# Hydrogen – Time to Put our Foot on the Gas?

Cardiff March 5th 2018

## BACKGROUND

This seminar at the National Museum in Cardiff was hosted by Innovate and the Advanced Propulsion Centre – two major government-funded organisations championing strategic technology research. Personal transport emissions from fossil fuel combustion is something governments and industry want to reduce, and renewably produced hydrogen may be the key.

Everyone trying to cut GHG emissions agrees that electrification of the transport system could be essential. But that leaves major issues, including:

1. Where will we get the electricity that is currently produced by burning coal, oil and natural gas and

2. How do we deliver that energy to its point of use – a particular in the case of transport, where the point of use is by definition constantly moving.

Hydrogen can play a key role in addressing these problems. Energy production will need to switch to renewable sources – essentially solar energy captured either directly or indirectly via wind, rain, and biomass. But renewable energy can't – except for biomass – be generated on demand, so we're going to have to store it, and hydrogen offers a flexible storage medium.

Electricity, in developed economies, is available everywhere for static points of consumption. The ubiquitous electricity grid delivers the energy we need to homes and factories whether as heat, light or mechanical power. Unfortunately, 2/3rds of our energy consumption is in the form of heat, and even in developed countries the majority of this is still produced from local combustion rather than electricity. If all future energy is to come from remotely produced electricity, our electricity grid may need significant upgrade even to service static consumption points.

However, the energy for the vast majority of transport, and certainly personal transport, still comes from burning fossil fuel in vehicles. Delivering that energy as electricity poses technological challenges with few solutions that promise a complete replacement for what we have now:

1. Catenary or underground inductive cables delivering electricity to every point along a restricted set of transport routes. This is fine for railways and trams but it difficult and expensive to for all transport routes.

2. Portable batteries in the vehicles can store and deliver electricity on demand. This is the focus of most technical R&D today, but the energy density of current batteries means that long distance transport vehicles are heavy and difficult to charge quickly, cheaply and safely – particularly at locations remote from the power grid.

3. A new portable fuel, with energy density comparable to fossil fuel but derived from renewable sources would be ideal. It could in principle be stored and distributed in much the same way as fossil fuels are today. It could then be burned directly in an internal combustion engine or used to produce electricity to power an electric motor. The most promising candidate for this new fuel, in the eyes of many, is compressed hydrogen.

One of the things we learned from this seminar and others we've attended is that the electricity grid was preceded by, and is still outperformed by, the gas grid both in terms of capacity and resilience. And before the advent of North Sea Gas, the predominant component of "town gas" was hydrogen.

However, this seminar was about hydrogen as a transport fuel, how you produce, store and distribute it, and how you convert it to electricity. Interestingly, most UK electricity is produced by burning Natural Gas in Combined Cycle Gas Turbines, which begs the question of why, if we can produce hydrogen sustainably, we don't just burn it in the internal combustion engines of our cars. And while that could certainly be done, there is a more sophisticated technology that produces more electrical energy from a given amount of hydrogen – the fuel cell.

# INTRODUCTION – ADAM CHASE

The seminar was compered by Adam Chase, of the Advanced Propulsion Centre, who introduced the speakers. He explained that the seminar would consist of a number of short presentations about specific aspects of the problem, with a panel of speakers to answer questions and discuss points raised by attendees.

Curiously, he explained that there was no industry or government consensus on whether hydrogen would in fact become the universal energy exchange and storage medium of the future, and that there were strongly held views on various sides of the debate. He asked for civilized discussion and debate, which promised more excitement than was delivered, but raised our level of anticipation.

# HYDROGEN PROPULSION – JON MADDY

Jon Maddy, of the University of South Wales, runs its Hydrogen Research Centre at Baglan Energy Park. The centre provides, to quote its website[1]:

> ...a platform for the experimental development of renewable hydrogen production and novel hydrogen energy storage. The centre enables further research and development of hydrogen vehicles, fuel cell applications and overall hydrogen energy systems. The Centre is the focal point for a series of collaborative projects between the University of South Wales and other academic and industrial partners.

It is cooperatively supported by the Welsh Government and Neath Port Talbot council to provide a focus for hydrogen energy research in Wales.

