gas. It has a much broader explosive range, it is much more prone to leak, it has a much lower ignition energy level, it has a significantly higher flame speed, a higher flame temperature and can produce higher over-pressures on explosion.

With the aim of proving hydrogen to be as safe as natural gas from a fire and explosion standpoint, the UKGOV commissioned work pack 7 of the Hy4Heat programme [4]. The quantified risk analysis showed that, on a like for like basis, hydrogen was 4 times more likely to result in a fatality or injury to the householder. This is clearly not consistent with the aim "to be as safe as".

To moderate the like-for-like hydrogen case, two excess flow valves must be introduced into the household hydrogen supply. These valves are designed to close if a large gas leak is experienced. The assumption is that smaller leak rates will reduce the severity of hydrogen explosions and hence cause less injuries. However, the results of the safety studies show that fire and explosion incidents remain 3 times more likely than with natural gas. But because the explosion are smaller, the claim is the frequency of injury is less, resulting in an overall risk of fatality or injury (probability x consequence) that is the same as natural gas.

That is not a sound basis for claiming hydrogen is as safe as natural gas. Hydrogen safety in a domestic setting is seriously concerning, and this is demonstrated by the UKGOV's published figures.

Nitrous Oxides (NOx)

A further issue associated with combusting hydrogen is the emission of oxides of nitrogen. Many hydrogen proponents cite that the only product of burning hydrogen is water. That is not true, air contains nitrogen and the combustion flame temperature produces side reactions where oxygen and hydrogen combine to produce NOx.

According to the DEFRA's report 'Emissions of air pollutants in the UK' [5], "Short-term exposure to concentrations of NO_2 can cause inflammation of the airways and increase susceptibility to respiratory infections and to allergens. NO_2 can exacerbate the symptoms of those already suffering from lung or heart conditions".

The higher flame temperature associated with burning hydrogen than natural gas results in *higher NOx emissions*. This further undermines the case for using hydrogen for domestic heating.

Conclusion: Introduction of hydrogen into UK homes will significantly increase the risk of serious explosions and fires as well as increasing exposure to NOx emissions which pose a significant health risk.

Compulsion to take part in hydrogen studies

There have been 18 independent studies on use of hydrogen for heating since 2019 [6], by organizations including IPCC, IEA, McKinsey, Imperial College London, Potsdam Institute, University of Manchester, Wuppertal Institute, Element Energy, the International Council on Clean Transportation, the Energy Transitions Commission, etc. **Every one of these studies** has ruled out hydrogen playing a major role in heating buildings, because it will be too expensive and inefficient compared to other clean alternatives such as heat pumps and district heating.

Under these circumstances, it is very difficult to understand why the Energy Bill includes a provision to compel homeowners to take part in hydrogen heating trials. Just how many reports and how much evidence is needed to conclude that hydrogen heating is a bad idea that should be rejected?

Conclusion: The provisions of Clause 108 of the Energy Bill 'Modifications to the Gas Code' that compel consumers to take part in hydrogen heating trials are unjustified. Home heating with hydrogen has been shown conclusively to be a dead-end and to have significant safety risks and increased exposure to health-endangering NOx emissions. This bill should not be promoting hydrogen heating trials that expose consumers to health and safety risks nor compelling consumers to take part in trials against their will.

Electrify Everything Possible

The efficiency and cost benefit of electricity over hydrogen for heating is due to a fundamental aspect of energy systems, governed by the laws of thermodynamics.

When water is electrolyzed to make green hydrogen it converts Thermodynamic 'Work' (electricity) into Thermodynamic 'Heat' (hydrogen). Thermodynamic heat is much less useful than thermodynamic work. It has half or less of the energy 'value'. Consequently, electrolysis discards at least half of the value of the electrical energy.

