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Special Issue on Decarbonising Heat

Introduction

According to the Committee on Climate Change (CCC) emissions from fossil-based heating systems and stoves were 85 $MtCO_2e$ in 2015, or 17% of the UK total. These are mainly from homes, which make up three quarters (64 $MtCO_2e$) of direct emissions (i.e. fossil-based, rather than electric). Non-residential buildings account for the remaining quarter of direct emissions, split into 13 $MtCO_2e$ from commercial buildings and 9 $MtCO_2e$ from public buildings.

The majority of residential buildings (85% or 23 million) are currently connected to the gas grid, using a boiler and wet-based central heating system. The remaining 15% of homes (4 million) are not connected to the gas grid, using either oil or liquid petroleum gas (LPG) as their main heating fuel or electric heating. These 'off-gas' homes make up a greater share of heating emissions (23%) due to the higher carbon intensity of oil and LPG - and electricity currently - compared to gas. Most electric heating is used in off-gas homes (77%) with the remainder used as 'top-up' heating. (1)

Overall, approximately 19% of the UK's total emissions come from heating buildings: homes comprise 77%; commercial buildings 14%; and public buildings 10%. To meet net zero, the building stock needs to be nearly completely decarbonised by 2050. (2)

Rather than looking at heat in isolation, there is a strong case for a decarbonisation approach that aligns renewable energy, electrification and energy efficiency. Measures to reduce carbon dioxide emissions are often considered separately, in terms of electricity, heating, transport, and industry. This can lead to prioritisation of the wrong sectors, and neglect of interactions between the sectors. Heat decarbonisation should not be delivered in isolation. (3) When considering how to transform our heat system to a low or zero carbon system, the solution is not as simple as choosing a single, or even several replacements for fossil fuels. There are other important factors which should also be taken into consideration.

Firstly, energy efficiency will crucial to any programme of heat decarbonisation. Many forms of decarbonised heat will tend to be more expensive than fossil fuel derived heat, so the total cost of decarbonising heat will be significantly higher without implementing an energy efficiency programme to reduce heat demand, and energy efficiency will be a crucial ingredient to transform heat in an equitable manner without exacerbating fuel poverty. In addition, heat pumps work more efficiently at lower flow temperatures than fossil-fuel systems normally operate, so an energy efficient building has more low-carbon heat options.

Secondly, decarbonised heat demand needs to be delivered flexibly, wherever possible, in a way that is most beneficial for the energy system, integrating variable renewable resources, lowering carbon emissions and reducing cost for consumers. Whilst there are uncertainties around the optimal technology mix for heating in the future, and disagreements amongst energy professionals, it is clear that electrification will have to play a significant role, whether through individual heat pumps or through renewable electricity used to power district heating networks via large-scale heat pumps. Efficient electrification will require the flexible operation of heating systems, both diurnally and intra-seasonally. Intra-seasonal heat balancing remains a key issue for heat decarbonisation, via electrification, at scale. Energy efficient buildings can be very flexible, and there is experience with managing them in such a way to avoid the most carbon intensive peak hours. A smart heat policy would encourage flexible operation of electric heating systems, for instance, through time-of-use tariffs coupled with thermal storage. If designed smartly, low-carbon heating systems can offer tremendous value through their diurnal flexibility and their ability to absorb excess renewable electricity and shift load to off-peak periods. The flexible operation of heating systems can deliver substantial value for the energy system, society and consumers. Smart pricing, in turn, can encourage customers to shift their electricity use to capture that value.

Thirdly, the needs of the transport sector and industry need to be taken into consideration. For instance, hydrogen is a highly valuable resource – perhaps too valuable to be used for low-grade heat provision. It could well be better to preserve it for industry applications, aviation, long distance vehicle travel, heavy-duty vehicles and power generation. It can also be used to store large amounts of energy. Whilst hydrogen is often presented as a less disruptive approach to decarbonisation, it cannot be provided at the cost of current fossil energy sources and it will require significant changes. (4)

Fourthly, we should be looking at ways to implement a 'Just Transition' for the fossil fuel workforce away from work in fossil fuel industries to work associated with the decarbonisation transition.

Forecasting the impact of heat decarbonisation

Forecasting the impact of heat decarbonisation on energy demand is complex. The July 2011 National Policy Statement on Energy said "*the 2050 pathways show that the need to electrify large parts of the industrial and domestic heat and transport sectors could double demand for electricity over the next forty years*." (5) In 2006 electricity consumption levels were being forecast to increase by over 15% in the ensuing decade, but demand actually dropped by 15.2% in those 10 years. This was prompted by vastly improved electricity efficiency in industry, in consumer white and brown goods, and in areas like lighting. (6)

There are three main ways in which heat might be decarbonised – converting the gas grid to run on hydrogen instead of methane; electrification of heating systems; and thirdly extensive use of heat networks. The Government's 2017 Clean Growth Strategy (7) says the groundwork needs laying so that decisions can be taken in the early 2020s on the long-term future of heat. It will assess a range of options for decarbonising heat, including electric heat pumps, using hydrogen or biogas in the gas grid and heat networks. A full report was promised by summer 2018. An overview of the evidence was eventually published in December 2018. (8) This stated that:

"*…the way heating is supplied to nearly 24 million homes, businesses and industrial users connected to the gas grid will need to change. Ensuring this transition is as smooth as possible represents a major national challenge over the coming years*."

