Briefing on the Energy Bill

By: Hydrogen Science Coalition 28/8/2022

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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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Summary

(i) The Energy Bill is unclear about energy efficiency, which should be its central policy.

(ii) Promoting heat pumps is 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 compared to the alternative of heating by green hydrogen boilers.

(iii) It is unlikely that the UK could ever build a heating system based on green hydrogen. The amount of renewable electricity required and the economic costs are both implausible. Building sufficient renewable electricity generation would indefinitely delay decarbonisation of the UK economy.

(iv) The UK would need to use 45% more natural gas for heating if the energy was delivered via blue hydrogen boilers than if the heat was delivered by natural gas boilers. Based on 2022 figures, the switch to blue hydrogen would increase the UK's natural gas imports to 66% of consumption, significantly damaging the nation's energy security. This proportion of imported gas will increase significantly in the next decade as North Sea gas production falls.

(v) Heating UK homes via blue hydrogen would increase domestic gas bills by 70% to 80%.

(vi) To ensure that hydrogen production is sufficiently clean for heat decarbonisation out to 2035, the BEIS 'Clean Hydrogen Standard' needs to be tightened to a threshold emissions value of 1.0 $kgCO_2e/kg\ H_2$.

(vii) 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 public health risk.

(viii) 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. This bill should not be promoting hydrogen heating trials that expose consumers to health and safety risks and excessively high energy costs.

(ix) 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 detrimental to the national energy transition and very expensive for the economy. The proposed hydrogen levy should be removed from the bill.

(x) The Energy Bill should include provisions to electrify everything possible and only use hydrogen where absolutely necessary, for chemical applications.

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.

Improving energy efficiency will:

(i) Directly reduce carbon emissions from the UK's economy;

(ii) Reduce the amount of renewable electricity generation needed to decarbonize the country, thereby speeding-up the energy transition;

(iii) Reduce consumption of gas and the resulting fugitive methane and combustion CO2 emissions.

(iv) Improve the country's energy security by reducing the need to import energy;

(v) 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.

Figure 1 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.)

[1] Energy Bill Clause 198

[2] Energy Bill Clause 112

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].

