Written Evidence Submitted Professor Gordon Andrew, Professor of Combustion Engineering, University of Leeds
(HNZ0010)

Introduction to Prof. Andrews and the Hydrogen Consortia that he is part of.

Technical Lead on the Clean Burner Systems (CBS) consortia for hydrogen gas fires under the Hy4Heat WP4 Hydrogen for Heat programme (3 contracts)
Member of the Glass Futures consortia for fuel switching in the glass industry, which includes work on hydrogen use for glass manufacture.
Technical Lead on Colorado Construction and CBS consortia on Green Distilleries for hydrogen and biomass distillery heating (2 contracts).
Expert in hydrogen combustion, low NO_x burners and hydrogen explosion safety. Worked on hydrogen combustion since 1970 (PhD) and published (2007, 2012) on a 100 KW low NO_x emissions hydrogen burners. Director of the Leeds University CPD course on Combustion in Boilers and Furnaces for 20 years.

Reason for submitting evidence.

I am a World expert on hydrogen combustion, low NO_x emissions and hydrogen explosion safety. I am also a research partner with industrial teams that have BEIS contracts for hydrogen for heat: domestic hydrogen fires (3 contracts with CBS, 2019 - 2021); Glass manufacture (Glass Futures, 2019 - 2021); Green Distilleries (Colorado Construction, a Distillery design and installation company – 2 contracts 2021 - 2023).

I am concerned at the negative attitude to hydrogen combustion as a route to green heat and power by several of the consultancies used by the Committee on Climate Change (CCC) and the CCC's public statements on decommissioning the gas grid and preventing new houses from having a gas connection. Some University teams of energy economists are equally negative on hydrogen as the route to decarbonisation, mainly through a series of false assumptions. The EPSRC has also not funded any research into hydrogen for heat via combustion and some of the referees that they use are clearly in the anti-hydrogen lobby.

In contrast BEIS have, correctly in my expert opinion, largely been following the recommendations of the NGN H21 report (2016) that the gas grid could be re-purposed for hydrogen at a relatively modest cost. A roadmap to introduce hydrogen throughout the UK gas grid was set out, that would decarbonise all the UK gas grid by 2045. As this comes from a gas network operator, the predictions are going to be more technically competent than the views of consultancies that are not experts on the operation of the gas grid or the properties of hydrogen combustion.

However, before the investment in the gas grid is made, to repurpose it for hydrogen, all existing appliances and industrial uses of natural gas (NG) have to be shown to be capable of being modified to work on hydrogen. It is this area that BEIS has committed significant funding that is still ongoing. This is a sensible policy and should be continued and extended. The negative views of the CCC and others on hydrogen and the gas grid should be ignored.

No doubt this House of Commons Inquiry will have lots of negative comments on the BEIS support for the repurposing of the gas grid for hydrogen and for hydrogen combustion for domestic and industrial heat. But it is, in my expert opinion, a good programme that is a necessary part of the decarbonisation of heat and will also enable low carbon electricity and from this low carbon electric vehicles (they are NOT carbon free at present because the electricity grid is not carbon free). The policy offers a viable cost effective route to zero carbon on a sensible timescale and most alternatives do not stand up to scrutiny in the short term (next 20 years).

Summary

100% hydrogen in the gas grid, with green hydrogen from electrolysis using renewable or nuclear electricity or blue hydrogen from natural gas (NG) with CCS, offers a route to decarbonise heat and electricity from gas (40% of electricity currently). Green/blue hydrogen is one of the lowest cost ways of reaching zero carbon emissions, as it utilises the existing £100bn+ investment in the gas grid and the current £6bn per year conversion costs of cast iron pipes to polyethylene (PE) yellow pipes. PE pipes are needed for local hydrogen transmission in the gas network. The UK NG gas network is the source of heat for 24 million properties, 84% of homes are connected to the gas network. 56% of cooking is done by gas, 77% of space heating is by gas and 80% of water heating is by gas. Two-thirds of residential and commercial energy consumption is met by NG. Repurposing the gas grid for hydrogen keeps all these premises connected to a decarbonised fuel source and is the most practical and cost effective way of decarbonising heat and generating green electricity from hydrogen from existing CCGT plants, with new hydrogen combustors.

