The role of electricity, hydrogen, fuel cells and carbon capture in our future UK energy mix.

Summary

Scotland and the UK must reduce their carbon emissions to zero by 2045 and 2050 respectively. This means that by then we have either to stop using fossil fuels altogether, route CO_2 from burning fossil fuels underground, develop methods that increase natural CO_2 sequestration, or a mix of all three. The advantage of hydrogen as a fuel is that it does not produce CO_2 when burnt. The product of combustion is water. However, unlike coal, oil or natural gas, it does not exist as a free element in nature, it has to be manufactured. Hydrogen production normally uses electricity to split the hydrogen and oxygen by electrolysis. If the electricity in this process is made by burning carbon dioxide producing fossil fuels, it is termed “blue” hydrogen. If the electricity is produced from renewable devices like wind turbines, solar panels and possibly nuclear power, the hydrogen is called “green” hydrogen. The production of green hydrogen produces no CO_2.

Of all the forms of energy there are, electricity is the most versatile. It can power electric heaters, heat pumps, lighting, electric motors, TVs, and computers. It is easy to control, has a very high efficiency in use, can be distributed across the country via the grid network and can be stored in batteries to power cars and mobile transport. Since wind turbines and Photo Voltaic Cells produce electricity, it is best to keep this as electricity, and not convert it into hydrogen or synthetic fuel. For example, the overall efficiency to power an electric car is 73%. If the electricity is used to manufacture hydrogen, for use in a fuel cell driven car, the overall efficiency reduces to 22%. If instead the electricity is used to make a liquid fuel, the efficiency drops to 13%. Converting one form of energy to another always results in losses in efficiency. As a rule, using electricity from renewables directly is the preferred option, with less efficient hydrogen utilized for niche uses such as heavy lorries, trains on branch railway lines, long route ferries and aircraft. This assumes that sufficient lithium and other battery components are available on the planet to provide the battery power required.

While carbon dioxide injection into partially spent gas and oil fields in order to increase fossil fuel recovery is routine, efforts to do this for environmental reasons alone, to sequester CO_2, have not been promising. The application of this to sequestering CO_2 produced from burning biofuels at the Drax generating station may be an exception, but the true CO_2 balance from shipping timber from North America needs to be assessed. Sequestration will probably best be left to nature, in photosynthesis on land and in shallow seas, and in agricultural practices which favour increases in organic matter.

When zero carbon has been achieved, hydrogen as a non-carbon dioxide producing fuel, will become more important, but its inefficiency will still be there. Either hydrogen fuelled transport will have to be limited or the number of wind turbines and solar panels could become excessive. In terms of job opportunities in the immediate future, it is more sensible to create jobs in energy minimisation, such as refurbishing leaky, uninsulated old houses, than create expensive energy that is then wasted in old technology and inefficient buildings.

1. Introduction

The worldwide use of fossil fuels over the past 200 years has resulted in carbon dioxide emissions raising the planet’s temperature since pre-industrial times by 1.1°C. Continued emissions will raise the temperature further. By 2045-2050, we need to stop emitting any more CO_2 into the atmosphere if we are to stop global temperatures exceeding 1.5 - 2.0 °C above pre-industrial levels. This means that we must stop emitting CO_2 altogether.

Since we need energy to keep us warm, power machines and provide transport, we must make electricity and heat from renewables. As wind and solar energy are intermittent in the location that they are produced, we need electricity distribution and storage systems to provide continuity of power across the UK. While hydrogen is not a naturally occurring fuel like oil or gas, it can be made into a combustible gas or liquid by electrolysis, which can then be stored. When burnt to produce energy, it combines with the oxygen in the air to produce water. No CO_2 is produced. The creation of hydrogen by electrolysis is very inefficient, so it is better to use renewable energy in the form of electricity. Only when this is not possible, as in distant air travel, heavy freight lorries or shipping, should hydrogen manufacture be considered.

