Humshaugh Net Zero Hydrogen Report

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Executive Summary

There has recently been much in the News about Hydrogen as a fuel of the future. Announcements from the Prime Minister and his colleagues promoting hydrogen as a new energy source have hit the headlines. There appears to be a genuine desire to make significant progress towards delivering the UK's 2050 net zero CO_2 target, partly as it could be a future winning technology for the UK and partly to show some progress before the COP26 conference to be held in Glasgow in 2021.

The UK is blessed with significant wind resources, especially offshore to the north of Scotland. The UK already has the world's largest electrolyser factory, so has a lead on this key technology, and also have several companies active in the fuel cell production market too, although the market leaders in this field appear to be in Japan, South Korea, and the USA. Electrolysers use electricity to produce hydrogen (and oxygen) from water. Fuel cells do the opposite, combine hydrogen and oxygen to produce electricity.

Current announcements however are largely aimed at large scale hydrogen production, using electricity from offshore turbines to operate electrolysers and then using the existing offshore and distribution gas grid to distribute increasingly hydrogen rich gas to consumers. In the period 2030-2060 a significant method of producing hydrogen will involve striping it from methane and storing the carbon dioxide simultaneously in old natural gas caverns under the North Sea. This carbon sequestration, as it is called, would prevent the release of the carbon dioxide into the atmosphere that would result if the methane was simply burnt. This 'blue' hydrogen would be replaced by 'green' hydrogen produced using renewable energy as the technology evolves.

Converting electricity generated by offshore wind turbines into hydrogen, either on the turbine platform or on an island hub seems to be the most likely way forward. Offshore wind turbines are already significantly larger than their onshore equivalents, as they avoid most of the size-limiting constraints associated with onshore sites. Winds are generally stronger over the sea than on land so wind turbines sited offshore produce more electricity.

Hydrogen is and can be used for many purposes. It is used in the chemical industry for a range of products including, for example, the production of ammonia for the fertiliser industry and the steel industry in the tin plating process. It can of course be burnt to produce heat or used in fuel cells to produce electricity. In the future therefore, the likely uses of hydrogen in Humshaugh are for heating and providing power for transport.

At present though, hydrogen is not approved for central heating applications, although work is progressing in projects to change this. Using hydrogen from non-green sources such as methane would produce lower emissions when compared with more conventional fuels such as coal and LPG, but better technologies such as heat pumps and biomass boilers are currently available that are more carbon efficient.

For transport, hydrogen solves the range/weight/refuel times that battery electric vehicles have, so is a fuel particularly suitable for HGVs, ferries, trains (that can't be electrified), agricultural vehicles, and vehicles in constant use such as taxis, light vans, ambulances, police cars, etc. Because hydrogen is a fuel made by using electricity, compressed, stored, and then converted back to electricity for use in transport application it is not as energy efficient as using a battery for smaller vehicles including private cars.

The phasing out of new cars wholly powered by petrol or diesel by 2030 is a significant driver for change in the transport industry and while there is little infrastructure or choice for hydrogen cars today, this is likely to change very quickly.

In order to produce hydrogen at a price where it can be switched to as a transport fuel or as a replacement for natural gas without financial penalty, three sets of economic drivers need to come together: size, utilisation and location. Offshore, electrolysers at the multi-MW scale powered by wind at 50-60% load factor and a pumping the hydrogen directly into the offshore gas main holds the promise of achieving a fuel priced similar to natural gas. Using an electrolyser fed from a green electricity tariff or small-scale renewables with a low utilisation produces hydrogen at approximately twice the current price of diesel.

I recommend that you avoid hydrogen as a fuel for heating and once you have finished your analysis of the potential for renewable energy in the Humshaugh parish, if there is a significant mis-match in supply/demand in electricity (especially with over-supply), you consider producing hydrogen for transport once it becomes apparent that this is a fuel that will be adopted in the village. This is unlikely to be apparent in the next 10 years.

Government support for Hydrogen

In November 2020, Prime Minister Boris Johnson released details for a 10-point plan to turn the UK into the world's number one centre for green technology and finance, creating the foundations for decades of economic growth. Four of those points are

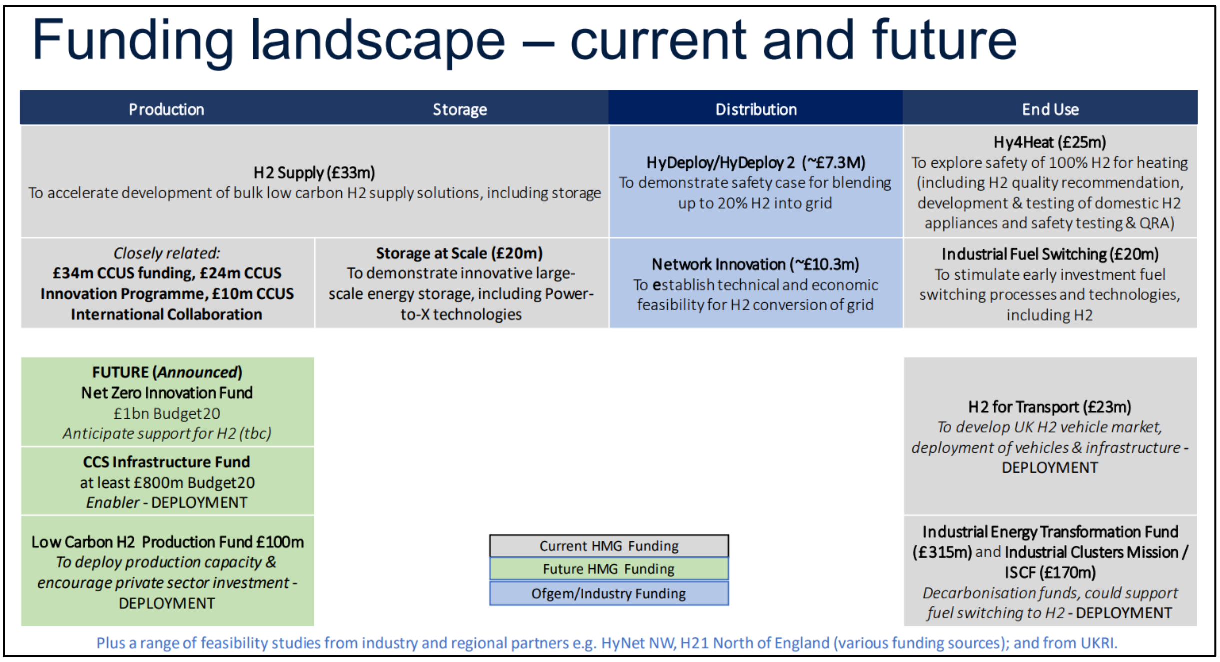
- Plans to make the UK the 'Saudi Arabia of wind' with enough offshore capacity to power every home by 2030.
- Plans to turn water into energy with up to £500m of investment in hydrogen.
- An ambition to achieve the first nonstop transatlantic flight with a zero-emission plane.
- Plans to establish a new world-leading industry in carbon capture and storage, backed by £1bn of government investment for clusters across the North, Wales, and Scotland.