Their goal is to explore the use of hydrogen as a means to reduce our "carbon footprint" by making renewably produced hydrogen a universal energy storage and transport medium. The government has set itself the goal of reducing our GHG emissions by 50% from their 1990 levels by the year 2050. 25% of those emissions come from personal transport (cars), and greatly exceed those of public and goods transport.

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[1] http://www.h2wales.org.uk

So if we're going to fuel our cars with hydrogen, how much hydrogen would we need to travel how far? Battery electric vehicles are heavier than ordinary cars because of the weight of the batteries. Energy is measured by consumers and energy companies in kilowatt-hours, but scientists like Jon Maddy use joules[2] – or in his case *mega*joules.

So Jon listed 4 possible energy stores for cars in terms of how much energy each can store for a given weight:

1. Lead acid battery – 0.14 Mj/kg (about 0.03 kWh)

2. Lithium battery – 0.58 Mj/kg (about 0.16 kWh)

3. Petrol – 46.4 Mj/kg (about 12 kWh)

4. Hydrogen – 142 Mj/kg (about 39kWh)

Our Kangoo electric van claims about 62 miles on a full 22kWh battery or just less than 3 miles per kWh. Clearly, then, hydrogen is the way to go, because a single kilogram of it would take you nearly 120 miles.

But here we encounter the downside of hydrogen. A kilogramme of it certainly stores a lot of energy for its weight, but how big does the tank have to be? A kilogramme of hydrogen at atmospheric pressure (uncompressed) would need an 11 cubic metre tank - 11,000 litres. A kilogramme of petrol, on the other hand, only needs about 1.5 litres, and a 60 litre fuel tank holds 480 kWh of energy in the space of a rucksack. To store anything like that amount of energy as uncompressed hydrogen would require cars the size of airships, so it has to be compressed into a manageable space, which adds weight, complexity, and additional energy.

Hydrogen is stored industrially at 350 and 700 bar (approximately 350 to 700 times atmospheric pressure) and not surprisingly a tank that can hold gas at that pressure tends to be heavy. You need to be storing a lot of compressed hydrogen before the weight of the tank becomes less than the weight of the content.

Gliding gently over that point, Jon felt able to claim that 6.3kg of hydrogen would be enough to take a standard saloon car 500 miles.

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[2]And with reason. After all, we say “1 mile” rather than “60 mph minutes”.

Hyundai, Toyota and Honda are the major car manufacturers who have shown enough interest in hydrogen to make and sell hydrogen cars. They use fuel cells to convert hydrogen to electricity as efficiently as possible. Interestingly, they all use buffer batteries to cope with a major limitation of fuel calls – that they aren't as good as batteries at providing the high power drains required for acceleration, and aren't reversible in the sense of being able to re-generate hydrogen from braking energy which is routinely used to charge batteries (and super-capacitors).

However, Jon did bring up an intriguing and potentially strategic role for hydrogen in the modern energy mix. The UK in general, and Wales in particular, is blessed with a lot of wind power – enough to provide a significant proportion of the country's power needs when the wind is blowing. Unfortunately, like all other renewable energy sources other than biomass, wind power sometimes exceeds demand when you factor in other power stations (such as nuclear) that cannot easily be shut down at times of low demand.

This means that last year, over a terawatt-hour of wind power was “curtailed” - grid-speak for forcibly shut down and wasted. That's not a huge proportion of the UK's annual power consumption (about 300 terawatt-hours), but consumers still have to pay for it through the supply contracts that compensate generators whose output wasn't needed.

If that otherwise wasted energy were stored by using it to generate hydrogen then it could be released during times of higher demand, at negligible marginal cost. If the Welsh government invested the money it saved from the aborted electrification of the Swansea to Cardiff railway into development of electric trains that ran on hydrogen – how much energy would that use?

It turns out that we could effectively electrify all the railways in Wales from the output of the Pen-y-Cymoedd wind farm (about 540MWh) – if we stored all of it. Food for thought, particularly when you consider that the energy required to power an electric train *is* large enough for the hydrogen's weight advantage to show. A hydrogen powered train would certainly be more feasible than a lithium battery powered one.