While there is a huge amount of literature on the relative merits of electric versus hydrogen powered vehicles in particular, this efficiency aspect is often overlooked. In the last page of "The Hype about hydrogen" (Romm, JJ, 2004), his final statement is "The nation and the planet simply do not have the luxury of squandering scarce clean energy R&D dollars on technologies whose pay-off, if any, won't come for three or more decades".

2. Utilisation of existing gas network for methane production

While the use of natural gas to heat homes will have to stop by 2045, methane from decaying organic matter can be utilised instead. Any organic matter, such as sewage sludge, animal manures, brewers waste, etc, will decay to produce CO_2. Since this organic matter is produced every year, it absorbs CO_2 as it grows only to release it as it decays. This process therefore does not contribute to global warming and climate change.

If the organic matter is put in a sealed container (anaerobic digester), methane is produced which is then stored in the digester tank. The digester can then be connected to possibly redundant town gas pipes, and supply methane to the various consumers. The calorific value of the gas can be increased by adding hydrogen up to a level of about 7%. More likely than distributing the gas, the digester will use the gas produced on site to generate electricity which will be fed into the grid.

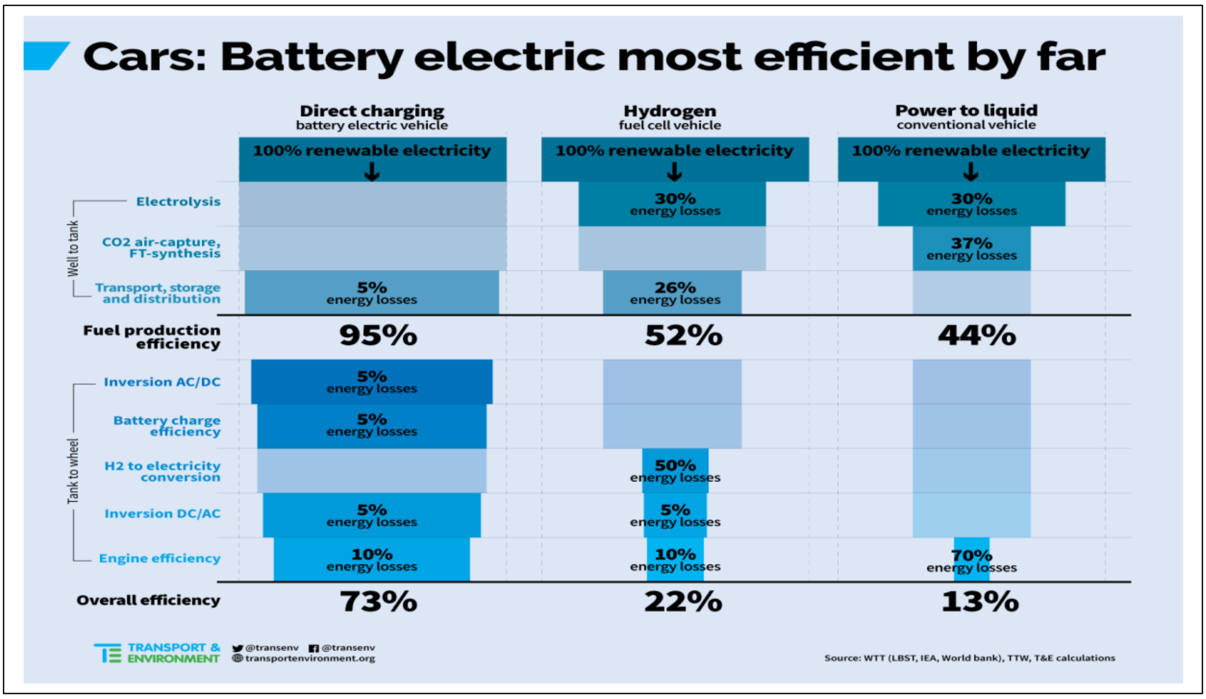
Anaerobic digesters have recently been built on farms, either fed with organic wastes from homes or commerce or with harvested farm crops like grass or maize. They are recognisable by their large blue or green tanks fitted with large "space age looking" domes. They are usually located on farms, as this enables their liquid digestate waste product to be spread on to land to fertilise growing crops. The profitability of these digesters has been enhanced (or made viable) by the government's Renewable Heat Incentive (RHI), which guarantees a fixed payment for electricity for 20 years, but is likely to be reduced in value or completely phased out over time. In future, digestion of wastes is likely to be more profitable than crops grown for digestions as a gate fee can be charged on wastes received.