It is not yet clear whether the Government favours converting the gas grid from methane to hydrogen, or whether it will promote the electrification of heat and what role heat networks will play. So, making accurate predictions about the impact of heat decarbonisation is impossible.

The Government's approach, according to the report, is to reduce demand by: building a market for energy efficiency; promoting heat networks with grants and loans; using the Renewable Heat Incentive (RHI) to promote heat pumps, biomass boilers and solar water heaters; phasing out the installation of high carbon fossil fuel heating in buildings off the gas grid during the 2020s. But, so far, the Government's review of the range of technologies with the potential to offer low carbon heating choices has only concluded that there is no consensus on which technologies will be able to achieve this most economically and effectively at the scale required.

The Government says the range of options includes technologies using electricity, hydrogen and bioenergy. Widespread use of electric heating has the potential to deliver very deep reductions in carbon emissions, but this is dependent: on the development of new, and reinforcement of existing infrastructure to generate, store and distribute low carbon electricity; innovations in demand reduction, system flexibility and energy storage to help manage the greatly increased demands on the electricity system; and, the extent to which a minority of buildings and some heating processes are likely to be unsuitable for switching to electric solutions.

Widespread use of hydrogen also has the potential to deliver deep reductions in carbon emissions, but this is dependent on: establishing the feasibility of safely converting the gas grid; the development of significant new infrastructure, including a new transmission system, hydrogen production and storage facilities, and sufficient carbon capture and storage capacity; and, sourcing a secure supply of natural gas to meet a significant increase in demand; the practical feasibility of producing sufficient volumes of very low carbon hydrogen and the potential for methane leakage.

Finally, bioenergy has potential to make substantial contributions to emissions reductions from heating through a variety of applications, including the production of biomethane for use in the gas grid. But the scale of emissions reduction potential is limited by the volume of biomass available, the prioritisation of its use across the energy economy and lifecycle emissions from production.

All the approaches will require very substantial new capital investment. Electrification will require major changes in each household. Even hydrogen will require all gas appliance to be changed, but the level of disruption might be less.

Hydrogen vs Heat Pumps

An argument about the future use of hydrogen, in particular for heating, has been raging amongst energy professionals and lobbyists since the Government announced, in early 2020, it was looking at setting a date by which all boilers on sale would need to be "*hydrogen ready*", meaning they can burn natural gas but can also be converted easily to burning hydrogen. (9) It was also announced that the natural gas supply at Keele University is being blended with 20% hydrogen in a trial that's of national significance. (10)

Commentators argue about the cost with some saying hydrogen will prove too expensive for mass usage, while others say switching to the use of electricity for heating will be far more costly than gas central heating and will put enormous strains on the grid during the winter months.

One of the problems with hydrogen is that it can be produced in a variety of ways. So-called 'green' hydrogen is produced using renewable electricity to generate hydrogen from water by electrolysis. 'Blue' hydrogen is produced from natural gas by a chemical process known as Steam Methane Reforming. This causes emissions of carbon dioxide which would have to be captured in a carbon capture and storage process in order to get anywhere near carbon emission targets. Hydrogen could also be produced by electrolysis using nuclear electricity.

One of the attractions of hydrogen is that "*for a lot of consumers, they wouldn't notice any difference. Customers would continue to use a boiler to heat their homes in a similar manner to natural gas*," according to Robert Sansom of the Institution of Engineering and Technology's energy policy panel. He is the lead author on a study conducted by the institute called Transitioning to Hydrogen. Together with colleagues, Sansom assessed the engineering risks and uncertainties associated with swapping our gas network to hydrogen. Their conclusion is that there is no reason why repurposing the gas network to hydrogen cannot be achieved.

But not everyone is convinced. Richard Lowes of the University of Exeter Energy Policy Group says that until recently the received wisdom had been that heating would have to be electrified in some way to meet our climate-crisis commitments. The problem is that Hydrogen is not found on Earth in a pure state. Instead, it has to be extracted from other substances, and the best one to extract it from is methane – in other words natural gas. Hence, the gas companies could effectively keep their current operations running. But the extra steps involved in extracting the hydrogen would push the price up. Additionally, the extraction creates CO_2 as a by-product, so large-scale carbon capture technology would need to be developed to prevent it escaping into the atmosphere and this increases costs. (11)

For the gas industry it's a question of survival which is why it funds many of the studies, pushing so hard for hydrogen? According to Chris Goodall, energy economist and author of 'What We Need to Do Now for a Zero Carbon Future': "*They do not wish for their industry to be eaten up by a switch to electricity for heating. So, they are moving as fast as they can to persuade us about hydrogen*."

Households could soon be required to install a boiler capable of burning hydrogen when they next upgrade their central heating system. The government has already pledged to ban installation of fossil fuel heating systems in new homes from 2025. In November, former chancellor Sajid Javid visited the headquarters of Worcester Bosch to inspect its prototype hydrogen-ready boiler. The company says the boilers will be available by 2025. They would be £50-£100 more expensive than existing boilers, which typically cost about £900. The benefit over existing boilers is that they can continue burning natural gas but be converted to burning hydrogen in an operation that will cost about £150 and take a gas engineer one hour.