His ministers and civil servants have been working on a range of policies that support Hydrogen. At the Annual Scottish Hydrogen and Fuel Cell Association, one of his civil servants opened the conference.

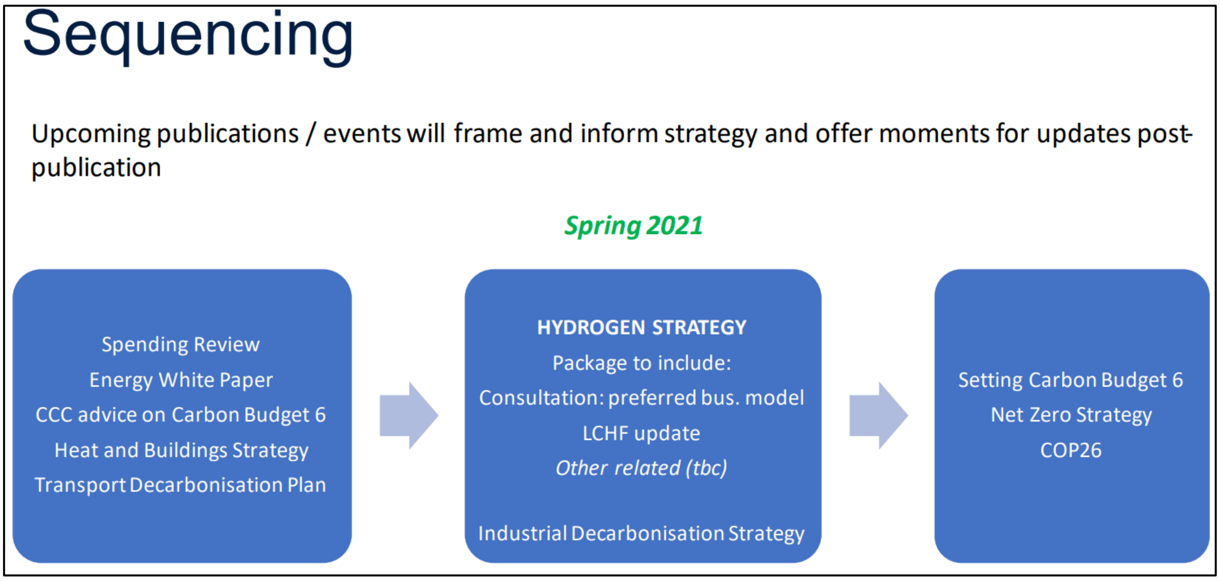
Quotes from Paul Henderson – Head of Hydrogen Supply, Hydrogen Economy, Department for Business Energy and Industrial Strategy (BEIS) - to the Scottish Hydrogen & Fuel Cell Association conference:

BEIS and Committee on Climate Change (CCC) analysis shows we will need significant amounts of low carbon hydrogen in energy system to meet net zero (BEIS: 150-450TWh by 2050)	Consensus of Views • National Grid's annual Future Energy Scenarios (July): Hydrogen and carbon capture and storage must be deployed for net zero. H_2 provides between 152 - 591TWh by 2050. • Aurora: 2050 scenarios range from 210-500TWh, mix of green & blue H_2 • UK H&FC Research Hub: H_2 consumption by 2050 120-750TWh. • Bloomberg (May): Meeting climate targets likely to require a clean molecule, especially for the hard-to-abate sectors. Hydrogen could meet up to 24% of the world's energy needs by 2050.

The government is already committed to some funding to make a future hydrogen economy a reality.

