Smart Energy Wales 16/9/15

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INTRODUCTION

We attended a Welsh Government sponsored conference - Smart Energy Wales – to learn about energy, energy storage, and the grid.

The themes developed the consequences of a transition to renewable energy sources, most of which aren't available "on demand". At present, most energy in developed economies comes from burning fossil fuel. There are two main reasons why that will have to change, though they have different time-scales:

1. In the short term, burning fossil fuels - coal, oil and natural gas - puts back into the atmosphere carbon dioxide that was taken out 300 to 400 million years ago by plants and other organisms. The Earth was warmer then, partly because CO_2 is a "greenhouse gas", and higher concentrations of it trap more solar energy, warming the air, making winds wetter and stronger, and raising sea levels by melting ice. Most relevant scientists seem to agree that this is something we cannot continue to do safely over the relatively short period we appear to be attempting it.

2. In the longer run, whether or not it is safe to burn through our fossil fuel supply, at current rates we will do so in less than 400 years, of which we're on the last 100. After that, we'll have to depend for our energy on solar radiation (either directly through solar and biomass or indirectly through wind and rain), gravitational energy (tide), geothermal and nuclear energy. So some time this century we're going to be reliant on renewable and nuclear energy anyway.

This is both an issue and an opportunity.

The U.S. Department of Energy predicts that mankind will need 43 Tera-watts of energy by the end of this century, about three times as much as we needed at its start. Their predictions factor in population growth and a higher mean living standard. They cannot, of course, predict technology and societal changes that may act to curb energy demand in a more developed world, so they may be too high. But if we can produce, say, 50 TW of energy renewably, we should be OK!

To put some perspective (and hope) on this challenge, modern solar PV panels, which convert about 10% of the solar energy to electricity, could provide all our 2100 energy needs, albeit in electrical form, from about 0.5% of the earth's surface.

But fossil fuel isn't simply a source of energy - unlike most renewable sources, it can be despatched on demand. And it has been clear for some time (except perhaps to Green extremists) that while renewable sources could potentially meet our energy needs over the course of a year, they cannot do so over the course of a day. Fossil fuels can, and since we have evolved as a society to depend on instant energy, we need to do a lot more work before we can rely on renewable energy sources for all our needs.

Energy storage has long been an "elephant in the room" of the carbon reduction debate, with the general public and hence politicians' interest in it very limited. It is perhaps a sign that politicians are finally "getting" the idea that we really are going to need to plan for a renewable energy future that interest has suddenly been awakened. And although the speakers at this event talked about green energy in general, an underlying theme for most of them was about how we are going to store energy between when it is available and when we need it.

OPENING SESSION - SMART ENERGY.

Since this one was sponsored by the Welsh Government, it needed to address the main political concerns in the economy - business and employment growth. The first session chair was Kevin Bygate, who heads a Swansea University based academic/industrial consortium called SPECIFIC which helps turn buildings of all sorts, but particularly industrial buildings, into power stations. Increasingly, forward-looking companies are aiming to be self-sufficient in energy. SPECIFIC has helped Jaguar Land-Rover meet this goal with its new factory which generates the 6MW of electricity it uses entirely from its roof panels.

But one thing this conference brought home to us is that electricity is only one form of energy. It happens to get most of the attention in discussions of renewable energy, and it may not be a myth that the Blair Government made the mistake of confusing energy and electricity when it agreed to particularly ambitious UK emission reduction goals in 2005. De-carbonising our electricity supply is challenging but tractable if we can solve the storage problem. De-carbonising our heating - and the average gas-fired home consumes 4 times as much heat energy as it does electrical energy - is going to be far harder. Particularly when you realise that we're going to have to do that, in the main, by using sources of renewable electricity to provide our space and water heating.

Still, one good thing about heat is that you can reduce the amount of it you need far more easily than you can reduce the amount of electricity you need. Insulating our buildings enables them to hold onto more of the heat we put into them, and OfGem's “typical” house now uses only 80% of the gas it did in 2003. Taken to the extreme, we can reduce the heat input to a house almost to zero. A demonstration house in Bridgend, built from designs originating in Cardiff School of Architecture, actually generates 50% more energy than it uses, and that includes the heat.

