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(HNZ0012)

Introduction

Hydrogen as a net zero enabler must be assessed using the sustainability pillars of society, environment and economics to justify investment decisions. Despite numerous reports to the contrary, I am not convinced hydrogen can be sustainably justified against other net zero enabling technologies in many applications.

Influential lobby groups, with business models that would benefit from hydrogen production, are pushing hydrogen in the absence of evidence based, holistic sustainable comparisons with other energy vectors and options. Hydrogen is being over-sold to the UK taxpayer, media and politicians. This is addressed in a recent Heating in Great Britain: An incumbent discourse resists an electrifying future, here it is concluded 'Incumbents are over-selling 'green-gas' to policy makers in order to protect their interests and detract from the importance and value of electrification.'

Energy Strategy

Firstly, an overall UK energy strategy is required. As described in the recent Energy White Paper, the UK overarching strategy is still in progress; 'In the runup to COP26 we will bring forward a series of sectoral strategies, and our overarching Net Zero Strategy, which will set out more detail on how we will meet our net zero target and ambitious carbon budgets.'

In the absence of a UK strategy, the EU recently produced their report - Powering a climate-neutral economy: An EU Strategy for Energy System Integration. To my mind it presents an energy plan that the UK could do well to adopt.

The three key elements of the strategy are;

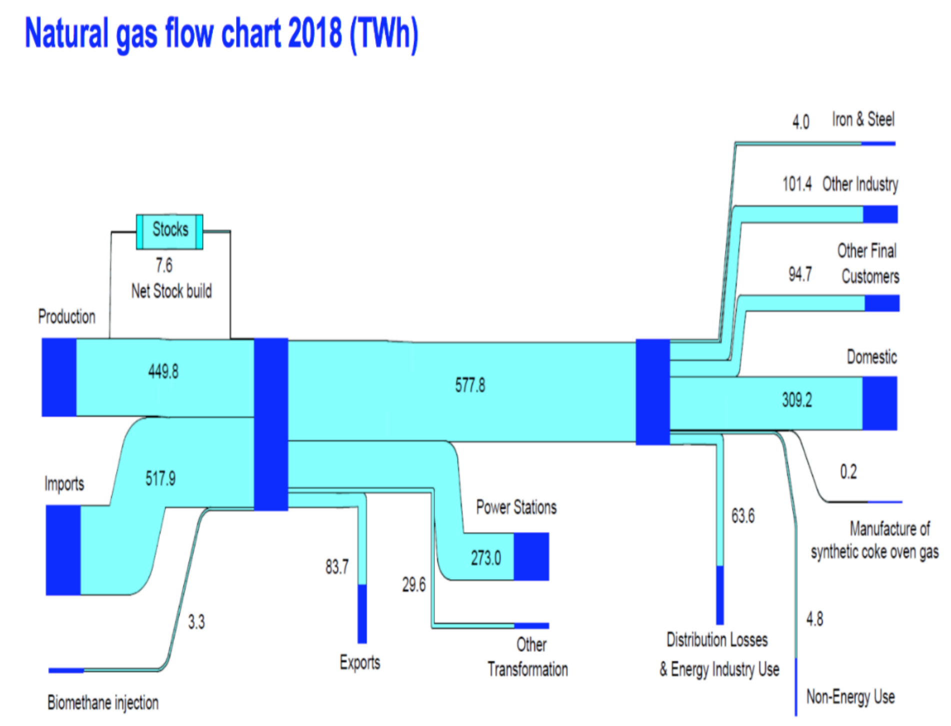
1. A more 'circular' energy system, with energy efficiency at its core.
2. A greater direct electrification of end-use sectors (heat pumps for space heating or low-temperature industrial processes, electric vehicles for transport, or electric furnaces in certain industries).
3. Use of renewable and low-carbon fuels, including hydrogen, for end-use applications where direct heating or electrification are not feasible.

The EU Strategy is at the core of my evidence.

Building Heating

As a focus, the following Sankey diagram is extracted from the UK Government's DUKES (Digest of UK Energy Statistics) data base – Figure 1. It clearly shows the UK natural gas users – the candidates for hydrogen replacement.

Figure 1- UK Natural Gas Flow Chart



Like the European Union, I believe energy efficiency should be at the core of energy policies. So my first take on reducing CO_2 and other harmful emissions is to use less energy. Treat the cause not the symptom; tackle the demand side.