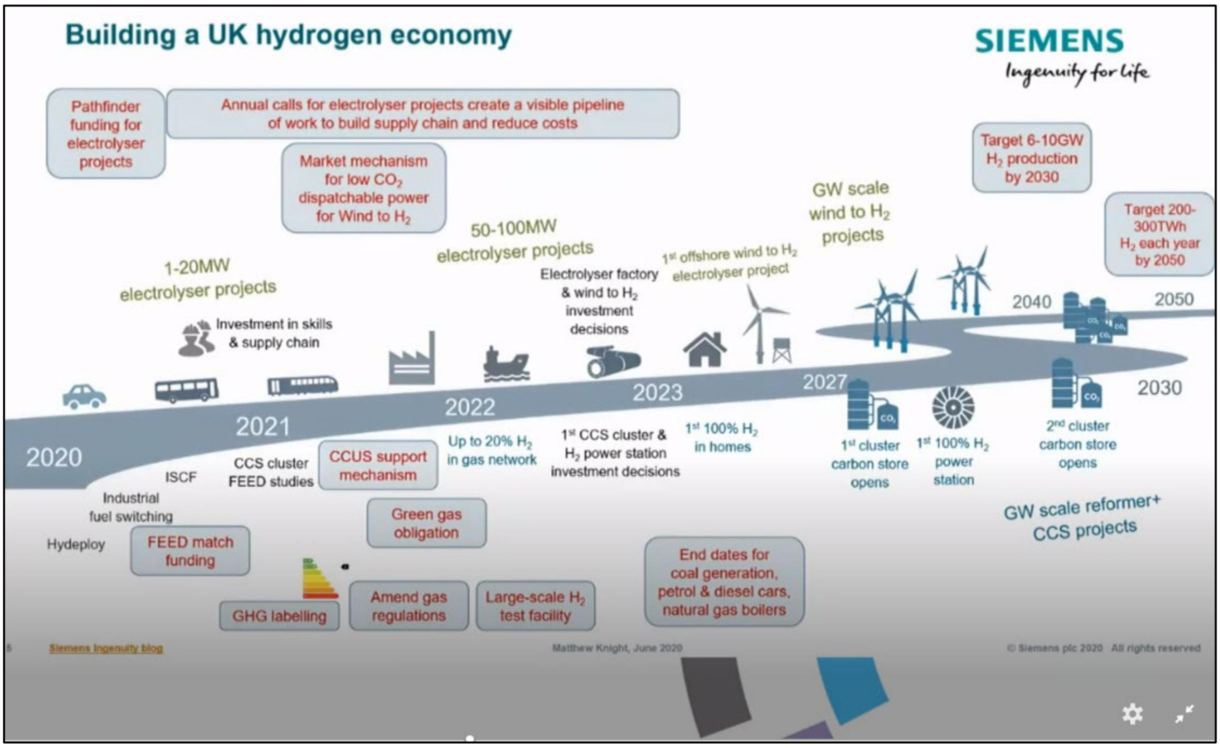


The Government is also committed to producing a hydrogen strategy next spring, which may lead to other funding opportunities.



Large scale Hydrogen production

A slide from Siemens PLC suggesting the likely scale up of hydrogen from 2020 to 2050 and some of the support they think is needed to make the idea a reality.



On the production side, in the near future carbon capture and sequestration technologies are to be developed then deployed at scale by 2030. In a similar way, offshore wind to hydrogen technologies are to be developed and deployed at scale by 2040.

On the consumption side, transport is starting to switch to hydrogen now and factories and homes may be switching to hydrogen by 2030.

On the production side, some of the scale of the change envisaged can be seen in the following reports - the first by the Oil & Gas Authority looking at re-use of the gas network and storing carbon dioxide and hydrogen in depleted gas fields. The second is by element energy looking at carbon capture in Aberdeen (although this will also be applicable to Teesside, Humberside, Cheshire and other areas), and the third is by consultancy ERM looking at making hydrogen from offshore wind.

1. https://www.ogauthority.co.uk/media/6257/ukcs-energy-integration-interim-findings.pdf
2. https://theacornproject.uk/wp-content/uploads/2020/09/Hydrogen-in-Scotland-The-role-of-Acorn-Hydrogen-in-Enabling-UK-Net-Zero.pdf
3. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866375/Phase_1_-_ERM_-_Dolphyn.pdf
4. https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

On the demand side, significant work is looking at hydrogen for green heating. Hydrogen gas boilers already exist, produced by Baxi Heating and Worcester Bosch although they are not yet approved for use in the UK. They are undergoing trials as part of a project H21 looking at the use of hydrogen in homes. This project compliments other work ongoing at Keele University where hydrogen has been injected into a small network and a project H100 looking to develop a hydrogen supply network in Fife.

More on these projects can be read about here:

1. https://www.theconstructionindex.co.uk/news/view/demonstration-project-showcases-hydrogen-heating-for-homes
2. https://www.h21.green/building-h21-houses/
3. https://www.keele.ac.uk/discover/news/2020/june/hydeploy-update/pilot-positive-results.php
4. http://www.shfca.org.uk/news/2020/5/18/sgn-h100-the-worlds-first-100-hydrogen-network-for-fife-consumers

Hydrogen for heating in Humshaugh

Humshaugh is not served by the gas grid, which is the case for around 4 million homes in the UK. The main focus of Government efforts to deliver a hydrogen economy appear to be paving the way for the conversion of the Natural Gas Grid to a hydrogen grid to accommodate both hydrogen generated by offshore wind produced electricity used to convert water to hydrogen (and oxygen), and hydrogen stripped from natural gas, where 80% to 90% of the remaining carbon in the form of carbon dioxide is sequestrated. Ultimately this will produce increasing volumes of green hydrogen which could then be made available in bottled form and used to heat homes in Humshaugh.