The BEIS initiatives to develop domestic appliances and large industrial processes to operate on 100% hydrogen is both welcome and essential, if the hydrogen route to decarbonisation is to move forward rapidly. The BEIS Hy4Heat WP4 programme has achieved its aims and the work I have been part of on different types of gas fires will be certified for use in homes later this year. The same is true for hydrogen central heating boilers. Unfortunately, there are many domestic gas heating appliances, including cookers and hobs, that have had little work on conversion to hydrogen carried out. Also, WP5 of Hy4Heat for commercial and industrial heat has not been funded, which leaves a large sector of gas fired heating that has had no work done on hydrogen conversion. Some of the new funding needs to be allocated here. Currently BEIS have allocated substantial funding to specific high gas use industries (glass, steel and whisky) which is also sensible, but to do this at the expense of not funding Hy4Heat properly is a mistake. Domestic and commercial use of gas in 2019 was 400 TWh and industrial use was 102 TWh, so more support is required for the much larger domestic and commercial sector decarbonisation using hydrogen, or the zero carbon target will not be met.

Evidence

1. **Hydrogen manufacture and distribution through the existing gas grid for use in existing appliances with modified burners, is the policy that should be followed for zero carbon.**

Hydrogen is the lowest cost method of decarbonising heat and if the gas grid is converted to hydrogen with CCS (upstream carbon removal) the ‘blue’ hydrogen can be burnt in existing combined cycle gas turbines (CCGT), with modified combustors, to generate green electricity. This is preferable to each gas power station having its own CCS, as larger CCS plant can be built which is more efficient. This means that hydrogen for net zero is intimately linked with CCS. If all the infrastructure for CCS was built to convert NG to hydrogen then there would be no need for any other CCS, which is mainly post combustion flue gas carbon removal. Hydrogen can be used to generate electricity in the same CCGT power plants currently using NG to generate electricity. Pre combustion carbon removal to produce hydrogen is less costly with smaller plant than post combustion flue gas removal. Unfortunately, in the UK focus has been on the post combustion removal of carbon in coal fired power stations, all of which will close in the next few years thus making the post combustion carbon capture technology redundant.

Hydrogen is also the lowest cost and most effective method of storing energy, which is a major requirement for the UK electricity grid with very large renewable inputs. The alternative is pumped storage (2.6GW in the UK mainly installed by the CEGB pre 1990) or batteries. Batteries are a MW store in a world where GW storage is required. Also, batteries rely on exotic metals lithium and cobalt with dubious environmental records on their extraction (60% of cobalt comes from DR Congo in largely unregulated mines and lithium extraction in Tibet and S. America has caused massive water pollution problems). Hydrogen production, whether from NG or by electrolysis, does not have these other environmental problems.

At present there are many times when there is more renewable electricity than the grid can use and suppliers are paid NOT to generate electricity. With a hydrogen grid this surplus renewable electricity can be used to electrolyse water to generate hydrogen, which is put into the gas grid, where large scale hydrogen storage will be part of the grid infrastructure (NGN H21, 2016). When the wind does not blow or the sun does not shine, then the stored hydrogen can be used to generate green electricity via existing CCGT. It also helps to meet sudden changes in electricity demand. With the green electricity from hydrogen comes green electric transport, as the electricity will be zero carbon, which it is not at present. Without hydrogen, electricity is not likely to be green in the near future, as there is insufficient wind, solar and nuclear green electricity to achieve net zero for electricity (current average 150 – 200 g/kWh CO_2 and an electric car has about 40 g_{CO2}/km which is very low but NOT zero and can be bettered by series hybrid vehicles).

The biggest advantage of hydrogen in the grid is that it decarbonises domestic, commercial and industrial heat, which is very difficult or expensive to do using other methods such as heat pumps.

So hydrogen is clearly the key pathway to net zero for heat, electricity and transport (via green electricity). The question is why has hydrogen not been invested in until recently by BEIS and why has CCS not been built for large scale hydrogen supplies. Initially hydrogen will have to come from NG with SMR and CCS (blue hydrogen) as there is insufficient electrolysis capacity for it to come from surplus green electricity (green hydrogen). Also, the surplus green electricity cannot be effectively used until there is a hydrogen gas grid. It appears that some influential groups do not like the hydrogen solution, perhaps it appears to them to be cheating, as it enables NG to continue to be used as a source of hydrogen. The EPSRC for example has not funded a single research project in the hydrogen for heat area i.e burning hydrogen – even when they had a specific call for the decarbonisation of heat. The Committee on Climate Change (CCC) has advocated that the gas grid should be decommissioned (a £100bn+ asset) and the Building Regs changed so that new houses could not have a gas supply. This would prevent hydrogen for heat and the decarbonisation of heat and massively increase fuel poverty, as all the alternatives are more expensive. Gas fires are the lowest cost form of heat in terms of equipment and installation costs, so they are used by the poorest families. They can be designed to safely operate on hydrogen, thus enabling the lowest cost heating equipment to continue to be used.