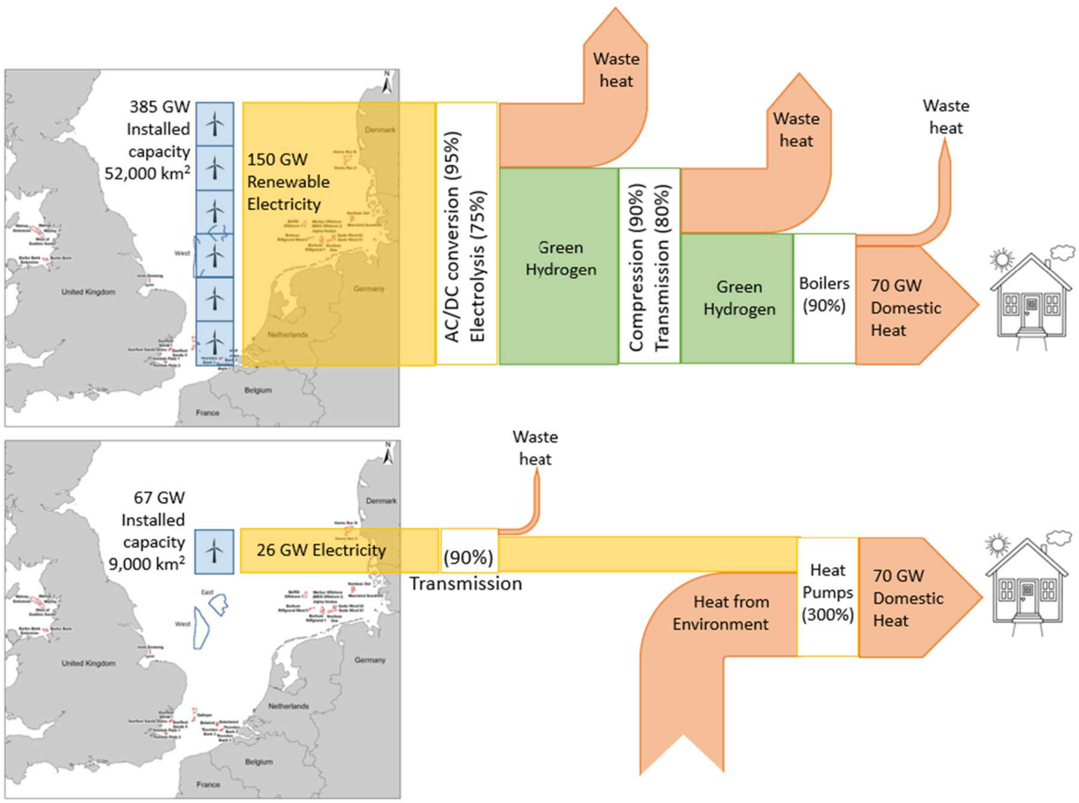

Fig. 1 Providing domestic heating in the UK using either Green Hydrogen or Heat Pumps. The colours of the arrows indicate the type of energy: electricity, green hydrogen or heat. The widths of the arrows are proportional to the power flows (in units of GW). The blue boxes show scaled areas of wind turbine 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'. This means that one unit of electricity can be used to provide three units of heat. 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.

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[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.

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.

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 11GW, 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 scenario.

'Clean' Hydrogen for heating

An alternative to green hydrogen for heating buildings might be to use so called 'clean' (blue) hydrogen, made by reforming natural (fossil) gas, and using carbon capture and storage (CCS) to dispose of the CO_2 in permanent geological storage. Such 'clean' hydrogen is a very poor choice for heating buildings for the following reasons:

(i) **Rebuilding of the Gas Grid:** As explained in Appendix A, the infrastructure required to generate and transmit blue hydrogen would require rebuilding most of the NTS (gas grid) and development of CCS at scale. The latter does not exist at all in Europe and is hardly more than experimental anywhere in the world. The 'technology readiness' of the Blue Hydrogen route is therefore low, which significantly undermines its ability to be rolled-out at scale by 2050.

(ii) **Hydrogen has a much lower energy content than natural gas** (See Appendix A). This is because stripping the carbon atoms from the methane molecule (and discarding the resulting CO_2) removes a large proportion of the energy content. Consequently it takes about 45% more natural gas to heat a house via blue hydrogen than heating it directly with natural gas.

(iii) **Using clean Hydrogen will substantially increase gas imports**: As a consequence of (ii) it will be necessary to import 143 TWh more natural gas into the UK each year, taking the imports to 66% of total consumption. This will increase dependence on overseas gas supplies, significantly degrading the nation's energy security.

(iv) '**Clean' hydrogen will be much more expensive** for heating than natural gas. As a consequence of (ii) 45% more gas will be used for domestic purposes. This is the *minimum* amount by which the cost of heating would rise for UK consumers. However, because of the high cost of manufacturing blue hydrogen, including the costs of the SMR and CCS processes, it will cost between 70% and 80% more to heat a house with blue hydrogen than with natural gas [4].

(v) **Clean' hydrogen is dirty:** The UK Low Carbon Hydrogen Standard' [5] has been defined by BEIS with the aim that fossil hydrogen used in the UK should not contribute to global warming. Appendix B to this document analyses this standard. It shows that 'clean' hydrogen according to the standard will have 60% lower carbon emissions than heating with natural gas in 2022. However this isn't nearly clean enough to decarbonise heating. Consequently, **such hydrogen will become a major obstacle to decarbonising the UK economy by approximately 2030**. Because the electricity grid is continuously decreasing in carbon intensity, by 2035 a 'clean' hydrogen boiler will generate CO_2 emissions approximately 6.2 times higher than a heat pump run on grid electricity. The only way to prevent this situation will be to tighten the specification of the Clean Hydrogen standard significantly (See Appendix B).

Hydrogen safety

Risk of Explosions

Hydrogen safety in a domestic setting is seriously concerning, and this is demonstrated by the UKGOV's own published figures [6].

Hydrogen – whether blue or green - 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 package 7 of the 'Hy4Heat' programme [6]. The quantified risk analysis showed that, on a like for like basis, **hydrogen is 4 times more likely than natural gas 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 fewer injuries. However, the results of the safety studies show that fire and explosion incidents remain 3 times more likely than with natural gas [6]. But because the explosion would be smaller, the claim is that 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. "There will be 3x more explosions, but each explosion may be smaller than for natural gas – therefore the risk is the same". This is not a sound basis for claiming hydrogen is as safe as natural gas and the results of this analysis are therefore questionable.

Nitrous Oxides (NOx)

A further issue associated with combusting hydrogen is the emission of nitrogen oxides. 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 generates reactions where oxygen and nitrogen combine to produce NOx.

According to the DEFRA's report 'Emissions of air pollutants in the UK' [7], "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". Lebel et al [8] showed that households who don't use their cooker hoods or who have poor ventilation can surpass the 1-h US national standard for NO_2 (100 ppb) within a few minutes of gas stove usage, particularly in smaller kitchens. Consequently, NOx emissions are a health hazard in kitchens with gas stoves.