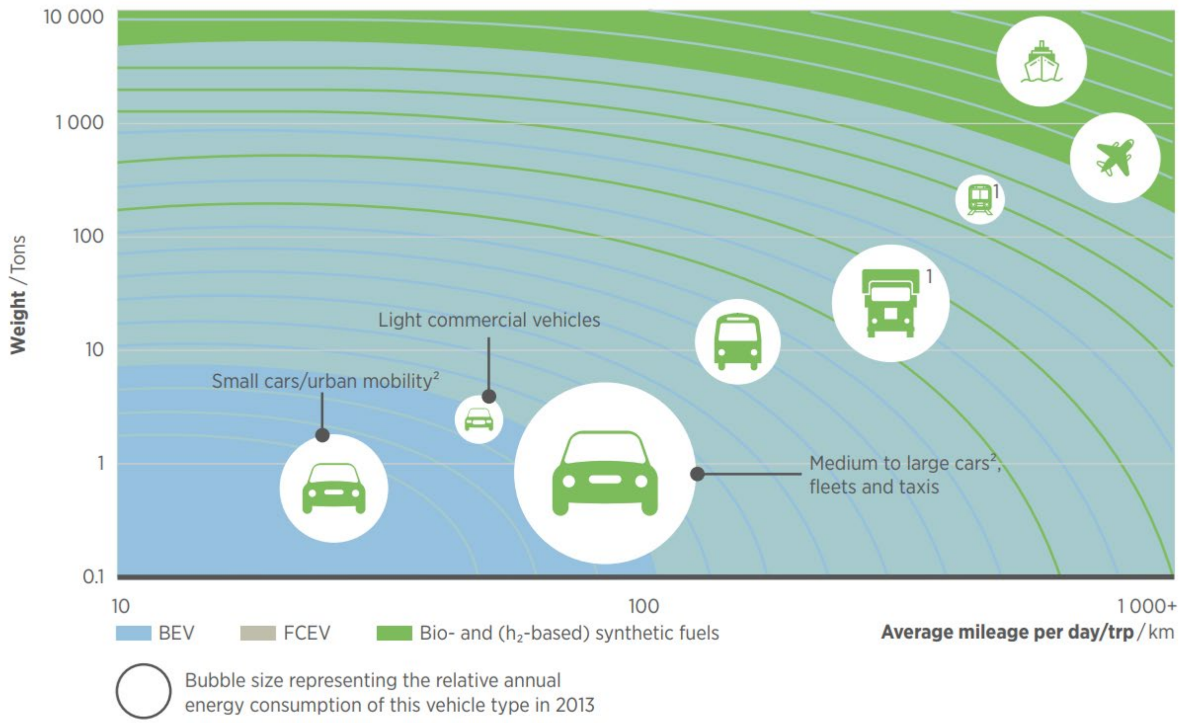
Converting to hydrogen produced from natural gas is potentially better than using other fossil fuels, but not as good as low carbon technologies such as air or ground source heat pumps, or biomass as can be seen in this table:

	kg CO_2 / kWh
Oil	0.333
LPG	0.230
(Grey) Hydrogen	0.126
Air source heat pump driven by electricity	0.101
Ground source heat pump driven by electricity	0.063
Wood	0.015

At present, however, hydrogen is not approved for use in domestic appliances and the safety case for using it in a domestic context is still being developed. Also, while hydrogen has a higher heating value than the natural gas from which it was stripped, it will need to be transported in high pressure cylinders from the production sites in Teesside and Cheshire to Humshaugh, requiring significant energy in the compression process and some additional fuel for the transport compared to LPG or Oil due to the thick metal cylinder walls used to contain the high pressure gas. Other methods of transporting the hydrogen (liquid or in the form of e-fuels such as ammonia) are more energy intensive and economically worse at this scale (compared to the scale needed for long distance shipping for example).

Hydrogen for transport for Humshaugh residents

Hydrogen can also be used as a fuel in transport applications. It is particularly suited to heavy vehicles that travel for greater distances as this chart from the International Renewable Energy Agency shows:



https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf

Hydrogen powered cars are not yet readily available – according to Wikipedia just three are in production; Toyota's Mirai, Honda's Clarity and Hyundai's Nexo.

Buses are making progress with manufacturers in Northern Ireland (Wrightbus) and Leeds (Optare) now producing Hydrogen Fuel Cell Buses. Some are already deployed in Aberdeen and London with more expected in Birmingham, Dundee and Brighton this year.

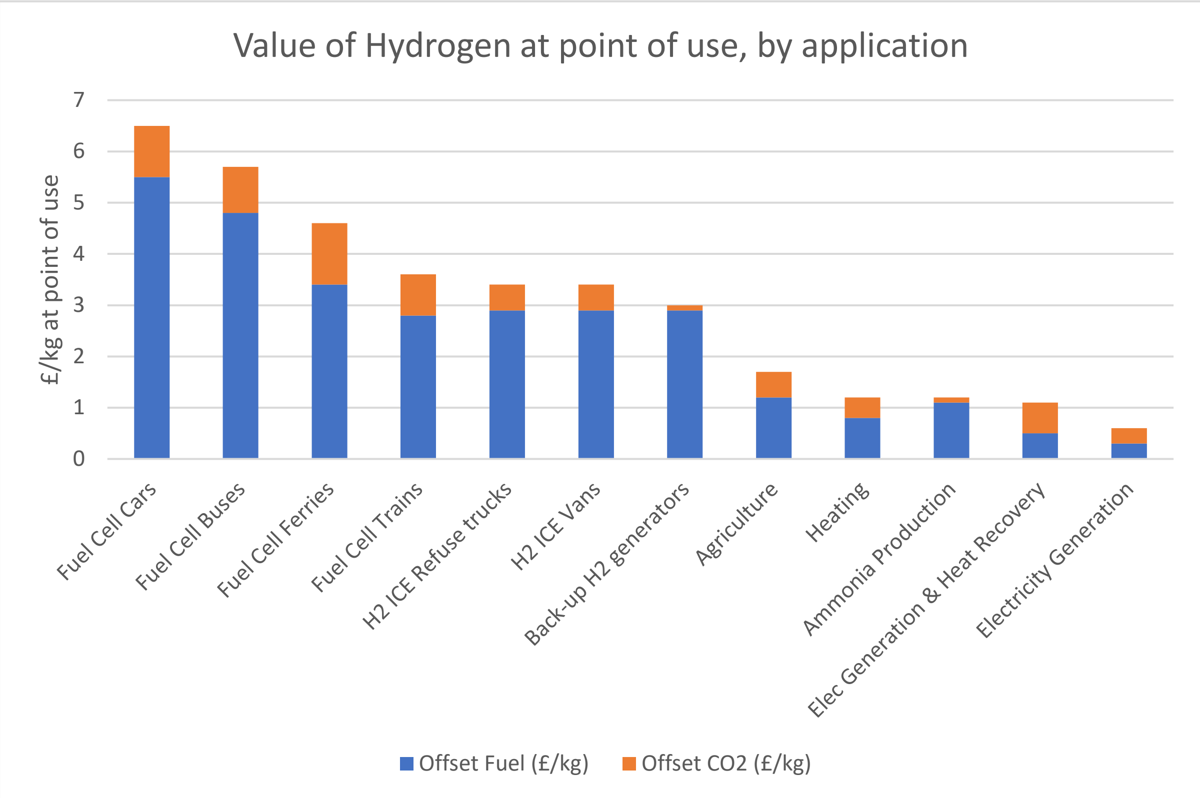
1. https://www.sustainable-bus.com/fuel-cell/wrightbus-hydrogen-double-decker-bus-birmingham/
2. http://www.optare.com/news/2020/4/28/optare-amp-arcola-energy-partner-to-launch-a-fuel-cell-double-deck-bus
3. https://www.fuelcellbuses.eu/projects/jive
4. https://www.fuelcellbuses.eu/projects/jive-2