False news on hydrogen is given out by consultancies with Government contracts – like the gas grid cannot be used for hydrogen and it would all have to be rebuilt (nonsense – see NGN H21) so it is too expensive a solution. Hydrogen flames are invisible so can't be safely used (more nonsense – they are orange and very attractive). Dual fuel burners are impractical [Frazer-Nash Consultancy, Appraisal of Domestic Hydrogen Appliances, BEIS, Feb. 2018]. This is nonsense and the CBS consortia, that I am the technical lead for, have shown that dual fuel cooker hobs and gas fires and 100 kW industrial dual fuel burners are practical and achievable. Hydrogen is an explosion risk – yes it is, but so is NG and there will be no more explosions with hydrogen than with NG, most of which are due to leaks in the gas mains not in the equipment using gas. The current programme to change from cast iron pipes to PE gas pipes not only stops the gas mains leaks but enables hydrogen to be used in the local gas grids (<7bar gas is in PE pipes). The programme to fit PE pipes in the grid will be completed in about 2030 and the grid would then be capable of hydrogen use with no leaks.

NO_x emissions are always said to increase with hydrogen and damage the environment and people's health. This can occur, but it is up to regulators to ensure that hydrogen appliances comply with the NO_x standards for NG, which is the current position. So in reality NO_x will not increase and I can testify that it is possible to design heating equipment for hydrogen with lower NO_x than for NG. Rarely mentioned is that fewer people will die when hydrogen is used for heat as there are no CO emissions and about 10 times as many people die of CO poisoning from faulty NG heating equipment than die in explosions. BSI has already issued guidance on the safe use of hydrogen for heat (PAS4444 2020), so the safe use of hydrogen in appliance design is now subject to a test regime and unsafe hydrogen equipment could not be put on the market.

2. The House of Commons consultation questions.

2.1 The suitability of the Government's announced plans for "Driving the Growth of Low Carbon Hydrogen"

2.1.1. The focus, scale and timescales of the proposed measures

In the UK in 2020 66% of natural gas was used for domestic cooking and heat (DUKES 2020 Chapter 4) and thus it was sensible for BEIS to fund the Hy4Heat WP4 for domestic heat. However, this funding was inadequate and covered a small fraction of heat and cooking appliances, when the grid converts to hydrogen ALL appliances must work on hydrogen. Under pressure from the CCC, who do not favour domestic gas supplies – NG or hydrogen, funds were switched to the industrial sector with major funding of hydrogen for glass and steel manufacture and more recently for decarbonisation of the distillery industry (I and an industrial consortia have 2 contracts). More realistic funding has been made available for the large industrial heat requirements and the greater challenges of using hydrogen for processes such as glass melting. However, decarbonisation targets will be missed if the domestic sector is not given more funding. Small scale commercial and industrial users of gas have also not been funded (hy4Heat WP5) and this is regrettable. Hy4Heat is a good project area, sadly underfunded in spite of it dominating gas use.

Essentially policy makers appear to have decided that the domestic sector will be electric for heat, cooking and transport. This is a misguided CCC policy that the Government is following and will fail to decarbonise the domestic sector, as it is a high cost option with maximum disruption to domestic users. Also, there is simply not sufficient renewable or nuclear electricity to provide all energy needs from electricity for domestic heat as well as for transport and existing electricity use. This is easy to show as the 2019 gas usage shows (DUKES, 2020). Domestic use of gas is 310 TWh and industrial use is 102 TWh and commercial use is 96 TWh. The use of gas for electricity is 270 TWh. So the domestic use of gas for heat is larger than all the gas used to generate electricity and this gas provided 40.6% of electricity in 2019. To concentrate hydrogen use for industrial heat only, while being a good policy in terms of the decarbonisation of industry, it is not a good policy to ignore hydrogen for domestic and commercial heat. If this is combined with the closure of most existing nuclear power stations in the next decade, then the policy will effectively stop zero carbon from being achieved. All the increase in renewable electricity in the next decade will be needed to replace nuclear closures and will not be available for domestic heat.