## A GLOBAL PERSPECTIVE – GUTO OWEN

Guto Owen is an energy consultant and runs a Cardiff-based consultancy – Ynni Glan – which caters to organisations looking to make the transition to so-called "clean" energy. Ynni Glan specialises in fuel cell and hydrogen technology, and Guto has helped organise a number of hydrogen tours of the UK and Europe using hydrogen powered vehicles to demonstrate the benefits of pollution free and energy efficient personal travel.

Guto introduced us to some recent developments in progress to towards the "hydrogen economy" that has been incubating for some time. The recently introduced BlueGen Micro CHP is described as a "small" fuel cell that generates 13,000 kWh of electricity annually but enough heat to produce 200 litres of hot water a day. This is enough for a small office or a large house, and is an interesting and relatively new example of using the (generally unwanted) heat that a fuel cell generates to further improve its overall energy efficiency.

Guto also mentioned increased interest in hydrogen fuel cells from operators of server farms – vast arrays of computers that manage the data banks of companies like Microsoft, Amazon and Google – massive users of energy, but also strong advocates of clean energy.

Microsoft is currently testing a hydrogen powered generator for a data centre, exploiting the fact that fuel cells – like solar farms – generate DC which is a much more efficient power source for a computer. This could, if cost effective, become a huge market, since these giant users of electricity – if they want that electricity to be "clean" - are also major producers and consumers of renewable energy which could be truly reliable if stored as hydrogen.

Guto also endorsed the idea of electrifying the rail system with hydrogen powered trains, mentioning in passing a major advantage it has as a storage medium – its longevity. Most electricity storage systems work on charge-discharge cycles of hours or days, but the UK, for example, has a massive solar surplus in mid-summer and frequent wind surplus on mid-winter, and to be able store energy between times of surplus and times of scarcity is a valuable property which the storage density of hydrogen offers. Storing a month's worth of electricity in batteries, or even pumped hydro, would be terribly expensive even if there were the space to do it.

But coming back to hydrogen as a transport fuel alternative, opponents cite the cost of the necessary infrastructure as a serious impediment. Hydrogen fuel stations are certainly more expensive than the charge points we use to recharge batteries. However, as the number of battery electric cars goes up, multiple charge stations – especially high speed chargers – will also need to ramp up. So while a couple of Tesla charge-points at a popular motorway service station doesn't add significantly to the overall electricity load of the facility, a charging station able to provide 10 minute refuel times for, say, 50 high speed chargers would present the kind of grid load that would need its own substation.

The maths is fairly straightforward. A battery electric car with a range of 300 miles needs at least a 75kWh battery. Ignoring charger efficiency (which makes things even worse) if you want to pick up 75kWh in (say) 10 minutes, the charger power needs to be 6 (the number of 10 minute intervals there are in one hour!) times 75kW – 450kW. A fuel station that can simultaneously charge 40 cars would present a grid load of 18MW. The cost of building one will then, in some cases, need to include the cost of the pylons to connect it to the nearest high voltage sub-station.

Juelich, a German research organisation has produced a report that concludes that, when the number of electric cars exceeds 1 million, the cost of a hydrogen based infrastructure becomes cheaper. Such an infrastructure would also be able to fulfil the requirements of battery electric cars as well, by generating the electricity to charge them on the spot.

An interesting aspect of the Juelich report is the built-in assumption that some time in the comparatively near future Germany expects all its energy to be generated renewably. You don't see that spelled out as clearly over here, even by passionate supporters of decarbonisation. The obvious problem with a totally renewable energy supply is that it will necessarily be in surplus a lot of the time, while also needing to cope with severe shortages. Storing the "surplus" energy is therefore, for Germany, an imperative, and large scale production and storage of hydrogen from electricity a compelling technological solution. It's encouraging to see a country not only accepting that, but planning for and costing it.

Guto claimed that the Chinese government is busy doing the same thing, and is even planning a "hydrogen city" of 11M people in Wuhan by 2025. The South Australian government, not surprisingly, is also very interested in energy storage – Elon Musk has built them a lithium battery grid store to eliminate the recent power cuts they've suffered from over dependence on renewables, but they plan to be a leader in hydrogen technology.

Finally, Guto drew our attention to Hydeploy a trial taking place on the Keele University campus where hydrogen is being injected into the local gas grid as an experiment in converting the gas grid to carry hydrogen. To start with, Hydeploy will simply inject 20%

hydrogen into the normal natural gas supply, with a view to establishing what proportion of the supply can be replaced by hydrogen without affecting normal usage or requiring changes to appliances.