There are several UK hydrogen train trials underway in the UK, and it is more likely that the Newcastle-Stranraer line will hydrogen powered by 2050, rather than battery powered, or the line electrified.

1. https://www.birmingham.ac.uk/research/spotlights/hydrogen-powered-train.aspx

2. https://www.railwaygazette.com/traction-and-rolling-stock/scottish-hydrogen-train-demonstrator-procurement-begins/57360.article
3. https://www.arcolaenergy.com/vivarail-and-arcola-announce-partnership/
4. https://www.alstom.com/press-releases-news/2019/1/alstom-and-eversholt-rail-unveil-new-hydrogen-train-design-uk

Some work for EMEC on Orkney identified the following price levels before switching fuel is economically driven. In Aberdeen, the cost of Hydrogen for their busses is £12/kg and in London a contract has been drawn up with the price set at £10/kg. (ICE=Internal Combustion Engine)

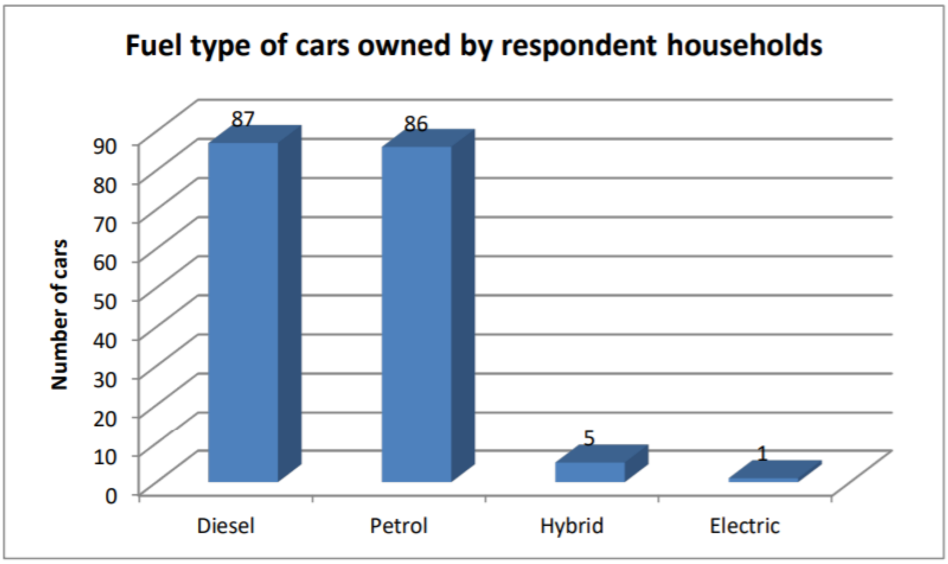


This implies that hydrogen for transport is a field that is likely to change extremely quickly. As the cost of hydrogen production reduces below £6.5/kg it will be economically sensible to switch from petrol to hydrogen, assuming the car cost is equivalent.

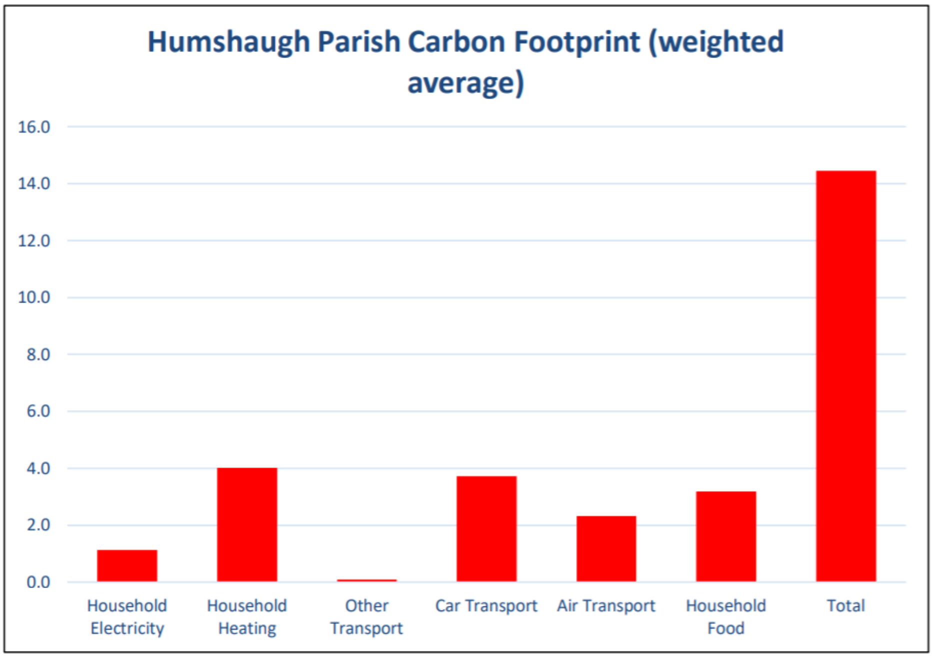
Cars at Humshaugh

From the Humshaugh Carbon Footprint Household Survey 2020 SUMMARY REPORT published in June 2020, complied responses from a total of 110 households within Humshaugh Parish. The number of responses approximates to a 30% response rate.