Hydrogen for domestic and commercial heat is as essential for zero carbon as is its use for industrial heat.

The BEIS funded hydrogen programmes are very welcome and Hy4Heat WP4 has achieved its aims and the work we have done with 3 contracts on different types of gas fires is near completion and effective fires with low NO_x emissions will be certified for sale later this year and available for demonstrations at COP26 in Glasgow. The same is true for hydrogen central heating boilers. However, WP5 of Hy4Heat for commercial and industrial heat has not been funded, although the CBS consortia that I am part of was awarded 11 contracts, the Hy4Heat project ran out of money. So currently there is a large sector of gas fired heating that has had no work done on hydrogen conversion. Some of the new funding needs to be allocated here or the PM will not be able to sit down at COP 26 to a breakfast cooked on hydrogen (The Ten Point Plan for a Green Industrial Revolution, Dec. 2020, PM's Forward). To my knowledge contracts for domestic stoves were not awarded and a viable hydrogen cooker hob does not exist, although we have a design that works. We were awarded contracts for commercial hobs that were not funded. So more funds needs to be allocated for Hy4Heat, if the full cross section of users of NG for heat is to be addressed. A year has been lost with this lack of funding.

2.1.2 How the proposed measures—and any other recommended measures—could best be co-ordinated

A national centre for hydrogen for heat would be useful, as putting different firms in competition with each other, as in the Hy4Heat programmes, is not conducive to sensible progress. In the USA the private gas industry funds, from a levy on sales, a central gas research institute (GRI) in Chicago. We have no equivalent to this in the UK, as the central research laboratories of British Gas were all closed in 1990 and no replacement of their R&D function was required by legislation. This should be based at a University with relevant research experience, which used to be the case with British Gas who supported a gas research centre at Leeds University for 80 years. This centre could develop hydrogen burners for all manufacturers of all appliances, which would be more cost effective than competing teams.

All current NG appliances must be converted to hydrogen and all could be made dual fuel (no change in the appliance when conversion occurs) but the hy4heat programme has not encouraged dual fuel work and my consortia are the only ones committed to dual fuel appliances. We have been actively discouraged from the dual fuel approach, which seems strange to us as it makes the transition from NG to hydrogen easier if no change in the appliance is required. All gas appliances could be required to be dual fuel, but that is not the current policy due to bad advice on its feasibility. All three gas fires that we have developed are dual fuel and this eases the transition to hydrogen, as all new fires and boilers could be legislated to be dual fuel from say 2023 so that the appliances were ready when hydrogen was available. Both BEIS and the rest of industry have not recognised the importance of dual fuel capability and that the properties of hydrogen and NG enable dual fuel to be possible. We were left to develop dual fuel largely on our own initiative and with no additional funding for our Hy4Heat work.

In the industrial sector, the large burners used are common to various applications. We are developing steam boiler hydrogen burners for the whisky distillery area with funding for this from the BEIS Green Distilleries initiative. But the burner is fitted in a standard steam boiler and could be applied in other areas, but the funding is not for this. This is just one example of the lack of co-ordination.

2.1.3 The dependency of the Government's proposed plans on carbon capture and storage (CCS), any risks associated with this and how any risks should be mitigated

Green hydrogen can be generated by electrolysis of water using renewable electricity during periods when the supply of renewable electricity exceeds the demand for electricity, which occurs quite often when there is a large wind and solar supply of electricity. BEIS and EPSRC have been funding research into more efficient electrolysis systems which is sensible. However, currently 96% of hydrogen comes from steam methane reforming (SMR) of NG and it is clear that initially large scale hydrogen production must come from SMR with CCS of the CO_2 released in the process. This is most efficiently done on a large scale with grid NG supply and connections to the pipelines for CO_2 disposal. In comparison making hydrogen on the site of large users is less efficient and more costly in building connections to the CO_2 pipeline to disposal sites. Thus, hydrogen for heat is dependent on CCS and will have limited impact if a major construction of CCS plants and CO_2 pipelines is not undertaken. However, the lack of progress on building CCS plants and the low ambition for this area up to 2030 will limit progress on decarbonisation using hydrogen.