Some consequences of this are:

- it takes 6 times more electricity to heat a house with hydrogen than to heat the same house with a heat pump, as explained above.
- it takes about 3 times more electricity to run a green-hydrogen-powered lorry than to run a battery electric lorry and
- energy storage systems that use green hydrogen will supply electricity to the grid (or consumers) at least 2 to 3 times the cost of alternative systems such as: pumped-storage hydro-electricity, batteries or liquid air storage systems.

The reason that the hydrogen processes are fundamentally inefficient is that a large amount of valuable energy is unavoidably wasted as low-grade heat.

The lesson that can be learned from this is that promoting inappropriate use of hydrogen is probably the worst thing that governments can do for the energy transition, because it causes so much energy to be wasted. Someone has to pay for that wasted energy and that will end up being the national economy. For example, government will have to subsidize the price of hydrogen to make heating and trucking affordable.

The government should focus on decarbonising the electricity grid and promoting electrical solutions and energy efficiency wherever possible. This is a much better strategy than wasting more than half of the energy value by first converting it into hydrogen.

Consequently, policy focus should be to *electrify everything possible*: all ground transport (cars, trucks, buses and trains), home heating, coastal and short-sea shipping, short-haul aviation, industrial processes, etc.

Hydrogen should only be used when absolutely necessary: as a chemical feedstock, to make fertilizer, to process oil for polymer production and possibly for steel making.

A strategy to 'electrify everything possible' would hit many of the governments goals simultaneously:

(i) It is clean and green
(ii) It is efficient and low cost
(iii) It reduces primary energy consumption
(iv) The efficiency gains provide headroom for energy tax generation (eg to replace diesel excise duty) [7].
(v) It reduces reliance on imported energy and consequently improves energy security
(vi) It provides opportunities to create many new jobs to replace jobs lost from traditional UK manufacturing industries over the years. For example, in electric vehicle and EV charging industries; the renewable energy industry; the rooftop solar industry; electrical heating industry (heat pump manufacture and installation); high tech industries involved in electrical device design, control, management, communications and digitalization, etc.

Conclusion: The Energy Bill should include **provisions** to *electrify everything possible* and only use hydrogen where absolutely necessary, for chemical applications.

The Proposed Hydrogen Levy

To be effective in setting the market conditions needed for the country to transition to a low carbon economy, this bill should be concerned with encouraging **electrification** of everything possible and **energy efficiency**, not promoting hydrogen solutions. If there is to be a levy on electricity bills, it should be used towards these two ends and not to cross-subsidising the gas industry to develop energy-wasting, high carbon hydrogen technologies.

At a time of soaring energy prices, a poorly-conceived levy on electricity bills will cause unnecessary financial hardship for consumers. It will not be lost on consumer groups that the beneficiaries of the levy (tax) will be the hydrogen industry, which largely comprises fossil fuel interests.

Conclusion: The proposed hydrogen levy on electricity consumption and the raft of associated provisions in the Energy Bill are ill-conceived and will cause **wasteful high carbon solutions** to be promoted **instead of energy-efficient electrical** solutions. This will be highly detrimental to the national energy transition and very expensive for the economy.

Definitions of 'Clean' Hydrogen

'Clean' Hydrogen

When 1kg of hydrogen is made from methane (CH_4), it generates 10-12 kg CO_2 emissions, ie 10-12 kgCO_2/kg H_2.

The Department of Business, Energy and Industrial Strategy (BEIS) currently defines 'Clean Hydrogen' as meeting the UK Low Carbon Hydrogen Standard (UKLCHS)[4] [8]. For hydrogen to be considered 'low carbon' it must have a greenhouse gas (GHG) emissions intensity of 20g CO2e/MJLHV of produced hydrogen, or less. This is equal to 2.4 kg[5] of equivalent[6] CO_2 emissions for every kg of hydrogen, ie **2.4 kgCO_2e/kg H_2**. This level

[4] The BEIS definition accounts for greenhouse gas (GHG) emissions up to the 'point of production', including feedstock supply, energy supply, input materials, process, fugitive non-CO_2 emissions, CCS process and infrastructure, CO_2 sequestration and compression and purification.
[5] The 'Lower Heating Value' (LHV) of hydrogen is 120 MJ/kg, so 0.02 kg/MJ x 120 MJ/kg = 2.4 kgCO2e/kg H_2.
[6] Equivalent CO_2 emissions account for the global warming potential of all greenhouse gases emitted during manufacture, not just the CO_2.

is approximately one quarter of the emissions released in manufacture of grey hydrogen, so it represents approximately 75% emissions reduction compared to 'unabated' manufacture of hydrogen.