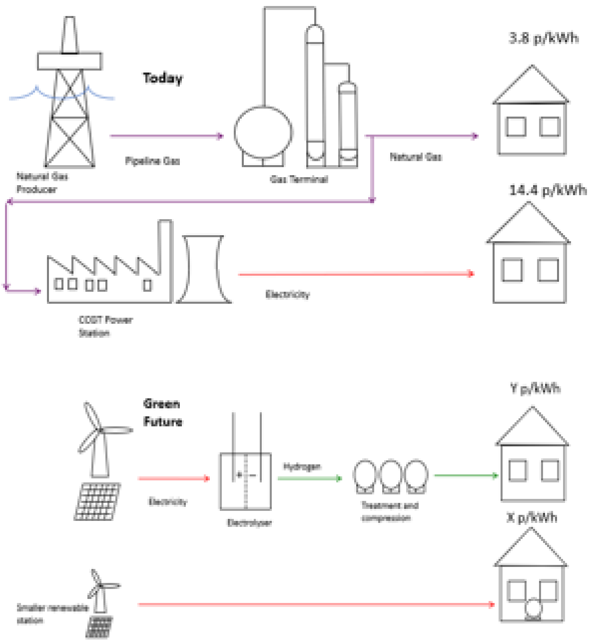
From the flow chart it is evident that the domestic household is the UK's largest direct gas consumer. Not only that, a large portion of the natural gas used for power generation is consumed to support the electrical demand from residential households. It is therefore obvious that if we can deliver on the carbon neutral house the contribution to net zero is hugely significant.

There are no technical barriers to delivering the carbon neutral household. Insulation, heat pumps, solar, battery storage, thermal storage, controlled ventilation come together to deliver a zero carbon footprint. The net zero house needs minimal upgrades to gas or electricity grids as energy usage is minimised.

The Rankine cycle tells us that household heating requires four times more energy via hydrogen than a heat pump – the consequence being a power supply four times larger for hydrogen than a heat pump.

In addition, if hydrogen is synthesised from electrolysis it stands to reason that hydrogen per kWh will cost more than the electricity it was derived from. This is illustrated in the following figure 2.

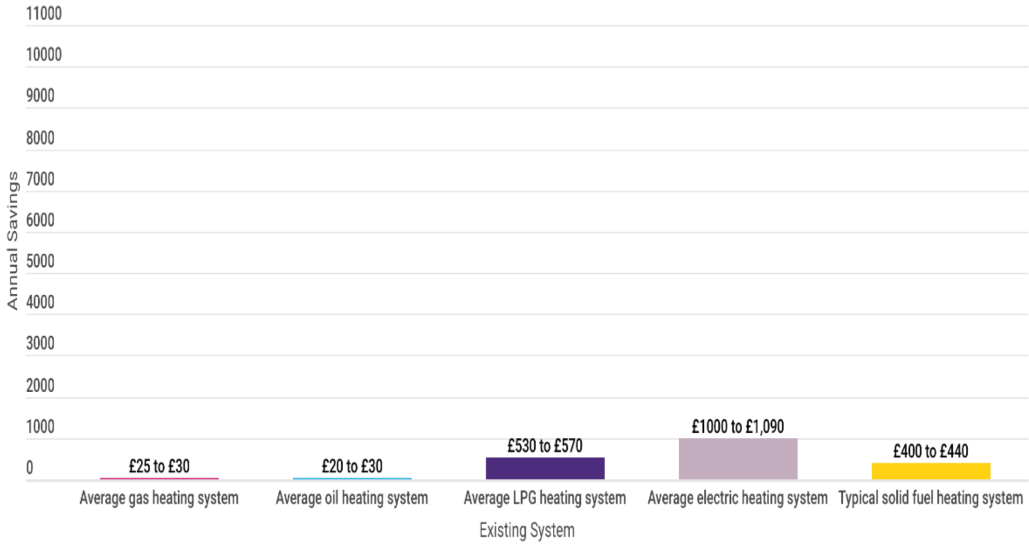
Figure 2 – Current and Future Energy Prices



Moreover, methane reformed hydrogen with CCS (blue hydrogen) will cost more than natural gas. The differential cost of green and blue hydrogen with electricity will transform heat pump justification; presently heat pumps can be difficult to justify with today's favourable natural gas price compared to electricity.

The [UK's Energy Saving Trust] provides the following information for domestic fuel bill saving from deploying a ground source heat pump.

Figure 3 – Cost Saving from deploying a Ground Source Heat Pump



As is readily seen, there is little incentive to change to a heat pump in a house that is currently supplied with natural gas. As previously mentioned that is an upshot of electricity being around four times more expensive that gas per kWh. Move forward to a choice between hydrogen and electricity, where green hydrogen costs more than the electricity it is derived from, the annual savings will show a very different picture in favour of the heat pump.