The CCS target in the Government's proposed plans of 10MT of CCS by 2030 lacks ambition and is too low for hydrogen supplies to be large enough to meet the need of industrial and domestic heat decarbonisation. The 310 TWh of domestic NG use in 2019 converts to 62 MT of CO_2. Net zero by 2040 requires a CCS build rate of 30MT per decade, just for domestic heat requirements and an additional build of 10MT of CCS for industrial heat CO_2. This shows that the current plans are not to decarbonise domestic heat with hydrogen and no viable plans exist to decarbonise by other routes. The target for hydrogen production of 5 GW by 2030 will create about 23 MT of CO_2 per year and so the CCS programme is not even matched to the hydrogen programme and this implies a major use of electrolysis, which also do not exist on a sufficiently large scale. A major programme of building CCS connected to SMR plants for hydrogen production is required. Government funding to facilitate this would be useful, otherwise hydrogen will not be the route to decarbonisation. We have been talking about CCS for 20 years in the UK and we need to stop talking and start building on a significant scale. The IPPC has stated in all its reports that zero carbon without CCS is unlikely to happen and this is true for the UK as well as the rest of the world.

The National Centre for CCS in Sheffield has a 250 kW demonstrator which is ridiculously too small to be useful. This Centre has swallowed £20M of research funds for little output and should be closed and real scale plants built. There is little research required for CCS as the plants are commercially available. The plants are conventional chemical engineering plants and CCS with SMR for hydrogen production is the most sensible technology, as the plants are smaller than for post combustion capture. The Sheffield plant is a post combustion CO_2 capture plant, which is not the technology that is relevant to a hydrogen decarbonisation future, which is pre-combustion CO_2 capture.

2.1.4 Potential business models that could attract private investment and stimulate widespread adoption of hydrogen as a Net Zero fuel.

The NGN H21 report also shows how the transfer to hydrogen in the grid could be paid for privately, through a modest increase in the current charge to customers for the network operating costs. This would simply be a continuation of the existing charge that is paying for the replacement of cast iron gas mains with polyethylene pipes (PE – yellow pipes) that is currently being installed throughout the UK, in a programme that started in 2002. The timescales of the H21 project are relatively long, but complete decarbonisation of gas usage could be achieved by 2045. If the programme was to be accelerated then more funds would be required and more staff trained and employed to do the work. This extra funding could be provided by the Government or a higher charge placed on consumers, which could lead to a worsening of fuel poverty. This is a political decision, but political policies to bring the date for decarbonisation forward from 2050 have cost implications. These decisions need to be made and are not helped by false predictions that hydrogen is not the route that should be followed for decarbonisation and zero carbon, when it is the most cost effective way of achieving these goals.

Once the technology for hydrogen combustion equipment has been developed with the financial assistance of BEIS, burner and appliance manufacturers will invest the capital to bring these to production. However, they need a market to sell in and the advantage of a dual fuel NG/hydrogen appliance is that it can be sold now for NG use with conversion to hydrogen in the future not requiring any change to the appliance. This makes transition to hydrogen for heat much easier and gives a market for the product now and not when hydrogen is available. It is not sensible to start selling hydrogen fires after the gas grid delivers hydrogen and so selling gas appliances that will work on hydrogen and NG will facilitate the widespread adoption of hydrogen for heat. Unfortunately, BEIS has not followed this approach, as it has had some bad advice on its feasibility by consultants it employed, who were not experts! In our Hy4Heat work on gas fires we have demonstrated dual fuel operation for three different fires with no change in the fire when the fuel was changed. We had little encouragement from BEIS to undertake this work, which means that the benefit of dual fuel operation in the transition from NG to hydrogen is not appreciated.

3. The progress of recent and ongoing trials of hydrogen in the UK and abroad, and the next steps to most effectively build on this progress

The hy4heat BEIS projects that I have been involved in have been successful and hydrogen appliances will be certified later this year. As far as I know other consortia are on track to certify central heating boilers and other types of fires. Domestic and commercial gas cookers and hobs are an area that has not been funded to my knowledge. Some funding needs to be allocated here or the PM will not be able to sit down at COP 26 to a breakfast cooked on hydrogen (The Ten Point Plan for a Green Industrial Revolution, Dec. 2020, PM's Forward). To my knowledge contracts for domestic stoves were not awarded and a viable hydrogen cooker hob does not exist, although we have a design that works. We were awarded contracts for commercial hobs that were not funded due to budget cuts for Hy4Heat. Other areas of commercial and small industrial heat (Hy4Heat WP5) were also not funded, due to funding problems.