In the report, the following car ownership details can be obtained:



Also, in the report, an estimate of the carbon emissions per household for car transport is 3.77 tonnes per year.



Taking these details, and data on car emissions and the carbon intensity of electricity from the Government's greenhouse gas conversion factors 2020 (https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020) the following can be deduced.

	Cars in survey	Cars in Village	Milage	Cumulative miles	kg CO_2/ mile	Cumulative emissions kg CO_2
Petrol	87	290	8500	2,465,000	0.2805	691,482
Diesel	86	287	8500	2,436,667	0.2711	660,532
Hybrid	5	17	8500	141,667	0.1860	26,351
Electric	1	3	8500	28,333	0.0849	2,405
			Total milage	5,071,667		
					Total Emissions	1,380,769
					Total Emissions per household	3,766

By 2050 petrol and diesel will not be readily available (due to the net zero targets), with the most likely replacement fuel sources being electricity and hydrogen. Assuming car ownership and milage remains static and assuming the village adopts 70% Battery Electric Vehicles (BEV) and 30% Hydrogen powered Fuel Cell Electric Vehicles (FCEV) then the table could look like this:

	Cars in village	Milage	Cumulative miles	kg CO_2/ mile	Cumulative emissions kg CO_2	Carbon intensity of electricity	Annual electricity needed for car fuelling kWh
BEV	418	8500	3,550,167	0.0849	301,303	0.25319	1,190,026
				Kg H_2 / mile	Total H_2 required	kWh / kg H_2 needed by a PEM Electrolyser	
FCEV	179	8500	1,521,500	65.322	22,244	45	1,000,987
		Total milage	5,071,667			Total Electrical Energy Required	2,191,013

This will more than double the current electricity consumption of around 1,681,425 kWh per year although 1GWh of the energy will be for making hydrogen and some of the BEV charging could be done at work, so some of this consumption could be outside of the village.

A battery electric vehicle will travel on average 2.98 miles / kWh whereas a fuel cell electric vehicle will travel 1.45 miles / kWh. The range of a BEV is between 57-259 miles whereas the Toyota Mirai, a FCEV, has claimed a range of 342 miles. A Tesla S 75D takes 11 hours to charge at home or 30 minutes to reach an 80% charge from a Tesla Supercharger. A Toyota Mirai takes 3-5 minutes to refuel.

The BEV range information has been taken from a What Car real life range test of electric cars, found at the link below and summarised in a table. The Toyota Mirai brochure provides the rest of the information (link below) although the claimed fuel consumption performance has been reduced to 95.5% of the brochure figure to mirror the performance of the Toyota Corolla Hybrid in real life tests.

https://www.whatcar.com/news/what-car-real-range-which-electric-car-can-go-farthest-in-the-real-world/n18159

https://www.toyota.co.uk/download/cms/gben/Mirai-brochure-2020_tcm-3060-1884525.pdf

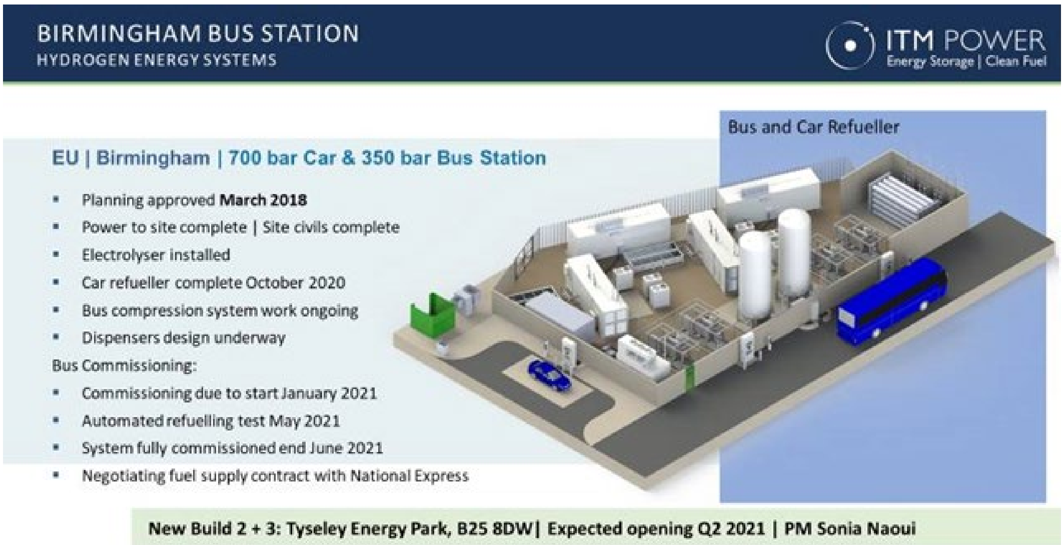
	kWh/mile	Range (Miles)
Smart Forfour EQ	2.9	57
Smart Fortwo EQ Cabrio	2.9	59
VW e-Up	3.5	66
Seat Mii Electric	3.2	111
VW e-Golf	3.3	117
BMW i3 94AH	3.1	121
Nissan Leaf	2.8	128
Renault Zoe R110	2.9	146
Hyundai Kona Electric 39kWh	3.6	158
BMW i3 120Ah	3.3	165
Tesla Model 3 Standard Range Plus	3.1	181
Renault Zoe R135	3.1	192
Audi E-tron 55 quattro	2	196
Tesla Model S 75D	2.4	204
Mercedes EQC	2.2	208
Tesla Model 3 Long Range	2.6	211
Nissan Leaf e+	3.1	217
Tesla Model X 100D	2	233
Tesla Model 3 Performance	2.8	239
Kia e-Niro 64kWh	3.5	253
Jaguar I-Pace	2.6	253
Hyundai Kona Electric 64kWh	3.6	259
Average		172