If the initial 20% causes no problems, then (depending on where they got the hydrogen from) that would immediately reduce the fossil carbon emissions from burning gas. It is interesting to recall that the original gas supply derived from coking plants was a mixture of 50% hydrogen, 35% methane, 10% carbon monoxide and ethylene. The current gas supply still uses a lot of the original pipework, but this will gradually need to be replaced, especially if and when we shift to a pure hydrogen based gas grid.

## CURRENT HYDROGEN CARS – JON HUNT, TOYOTA

The next presentation was from Jon Hunt, the alternative fuels manager of Toyota UK. Toyota is one of three major car manufacturers betting on hydrogen fuel cell electric vehicles (FCEV's) as the best way forward to full decarbonisation of personal transport. But Toyota is an electric vehicle pioneer, having introduced the Prius hybrid over 20 years ago.

Toyota's approach to technology development is what one might expect from a major company – gradual evolution of the basic product and the technology, taking the customer base with you as you go. Toyota's experience with the Prius hybrid taught them that this can be a long process – it took several years to become a mass market product and has since evolved from a hybrid with a relatively small battery to a plug-in hybrid with a much larger one.

Jon expects the introduction of FCEV technology into Toyota's cars to take 25 years, but that they are – thanks to the Prius – already 20 years into the cycle. Since hydrogen fuel cells look like a rather radical technology shift, it might seem surprising that they can introduce it in such a short space of time. But Toyota, correctly for them, see FCEV's as simply another car, with a single new element – the fuel call and the tank – replacing the petrol generator they previously used. All the other technologies – the battery buffer, the braking system, the body, suspension, transmission are retained and continuously refined.

The Toyota Mirai uses a development of the NiMH battery that Toyota uses in its hybrids. No-one else uses NiMH batteries in battery electric vehicles, where lithium batteries are now the standard. But if your previous design only requires the battery to act as a buffer between the generator (in the Prius, a petrol engine) the electric motor and the braking engine recovery systems, then it doesn't need the capacity (or costs) of lithium.

Toyota has needed to develop tanks able to hold 700 bar Hydrogen, made of carbon fibre, to hold enough gas for 300 miles. Jon claims that the cost and time to refill the tank is about the same as petrol. The fuel cell is expected to outlive the car, and the projected life of the tank is 20 years.

The Mirai isn't aggressively marketed in the UK, partly because there are relatively few 700 bar hydrogen stations. They also cost £61,000 even after the government's £4,500 grant. 5,500 have been sold world-wide, but only 45 in the UK so far. Jon reckons the whole life cost of ownership will be comparable with an equivalently priced luxury saloon.

A lot depends, therefore on the development of a hydrogen-based charging infrastructure and expanding generation capacity. On the latter point, Jon reiterated the 1TWh of renewable energy that is currently curtailed annually – a figure that will inevitably rise as renewable generation capacity increases.

## RIVERSIMPLE – HUGO SPOWERS

Hugo Spowers, an ex-racing driver, is one of the founders of this start-up company developing a lightweight, energy-efficient, hydrogen fuel cell powered runabout. The company moved to Wales with some government support a few years ago, and now has a prototype it plans to test in Abergavenny, hopefully this year.

RiverSimple's design, like all FCEV's, has to address the huge difference between the maximum power required to accelerate a car and the average power needed to propel it at constant speed. A big enough battery can deliver both, but if a fuel cell had to do that then:

1. It would need to be large and heavy and
2. It would operate inefficiently most of the time.

So RiverSimple's idea, like Toyota's, is to put a buffer store between the fuel cell and the motor/brake recovery system which only needs to hold enough power for the next acceleration burst, allowing the fuel cell to generate the average power a car needs. And in River Simple's case, the buffer is an array of super-capacitors.

Super-capacitors are used in Formula 1 cars to capture braking energy to be subsequently released in 10 second, very high power bursts for overtaking. Super-capacitors can absorb and release much higher power surges than batteries, but they can't hold onto that energy for as long. This doesn't matter in a car that has a reliable and constant source of new power.