The proposition that Wales is well-placed to lead a global transition to a renewable energy future looks credible, and sits well alongside its role in the high carbon energy transition that was the industrial revolution. If there were such a thing as national guilt, Wales would do well to play down the proportion of the increase in atmospheric CO_2 that originated deep beneath its formerly green valleys.

The next speaker was Derek Stephen, of Natural Resources Wales, who gave a very up-beat pitch on the role his organisation can play in any Welsh transition to a more renewable energy future. I was expecting this presentation to be delivered by someone from the old Environment Agency and Countryside Council parts of the new organisation, so was surprised and pleased to see that most of it was about the former Forestry Commission.

NRW is a major landowner in Wales, because the former Forestry Commission was. They own 125,000 hectares, about 6% of the country, much of it remote upland of limited agricultural or residential value, but just the sort of place where you find high winds and mountain streams. NRW (or more probably the Forestry Commission at that time) was quick off the mark in realising this potential. Since high voltage pylon lines tend to avoid prime agricultural and residential areas, NRW hosts more than its fair share of them, putting it in the happy position of having surplus grid connection capacity at one of its wind farms in the Neath valley.

Even when NRW doesn't own neighbouring land, it can open its roads and quarries to its neighbours, for example, to help build their own wind and solar farms, or hydro systems. NRW is thinking of installing on-site biomass generators - particularly where they have a grid connection - to convert the proportion of forestry waste they otherwise have to move off site to green electricity.

And when they clear-fell an area of pine, they are starting to wonder whether it makes sense, given the current softwood market, for them to continue to grow 40 year life-span pine trees when they could be growing faster growing 5 year cycle biomass - willow, perhaps - and burning it to generate electricity. Alternatively, when you have an ugly bare patch on a hill side (and that grid connection, don't forget) you could also fill it with solar panels if it points in a useful direction.

They have a nice poster and a vision of an "energy park" on their land where you can see wind, hydro, solar and biomass in action, not to mention watching modern forestry at work (from a safe distance) in between riding a gravity switchback, or mountain biking one of those forestry roads.

They even have a video here:

https://www.youtube.com/watch?t=1&v=z3YSERDI0B0

Next up, Anthony Price of Electricity Storage Network, an industry group of companies and universities dedicated to promoting the use of power storage in the UK grid. They are campaigning to persuade the government that the UK should have about 2000Mw of electricity storage connected to the grid by 2020[1].

Currently, the UK electricity network has about 3GW of pumped hydro (Wales has most of the UK's pumped hydro capacity, with about 2.3GW) about 10MW of battery and (currently) an experimental 300kW of battery storage connected to the grid. These are used during peak demand having stored the electricity at times of low demand.

Currently, the electricity network is supplied by a host of private companies who negotiate a guaranteed price with the national grid for their electricity. That price is guaranteed to an extent, and they are compensated when they are required (as they sometimes are) to produce less than they are contracted to produce.

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[1](see http://www.electricitystorage.co.uk/files/7814/1641/4529/140509_ESN_Elec_Storage_in_the_National_Interest_Report_final_web.pdf)

This is a limited model, because it offers no incentive to develop or deploy large scale storage, which could potentially be a useful and profitable service if it transferred capacity from times of low demand to times of high demand. The UK power generation system is comfortably capable of producing the electricity it needs over the course of a day, but can struggle to do so over the course of an hour. This means it has to idle costly and inefficient power stations a lot of the time. This, as was pointed out several times at this event, puts the electricity grid in marked contrast to the gas grid, which (if you think about it) has always had energy storage built in, and uses a fraction of the energy to move it around. High demand for gas simply depletes the store, which a steady supply at the annual consumption rate will replenish even though the peak rate is many times higher than that average.

At the other end of the distribution system, electricity storage "behind the meter" in domestic and industrial premises could encourage the development of more local generation capacity in homes and factories. It could even - with the right pricing regime - make commercial sense for individual homes.