The Department for Business, Energy and Industrial Strategy's Hy4Heat programme aims to determine the feasibility of hydrogen for heating in homes and includes work with industry to develop prototype hydrogen appliances, including hydrogen ready boilers. About 1.7 million boilers are replaced each year so if they were required to be hydrogen-ready from 2025 most homes would have the necessary boiler by the mid-2030s to allow a switch to hydrogen. (12)

One of the arguments in favour of converting our gas boilers to hydrogen is that we have poorly insulated houses with insufficient space for installing a heat pump. If you were to design a heating policy from scratch, you would not choose hydrogen. You would build well-insulated houses that use electric heat pumps. (13) Worcester Bosch argues that a house needs to have an Energy Performance Certificate rating of C or above for a heat pump to be able to heat the house effectively. According to them of the 3,276,000 UK properties within the EPC band C rating, some 3,223,000 have a condensing boiler. One of the ways of jumping one clear band within the EPC methodology is to replace a non-condensing boiler with a condensing version. This means that many of the properties in band C are really constructed to band D levels of fabric and therefore unsuitable as they stand for a heat pump installation. (14)

Heat battery manufacturer, Sunamp, says it is often claimed that heat pumps output only at temperatures far lower than the 75 degrees or so that comes from gas boilers (around 35 degrees). This means you have to replace conventional radiators with something like underfloor heating, and your house needs to be very well insulated. Sunamp says it uses heat pumps that output up to 80 degrees. (15)

Hydrogen vs Heat Pumps - Cost

Hydrogen isn't widely used at present. In Britain, current annual production is about 700,000 tonnes or 27 terawatt hours (TWh) of energy equivalent, according to the CCC. That's just 1.5 per cent of total UK energy consumption. High production costs are one reason. And it is virtually all made by the Steam Methane Reforming method without any carbon capture. According to the CCC, a so-called "full hydrogen" scenario would see demand balloon from 27TWh to 700TWh. Where is that hydrogen to come from? It won't be from hydrocarbon feedstock without carbon capture and storage — technologies that have yet to be deployed economically at scale.

Many are therefore pinning hopes on renewable energy and "green hydrogen" using electrolysis. At the moment this electrolysis technology is expensive, and that would push the price of hydrogen up still further. Chris Goodall hopes that the cost will decrease as technology improves. (16) But low capacity factors (eg caused by only using the electrolysis equipment when there is surplus renewable electricity available) are one reason most current renewables have theoretical production costs for hydrogen in the $4-$6 per kilogramme range, according to research from Eric Ingersoll of the consultancy, LucidCatalyst. That's well above the $1-$2/kg cost from existing hydrocarbon sources. Unlike capital costs, which can be chiselled down, nature limits the amount that capacity factors can be increased. This could drive would-be electrolysis hydrogen producers to consider using nuclear electricity as their power source. (17)

EDF Energy is already looking at generating hydrogen at Heysham Nuclear Power Stations. The H2H plan would produce hydrogen gas in bulk from electrolysers. (18)

Producing the vast quantities of green hydrogen required would need an absolutely massive amount of renewable energy. According to the International Renewable Energy Agency (Irena), the world will need 19 exajoules of green hydrogen in the energy system in 2050. Producing this would require at least 6,690TWh of dedicated electricity every year — the equivalent of 1,775GW of offshore wind farms, 2,243GW of onshore wind, 4,240GW of solar PV or 957GW of nuclear power. To put this in perspective, at the end of 2018, the world had installed 540.4GW of onshore wind, 23.4GW of offshore wind, 480.4GW of solar PV and 397GW of operating nuclear reactors, according to Irena and the World Nuclear Association. And virtually all of this capacity is being used to generate electricity, not green hydrogen. Annual growth rates for wind and solar are increasing, but nowhere near fast enough for the world to be in line with Paris Agreement goals. (19)

Hydrogen costs falling

Now Bloomberg New Energy Finance's (BNEF's) 'Hydrogen Economy Outlook' estimates that renewable hydrogen could be produced for between $0.8 to $1.6/kg in most parts of the world within the next three decades, a cost roughly equivalent to today's natural gas prices in Brazil, China, India, Germany, and Scandinavia. But to reach that price point, approximately $150bn of subsidies over the next 10 years would be needed to scale up the technology and build necessary supply infrastructure, alongside joined-up policy coordination across government and new frameworks for private investment. As things currently stand, however, policy support for the hydrogen economy is "insufficient", the report notes.

But while infrastructure for producing green hydrogen remains relatively scarce in many parts of the world, clean hydrogen production costs are falling, largely due to the falling costs of electrolysers used in the process and the declining cost of renewable power.

"*If the clean hydrogen industry can scale up, many of the hard-to-abate sectors could be decarbonised using hydrogen, at surprisingly low costs*," says Kobad Bhavnagri, BNEF's head of industrial decarbonisation.