Making Hydrogen at Humshaugh

Modern PEM electrolysers, which are most likely to be coupled to renewable energy systems to produce green hydrogen, are already a significant electrical load – typically 1MW for an entry level system from a company like ITM power. Scaling up, rather than aiming at small, distributed systems is the theme, targeting the big opportunities. A system currently in production for Birmingham is such a device.

A discussion with the MD of ITM Motive, the UKs only active hydrogen fuel station builder, suggests that the key factors for success are 60m x 30m land space, good road access, Local Authority support, sensible land lease prices, 3.6MW of power available for around 8-9 hours every day, an LV back-up supply and an anchor tenant.

Continuous power availability (from renewables) and anchor tenants (customers for a large fraction of the hydrogen output who will commit to a long-term deal) are likely to be difficult to find in the Humshaugh area. For example, in Birmingham a 1100kg/day unit is being built and will fully commission in Q2 2021, although it has already produced some hydrogen. The anchor tenant is National Express who will refuel 20 coaches, each taking 40kg/day, so 800kg/day. A Figure from ITM Power (The owner of ITM Motive) shows in the arrangement of the site. It should be noted that it is best situated away from housing since the compressors are noisy.



1100kg/day unit being built by ITM Motive in Birmingham

If the village were to develop its own hydrogen supply for its own vehicles at this scale then annual consumption would be satisfied in 22 days, making the utilisation of this asset just 6%.

Small scale electrolysers are available, generally aimed at laboratory work, but some are a little more industrialised – the McPhy range for example. 1 Nm^3 of hydrogen weighs 0.0838kg so 22,244kg would require 727Nm^3 of production per day or 30.3Nm^3/hr at 100% utilisation. Two of the McLyzer 20-30 units could be used to make hydrogen if operated at 75% utilisation with a power connection of 200kW although a compressor would also be needed to reach a usable pressure for a car (700 Bar).   If operated from renewables with a lower utilisation then more units would be required.

https://www.itm-power.com/

https://cellar-c2.services.clever-cloud.com/com-mcphy/uploads/2020/08/20.05.McPhy_Portfolio_ELY_McLyzer_EN.pdf

Humshaugh Model

A model of a small local hydrogen production facility suitable for powering 30% of Humshaugh's vehicles was developed based on the design above and powered by a medium sized wind turbine, 800 kW and solar farm 750kWp. Using current costs and reasonable assumptions about performance, this unfortunately would not be economic. It is most likely that any hydrogen needed for the Parish's cars would come from larger facilities outside, as the petrol and diesel does today. See the Appendix for further details.

Conclusions

Hydrogen is a fuel that, in Humshaugh, has the potential to be used for heating and transport in the future as availability increases and costs reduce.

At the present time, hydrogen is not approved for domestic heating applications, but work is ongoing to change this.

At present, given the current availability and costs of hydrogen, and range of alternative heating options which area available, heat pumps and biomass make more compelling cases as heat choices.

Hydrogen can also be used in Fuel Cell Electric Vehicles. This is a more energy intensive fuel than electricity used in a Battery Electric Vehicle but is more convenient in terms of range and re-fuel time, where performance is similar to fossil fuelled cars.

Hydrogen fuelled cars are today very rare, partly due to the state of technology development and partly due to the availability of the fuel. This is likely to change rapidly now that sales of fossil fuelled cars are due to be phased out by 2030.

Making hydrogen at Humshaugh may be technically possible however it is unlikely to provide financially investible returns at the present time.

Appendix

Hydrogen Production Model:

An existing model has been re-programmed with the following inputs and delivers the following outputs:

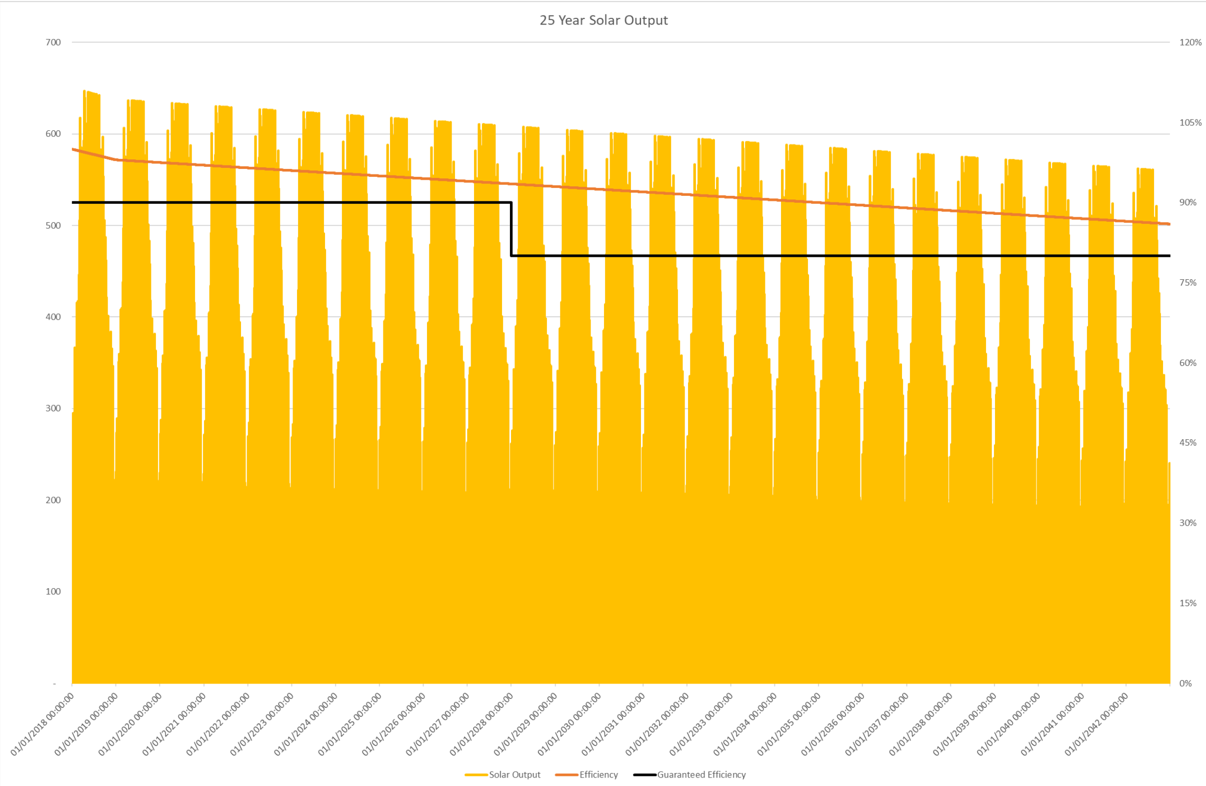
Inputs:

- 800kW of wind with load factor 24.6%. 6kW load when not operating.
- 750kWp of Solar, south facing at 30° with initial load factor 12.4% but dropping by 2% in year 1 and 0.5%/year thereafter.
- 3 x 100kW electrolysers with initial efficiency 74% dropping by 0.33%/1000 run hours
- 1 x 900Nm^3 LP Hydrogen store
- 1 x 200kW 400Nm^3/hr HP compressor (700 Bar)

Electricity Outputs:

25-year averages:

- Wind output 1,726 MWh pa
- Solar Output 750 MWh pa on average but declining as shown below:



Operational Mode:

1. Satisfy Wind Turbine Load
2. Make Hydrogen
3. Curtail output

(i.e. no village load is included)

Hydrogen Output:

22,165 kg / year with an average load factor of 51.4%

Discussion of the model results:

The model has been programmed to make sure that the hydrogen output was able to meet the demand if 30% of cars at Humshaugh converted to hydrogen. The input energy at 800kW wind and 750kWp solar is much larger than the 300-500kW load, that the electrolyser and compressor (when running) present.

No village load has been included in the model, however in reality it is likely that any renewable energy is used first to satisfy that load, including the new loads for BEVs and Heat Pumps, and then spare capacity would finally be used to make hydrogen. Such a load profile, once available from the other streams of work, could be incorporated into this model.

A schematic of the model is included overleaf.

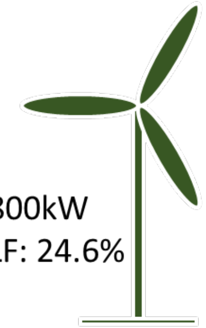
A financial model was also run with the same inputs and the following financial inputs:

	Capex
Wind	£1,104,191
Solar	£697,500
Hydrogen	£828,000
Total	£2,630,411

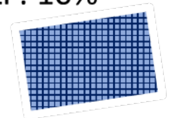
The Hydrogen is assumed to be sold at £7.15/kg

The financial model gives an Internal Return on Investment of **-1.3%,** i.e. it never pays back the capital.

The model however is based on generic values and an actual project calculation may provide a different output. At this point, without a village blueprint for becoming net zero, it is not worth obtaining the necessary input data to make a more accurate project calculation.



800kW
LF: 24.6%



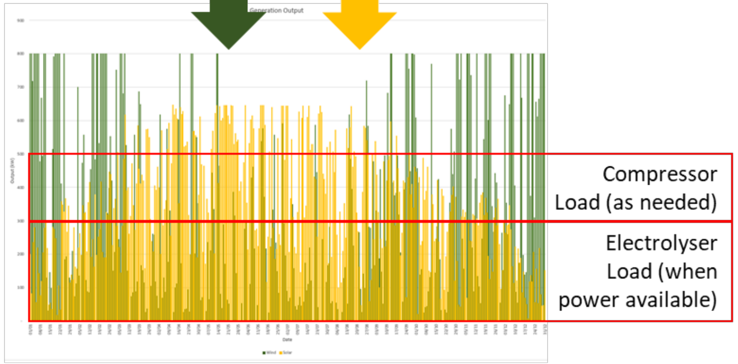
750kWp
LF: 10%

25 Year Averages, MWh pa					
Source	Load/H2 Prodn.	Sold	Curtailed	Total
Wind Farm (new)	983	0	743	1,726
Solar Park	646	0	104	750
Existing Wind Farm	- 0	-	0	-
Grid Import	6	-	-	6
25 year average Hydrogen Output	Tonnes per year		Kg per day	
	22.165		61	

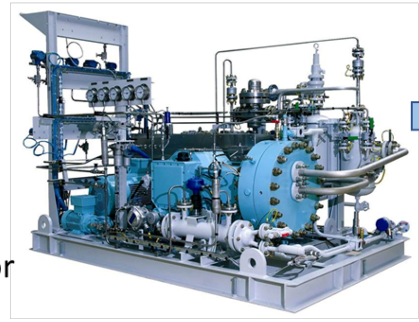
The Village Pump

1,726 MWh pa
743MWh unused

750 MWh pa
104 MWh unused



1 x 200kW Compressor



Storage at High Pressure

1629 MWh pa

3 x 100kW electrolysers