So, for example, if the retail price of electricity were as volatile as the demand for it ought to dictate, homes with sufficient storage could minimise their consumption during high demand (and price) periods. And if that applied to any electricity they generate and export to the grid, a home with storage could export its stored electricity for maximum price (relative to its own capacity). If consumer spot pricing reflected current demand, it would also be worth designing smart appliances which use as little energy as possible, and then only at the cheapest times.

Storage would enable renewable generators like wind turbines and solar PV installations, to sell *all* the electricity they generate and this is in fact the only way we can reasonably expect to transition to renewable sources of electricity, given that the wind doesn't blow and the sun doesn't shine all the time.

This can be done at the intermediate level between domestic industrial premises and large scale massive storage schemes like Dinorwig. The community of Wadebridge, in Cornwall, where 10% of the houses have solar panels, is determined to cut its annual electricity bill - currently twice what it makes from tourism - by collectively developing a suite of renewable energy generators, and eventually incorporating storage to provide a measure of grid independence (it experiences more power cuts than average because of its distance from the grid and the exposed overhead power lines). The goal is to become a net exporter of electricity from renewable generation, and that's going to require storage.

Next up was Grant Bourhill from the Energy Technology Institute, in its own words "a public-private partnership between global energy and engineering companies and the UK Government" and to that end it "brings together engineering projects that accelerate the development of affordable, secure and sustainable technologies that help the UK address its long-term emissions reductions targets as well as delivering nearer term benefits". Amen to that.

What he wanted to talk about was heat. Our tendency to confuse energy with electricity is not confined to the hapless Mr Blair (allegedly) and this is understandable when we are talking about renewable energy and the transition to a low carbon economy, because relying on biomass for heating isn't a viable option for most of the world, and the U.K. in particular.

When we burn a litre of fossil fuel to heat ourselves we do at least get the full 10kWh of heat from it. When we use it to drive a car, we get between 2kWh and 3kWh of work and 7kWh to 8kWh of waste heat which is only welcome in the depths of winter. If we use it to generate electricity, we get a bit more, but not much. If we use fossil-fuel derived electricity to heat ourselves, then we'd be better off (carbon wise) burning it directly in our homes. Even the most efficient type of electrical heater - the heat pump - cannot match that.

So if we are to move to electricity as a universal energy transport medium, then we'll need a lot more of it if we want to keep as warm. The average UK home uses 4 times more energy to heat its air and water as it does to do anything else. Over the whole country and all our uses of energy, at peak demand the ETI reckons the UK would need 132GW of electricity to provide all the heating energy we need, and that's 50% more than our current peak electricity load.

This is why the government is so keen on insulation - or was until the building industry pointed out that hard-working families would have to pay a few percent more up front for properly insulated homes, and would obviously prefer to pay more for their heating in perpetuity.

The bottom line is that we're going to have to work much harder to transition to a low carbon economy if we plan to be as warm. Insulation remains the most cost effective way, reducing dramatically the energy we use to heat homes. Better control systems to ensure that we don't heat what doesn't need heating would help. In some built-up areas, where we are still burning biomass (or even fossil fuel), we can use the waste heat from the process to heat nearby homes and offices. But there really isn't, nor will there ever be, a nationwide heat grid.

But neither is it clear that we need to, or will ever, eliminate the gas grid either. Unlike the electricity grid, the gas grid has storage built in, and provided the gas is generated renewably .....

SESSION 2. MINISTERIAL ADDRESS.

We then had a break for a message from our sponsor - the Welsh Government in the impressive shape of Carl Sargeant A.M. As a minister in a devolved government that does not yet control much of its revenue or its policy, he's constantly having to figure out how to implement the Welsh government's policies when the budget he has is designed and proportioned for the U.K. government's. On top of that, some aspects of energy policy in Wales are not, or are not sufficiently, devolved for him to be able to achieve Wales' markedly more forward-looking policies on sustainability - including, of course, energy sustainability.