This enable RiverSimple's car – the Rasa – to be powered by a fuel cell that only generates at the average, rather than the maximum consumption rate. It also means that the Rasa can use the super-capacitors to brake the car in all but the most extreme cases. This makes the Rasa very efficient, and much lighter than a full sized metal saloon car like the Mirai.

But efficiency, while obviously a worthy goal for the design engineer, is not necessarily profitable for the industry as a whole.

RiverSimple therefore proposes a rather different business model in which customers rent, rather than buy, their cars for a mileage based fee that includes the fuel. Improving vehicle efficiency is then very much in RiverSimple's interests because it improves their revenue. It also motivates them to upgrade their vehicles and keep them on the road for as long as possible. They will want to maximise the life of the components they use, maintain the car's performance and condition, and ensure proper end-of-life recycling of their vehicles.

Hugo reckons he can do this for the same cost of ownership as the existing car market business model. The Rasa has a 74 litre tank holding 1.5kg of hydrogen at 350 bar giving it a range of 300 miles. Like every other FCEV maker, RiverSimple is constrained by the availability of hydrogen refuelling infrastructure. It therefore intends in the short term to sell its cars to groups of owners who live close enough to share a filling station that is part of the package. And while this may limit the 2-seater cars to their initial target market of urban runabouts, he's going to be testing the system with a 20 user community in Abergavenny.

# RETHINKING HYDROGEN FUEL CELLS – DAN BRETT

Professor Dan Brett, of University College London and Bramble Energy, is part of a team that may have made a breakthrough in the design of hydrogen fuel cells. His was a technical presentation that would make sense to someone with a better understanding of how current fuel cells are designed than I have!

So to quote from a basic introduction to fuel cells from the Smithsonian:

> "A fuel cell is a device that generates electricity by a chemical reaction. Every fuel cell has two electrodes called, respectively, the anode and cathode. The reactions that produce electricity take place at the electrodes.
>
> "Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes.
>
> "Hydrogen is the basic fuel, but fuel cells also require oxygen. One great appeal of fuel cells is that they generate electricity with very little pollution – much of the hydrogen and oxygen used in generating electricity ultimately combine to form a harmless by-product, water.
>
> "A single fuel cell generates a tiny amount of direct current (DC) electricity. In practice, many fuel cells are usually assembled into a stack. Cell or stack, the principles are the same.
>
> "There are several kinds of fuel cells, and each operates a bit differently. But in general terms, hydrogen atoms enter a fuel cell at the anode where a chemical reaction strips them of their electrons. The hydrogen atoms are now "ionized," and carry a positive electrical charge. The negatively charged electrons provide the current through wires to do work.
>
> "Oxygen enters the fuel cell at the cathode and, in some cell types, it there combines with electrons returning from the electrical circuit and hydrogen ions that have travelled through the electrolyte from the anode. In other cell types the oxygen picks up electrons and then travels through the electrolyte to the anode, where it combines with hydrogen ions.

> “The electrolyte plays a key role. It must permit only the appropriate ions to pass between the anode and cathode. If free electrons or other substances could travel through the electrolyte, they would disrupt the chemical reaction.
>
> “Whether they combine at anode or cathode, together hydrogen and oxygen form water, which drains from the cell. As long as a fuel cell is supplied with hydrogen and oxygen, it will generate electricity.
>
> “Even better, since fuel cells create electricity chemically, rather than by combustion, they are not subject to the thermodynamic laws that limit a conventional power plant. Fuel cells are therefore more efficient in extracting energy from a fuel. Waste heat from some cells can also be harnessed, boosting system efficiency still further”.

From which we learn that hydrogen fuel cells – which incidentally were invented in Wales in the 1830's – each produce quite a small current and that in practice – like a battery – fuel cells tend to have large numbers of cells arranged in series to produce useful amounts of energy.  The most common type of fuel cell uses a Polymer Electrolyte Membrane (PEM) and combining large numbers of them is evidently expensive.

UCL/Bramble has devised a different way of constructing the fuel cell “stacks” using Printed Circuit Boards (PCB's), a well-established and widely available electronic production technology.