The higher flame temperature associated with burning hydrogen than natural gas results in *higher NOx emissions*, further exacerbating the very real dangers of indoor air pollution. This further undermines the case for using hydrogen for domestic heating.

Compulsion to take part in hydrogen trials

There have been 32 independent studies on use of hydrogen for heating since 2019 [9], 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. The time taken for hydrogen heating trials will significantly delay the inevitable decision to wholesale adoption of energy-efficient heat pumps, with a much lower total cost of ownership. This will delay the roll-out of heat pumps across the nation, damaging the decarbonization process.

Under these circumstances, it is very difficult to justify the provision of Clause 108 in the Energy Bill 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?

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.

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.

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 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 lorry than a battery electric lorry
- energy storage systems that use green hydrogen will supply electricity to the grid at least 2 to 3 times the cost of alternative systems such as: pumped hydro-electricity, batteries or other storage systems.

The reason that the hydrogen processes are fundamentally inefficient is that large amounts 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 road freight transport 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 plastics production, to manufacture glass and possibly for steel making.

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

(i) It would be clean and green
(ii) It would be efficient and low cost
(iii) It would reduce primary energy consumption
(iv) The efficiency gains would provide headroom for tax generation (eg to replace diesel excise duty) [10].
(v) It would reduce reliance on imported energy and consequently improve energy security
(vi) It would provide opportunities to create many new jobs to replace jobs lost from traditional UK manufacturing industries over the years. For example, jobs could be created in electric vehicle and EV charging industries; the renewable energy industry; the rooftop solar industry; electrical heating industry (heat pump manufacture and installation); as well as high tech industries involved in electrical device design, control, management, communications and digitalization, etc.

Appendix A – Blue Hydrogen Issues

Manufacturing Blue Hydrogen

Figure A.1 shows energy flows in the manufacture of 'Blue' Hydrogen through Steam Methane Reforming with Carbon Capture and Storage to manage the CO_2 emissions. Hot steam (H_2O) is mixed with methane (CH_4). This oxidises the carbon atoms to make CO_2 which has to be captured and stored (CCS) in permanent geological storage. The remaining hydrogen is stored, compressed and, in heating applications, transported to end users where it is burnt in a condensing hydrogen boiler.

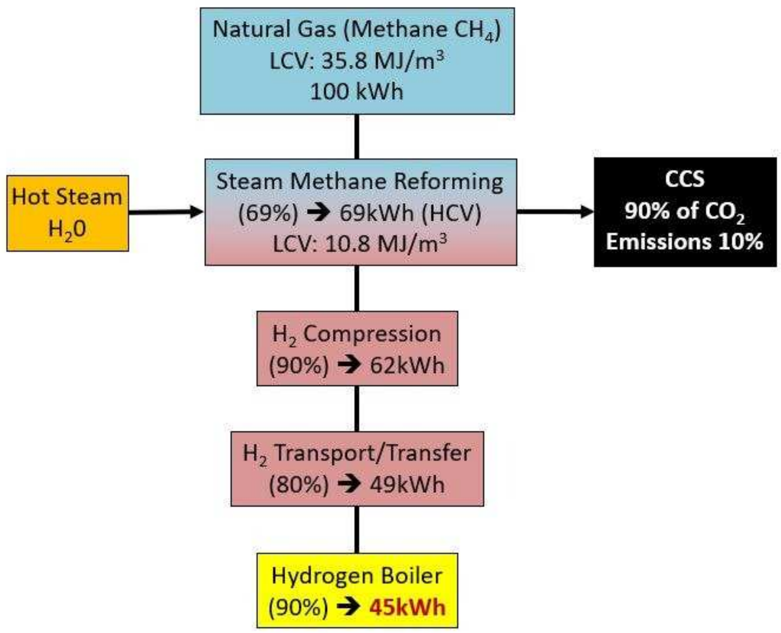

Fig. A.1 Generation blue hydrogen by the SMR process with CCS.

Infrastructure Requirements

Hydrogen has a significantly lower energy content per unit volume ('Lower Calorific Value' LCV=10.8 MJ/m^3) than Methane (LCV=35.8 MJ/m^3) [11]. See the top two central boxes in Fig. A.1. The factor of 35.8/10.8 = 3.3 means that transferring the same amount of energy to consumers through the NTS using Blue Hydrogen instead of Methane, at the same transmission pressure, would require all gas pipes in the system to carry 3.3 times higher volume flow rate of gas. This would require replacement of all compressors/pumping stations in the gas network with hydrogen-compatible versions having about 3 x the power rating. Furthermore, much of the gas pipeline network would have to be replaced to make it compatible with hydrogen: preventing leakage and embrittlement.