The report notes that the delivered cost of renewable hydrogen in China, India, and Western Europe, once storage and pipeline infrastructure is considered, could fall to around $2/kg ($15 per million thermal units - MMBtu) by 2030 and to $1/kg ($7.4/MMBtu) by 2050.

But despite falling costs, carbon prices and emissions policies will be essential to drive use, given that the hydrogen is likely to remain a more expensive form of energy for some time by virtue of its being manufactured, the report explains. Moreover, hydrogen's low density makes it considerably harder to store than fossil fuels. As such, BNEF notes that some $637bn may need to be spent on storage infrastructure to enable green hydrogen to replace and provide the same level of energy security as natural gas.

Bhavnagri said that $150bn in subsidies "*may sound daunting but it is not, in fact, such a huge task* [but] *Governments around the world currently spend more than twice that every year on fossil fuel consumption subsidies*." (20)

If gas grids were converted to operate with 100% hydrogen, considerable extra costs would be incurred to enable equipment to function satisfactorily. A study by Carbon Connect, a UK think tank, suggests a figure of around £200 billion for the UK, of which £75 billion would be for converting appliances, the remainder for the grid.

This figure provides a basis for establishing an equivalent "cost of carbon". UK natural gas consumption in 2018 was 880 terawatt hours (TWh) and emissions from gas are around 0.18 kg of CO2/kWh. If this gas was displaced by hydrogen, nearly 160 million tons of CO_2 would be eliminated. Carbon Connect estimates conversion costs at around £200 billion. If the capital costs of this conversion were spread over 25 years at a low interest rate, annual costs would be around £8 billion. But this is only half the story. The additional cost of the hydrogen then needs to be added, which, assuming an (optimistic) £30/MWh, would take total extra yearly costs to about £13 billion, with the cost per tonne of CO_2 saved at around £80.This figure is higher than the present cost of carbon in the EU, though studies from the UK, such as the 2006 Stern Review, and the US suggest the true cost of carbon is around, or even above, this level. (21)

Heat Pumps more efficient

Ed Matthew Associate Director at independent climate and energy think tank E3G says hydrogen is the wrong choice for heating homes. Blue hydrogen (manufactured from natural gas) needs CCS so would be massively expensive and keeps us hooked on gas. Green hydrogen (made by electrolysis using renewable electricity) is 4 times less efficient than using heat pumps. "*Hydrogen is being pushed by the gas industry. Beware*." (22)

Dr Dave Toke, reader in energy politics at Aberdeen University says hydrogen to supply heating would be a terrible choice. (23) He says using blue hydrogen would delay the transition to a sustainable clean energy economy and even if the hydrogen was sourced from renewable energy (and not much of it will be) the result would be a grandiose waste of renewable energy. This is because using hydrogen from renewable energy to heat buildings is around four times less energy efficient compared to using heat pumps (using renewable electricity) to supply heating in buildings. He calls using hydrogen to heat buildings: "*the start of one of the greatest pieces of greenwash that have been committed in the UK*."

Toke argues that the gas industry's plan is to start off with blue hydrogen, after which at an unspecified period this would be replaced by green hydrogen generated from renewable energy like wind or solar. There are three big reasons why hydrogen in general is a bad choice for our heating networks.

First, carbon capture, in the blue hydrogen production process, is unlikely to be close enough to 100% because carbon extraction processes become more and more expensive the higher the proportion of carbon is captured (over 85%). In practice, the carbon capture will probably not even be 85% as the gas industry seeks to produce hydrogen at a low commercial cost.

Second, such a programme will provide support for a continued fossil fuel industry (including unabated methane leakage from extraction activities). The reality is that 'blue hydrogen' in the UK will be used to develop new natural gas fields that will only be economic if they carry on supplying large quantities of unabated natural gas to other parts of the world.

A third reason why 'blue hydrogen' is bad is that using 'blue' hydrogen, in as much as it succeeds in paving the way for supply of renewable hydrogen, will lock in a huge wastage of renewable energy compared to using this renewable energy much more efficiently.

On the one hand the electrolysis process by which renewable energy is converted to hydrogen is only 80% efficient. That is bad enough since using renewable electricity to supply heating would not involve these losses. However, things get a lot worse when you realise that the best way of supplying heating in efficiency terms is through electrically powered heat pumps. Heat pumps multiply the heat from the electricity by around threefold (by using heat in the surrounding environment) and avoid losing energy through electrolysis. So, in terms of reducing carbon emissions we will need FOUR times the amount of renewable energy to produce the same heating effect in buildings if we turn it into hydrogen - compared to using the renewable energy delivered through the electricity system and used in heat pumps. (24)

We ought to focus on electrifying the heating system, not locking it in to hydrogen. New build properties can be built to maximise energy efficiency and using heat pumps to supply what should be a much-reduced need for heating services. Existing buildings can be heated with district heating supplied by large scale heat pumps, or at worst converted to electricity-only heating, or preferably fitted with heat pumps.

Hydrogen has its purposes, but heating buildings is not one of them, says Toke. Far from helping towards a renewable energy economy it may inadvertently promote nuclear power. Green energy involves energy efficiency as well as green energy supply, and blue and even green hydrogen should be ruled out as a means of heating buildings.