Their PCBFC™ offers design flexibility but more importantly cost saving compared with existing techniques. Professor Brett thought that their electric membrane technology could reduce the cost per kilowatt of fuel cells from $45 to $26.  The huge capacity and flexibility of PCB manufacture, which is heavily automated, will support mass production of these devices and open up new markets.

## ZERO CARBON FUTURES – COLIN HERRON

Dr Colin Herron is managing director of the company Zero Carbon Futures dedicated to making the most of zero carbon technology in cars and homes. He previously worked for Nissan in Sunderland, and was instrumental in the establishment of Lithium Ion battery production for Nissan-Renault in the U.K. It is fair to say that he is a strong advocate of battery electric vehicles, and keen to ensure that the UK has the high speed charging capacity to support the widespread switch to battery electric vehicles.

Colin was therefore inclined to introduce a note of caution into our enthusiasm for hydrogen as the future fuel for electric transport. As things stand, he said, it costs 3 times as much per mile, the cars cost much more, and there are currently only 12 hydrogen fuel stations in the whole of the UK.

These are all good points, and Colin's view is clearly shared by Tesla founder Elon Musk who also believes in batteries as the storage medium not just for cars but for all the other energy storage that everyone agrees is essential to any transition to total reliance on renewable energy sources. And rhe car industry as a whole is more heavily invested in batteries than fuel cells, if you consider where manufacturers are spending their R&D budget.

Battery research – especially into technology that improves energy density and reduces consumption of expensive minerals – is certainly enjoying the bulk of industry and government attention, but as we learned from Guto Owen, there are question marks over the long-term viability of a widespread high speed charging infrastructure that offers anything like the speed and ubiquity of fossil fuel refuelling stations.

Colin mentioned the next generation of high speed chargers which would be rated at 350kW (and will presumably require a new generation of batteries to cope with it!). If the goal is to be able to fill your future 300 mile range electric battery Nissan in the time it takes to fill your current diesel Nissan, 350kW might not be enough (though it might well be as much as you can expect a consumer operated charger to deliver safely).

The maths is simple enough. A diesel pump at a filling station produces 40 litres of diesel a minute and at 15 miles to the litre, that's a refill rate of 600 miles a minute. A 350kW charger produces about 6kWh a minute and at 3 miles to the kWh that's 18 miles.

## DEVELOPING THE H2 INDUSTRY – DENNIS HAYTER

Dennis Hayter was one of the founders of the company Intelligent Energy. They deliver "clean energy" solutions to the distributed energy, diesel replacement, automotive and aerial drone industries. He's been working with hydrogen fuel cells for years, and has experience of small power packs for aerial drones all the way up to 100kW power units for industry and vehicles.

An early partnership produced a Suzuki scooter powered by hydrogen delivered in swappable cartridges, and another converted a Peugeot Partner van to hydrogen using removable trays of cartridges. These may not be a long term answer, but it suggests that an alternative supply chain may be necessary for vehicles whose usage does not see them returning to a regular base to have an on-board tank refilled.

(I imagine the gross weight of swappable hydrogen cartridges limit their application, and long term we will probably use static hydrogen tanks refilled from mobile tankers or on-site compression of gas-grid hydrogen.)

Intelligent energy has demonstrated a hydrogen fuelled "black cab" in London where the need to reduce gas and particulate pollution is particularly (see what I did there?) pressing. Dennis thinks that the desire to reduce inner-city pollution may drive the adoption of interim solutions before the dream of a universal hydrogen economy comes to any kind of fruition.

Since, in the long run, such an economy will necessarily be creating its hydrogen from renewable electricity, it's likely that we will see smaller cheaper hydrogen filling stations that do "power-to-gas" conversion on site in off-peak demand or peak supply periods.

## HYDROGEN PRODUCTION – JOHN NEWTON

The next talk from John Newton of [ITM power] developed the theme of production and storage demands of a large scale switch to hydrogen power. You can produce hydrogen from water by simple electrolysis – old-fashioned lead-acid batteries give off hydrogen when charged. Modern electrolysis systems use what sounds like a reverse fuel cell, using the same kind of a Polymer Electrolyte Membrane (PEM) that most fuel cells use.