Green Hydrogen

An alternative definition of Clean Hydrogen is the 'Green Hydrogen Standard' proposed by the Green Hydrogen Organization (GH2) [9]:

> "Green hydrogen is hydrogen produced through the electrolysis of water with 100% or near 100% renewable energy with close to zero greenhouse gas emissions (**≤ 1 kg CO2e per kg H_2** taken as an average over a 12-month period)." [9]

The GH2 definition of Green Hydrogen includes 'scope 1' emissions from production, including water treatment and desalination and 'scope 2' emissions from on-site or purchased renewable electricity. According to GH2, this standard is "the only option [hydrogen definition] aligned with a 1.5 degree pathway"[7].

So hydrogen generated according to the Green Hydrogen standard would generate 1.0/2.4 = 42% of the emissions of hydrogen generated according to the BEIS 'Clean hydrogen' standard.

Yellow Hydrogen

It is commonly thought that heating using green hydrogen would be 'clean', ie near zero carbon. This is not likely to be correct. Even if there is sufficient electrolyser capacity available to generate the hydrogen, it will be necessary to use grid-mix electricity because there will not be sufficient renewable electricity for decades as explained above. Hydrogen made by electrolysis using 'grid mix' electricity is know as 'Yellow' hydrogen. It has a much higher Carbon intensity than Green hydrogen.

Is the BEIS standard clean enough?

The problem with the BEIS standard is that it is not sufficiently 'clean'. As the electricity grid is decarbonised with time and electrical systems become cleaner, 'clean' hydrogen according to the BEIS definition will rapidly become 'dirty' relative to all other solutions. Chemical engineering process plants that deliver products like blue hydrogen typically have a life span of 30 years. It is not economical to run them for shorter lives because of the cost of capital. The BEIS definition and approach will therefore build-in industries that rapidly become a problem to decarbonise in themselves, rather than being solutions to the energy transition.

An example of this issue is modelled in figure 2. Here, various energy sources for heating homes are compared in terms of their estimated future carbon emissions.

Projections of the future carbon 'emissions intensity' of the electricity grid are published by BEIS. According to the 'EEP 2018' carbon intensity projections [10], in 2022, each kWh of electricity will result in average emissions of 108 gCO_2. The 'emissions intensity' of the grid, is therefore 108 gCO_2/kWh. This grid intensity is gradually reducing as coal-fired power stations are phased out and the amount of renewable generation (wind, solar) increases. So electricity is becoming 'cleaner' with time.

The projected future carbon emissions from heating the UK's buildings can be estimated roughly using the EEP 2018 grid emissions intensity divided by the 'wind-to-heat' efficiencies in figure 1. For example, in 2022 a heat pump using grid electricity will generate carbon emissions of approximately 108/2.7=40 gCO_2 per kWh of heat

[7] The GH2 criterion is easy to understand. Since it takes approximately 50 kWh of electricity to manufacture 1 kg of hydrogen by electrolysis, the GH2 definition implies use of electricity with a low 'Carbon Factor' of 20 gCO_2e per kWh of electricity: 50 kWh/kgH_2 x 20 gCO_2e/kWh = 1000 gCO_2e/kg H_2 = 1 $kgCO_2e$/kg H_2.

delivered. As can be seen in the figure, this will fall to just 15 gCO2/kWh by 2035 due to decarbonisation of the grid.