It is interesting to note that Centrica have recently come out in support of the heat pump on cost grounds.

Despite my best efforts, I have yet to find a UK Gov domestic fuel analysis that uses projected costs of green hydrogen compared with projected electricity costs. From what I can find, option analysis of net zero enablers is carried out in silos – hydrogen, heat pump, CCS etc. - rather than a comparative, holistic analysis. Silo analysis invariably produces an unbalanced view.

The UK Gov needs to conduct a comparative analysis showing the impact on the UK consumer of likely future energy costs for blue and green hydrogen compared to electricity.

Industrial Heat

The largest energy consumers in this sector are the chemical industry, steel, cement, paper, ceramics, glass, food and drinks, mechanical engineering (car manufacture etc.) and mineral products. Frequently mentioned are steel and cement as hard to abate. This is only partially true as much of the required heat can be provided by electricity. The hard to abate part are processes that produce CO_2 or require reducing agents. Furthermore, unlike Germany for example, UK steel and cement manufacture have a much smaller percentage GHG contribution as evidence in the DUKES emissions data shown in figure 4. This indicates steel and cement are 2.2 and 1.6% respectively of the UK's GHG emissions. Important, but very much second order when compared to many other sectors.

Figure 4 – Million Tonnes Equivalent CO_2 emissions from UK Steel and Cement

Business	million tonnes CO2 equivalent	79.0	% UK GHGs 17.51
	Incidental lubricant combustion in engines	0.0	0.00
	Refrigeration and air conditioning	10.7	2.37
	Closed foams	0.5	0.10
	Firefighting	0.3	0.07
	Solvents	0.0	0.00
	One component foams	0.0	0.00
	Iron and steel - combustion and electricity	8.8	1.96
	Industrial combustion and electricity (excl. iron and steel)	45.7	10.12
	Commercial and miscellaneous combustion and electricity	11.7	2.60
	Electronics, electrical insulation, scientific research, military applications and sporting goods	0.6	0.14
	Non energy use of fuels	0.0	0.01
	Accidental fires	0.0	0.00
	N_2O use as an anaesthetic	0.6	0.13

Industrial processes	million tonnes CO2 equivalent	10.2	% UK GHGs 2.27
	Sinter production	1.3	0.28
	Cement production	4.4	0.97
	Lime production	1.1	0.24
	Soda ash production & use	0.2	0.04
	Glass production	0.4	0.08
	Fletton brick production	0.0	0.00
	Ammonia production	0.8	0.18
	Aluminium production	0.1	0.02
	Nitric acid production	0.0	0.01
	Adipic acid production	0.0	0.00
	Other - chemical industry	0.3	0.06
	Halocarbon production	0.0	0.01
	Magnesium cover gas	0.2	0.04
	Iron and steel production	1.0	0.23
	Titanium dioxide production	0.2	0.04
	Bricks production	0.3	0.07
	Non ferrous metal processes	0.0	0.00
	Use of N_2O	0.0	0.01

Hydrogen is also being proposed as a substitute for natural gas for on-site, industrial power generation. As described earlier, on site power generation using hydrogen will become much less attractive when industrial users are buying blue or green hydrogen compared to renewable electricity.

Akin to domestic heating, heat pumps will become much more cost effective for industrial heating due to their inherent energy efficiency. Also, direct electrical heating will be more energy efficient than hydrogen. The advantages of electrical process heating are set out in the EU report - The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat).

It is evident to me that options for industrial heat and power require to be fully analysed before setting future policy.

Electricity Generation

Reducing gas consumption and CO_2 footprint here is clearly a role for energy efficiency and renewables – hydro, solar, wind, tide, biofuels, etc. It should also be recognised that increased use of renewables, and adopting energy efficiency measures, means the fossil industry is using less energy to produce, transport and condition oil and gas for a reduced market. A double carbon win.

Combined cycle natural gas power stations with CCS and nuclear will also play an important part of net zero by 2050.

Why not use hydrogen for electricity generation? Presently 96% of hydrogen is fossil sourced and comes from reforming processes. Reforming requires a significant amount of energy with a consequent large carbon footprint, hence that would make little sense. Hydrogen from a reformer with a CCS abatement plant (blue hydrogen) would reduce GHG emissions by around 90%. That would work but why not utilise CCS with conventional Combined Cycle Gas Turbines (CCGT) power plant and achieve the same outcome, without the need for hydrogen production, storage and distribution, and hydrogen conversion at the power station?