The source of electricity, at the moment, is otherwise wasted power from wind farms. Evidently (figures between 1 to 2 terawatt hours per annum were quoted by various speakers) there already is serious curtailment of wind-farm output to the U.K. National Grid which is designed to produce its electricity on demand. If we are ever to switch to renewable energy for all our power, then we are going to need a great deal more renewable capacity than we have now, and that inevitably means massive surplus at times of low demand and high production.

Converting the surplus to hydrogen, which can be stored almost indefinitely and (in future) transported in bulk, is one of the the only practical ways to make totally renewable energy viable. We cannot afford the space or the money to store the hundreds of terawatt hours of power the UK uses in a year in today's lithium batteries. Other types of batteries can store energy in the electrolyte, but none as far as I know are being offered as viable long term stores – they are being used for short term time-shifting and so-called demand-lopping over days rather than months or years.

John reminded us that we should not confuse power with electricity. The UK consumes only about a quarter of its energy as electricity, the other three quarters is needed as heat. The gas grid currently transports 2 to 3 times as much energy as the electricity grid, and since the gas we burn is derived from fossil fuel, we either have to replace it with renewable electricity, or start putting renewable gas into our grid.

Hydrogen is a strong candidate for this role but most hydrogen today is still derived from a fossil gas – methane. In a future hydrogen economy, hydrogen would be derived from mass electrolysis of water by renewably produced electricity. This will require equally massive expansion of renewable electricity production, which means we 're going to have to learn to love our wind turbines!

This is all some way off, but already they are experimenting with injecting hydrogen into the gas grid, as a previous speaker mentioned. This isn't as dramatic a development as it might seem, given that gas derived from coal was already 60% hydrogen in content. It is thought that replacing 20% of grid gas with hydrogen would be feasible now, and would reduce the carbon dioxide emissions from gas burning by an equivalent amount.

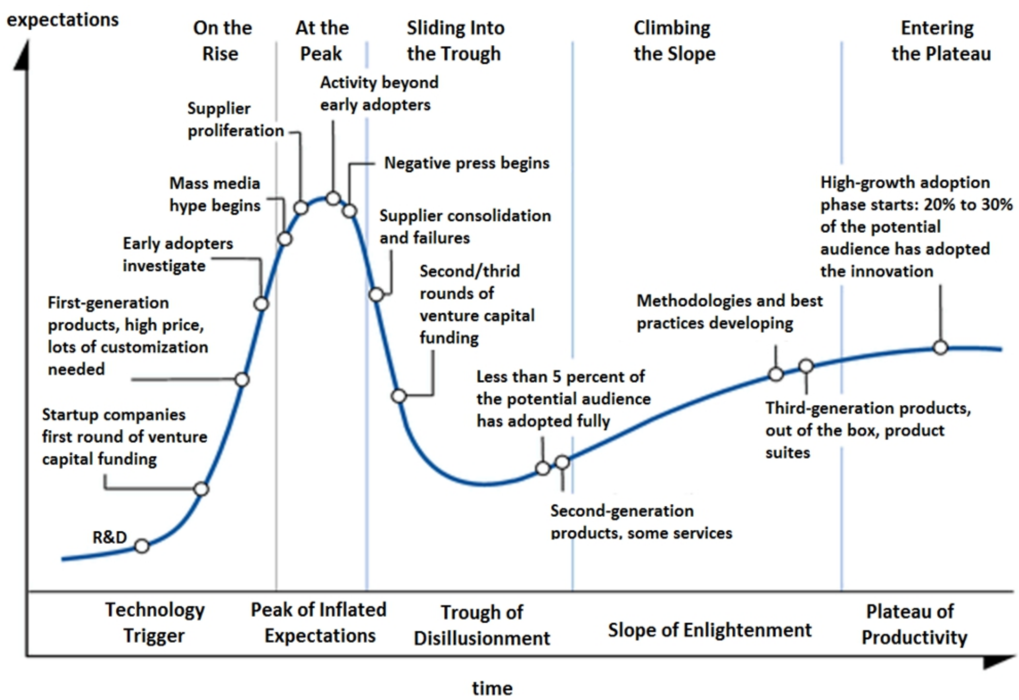
The next goal is to put hydrogen filling stations onto petrol forecourts, and it is encouraging that one of the largest electrolysis plants so far commissioned was bought by Shell.