Heat battery manufacturer, Sunamp, claims that using an air source heat pump on off-peak electricity in conjunction with a heat battery can heat a house for a price comparable with gas central heating.

Heat demand is, of course, seasonal. Switching from gas to an all-electric solution could create huge peaks in demand. One estimate suggests this would require the equivalent of 30 nuclear power stations. On top of that, the UK’s current distribution networks could not cope. (25)

Balancing renewables

Some market forecasters envision a future when on sunny and windy days more solar and wind energy is available than needed, or can be assimilated into the available grid network. On such days the “excess” electricity could be used to produce hydrogen, they argue, to be stored and used when needed. But a number of hurdles need to be overcome before this ambitious vision has a chance of becoming reality.

As the volumes of electricity generated by wind and solar energy increase, there are times when power output exceeds local demand. In the absence of sufficient capacity on the grid network to send the electricity to where it is needed, generation is curtailed unless a local use can be found for it. Hydrogen production on the spot seems an attractive solution, but is expensive given the cost of electrolysers and the short periods for which electricity is curtailed and the electrolysers would be in use. A better economic case could be made if the hydrogen were stored and used when a lack of energy has driven up its value and the price for which it can be sold.

Curtailment of renewables generation is actually fairly rare. In west Denmark, a high-renewables electricity system, wind production already met half of electricity demand back in 2016. Over that year, wind exceeded demand for only 1296 hours, less than 15% of the time, with an average level of surplus power of 527 megawatts (MW). And curtailment can be avoided by using interconnections to other countries. The west of Denmark is connected to the east of the country, to Norway across Scandinavian waters and to Germany by land, with more international interconnections being built. Curtailment can also be avoided by demand-side management, an often-automated process, that gets consumers to use more electricity at times when there is plenty of it.

Studies in the UK, California and Denmark suggest “surplus” energy with 50% variable renewables output and using current projections of demand is likely to be in the range of 6-9%. At that level, the volume of curtailed energy is still not enough to support a return on investment in hydrogen storage if the energy were fed back into the grid when needed. A more sensible option may be to accumulate the hydrogen — either locally or centrally — and use it for heating or transport, as is happening in some regions. (26)

Seasonal storage of hydrogen to balance renewable generation will be cost-competitive in 2050, according to Norway-based consulting firm DNV GL. The firm has modelled nonstop production of hydrogen every summer, using electrolysis units powered by market electricity. The hydrogen would be compressed and stored underground in salt caverns or depleted gas fields, and the following winter would be converted nonstop to electricity, using fuel cells. Daily balancing would be achieved using batteries and pumped hydro. To the extent the entire grid ran on renewables in the summer, the hydrogen would be “green,” or renewably produced. A similar project along these lines is under development in Utah, and would use underground salt caverns to store hydrogen. The hydrogen would be renewably produced by 2045, to help Los Angeles achieve its renewables goal. (27)

An alternative to using surplus renewable electricity to generate hydrogen would be to use time-of-use electricity tariffs in conjunction with electricity and/or heat storage batteries. Large-scale heat pumps generating heat for heat networks could also be operated when there is a surplus with excess heat stored in heat stores.

One consortium of clean tech companies has begun installing an AI system as part of a trial to deliver “smart hot water” that can help to balance supply and demand on the grid. Government funding is supporting the project, which will see the system used to optimise a virtual community of 350 homes across the country. The project aims to transform traditional hot water cylinders into “grid-interactive water heaters” that coordinate their operation in real time by switching on immersion heating elements according to what is most beneficial for each home, taking into account wholesale prices and the level of supply and demand on the grid. (28)

EDF Energy is working with Kaluza, and Dimplex.to trial more than 100 smart electric heaters in homes across the country which can be controlled remotely. The internet-connected storage heaters can charge overnight using off-peak electricity when prices are at their lowest and then use the power to generate heat during the day. (29)

Sunamp Heat Batteries can be charged using any energy source. You can off-set peak energy costs by charging your Heat Battery with cheaper off-peak electricity, (perhaps using a heat pump) or divert energy from your solar PV, heat pumps or other renewable sources. Once charged, the heat can be released instantly when needed, delivering hot water and space heating during peak times. (30)

Heat Networks

Many are sceptical about relying on the conversion of the gas grid to hydrogen, because of the likely reliance on carbon capture and storage and the fact that carbon emissions would still be relatively high. And moving to electric heating would roughly increase by a factor of five peak load on the grid which would require significant upgrades to cope. So, the idea of building district heating networks which can deliver heat from solar thermal, geothermal and industrial waste heat recovery is preferable. (31)

In the indicative scenarios set out in the Government Clean Growth Strategy heat networks are projected to meet 17% of heat demand in homes and up to 24% of heat demand in industrial and public-sector buildings in order to cost effectively meet 2050 decarbonisation targets. Heat networks currently supply around 1% of buildings heat demand. (32)

New research commissioned by industry body Scottish Renewables shows the Scottish Government’s new Heat Networks Bill could see the equivalent of 460,000 homes – around a fifth of Scotland’s total - heated renewably by 2030, cutting emissions from heat by 10% and helping tackle the climate emergency. The research found 46 potential heat network projects across Scotland’s seven cities. The networks would initially serve 45,000 homes but could, with the right Scottish Government support, grow ten-fold by 2030. (33)