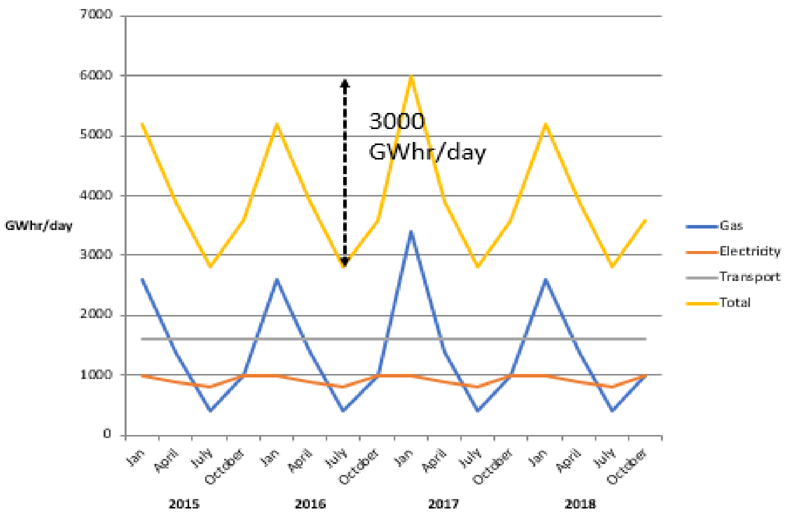
Using green hydrogen from electrolytic water cleaving and to utilise green hydrogen for power generation is a possible option. In this instance, we have green electricity that we convert to hydrogen to convert the hydrogen back to electricity with all the associated energy losses at each stage – a hugely inefficient round trip process.

Many commentators suggest using surplus renewables, particularly wind, to make hydrogen and store it for times when renewable supply is curtailed. On the face of it an attractive option for dispatchable heat and power.

Dispatchable Energy

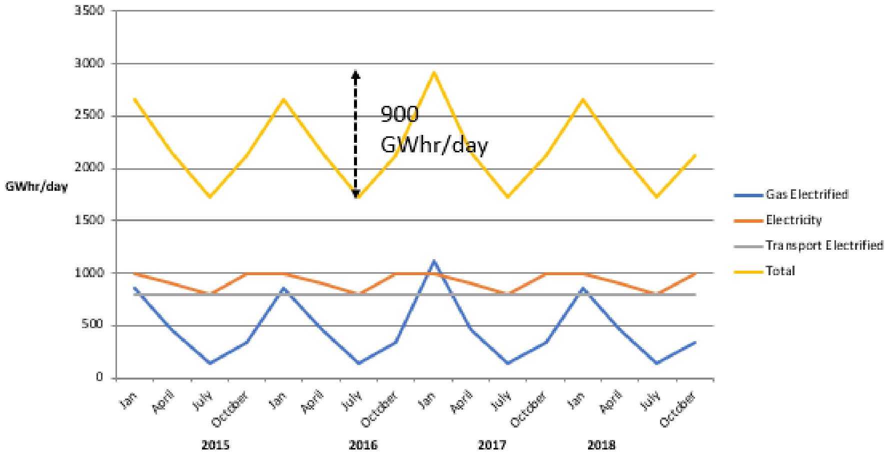
Security of energy supply during times of prolonged, slack wind conditions is a key aspect of a UK energy strategy. UK energy consumption clearly shows historical winter peak gas usage is illustrated in the following graph. An obvious concern is supplying energy when renewable electricity is weather curtailed.

Figure 5 – UK historical seasonal energy use variations



Clearly gas provides around four times more energy than electricity. As a consequence, a position is frequently taken that this differential is too much to allow for electrified replacement. However, it is important to recognise that, if the UK's core energy strategy is energy efficiency and electrification, heat and power demand is much reduced, consequently energy storage requirements are much reduced. This is illustrated in the following graph where UK heat is supplied by electricity and heat pumps and transport is electrified.

Figure 6 – UK seasonal seasonal energy use if widespread electrification and energy effriciency is adopted



As can be seen, electrification halves the total energy demand and reduces the seasonal variations by two thirds.

Hydrogen appears to have been selected by many as the only solution for dispatchable energy. Whilst hydrogen does appear attractive, there are a range of other options that could be used in combination to provide dispatchable energy. These are listed as follows.

- Gas no CCS – accept short term emissions
- Gas with CCS
- Thermal
- Batteries
- Hydro
- Nuclear
- Imports
- Bio-fuels
- Compressed gases
- E-fuels
- Tidal
- Geothermal
- Gravitricity

Again I have yet to source a UK Gov report that provides the evidence that hydrogen is the optimised solution for dispatchable energy. The UK Gov must analyse the range of options for energy supply and dispatchable power before hydrogen is selected.