3. The comparative efficiencies of electric and hydrogen vehicles.

Whenever one form of energy is converted to another, there is an efficiency loss. In an internal combustion car engine, for example, the mechanical energy produced is 30% of the heat energy from the fuel burnt in the cylinders. Renewable energy devices such as wind turbines and solar panels produce electricity directly, so in order to achieve maximum efficiency this energy should be used as electricity.

The figure, Cars: Battery electric most efficient by far, (Shahan, Z, 2020) below shows this well for battery electric cars. Five percent of the renewable electrical energy is lost in transmission via the grid. Of the energy supplied to the battery, 10 % is lost in the inverter and battery charger, giving the overall battery storage efficiency of 85.5%. When the car electric motor is run, there is a further 15% loss of efficiency, resulting in an overall loss in efficiency between energy generation and use of 73%.

If the electricity is used to produce hydrogen gas, to supply to a fuel cell, the overall efficiency is 22%. If the electricity is used to make a synthetic liquid “efuel”, using the Fisher Tropsch (FT) process, that can be used in a conventional internal combustion engine, the overall energy efficiency is 13%.



The key numbers to note are those for overall efficiency, 73%, 22% and 13% for the three systems. Since the fuel cost and associated carbon footprint of travel increases as fuel efficiency decreases, the case for electric vehicles is overwhelming. When people advocate hydrogen vehicles for their quick refuelling time, they are ignoring this efficiency and fuel cost difference.

The figure shows just why the emphasis in the UK and elsewhere should be on a wholesale move to electric vehicles and then linking their batteries to the grid when vehicles are not being used, to smooth out the grid’s electricity supply.

4. Fuel Cells

The previous section explains why Ellon Musk, of Electric car Tesla fame, calls Fuel cells, “Fool” cells. The fuel cell vehicle starts off at a considerable efficiency disadvantage compared to electric. However, there are situations where batteries are just not suitable as a power source, so that a compressed gas or a liquid fuel such as an “efuel” (synthetic fuel) is required. This may be required for large lorries, tractors, ferries, and long-range aircraft.

5. Hydrogen and synthetic fuels made using “free” electricity

The advocates of hydrogen fuels or synthetic efuels, made through the electrolysis of water using renewable energy, point out that at times renewable energy cannot be utilised, due to lack of grid capacity or insufficient demand. Its value in that situation is either zero or low. It is this assumption that makes hydrogen or synthetic fuel manufacture worth considering.

Using surplus electrical energy when it is available is attractive, but there is a dilemma. We can either upgrade the grid so it can cope with almost all the power that is produced, or we can keep the grid as it is and use surplus electrical power to produce hydrogen or a synthetic liquid fuel.

But is it worth building a synthetic fuel plant to utilise the surplus electricity for just a few weeks a year? If instead you build a plant that works all the time, you are manufacturing an inefficient fuel, when you would be better to use the electricity directly.

The conversion of electricity to a liquid fuel involves an inefficiency. If we can avoid this, there will be less energy wasted. If all our cars are battery powered, then the grid can utilise the energy in these batteries when the cars are parked and plugged in, to store surplus energy. This is called vehicle to grid (V_2G) storage. So long as car batteries are charged up for the morning or evening run, what use is made of the batteries at other times by the grid is of little interest to the car’s owner (Pringle, R.T., 2018).

The UK budget for hydrogen transport projects in 2020 is £23 m, while that for electric vehicles for recharging and infrastructure is £646 m, so the government is betting on electric rather than hydrogen (Staffell, I , 2019). Staffell further comments that while Tokyo planned to introduce 100 fuel cell hydrogen busses for the Olympics in 2020, the city of Shenzhen in China has electrified its entire fleet of 16,000 busses.