A report by SSE makes the case for increased use of district heating ‘Sustainable Heating: Reducing Costs, Improving Comfort and Lowering Carbon Emissions‘ – found that one retrofit project at the Wyndford housing scheme in Glasgow has delivered a 62% reduction in CO2 emissions since it was installed in 2012. (34) The results also show that lives have significantly improved, comfort has increased, and jobs and economic value have been created. (35) In the UK currently only about two per cent of heat is supplied via heating networks - in comparison, in Denmark 60 per cent of the population is connected to a heat network. As well as delivering significant carbon savings, district heating systems can also cut energy costs for billpayers – heating a flat via a gas-fired district heating system costs around 30% less than it would be using individual gas-fired boilers. (36)

District heating networks can be fed with heat from a range of sources from gas-fired and biomass-fired Combined Heat and Power (CHP) stations which also generate electricity, to deep boreholes which extract geothermal heat from underground. In Glasgow and Fife heat is being captured from trapped water in old flooded coal mines. (37) In Lerwick Shetland Heat and Power is hoping to extend its heat network by installing a 2MW heat pump made by Star Renewables in Glasgow to abstract heat from Lerwick Harbour. (38) In the London Borough of Newham there are plans to harness the energy from "fatbergs", the bus-size balls of grease which cost Thames Water an estimated £1 million a month to remove from its sewers. (39)

Illustrating the potential role of combined heat and power in balancing variable renewables an arms-length council-owed district heating company in Gateshead is set to boost its projected lifetime income by nearly £1m after signing up to a power demand-response scheme run by Flextricity based in Edinburgh. The Gateshead District Energy Scheme has become part of Flexitricity's demand response network netting the company more than £60,000 per year over the next 15 years for smoothing out peaks and troughs in national electricity demand. (40)

The successful combination of CHP and renewables elsewhere in Europe has been attracting increasing attention. (41) For instance, Denmark currently relies on wind power for nearly 30% of its electricity and combined heat and power (CHP) plants supply 50%. Plans are in place to increase wind power up to 50% by 2050. The challenge associated with this system is that as the share of wind power rises, there will be less demand for electricity from CHP plants, meaning that this energy could be wasted. A 'smart' solution would require flexible energy conversion and storage technologies to be incorporated. CHP plants could be provided with heat pumps and additional storage capacity to store additional energy on windy days. (42) So, district heating systems could absorb large quantities of surplus wind-generated electricity by using heat pumps and electric heaters for heating water. When demand for electricity is high, but the wind is low, CHP plants could sell electricity but store heat if there is no demand for it at the time. (43)

Energy Efficiency – the scale of the resource

Approximately 19% of the UK's total emissions come from heating our buildings: homes comprise 77%; commercial buildings 14%; and public buildings 10%. To meet net zero, the building stock needs to be nearly completely decarbonised by 2050. But when adjusting for temperature variation, building emissions rose by 1% in 2017, relative to the previous year. Building emissions were only 11% below 1990 levels, compared to the 17% reduction recommended by the Committee on Climate Change (CCC). The House of Commons Business, Energy and Industrial Strategy (BEIS) Committee concluded in July 2019 that: "*Existing and planned policies for carbon abatement from buildings will not achieve what is required to meet the fifth carbon budget*." (44)

Lord Deben, Chairman of the CCC, told the BEIS Committee that:

"*…energy efficiency is by far the cheapest way of reducing our emissions*."

As the UK moves towards decarbonising heat, the price of energy is set to rise and the fuel poor risk being disproportionately affected. Better insulation and more efficient heating are therefore crucial to alleviating fuel poverty. The CCC argues that the poorest can be protected from rising prices through improved energy efficiency. (45) If the gas grid was to be converted to hydrogen, in preference to the electrification of heating systems, mainly to avoid the expense of a large energy efficiency programme, this would have hugely negative effect on equality.

The BEIS Committee says "*total energy use could be reduced by an estimated 25 per cent by 2035 through cost-effective investments in energy efficiency and low carbon heat—equivalent to the annual output of six Hinkley Point Cs.*" (46) This would result in average energy savings for consumers of roughly £270 per household per year. Scenarios suggest that such an energy efficiency programme could create between 66,000 to 86,000 new jobs across all the UK. Similarly, the UK Energy Research Council, estimates that cost-effective investments in domestic energy efficiency alone between now and 2035 could save around 140 TWh of energy (roughly equivalent to the output of six power stations the size of Hinkley Point C). The investments would deliver net benefits worth £7.5bn to the UK, and could reach £47bn, if benefits such as health improvements and additional economic activity are counted. (47)

The Government's 2017 Clean Growth Strategy (48) set a target to upgrade as many houses to EPC Band C by 2035 "*where practical, cost-effective and affordable*", and for all fuel poor households, and as many rented homes as possible, to reach the same standard by 2030. The BEIS Committee said it is unacceptable that 18 months after publishing the Clean Growth Strategy the Government is yet to define the condition of "*where practical, cost-effective and affordable*".