Hydrogen Production

A key net zero area for the chemical industry is the production of hydrogen. According to the Royal Society hydrogen production accounts for 1.8% of global CO_2 emissions. Hydrogen is a hugely important precursor for many chemical processes. None more so than the production of fertilisers.

The UK's immediate focus for hydrogen should be reducing GHG emissions from current reformer based, hydrogen production facilities. Shell's Quest project in Canada is an example of what can be achieved here.

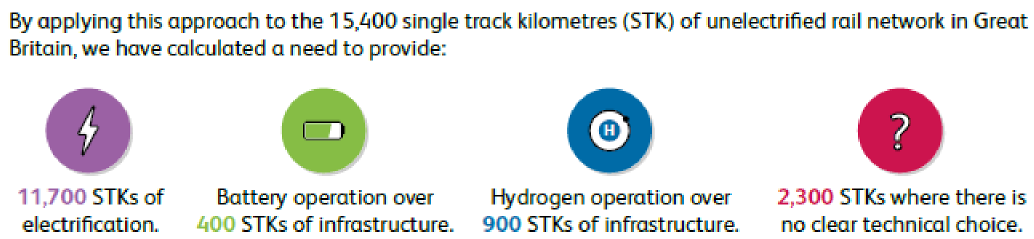
Surface Transport

The hydrogen argument also falls down in many aspects of transport. For the passenger vehicle the hydrogen fuel cell electric vehicle (FCEV) can't be justified against a battery electric vehicle (BEV) from an energy and cost standpoint. I point this out in a recent TCE article. Range and fill speed are seen as the main benefits for hydrogen. Battery technology is advancing on both counts and battery, swap, as done in China, is also a solution for range and fill speed. Penn State University is one of a number of organisations investigating reduced charge times – they have a concept for a 10 minute charge. Encouragingly, the recent Energy White Paper shows a clear preference for the passenger car BEV.

The hydrogen FCEV is viewed as a solution for long distance heavy haulage. This is primarily due to today's battery energy density and its impact on operational efficiency for large weight vehicles.

Based upon numerous technical papers reviewing future battery trends, for example the EU report Towards the battery of the future, where it states 'This could lead to a 70% increase in volumetric energy density, compared with those that use conventional anode materials, plus a better cycle life, lower weight and lower cost.' I believe batteries will become a much more attractive option for road haulage and buses and an assessment of future battery trends must be included in any UK Gov analysis of the heavy haulage sector.

Rail accounts for less than 2% of the UK's GHG emissions. It is therefore puzzling why the UK Gov announced a hydrogen train initiative as a revolution. Hydrogen for rail transport has very limited applications. Indeed Network Rail's recent report on traction decarbonisation concluded the following.



Clearly hydrogen has a very limited role compared to electrification.

Bio-fuels

For both heavy haulage and rail, drop-in bio-fuels offer a much more attractive alternative to hydrogen if bio-fuels can be produced in sufficient quantities. Unlike hydrogen, liquid bio-fuels need little or no engine modifications. Bio-fuels remain a very attractive net zero option but receive much less attention than other energy vectors in the UK.

Conclusions

1. The UK requires an integrated overall energy strategy prior to developing strategies for the energy vectors such as electricity and hydrogen.
2. Analysing energy options in silos, without comparison with alternatives, leads to unbalanced conclusions.
3. Hydrogen is being understandably pushed by influential companies who have business models that would benefit from hydrogen adoption. What is good for those businesses may not be in the long-term interest of the UK consumer.
4. Hydrogen for household and other building heating is energy wasteful. Heat pumps, combined with Passivhaus insulation standards present a much more attractive alternative.
5. Compared to electrification and heat pumps, hydrogen is an energy inefficient vector for supplying heat and power for most industrial applications.
6. A comparative analysis showing the impact on the UK consumer of likely future energy costs for blue and green hydrogen compared to electricity is required.
7. Low carbon hydrogen production should focus on current hydrogen production as a chemical precursor.
8. The passenger car, hydrogen FCEV should not be pursued any further.
9. With current battery densities, hydrogen FCEVs appears an attractive option for heavy haulage, that position will change as battery technology develops. However, powering UK Gov heavy haulage analysis should recognise future, expected battery energy density improvements.
10. Hydrogen for rail has very limited applications.
11. Energy efficiency and electrification significantly reduces the need for stored energy.
12. A fully holistic option analysis, recognising hydrogen and alternatives is required to establish the optimal arrangement for dispatchable power.

(January 2021)