There is already a [community energy scheme on Orkney] that is converting their massive renewable surplus from wind, tide and wave energy into hydrogen. They already produce way more electricity in a year than they use, and are hoping to pioneer a micro hydrogen economy while developing the skills and technology to take full advantage of it.

## HYDROGEN HUB – CLARE JACKSON

Clare Jackson is a policy and strategy consultant at Ecuity Consulting. They work with clients in the energy sector helping to shape future policy. She briefly explained where the industry is in its quest for renewable energy and cutting fossil carbon dioxide emissions to zero.

It's fair to say that the transition to a hydrogen economy has long been incubating, remains some way off, and that not everyone is currently persuaded of its inevitability. Here's a well-known Gartner graphic of the so-called "hype cycle", and hydrogen is only just emerging from the trough, but Clare thinks may be plateau-ing.




The challenge may be to persuade ourselves that we can really get all the energy we need from the sun, and that doing so is both desirable and necessary.

## MATERIALS – RICHARD PARGETER

The final presentation was from Richard Pargeter who is a member of The Welding Institute (TWI) the professional body that sets the standards for professionals and technology in industries reliant on welding.

If the future energy economy is going to depend on being able to store and transport highly compressed hydrogen safely, the materials used for the tanks and pipelines will clearly have to be as safe and reliable as possible. TWI has been conducting tests to see whether compressed hydrogen presents any particular challenges and what the best choice of material is.

It transpires that hydrogen, particularly if polluted with sulphur – as tends to be the case with industrial hydrogen extracted from fossil fuels – is both corrosive and can make containers and pipes more brittle. Pressurisation, not surprisingly, exacerbates these effects.

Stainless steel is less susceptible, and the highest quality (and presumably most expensive) type offers the best immunity. At the relatively low pressure of a gas grid, none of these effects is pronounced enough to cause concern, but hydrogen destined for vehicle fuel tanks will need to be highly compressed.

Though I couldn't claim to understand a lot of what Richard was talking about, it's gratifying to know that there are people thinking about and working on the infrastructure technologies now.

## CONCLUSIONS

The car industry, as a whole, isn't (yet) committed to hydrogen as the future fuel for an electrified personal transport system. Unfortunately for the dream of a hydrogen economy – which has a lot to commend it if you really believe we're going to need to stop burning fossil fuel and get back to total reliance on the sun - battery powered electric vehicles are the current focus of attention, and putting together the charging infrastructure for them is seen as the pressing problem.

So it looks like we're going to replace an infrastructure dependent on stored and transported fuel that can rapidly refuel with one that uses grid electricity to recharge vehicles much more slowly. It will be some time – if we ever manage it – before we recreate the safe

600 miles a minute refuelling rate of petrol/diesel technology with battery EV's.

Refuelling with renewably produced hydrogen can more credibly deliver fast refuelling and ironically – from an infrastructure point of view – offers a storage and distribution model much like the current petrol/diesel/lpg one.

If, as the fossil fuel industry hopes, we continue using fossil fuel power for personal transport for the foreseeable future, then we might see hydrogen being introduced to forecourts owned and operated by the same companies that provide us with petrol and diesel now. It is encouraging, therefore, to learn that the likes of Shell are commissioning large scale electrolysis plants and, who knows, might be persuaded to invest in wind farms of their own if those wind farms produced a product they already know how to sell.

Public transport can be, and to a large extent already has been, electrified using catenary cables, but electrifying existing non-electric railways, not to mention urban and rural buses, is likely to be very expensive. Already, the government has baulked at the cost of electrifying the line from Cardiff to Swansea.

Electric trains powered by fuel cells would be able to use compressed hydrogen and, unlike private cars, the weight penalty of the tank is less of an issue for a vehicle that already weighs – in the case of trains – several hundred tonnes. A smart design might even see hybrid electric trains that use catenary when available but can run on un-electrified track using hydrogen tanks at other times.

But perhaps the best hope for the emergence of a hydrogen based energy system is the gas grid, bearing in mind that even if all our electricity were produced renewably today, we still use twice as much energy in the form of heat. Burning hydrogen to create heat is both carbon-free and relatively efficient. The challenge is to create enough renewable energy, but at least in a hydrogen global economy we can distribute production of hydrogen to wherever it is cheapest, as we already have with fossil fuels.