The progress on hy4heat needs to continue with the manufacturers of the equipment leading public trials and demonstrations. The public need to be able to see that hydrogen is safe, provides the same heating function of NG and the appliances are attractive. Community based trials need to take place to show that the gas distribution systems as well as the appliances are also safe. It is vital that the current manufacturers of the hydrogen appliances are involved in this work, as the technology in the new fires, particularly the dual fuel fires, is outside the experience of conventional gas engineers.

In my opinion legislation should be passed (Building Regulations) requiring all new gas appliances to be dual fuel from say 2023. This will ensure that as hydrogen becomes available the appliances will be ready and the number of old appliances that need replacing will decrease with time. BEIS could help the transition with more Hy4Heat funding to develop the dual fuel equipment, but eventually manufacturers will bear the cost and pass this on to customers.

4. The engineering and commercial challenges associated with using hydrogen as a fuel, including production, storage, distribution and metrology, and how the Government could best address these.

The engineering challenges are formidable: to produce the hydrogen; distribute it to 24 million customers and industry; build the required CO_2 pipelines and storage systems; persuade the public that hydrogen is safe to use; develop appliances that heat as effectively as NG does with no additional environmental harm. However, all have known solutions and the issue is one of cost. CCS plant are commercially available as are SRM plants. CO_2 compressors are available and the construction of high-pressure CO_2 pipelines is a known technology. Appliances can be developed for dual fuel operation with NG or hydrogen. None of this will happen without legislation from Government and some help with the cost. What is required is a will from Government to decide that hydrogen is the way that the UK will get to zero CO_2 emissions for the heat sector. The massive project will be a great boost to the manufacturing industry and provide jobs for 30 years for the gas supply industry. Also, we would be the first country to commit to hydrogen as enabling the road to zero. The export potential would be enormous, but we cannot prevaricate any more as Germany has committed €60bn to hydrogen recently and we risk being left behind as we were with CCS.

5. The infrastructure that hydrogen as a Net Zero fuel will require in the short- and longer-term, and any associated risks and opportunities.

The required infrastructure for hydrogen is known and is all conventional engineering.

(a) Build electrolysers on a massive scale at locations connected to the high-pressure gas grid
(b) Build SMR plant at locations connected to the gas grid and to the CO_2 high-pressure gas disposal grid.
(c) Build the CO_2 salt cavern storage and offshore depleted gas field storage
(d) Complete the installation of PE gas pipes
(e) Connect hydrogen to the gas system section by section, as envisaged in H21 (NGN)
(f) Although the hydrogen for heat project does not specifically include electric power generation, it is clear that if the gas grid is hydrogen then other users of the grid, specifically CCGT for electric power, must also operate on hydrogen and this requires new low NOx combustors for CCGT plant, which have been developed by most of the big manufacturers.
(g) Ensure that all gas appliances are dual fuel or at least hydrogen ready, but if only hydrogen ready then gas engineers are required for conversion of 24 million homes (change of burner – cost at least £24bn). Dual fuel appliances avoid the cost of this burner change.

The cost of all the above is £100bn+ but this is lower than some alternatives – 24 million households with heat pumps is >£360bn plus the costs of the additional electricity supplies. The key risk in all of this is that if the gas grid is not converted to hydrogen or a commitment to do this, then why would appliance manufacturers develop products for hydrogen as the fuel, without BEIS covering some of the cost. The issue is one of confidence: decarbonisation using green/blue hydrogen must be committed to and the system at least be under construction before dual fuel gas appliances will be put on the market. If users know hydrogen is coming then they will opt for dual fuel appliances. It will take at least 10 years to build the hydrogen supply and distribution infrastructure and in that time a lot of appliances will be sold that could be dual fuel and so conversion issues will be greatly reduced.