A particular bugbear at the moment is the UK energy minister - Amber Rudd - scuttling all proposals for major wind farm development in mid-Wales, admittedly with the connivance of Powys County Council. Mr. Sargeant would clearly prefer the Welsh Government to have had the power to determine the fate of such developments itself, but obviously he is ham-strung by the current devolution settlement.

Still, he had more encouraging news on the building front, with the suggestion that Wales (if necessary through the injection of some government funding or other financial incentive) might be able to make progress on its ambition, until recently shared by the UK government until lobbied by house-builders and the new-found priority to make houses as cheap as possible for hard-working (as distinct from feckless, undeserving) British families to buy in 2015.

Although houses will now be much more expensive over their lifetimes to heat, the UK government hope to mitigate that by promoting the extraction of massive amounts of UK shale gas which it hopes will defy global pricing to the benefit of UK consumers. [Or failing that, at least generate much higher revenues and GDP growth for those companies in possession of fracking licences -

though that would be even more uncomfortable for the current Welsh government, which is not entirely persuaded of the benefits of fracking at the moment].

So, although he couldn't be specific, the minister pledged to work with, and support, the renewable energy industry in Wales despite the obstruction of the UK government. The Welsh government wants to work in partnership with the private sector, and will be looking to acquire greater devolved capability to offer such support. Mr. Sargeant talked of a "Green Growth" fund that might be used as a financial instrument to overcome, for example, the fact that the capital cost of more energy efficient houses might be higher, while their running costs ought to be lower. A little financial engineering - the branch of engineering the UK is still quite good at - ought to be able to provide a way of offsetting one against the other to the mutual benefit of the homeowner and the environment.

Mr. Sargeant urged us all to be "cleverer", and I think given the nature of the current devolution settlement that's probably the most positive attitude to have.

SESSION 3. SMART STORAGE.

This session was chaired by Steve Howell, of Freshwater - a public affairs and integrated communications consultancy, though there is no need to hold that against them.

It was opened by Chloe Bines of Eunomia, a consultancy specialising in energy and waste management. As a consultant Chloe was able to put together a wide ranging overview of the field with some diagrams to help us grasp the issues.

Energy storage is about disconnecting supply from consumption in time. There are different reasons for wanting to do this, and you can classify storage systems by how much energy they store, how quickly, for how long, and the rate at which they can subsequently produce. Which technology is best for a particular application depends on why you need to store energy in the first place.

The government and the consumer are mainly concerned about "security of supply". Politicians threaten us with the "lights going out" if opposing energy strategies are adopted, and although the generation industry is no longer publicly owned, we demand the government keep the lights on and blame it if the lights go out.

One threat to security of supply is peak demand exceeding generation capacity. The pumped storage scheme in Dinorwic is an example of energy security device. A private energy supply system would never have built such a thing because its economic viability depends on a massive spot price hike whenever peak demand threatens to exceed supply, and even if that could be engineered it would be difficult for competing suppliers to meet. Dinorwic is therefore the result of prudent planning by a responsible public electricity supply body - the Central Electricity Generating Board, which was publicly owned at the time.

Historically, Dinorwic was built to cope with the limitations of centralised nuclear power plants. These have very slow response times and are so expensive to build that it is commercially and technically important that they run close to full output at all times. The advent of nuclear power encouraged the introduction of night storage heaters and the Economy 7 tariff to shift consumer demand to the night. Dinorwic was originally regarded as a useful "dump load" which could absorb the difference between a supply that could not be turned off and a demand that could not be turned on.

Energy generation is also expensive, and storage also helps reduce costs by smoothing over the difference between average and peak demand over a given period. If we could turn electricity generation on and off as readily as we do our lights, pure market forces might be able to achieve such a cost reduction. In a totally free energy market, retailers would buy it when it's cheap and sell it when it isn't. Consumers would buy from retailers who would in turn buy from producers. But we are nowhere near having such a market today, and find ourselves in the unfortunate situation of having a free market oriented government having to guarantee private (or publicly-owned foreign) companies ludicrous prices for energy years in advance, *and* guarantee the loans these producers need to build the capacity. You don't have to be Jeremy Corbyn to question whether safe secure power is something we can expect the private sector and a free market to provide.