Of course, it would also be necessary to build the SMR and CCS plant to generate the hydrogen. There is no commercial-scale CCS facility in the UK. It would have to be developed and built before any blue hydrogen could be generated.

According to the database of CCS facilities, run by the Global CCS Institute, there are 25 'commercial' CCS facilities operational in the world today. Most of these are small scale and sequester less that 1 Mega tonnes of CO_2 per annum (Mt/a). The sum total capacity of these plants is 38 Mt/a. The largest in the world is a plant at Shute Creek in Wyoming, USA, with a capacity of 7 Mt/a. Its CO_2 is injected into oil wells and the revenue from enhanced oil recovery pays the costs of running the CCS plant. To put 38 Mt/a into perspective: a total of 37 Gt of anthropogenic CO_2 was emitted by humans in 2019. So the total sequestration capacity of the world is currently 1/1000 (0.1%) of global emissions. This industry has a long way to grow to make a significant impact on global CO_2 emissions.

A recent article by Deign [12] explains that the reason for low adoption of CCS is that there is currently no viable business case because the price of Carbon is too low:

> "For carbon capture to take off in a meaningful way, companies will need to have a clear financial incentive. That means having carbon pricing comfortably above the cost of capture, usage and/or storage"

Until this situation is resolved, the only way to finance CCS plants (apart from additional oil recovery revenues) will be through government subsidies. Therefore the industry will not be able to scale to the level needed to sequester the CO_2 generated in the manufacture of Blue Hydrogen.

Carbon Emissions

Carbon emissions due to the Blue Hydrogen process are not zero. Carbon capture from flue gases is not a perfect process. There are a number of available methods and technologies. In general, the higher the effectiveness of carbon capture, the more energy it takes and the less efficient the SMR process becomes [13]. Figure A.1 includes one version of the SMR+CCS process, ('SMR with CO_2 capture from flue gas using mono-ethanolamine'), from [13]. This is the most effective available CCS process and results in 90% of Carbon being captured from the SMR. However, this particular SMR+CCS process has an energy efficiency of only 69%. Other SMR+CCS processes have higher energy efficiencies (up to 76%) but CO_2 capture rates as low as 53% (ie 47% of carbon escapes into the atmosphere). See [13] for details.

The low percentage carbon capture combined with the high level of **fugitive carbon** emissions of upstream methane would make it impossible to reach the net zero carbon commitments of the UK government. The worst SMR+CCS process generates carbon emissions as high as a natural gas boiler [14].

If heat was provide by Blue Hydrogen boilers, fugitive emissions of CO_2 would always be significant- at least 10% of the carbon in the input methane, which would prevent 'net zero' emissions targets being reached. This contrasts with the heat pump route which would have decreasing emissions with time, reaching near zero by 2040.

Natural gas consumption

Substantially more natural gas would need to be imported or fracked to supply the blue hydrogen process.

Increased Gas Imports

The UK used 318TWh of gas per year for domestic purposes, mainly for heating in 2021 (Figure A.2). Increasing this by this 45% would correspond to importing or fracking an additional 143 TWh of natural gas. This would increase gas imports by 25%, from 561TWh to 704TWh. This would mean that 66% of the nation's natural gas would be imported, severely impacting energy security. (In fact, National Grid's future energy scenario sees the UK importing 100% of gas by 2040 because of depleting North Sea reserves. So the additional gas consumption for Blue Hydrogen would make the energy security situation considerably worse.)