It may be that liquid fuels will be created in dedicated plants in areas having plenty of wind or sun, like West Africa or the Sahara desert. Only sun, wind and electricity are needed. What we do know is that there will be a demand for liquid fuels, which must either be very low in carbon or zero carbon.

Synthetic fuels are made by first producing hydrogen from water by electrolysis, then using the hydrogen to convert carbon dioxide to carbon monoxide by reduction, involving a catalyst. The result is either a gas, petrol, kerosene, or diesel. If the carbon dioxide is a by-product of a natural unavoidable process like the breakdown of biomass, this will not add to CO_2 emissions. If the CO_2 comes from burning fossil fuels, then this does add to CO_2 emissions.

6. Carbon capture and storage

Carbon capture schemes (CCS) can be used in large electrical power stations, or large factories, if these use coal, oil, or gas as fuel. CCS is used to capture the exhaust carbon dioxide and pump it into old exhausted oil wells. Successful CCS could allow fossil fuels to continue to be used past 2045, as they should not release carbon dioxide into the atmosphere.

At minimum, CCS must ensure that the amount of carbon dioxide emitted in the manufacture of the CCS plant and during its operation is less than the amount of carbon dioxide being sequestered. The greater the difference, the more worthwhile the installation will be.

6.1 Peterhead CCS Project

The Peterhead CCS project was part of the UK Government's CCA Commercialisation Competition and in March 2013 was shortlisted as one of the two preferred projects bidding for funding. (Shell, 2015)

The project was based on post-combustion capture and was to use amine chemicals to absorb the CO_2, a method that has been used by industry for around 50 years. It was therefore a mature and cost-effective solution. It had already been demonstrated as feasible, having been deployed in several small installations in the USA and was recognised as the best available technology for post-combustion CO_2 capture.

Following feasibility studies on a variety of options, Shell proposed to build a short length of new pipeline from Peterhead Power Station and link this into the existing 0.5 m diameter offshore pipeline from St Fergus to the Goldeneye reservoir, approximately 12 miles (20 km) from the shore.

Carbon dioxide was to be stored in the depleted Goldeneye reservoir, which lies about 62 miles (100km), from the shore in the outer Moray Firth and 2.5 km beneath the seabed. The reservoir has the key geological features necessary for storing CO_2 permanently: a body of high-quality porous rock overlain by impermeable rock to seal the CO_2 in place.

Goldeneye was a producing gas field from 2004 to 2011. Injection is the reverse of production: during production, natural gas was drawn from the rock and naturally replaced by salt water; injection of CO2 would drive the salt water back out of the store and into the adjacent rock formations from whence it came. The Goldeneye CO_2 gas store was to be monitored throughout its life.

While most of the infrastructure for the project is already in place, construction was expected to create between 100 and 150 jobs. When operational, the proposed project was expected to support 20-30 jobs over the ten-year period.

The cost of the scheme was £1.0 bn. After an assessment by AtkinsGlobal, Engineering consultants, the UK Government decided to abandon the scheme. What appeared like the perfect model for future CCS schemes, using existing redundant gas pipeline, and proven technologies, was deemed a non-starter. I have not been able to access Atkin's evaluation, but it is likely to have been a thorough assessment.

6.2 Stanford Study

Prof Mark Jacobson, of Stanford University, USA, (Jacobson, M Z, 2019) published a paper suggesting that CCS is a non-starter. He looked at a coal powered plant fitted with CCS, with the capture equipment powered by natural gas. While the theoretical efficiency of these plants is 85-90%, the highest efficiency he could achieve was 55.4%. Even when he assumed that the energy to run the CCS came from renewables, the system was still not worthwhile. In all cases it was better to generate electricity using renewables, than use coal or gas, and then capture the CO_2.