A heating system based on 'Yellow hydrogen' (ie hydrogen made by electrolysis, using electricity from the grid) will generate carbon emissions of 108/0.46=235 gCO_2 per kWh of heat delivered in 2022. The ratio of carbon emissions from the Yellow Hydrogen boiler to the heat pump, (235/40) is the same factor of 6 as the ratio of energy efficiencies of the two process routes.

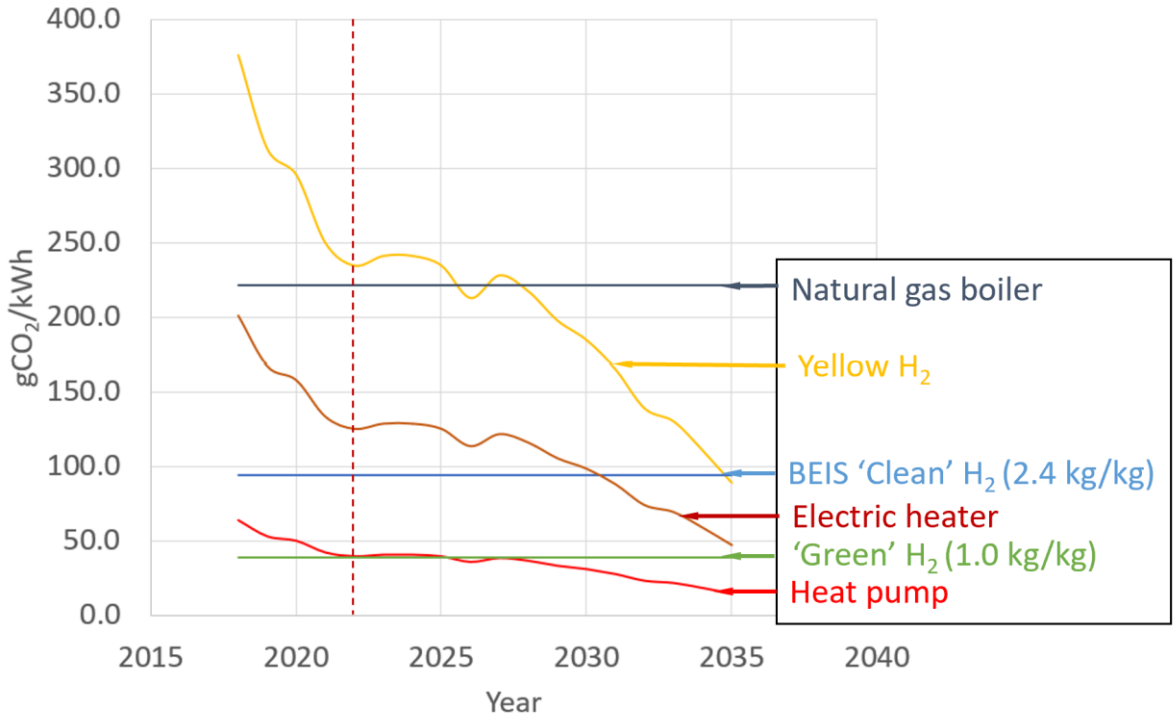


Figure 2. Projected carbon emissions generated by various possible heating energy systems, based on the BEIS 'EEP 2018' carbon intensity projections [10]. The Yellow hydrogen boiler, electric heater and heat pump are all assumed to run on grid-mix electricity, which is an appropriate assumption when considering UK-wide heating.

Similarly, a portable electric heater, that can be purchased from any high street department store, will have a 'wind to heat' efficiency of about 86% [11]. So in 2022, it will generate carbon emissions of 108/0.86 = 126gCO_2 per kWh of heat delivered. Compared to a Yellow hydrogen boiler, this is 126/235 = 54%, ie about half the emissions[8]. So if heating is to be based on electricity, a simple electric heater generates much lower carbon emissions than a hydrogen-based route. Furthermore, the electric heater is low cost, is available now, and requires no infrastructure other than possibly upgrading the existing electricity grid in places. So the case for hydrogen heating as a route to decarbonisation is difficult to justify.