Only around 30% of homes in the UK currently meet EPC Band C. Current Government policy will fail to upgrade the remaining 70% which is around 19 million homes. The current rate of renovation in the UK needs to increase by around 7 times. Behind this headline figure lies a variance between the increase in energy efficiency renovation needed in England compared to the devolved nations. For example, in England the rate needs to increase by a factor of 9, compared to a factor of 2.5 in Scotland. (49)

Energy Efficiency - Lessons from Scotland

Unlike England, Scotland has made Energy Efficiency a National Infrastructure Priority. Scotland has an Energy Efficient Scotland (EES) route-map which is a 20-year programme designed to make its existing buildings near zero carbon wherever feasible by 2050, bringing the provision of energy efficiency and low carbon heat together under one umbrella, to be overseen by a dedicated delivery agency.

The Scottish Government has backed up their EPC targets with a range of centrally funded schemes that provide property owners with a route to making energy efficiency upgrades. (50)

The National Infrastructure Commission

Although the National Infrastructure Assessment recognised the critical role of energy efficiency in the future low carbon energy system, (51) it did not clarify the full level of investment necessary to meet the Government's energy efficiency targets. The BEIS Committee called on the Government to ask the National Infrastructure Commission (NIC) to produce a dedicated report on energy efficiency that quantifies the investment needed to meet its EPC targets.

Government Response to BEIS Committee

The Government says it agrees wholeheartedly that energy efficiency is a fundamental pillar of its approach to reaching net zero emissions, addressing fuel poverty and cutting energy bills, but disagrees that its policy is failing. It does, however, agree that a significant increase in deployment rates will be required in order to deliver the transition to net zero.

Currently, around 17 million homes in England are below EPC Band C. The Government's preliminary estimates suggest this will cost between £35–£65 billion across the UK (It used a number of illustrative scenarios to come up with this range). But it believes defining "practical", "cost-effective" and "affordable" too prescriptively could be counter-productive, and the optimal level of energy efficiency depends on the preferred heat decarbonisation pathway.

The Government told the Select Committee it would set out further details of its plans for decarbonisation in the infrastructure strategy (which was due out later in 2019, but has now been delayed until at least May 2020). But it doesn't believe deeming energy efficiency a "national infrastructure priority" is a pre-requisite for action, nor has it agreed to ask the NIC to produce a dedicated report on energy efficiency that quantifies the investment needed to meet its EPC targets.

The Government says the Energy Companies Obligation will result in £6 billion being invested in domestic energy efficiency over the next decade (compared to the £35–£65 billion it says will be required by 2035) but "*New spending decisions are for future fiscal events*". (52)

Electricity Demand

The UK has been decarbonising emissions from the power sector faster than anywhere else in the world. Statistically the biggest decarbonising driver has been energy efficient technology. Reductions in demand have dwarfed switches from coal to renewables. Primary energy consumption is down 20% since 2000. Sales of natural gas have dropped by almost a third. Hinkley Point C and Sizewell C were both planned in the 2005 Energy White Paper to deal specifically with a 15% rise in electricity demand by 2020. Today's electricity demand forecasts more realistically predict a further to fall of 11% by 2025, but after that expect growth to re-start. Not everyone agrees. Imperial College says electricity demand may bottom out towards the end of the 2020s and then begin growing. But on the other-hand "*it may continue its gradual decline*". (53)

According to Andrew Warren, chair of the British Energy Efficiency Federation, the impact of efficiency on natural gas demand has been even more pronounced:

"*Sales have dropped by approaching one-third, largely due to better insulation and more efficient boilers and heating systems.*" (54)

Transport Demand

One of the reasons why the Government in 2005 predicted a doubling of electricity demand by 2050 was because it expects to see the electrification of transport. Forecasting electricity demand increases as a result of low carbon transport should, in theory, be relatively straightforward. In 2018 National Grid said there could be up to 25m EVs by 2035 and 36m by 2040 – saturation point, with all possible vehicles electrified and new EVs replacing old ones as they retire. (55)

Conventional wisdom seems to suggest that most of the 38 million vehicles currently on UK roads will be replaced by electric vehicles. But by doing this we could be introducing a whole new set of environmental and social problems, such as the problems associated with mining cobalt, (56) and the particulate pollution caused by brake, tyre, and road surface wear which directly contribute to well over half of particle pollution from road transport. (57) And if everybody switched to an EV it would be a huge missed opportunity to deal with a national health crisis caused by lack of exercise. (58)

It is becoming increasingly clear that car use will still need to be curbed even when all vehicles are powered by clean electricity. The Centre for Research into Energy Demand Solutions (CREDS) warns that electrifying cars will not address traffic jams, urban sprawl and wasted space for parking. The government says it is spending £2bn to promote walking and cycling. Many young people in cities are choosing not to buy cars. Instead they are using public transport, walking, cycling, taking minicabs and hiring cars when they are needed. Car ownership is wasteful because cars are parked for 98% of their lifetime, with a third of cars not going out every day. (59)