6.3 Aberdeen/Southampton Study

A paper was published in the journal GCB Bioenergy, by a student of Dr Astley Hastings, (Hastings, A, 2019), University of Aberdeen and Prof Gail Taylor of the University of Southampton, where a modelling study was carried out on six possible UK sites for CCS. The Drax power station in Yorkshire was chosen as the site most suited, though a smaller scale plant would have been preferred. It showed that CCS could work when the fuel was biomass.

To be successful, the use of biomass and crushed limestone to absorb CO_2 were part of the requirements. The biomass is supposedly zero carbon and the limestone is obviously a sequestration material in its own right.

As one of a team who worked on biomass with AU Forestry Professor Paul Mitchell in the 1990s, I sat through multiple Energy Technology Support Unit (ETSU) workshops, waiting for evidence that energy gains from growing and harvesting biomass exceeded the energy inputs. Only the utilisation of forest residues for burning had an Energy output/Energy input ratio greater than one, and even then 40% of the residues were needed to be left in place to provide a matt to stop machines breaking through the soil and to provide fertiliser for the next crop of trees.

With the Drax site, the biomass comes from the USA by ship, an additional energy input. Whether the operation is therefore carbon neutral is open to debate.

6.4 St Fergus hydrogen and carbon capture, utilisation and storage (CCUS) project

The CCUS project was drawn up by Element Energy, a strategic energy consultancy, with 50% funding from the Department for Business, Energy and Industrial Strategy (BEIS). (Acorn Hydrogen, 2020). The site at St Fergus was selected for its proximity to exhausted gas fields and the potential for injecting into underground depleted gas reservoir CO_2 produced during the making of hydrogen. This would allow “blue” hydrogen, made from fossil fuels, to be manufactured. As electricity becomes increasingly made from renewables, the surplus electricity from wind and solar can then be used to manufacture “green” hydrogen. The idea is to get a head start on hydrogen production, so that Aberdeen can be a centre for a new hydrogen economy. The report is upbeat on potential jobs and business opportunities.

The hydrogen produced would be piped from St Fergus through the existing gas pipeline, for injection into the present natural gas network, to fuel existing gas boilers. Not only would this allow gas central heating to continue, but the manufactured hydrogen could be used to power internal combustion engines in cars, busses, and heavy equipment.

In part this allows a business-as-usual approach to society, with non-polluting hydrogen replacing dirty diesel and gas. However, several issues arise.

As we have seen, CCS does not look promising. Until renewable electricity in the grid becomes dominant, making blue hydrogen gas produces more CO_2 than if natural gas were used instead. The scheme initially would have an adverse effect on climate change. (While Scotland may get there before the UK, it makes more sense to send our carbon free electricity to England than to make hydrogen).

As we showed above, electricity from renewables should if possible be kept as electricity to power anything. Electric motors, electric heating, electric heat pumps and Infra-red heating are all incredibly efficient, in part as they are very controllable. Burning hydrogen in boilers or internal combustion engines is certain to be much less efficient.

While it is suggested that hydrogen fuel in IC engines will only produce water as a waste product, in practice, NOx is produced too, as the nitrogen in the air is involved in the combustion (Staffell, I , 2019). Since oxides of nitrogen are harmful to humans, this is not a good outcome. Fuel cells do not have this problem, but they are still in the early stages of their development.

In terms of the manufacture of hydrogen for air travel, the water produced is twice that when burning kerosene, so the contrails contribute to short term global warming.

6.5 Overview of CCS

In summary, the Peterhead project was cancelled in 2015, due I imagine to AtkinsGlobal giving it a bad assessment. The Stanford study suggests CCS is a non-starter and that electricity generation is better done by renewable energy systems rather than by coal, oil, or gas together with CCS. The Drax study suggests that only by involving biomass and crushed limestone, will CCS make any possible sense.

In my readings on the subject of carbon sequestration, there are four sure ways of doing this, 1) planting trees or allowing natural climax vegetation to flourish, 2) returning drained peat bogs to wet bogs, 3) increasing the organic matter of agricultural soils, and 4) allowing the sea bed and its natural ecosystem to recover from trawling so that carbon is captured in the re-establishment of the ecosystem. All use biological activity to achieve the result, none use mechanical means.