Also plotted in grey on figure 2 are the levels of carbon emissions generated by a modern condensing boiler burning natural gas, which is approximately 220 gCO_2 per kWh of heat delivered; a condensing boiler that burns 'clean' hydrogen according to the BEIS standard (2.4 $kgCO_2e/kg\ H_2$) and a condensing boiler that burns 'green' hydrogen according to the Green Hydrogen standard (1.0 $kgCO_2e/kg\ H_2$). These are shown as horizontal lines in figure 2, since they are expected to stay constant with time.

Some further observations can be made from Figure 2:

[8] The same factor will apply if both the electric heater and the hydrogen boiler were powered on low carbon electricity. The electric heater will always be 54% lower than an electrolytic hydrogen boiler powered by the same electricity.

(i) Electric heaters, running on grid electricity in 2022 will generate approximately half the emissions of a natural gas boiler. The emissions of the electric heater will improve with time, while the emissions of the natural gas boiler will stay constant.
(ii) Yellow Hydrogen boilers would have approximately the same emissions as natural gas boilers in 2022: both about 220 gCO2 per kWh of heat generated.
(iii) Yellow hydrogen boilers won't reach the performance of 2022's heat pumps until nearly 2040.
(iv) Heat generated by 'green' hydrogen that satisfies the GH2 standard of 1.0 kg/kg would generate emissions at close to the same level as a heat pump in 2022, but are expected to stay at that level in future, whereas heat pump emissions will fall with time. By 2035, the green hydrogen boiler will generate 2.6 times higher emissions than a heat pump running on grid electricity.
(v) Hydrogen, satisfying the BEIS 'clean' hydrogen requirement of 2.4 kg/kg will generate emissions of 94 gCO2/kWh in 2022 and this is not expected to change in future. By 2035 this will be 6.2 times higher emissions than a heat pump run from grid electricity.

Conclusion: Although the 'clean' hydrogen standard will give a 60% reduction in carbon emissions in 2022 compared to natural gas, by 2035 a 'clean' hydrogen boiler will be generating a completely unacceptable level of emissions, 6.2 times higher than the alternative heat pump solution and just slightly less than 2022's electric space heater.

It is difficult to see the current BEIS 'clean' hydrogen standard as a real pathway to net zero by 2050, because it will never be better than 60% improvement on a natural gas boiler.

An alternative definition for 'Clean' Hydrogen

To be defined as 'Clean' in 2035, It could be argued that Hydrogen heating must at least meet the same emissions levels as the Green Hydrogen standard, ie 1.0 $kgCO_2e/kg\ H_2$. This would mean that a clean hydrogen boiler would generate emissions 18% of those of a natural gas boiler and would be cleaner than an electric space heater until around 2035. Consequently it is proposed that *the greenhouse gas emissions threshold of Clean Hydrogen should be specified to be the same as those of Green Hydrogen, ie* ***1.0 $kgCO_2e/kg\ H_2$***.

This reduction in threshold would ensure:

(i) A 'level playing field' in the Hydrogen industry: all hydrogen would meet the same emissions standards and satisfy rigorous 'net zero' emissions standards into the future.
(ii) When 'Clean' Hydrogen is used (eg for decarbonizing industry, transport or heating) it would have equally low carbon emissions, *whatever the source of the hydrogen*.
(iii) Anyone specifying systems that use Clean Hydrogen would be confident of the level of embodied carbon, without having to perform a detailed analysis of the pedigree of the hydrogen.
(iv) Best available technology would be used uniformly in hydrogen production.
(v) Any government subsidies applied to clean hydrogen manufacture would be applied in the best interests of the environment. There could be no implication of favouring fossil hydrogen over electrolytic hydrogen.

Conclusion: To ensure that future hydrogen production is sufficiently clean for heat decarbonisation needs out to 2035, the BEIS clean hydrogen standard should be adjusted to a threshold emissions value of ***1.0 $kgCO_2e/kg\ H_2$.***

Further Information

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