6. Cost-benefit analysis of using hydrogen to meet Net Zero as well as the potential environmental impact of technologies required for its widespread use

Hydrogen is one of the lowest cost ways of reaching zero carbon emissions as it utilises the existing £100bn+ investment in the gas grid. Currently gas network operators are spending about £6bn per year on the conversion of cast iron pipes to PE pipes, which are compatible with hydrogen, but the purpose of the investment was to eliminate leaks from the gas mains (30% of NG in the gas main used to leak and never arrive at the customer). Thus, this expenditure is not part of the cost of conversion to hydrogen as the investments has already been made. 24 million households are connected to the gas grid and no major expenditure in each household is necessary for decarbonisation with hydrogen in the gas grid. If gas appliances are regulated to be dual fuel, which can be done at a similar price to existing gas appliances, then the capital cost to each household is minimal as they would change the heating appliance every 10 years or so anyway. The cost of hydrogen as the solution to decarbonisation is then limited to the above costs for the generation of hydrogen and the disposal of the CO_2. These costs can be recovered from the consumer via the grid operational charges on the gas bill, in the same way that the cost of PE pipework installation is being met at present (NGN H21 has full details). The cost of hydrogen infrastructure for the gas grid supply was estimated in the H21 report as an increase from 17% of the gas bill to 22%. The gas network companies borrow the money for the conversion over a 50 year mortgage, so the customer pays over a 50 year period but the work is done quickly without personal borrowing by the customer. Most alternatives, such as heat pumps, require the customer to borrow the money to install the decarbonisation devices or the house insulation, at a much greater borrowing cost then the large gas network companies can access finance. This is why the hydrogen route to decarbonisation is not only practical to deliver from an engineering viewpoint, it is also practical to finance and does not need large Government grants or subsidies.

The main environmental impact of hydrogen combustion for heat is that of potentially higher NO_x emissions. However, currently the ecostandards and the Large and Medium combustion plant directives control the allowed NO_x emissions from heating and power generation plant and these controls will continue post Brexit. It is for the burner and appliance manufacturer to meet these regulations with hydrogen and that is a matter of burner design. Low NO_x with hydrogen can be achieved, as has been shown by the work of the CBS consortia that I am technical lead for in Hy4Heat. Unfortunately, BEIS has not required NO_x compliance at an early stage in hydrogen burner development in the Hy4Heat programme and this has resulted in hydrogen appliance development potentially failing at the last stage of development, due to non-compliance with NO_x regulations, which are only tested at the end of the programme. Hydrogen has major environmental benefits with no CO or hydrocarbon emissions and no soot or particulate emissions. The net result will be a significant improvement in air quality.

7. The relative advantages and disadvantages of hydrogen compared to other low-carbon options (such as electrification or heat networks), the applications for which hydrogen should be prioritised and why, and how any uncertainty in the optimal technology should be managed.

The UK NG gas network is the source of heat for 24 million properties, 84% of homes are connected to the gas network. 56% of cooking is done by gas, 77% of space heating is by gas and 80% of water heating is by gas [KPMG and KIWA/Gastec, The UK Gas Networks role in a 2050 whole energy system, July 2016]. Overall, approximately two-thirds of residential and commercial energy consumption is met by NG. Repurposing the gas grid for hydrogen keeps all these premises connected to a decarbonised fuel source and is the most practical way of achieving widespread adoption of decarbonised heat.

Peak gas use in 2018 was 130GW which is much greater than the peak use of electricity, and the installed total capacity of 85GW electric. The median gas use was 12 MWh compared with 3 MWh of electricity. Thus, an electricity-based decarbonisation of heat requires large additional renewable or nuclear electricity capacity at the same time that extra electricity capacity will be needed for electric vehicles in transport. A non-electric route to decarbonisation of heat is clearly more viable than an electric heat route. The Committee on Climate Change (CCC) [Road to zero] found that re-purposing the gas grid to deliver low carbon hydrogen is the lowest cost option under most scenarios studied. However, they still did not recommend the hydrogen solution to decarbonisation. Once a hydrogen gas grid exists then it will be available to store surplus renewable or nuclear electricity, via electrolysis, at times of low demand but high generation. That stored hydrogen can then be used to generate electricity via existing CCGT providing a further benefit of the use of the hydrogen grid. This benefit is lost if heat is sourced from electricity and it also makes efficient use of renewable energy more difficult to achieve. Element Energy [Element Energy, Extension to Fuel Switching Engagement Study – Deep decarbonisation of UK industries, April 2019. Commissioned by CCC.] concluded that hydrogen is suitable for almost all heating applications and can be delivered at a price of 4.9 p/kWh compared with 9 p/kWh for clean electric heating. Hybrid solutions, with the bulk of heat demand, met by electricity, and peak demands met by green hydrogen are advocated by CCC as the lowest cost option [Road to Zero, 2019. Hydrogen in a low carbon economy, 2018]. In contrast to the above, work at Northern Gas Networks [H21, 2016] showed in great detail how the conversion of the gas grid to distribute hydrogen from SMR with CCS production sites could achieve the decarbonisation of heat using the existing NG grid distribution system. Their analysis was supported by a gas network study [KPMG and KIWA/Gastec, The UK Gas Networks role in a 2050 whole energy system, July 2016:]. Whilst heat pumps could be easily integrated into newly built homes the conversion of existing properties would be substantially more difficult and costly. In addition the inter-seasonal storage of electricity poses difficult challenges that may prevent large scale uptake of electrically supplied heating systems [H21].