National Grid anticipates that most EV drivers will avoid peak time charging using of smart chargers and vehicle-to-grid technology. A number of energy suppliers have launched EV specific tariffs that have a time of use element [pricing to encourage off-peak charging]. (60) So peak electricity demand could be increased by between 3-8 GW in 2030 (4-14%) and by 3-13GW in 2050 (6-22%) - a "net" maximum increase in demand as a result of electric vehicles of 12.7GW by 2050. (61) An alternative scenario in a recent report by Redburn, a UK research and investment company, suggests the increase in demand as a result of the electrification of transport may be very limited and won't dent the established trends towards reduced electricity consumption because ever more energy-efficient lighting and motors will offset any increases in electricity consumption due to EVs. (62)

Hydrogen's future may not be for heating

Great uncertainty exists on the use of hydrogen in heating, as questions remain around production methods, transmission, its performance as a heating fuel and the cost of production. The more important question is whether a highly valuable resource such as hydrogen should be used for low-grade heat provision when there are many potential other uses that would facilitate decarbonisation, including transport.

Whilst battery vehicles are a much cheaper option than hydrogen-powered ones, costing about half as much, developing freight vehicles is a bigger prize and pilot projects are under way. The first of Hyundai's hydrogen fuel cell-powered, heavy duty trucks will be in operation in 2020 on the roads of Switzerland. They are part of an order for 1600 trucks that will be delivered between January 2020 and 2025. Elsewhere, the Canadian Hydrogen and Fuel Cell Association reports that a CA$15 million ($11.1 million) project will develop two heavy-duty, 65-ton hybrid trucks with hydrogen fuel cells.

Fuel cell trains are showing significant promise, and there is a case for using hydrogen powered trains, rather than electrifying some rail routes. Once the infrastructure for supplying hydrogen is in place, little further investment is required. Electrification requires substantial investment in power supply equipment and bridges may need to be raised or the track lowered to provide clearance for overhead power supplies. Bigger transport in the form of aviation and shipping areas where many would like to see greater focus on using hydrogen as a decarbonisation solution.

For the moment, renewable hydrogen is mainly used for niche applications in Germany, Texas and the UK. On the island of Eday, one of the Orkney islands off the north-east coast of Scotland, surplus wind energy is used to generate hydrogen using a 0.5 MW electrolysis plant. The hydrogen is then used to fuel ferries that can be charged overnight and transport goods and people between the islands.

Many also expect green hydrogen, in time, to be a solution in industrial processes where it is hard to remove CO_2 emissions any other way, such as in steel production, as feedstock for chemicals and for high grade heat in energy intensive industry. Hydrogen use in industry could reach between 5% and 20% of total energy consumed (or about 30% if non-energy uses are included) by 2050 in the EU, suggests the European Commission. (63)

Hydrogen may also have significant value particularly because it can be used to store large amounts of energy.

Rosenow and Lowes conclude that whilst hydrogen is often presented by incumbent voices as a less disruptive approach than widespread electrification, even ignoring its uncertainty, it cannot be provided at the cost of current fossil energy sources and it will require significant changes. Hydrogen is still likely to require substantial disruption for both consumers and industry with the requirement for hydrogen-suitable appliances, modifications to gas transportation infrastructure and rapid growth in hydrogen production facilities. The costs associated with hydrogen conversion, and the associated uncertainties, mean that electrification is still regarded as a core strategy for heat decarbonisation, even in the UK, where there is a well-developed gas grid.

On the future production of hydrogen, the UK's Climate Change Committee concluded for the UK that 'producing hydrogen in bulk from electrolysis would be much more expensive [than producing it from natural gas with carbon capture and storage] and would entail extremely challenging build rates for electricity generation capacity'. The approach of using 'green' renewable hydrogen for heating also appeared significantly more expensive than heat pumps, in part due to the relative conversion efficiencies described previously.

CCC says low-carbon hydrogen cannot be produced in large enough quantities to completely replace natural gas but this view is being challenged by the falling cost of renewables combined with the significant cost reduction potential of power-to-gas technology which could lead to much cheaper electrolytic hydrogen production than many have previously thought. Energy commentator Chris Goodall told Carbon Brief that

"*Cost competitive hydrogen from renewables makes full decarbonisation possible through power-to-gas and power-to-liquids*." (64) German think thank Energy Brainpool claimed hydrogen produced by surplus wind and solar energy could be cheaper than natural gas as an energy source itself by the 2030s. (65)

On the other hand, Rosenow and Lowes have suggested that falls in the costs of green hydrogen produced from renewable electricity will largely be associated with drops in the cost of renewable electricity generation. Reductions in the cost of renewable electricity generation would also lead to cheaper heat electrification. The relative cost differential between green hydrogen and heat pumps would remain, suggesting that heat pumps are always likely to be cheaper than using the combustion of green hydrogen.

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Outstanding Questions

1. Is there an optimal number of houses which are needed to remain on the gas grid after conversion to hydrogen to make it economic to maintain the grid?
2. How well can heat pumps operate in not well insulation houses? Is Worcester Bosch right or Sunamp?
3. Is it possible to install an Air Source Heat Pump in a flat above the ground floor? What are the noise implications for neighbours?
4. What is likely to be the economics of operating an electrolyser to produce hydrogen just when there is a surplus of renewable electricity?