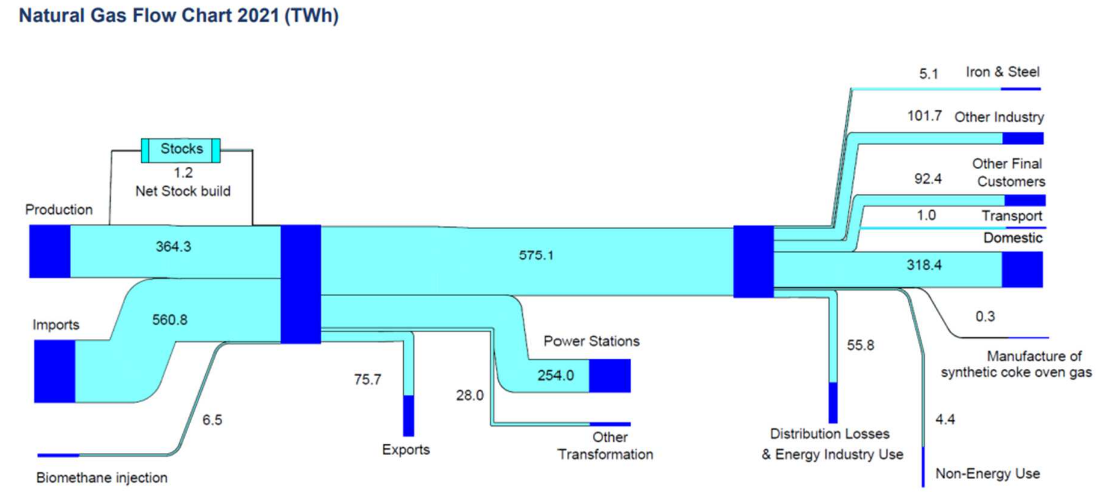

Fig. A.2 Natural Gas supply and demand in the UK in 2021. Numbers indicate TerraWatt hours (TWh). From BEIS [15].

Appendix B : The cleanliness 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] [5]. 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 equivalent 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 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) [16]:

> "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)." [16]

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].

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[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 H2.

[6] Equivalent CO_2 emissions account for the global warming potential of all greenhouse gases emitted during manufacture, not just the CO_2.

[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.

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 'clean' hydrogen 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 A.3. 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 [17], 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 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.

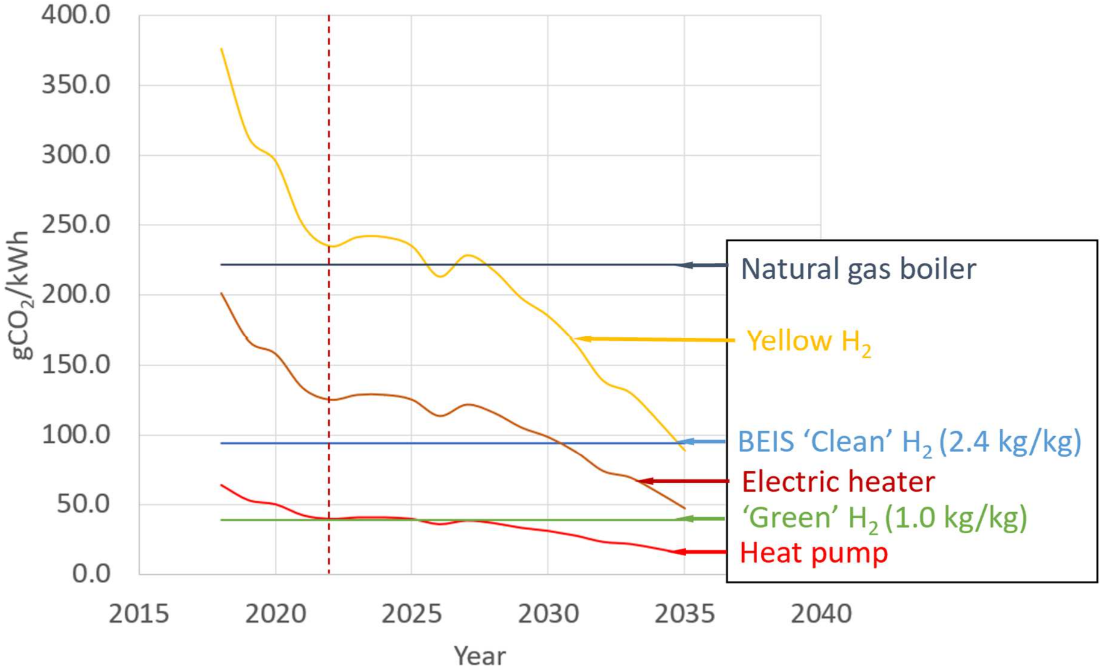

Figure A.3. Projected carbon emissions generated by various possible heating energy systems, based on the BEIS 'EEP 2018' carbon intensity projections [17]. The Yellow hydrogen boiler, electric heater and heat pump are all assumed to run on grid-mix electricity, which is an appropriate assumption when 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% [18]. 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 A.3 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 A.3, since they are expected to stay constant with time.

Some further observations can be made from Figure A.3:

(i) An electric heater 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 will 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 burning '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 these would 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.

[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.

(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.

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 (ie 82% emissions reduction) 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.
(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. This contrasts with the current BEIS standard which favours fossil hydrogen over electrolytic hydrogen and therefore gives a significant advantage to the fossil fuel industry over the renewable energy industry.

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