7.0 Job Opportunities

Much emphasis is placed on the potential for Aberdeen to embrace the hydrogen economy and CCS to provide jobs for former oil and gas workers. Much of the technology is the same: the generation and storage of hydrogen, compression of the gas and distribution networks to filling stations, the modification of the natural gas network to allow it to take hydrogen, refurbishment of heating boilers to cope with the different characteristics of hydrogen gas and so on. However, if this development is based on the fundamental inefficiency compared to an electrical economy, this is not a route we should take.

There is potential to utilise surplus electrical energy when excess becomes available in very windy or sunny weather, but utilisation of these energy peaks may be expensive if only used occasionally.

In the longer term when hydrogen becomes a key fuel for certain activities, the emphasis will again be to minimise how much hydrogen is needed. This points to reducing energy use as the main aim. This will provide a major employment opportunity for technical people. The whole existing housing stock in Aberdeen and Aberdeenshire needs major refurbishment to reduce its energy use. This is where the real job opportunities are, on technologies which are feasible with the technologies that we already have.

8.0 Enthusiasm for hydrogen by business

There is much enthusiasm in the press for the development of a hydrogen economy, but where is this push coming from? Dr Tom Baxter, from Aberdeen University, has strong views on this. "The sponsors (for hydrogen) were businesses with a vested interest in promoting hydrogen: domestic gas boiler providers, gas network operators and fossil fuel producers who know that for the foreseeable future, hydrogen will be fossil derived. But is the vested interest of business best for UK consumers? (Baxter, T, 2020)"

Bob Pringle bobpringle@btinternet.com Mobile 07821153389

References

Acorn Hydrogen, 2020	Hydrogen in Scotland. Report by Element Energy Strategic Consultants, 50% funded by BEIS, pp50 https://theacornproject.uk/wp-content/uploads/2020/09/Hydrogen-in-Scotland-The-role-of-Acorn-Hydrogen-in-Enabling-UK-Net-Zero.pdf
Baxter, T, 2020	Hydrogen isn't the key to Britain's green recovery - here's why. July 22, The Conversation. Tom Baxter is a senior lecturer in Chemical Engineering at Aberdeen University
Hastings, A, 2020	Research identifies optimal site for UK carbon capture and storage facility, 26 June 2020. file:///C:/Users/Bob%20Pringle/Documents/Sustainability-in-practice/WebsiteContent/OnePlanetTopics/Transport/Hydrogen%20Economy/Research%20identifies%20optimal%20site%%20Economy/Research%20identifies%20optimal%20site%20for%20UK%20carbon%20capture%20U-Aberdeen-20.html#main
Hydrogen, a business opportunity, 2018	Conference on the Hydrogen Economy, Aberdeen. https://erm.com/Hydrogen-Scotland-Conference-Oct2018
Jacobson, M Z 2019	Stanford study casts doubt on carbon capture. Energy and Environmental Science. Royal Society of chemistry.
Pringle, RT, 2018	Travel, electric cars, and vehicle to grid https://sustainability-in-practice.org.uk/three-to-two-planet-living/travel/
Romm, J J, 2004	The hype about hydrogen: Fact and fiction in the race to save the climate. ISBN 1-55963-704-8. Pp 256
Royal Society, 2019	Sustainable synthetic carbon-based fuels for transport: Policy briefing Issued: September 2019 DES6164 ISBN: 978-1-78252-422-9, © The Royal Society
Shahan, Z, 2020	Why battery electric vehicles win. Transport and Environment, 10th June. https://cleantechnica.com/2020/06/10/this-stunning-chart-shows-why-battery-electric-vehicles-win/
Shell, 2015	Peterhead CCS Project, FEED Summary Report for Full CCS Chain, pp 135
Staffell, I , 2019	The role of hydrogen and fuel cells in the global energy system. *Energy Environ. Sci.,*12, 463, pp 29