Green/blue hydrogen offers a solution to the decarbonisation of heat, electricity and transport (electric cars). However, there is no co-ordination of the three areas and some hydrogen advocates think hydrogen fuel cells should be funded for cars but these are more expensive than electric cars. The Government and EPSRC has sunk millions into support for fuel cells over the last 20 years, but there is little evidence of a viable economic product coming to market with significant scale production. So hydrogen to electricity via CCGT and then electricity for charging batteries for transport electric vehicles is a more sensible use of hydrogen for transport. The gas grid then transports the hydrogen to the CCGT plant and there is no need for a hydrogen distribution system to hydrogen vehicle filling stations.

7.1 The applications for which hydrogen should be prioritised and why.

If the grid was converted to hydrogen then all current uses of NG for heat would be done by hydrogen and this would include both domestic, commercial and industrial usage. This is the best option. However, it also means that no carbon reduction occurs until the gas grid is converted to hydrogen. It is possible for industrial usage of hydrogen, such as glass and steel manufacture or whisky distilleries, could be met by local NG to hydrogen plants with local CO_2 storage. This would avoid the need to convert the whole gas grid and could be the fastest way to get decarbonisation via hydrogen. Once the whole grid was converted to hydrogen these industrial hydrogen gas supplies could be connected into the hydrogen grid.

The decarbonisation of domestic heat requires the gas grid conversion to hydrogen to be complete in local areas with a single gas pipe network. By connecting hydrogen to local networks, only as the hydrogen becomes available, leads to an earlier introduction of hydrogen [NGN H21]. As this is how the transition from NG to hydrogen will be achieved, it is possible for rapid local use of hydrogen in the grid [NGN H21]. In the H21 study Leeds was the first area for conversion and could have been achieved this decade, with other cities following later. This is a viable approach and is the one that should be followed as it gets an early start to the decarbonisation of heat. It is possible that industrial decarbonisation of heat for specific large energy use plants could be built at the same time, but would the network operators borrow the money to do this or is the investment left to the large energy users?

7.2 How any uncertainty in the optimal technology should be managed.

The hydrogen route to decarbonisation of heat has few uncertainties, especially after the BEIS investment to show that hydrogen fired heating appliances can be designed to operate safely on hydrogen. All the equipment required, listed in s.5, are available and do not need development. Dual fuel heating equipment has been shown by the CBS consortia to be viable for heat purposes. There are thus no major uncertainties in the hydrogen route to decarbonisation of heat. The major non-technical uncertainty is whether the Government has the political will to get on and action the re-purposing of the gas grid for hydrogen and to build the hydrogen production facilities. The H21 report shows that the finance can largely be through the existing gas grid charges in the gas bill, so that the polluter pays principle is applied.

Other decarbonisation methods have more uncertainties than hydrogen. Heat pumps have a major barrier of costs and disruption during the retro-fitting to existing houses. How could you force a householder to make this investment? If it was confined to new builds this would be a very slow penetration of the heat market. The householder would have to borrow money to pay for heat pumps, the electricity network is unlikely to borrow the money for him, whereas for hydrogen it is the gas network operators that would borrow the money for the conversion to hydrogen. House insulation, solar panels etc. all involve the owner in borrowing money to install the technology. This is a major barrier to the implementation of decarbonisation that is not there with the hydrogen approach.

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