Some of these issues - with regard to efficient operation and handling peak demand - are self-inflicted. Historically, we have a power generation and a distribution system that is heavily centralised and hierarchical in its design. It wasn't designed at a time when the average home could generate all the electricity it needs and export any surplus to the grid. But that world is now upon us as domestic consumers in many developed countries are becoming electricity producers as well.

The future may therefore be dominated by distributed micro-generation - installed primarily to service domestic demand - coupled with domestic or factory level storage to offer the same balancing over time of energy production and consumption that Dinorwic does for the UK as a whole. Micro-generators might be able to operate in a free market with wildly fluctuating energy prices. Some of them might even be able to make a profit simply from storage, rather than generation plus storage.

There are other, wildly different applications of energy storage that offer the same load balancing but of radically different loads and time-scales. Lewis Hamilton's F1 car has a kinetic energy recovery system (KERS) that stores 6 seconds of 80bhp boost, sufficient to overtake a competitor without using more liquid fuel. The energy to do this is harvested from his brakes, which pick up enough energy in a lap to give him about 10 seconds of boost. The battery and capacitors that store this energy holds just under 400 kilo-joules of energy - about 110 watt-hours, or enough to boil a litre of water. It's not much - about the same as my battery-power lawnmower's batteries which provide about 20 minutes of mowing.

The batteries in the early Toyota Prius held about 2kWh, enough to ensure that the petrol engine only has to generate average power output, rather than peak output, and therefore run at maximum efficiency. This energy would be stored and dissipated over the course of about an hour.

If you only have to store energy for a very short period of time, you can use mechanical flywheels - Williams developed such a flywheel for their F1 cars but they are now used to cope with demand "spikes" which would otherwise put undue strain on, say, a big battery or a small generator being used for, say, arc welding. On the supply side, storage systems can also help cope with wildly variable input. Many renewable sources - turbines, solar panels, and wave power devices - can show massive fluctuation in output over short and long periods of time. Putting that energy into a battery is the only way to deliver reliable, stable power to the consumer.

But all these storage systems are only doing what Dinorwic does on a different scale in load and time-span - matching variable supply with variable demand. Dinorwic typically stores and discharges its energy over the course of a day taking a massive country-wide load for a few minutes and charging up the rest of the time. An electric vehicle battery charges and discharges over the course of a few hours. Lewis Hamilton's kinetic energy system over a few seconds.

Household storage systems will initially work on a day cycle - discharging at night the energy they captured during the day. It would be nice if they could store energy for the winter that was captured during the summer, but it will be a long time before electricity storage systems do that.

On the other hand, the gas grid does it today, as we shall see. And when we talk about storing electricity in any kind of battery, we're not actually filling up a container with a load of electrons (except, arguably, when we use a capacitor, which tends today to be a very short duration store.

What we do is store the energy mechanically - by pumping water up a hill at Dinorwic, compressing air in a cavern, or spinning a flywheel - or chemically, by charging a battery or fuel cell. And the difference between storing electricity as chemical energy in a battery or in the form of hydrogen we can either burn or put back into a fuel cell to generate electricity, is moot to say the least. I think you can claim that any system that is charged by electricity to a state where it can subsequently generate electricity is an electricity storage system. More on this later.

The big commercial opportunities for energy storage, according to Chloe, are:

1. "Behind the meter" - in the home, isolating the home from the grid behind a battery.

2. Alongside variable generators - to smooth their output, hold onto it when it isn't needed or until you can get more for it.

3. DNO's - sub-grid distribution companies – as an alternative to "reinforcement". DNO's are under pressure to support micro-generation. Their transmission lines can't cope with aggregate counter-directional flow, and upgrading power lines is expensive. Storing local surpluses on, say, sunny summer days would allow them to connect more distributed capacity.

4. The National Grid itself. This already has Dinorwic-like installations, but current generator contracts mean that the grid has to pay generators not to generate when there is low demand. If the grid could simply buffer that surplus nearer to the generator, everyone would be better off.

Next up John Prendergast from RES - a developer and installer of wind and solar farms. They've put in about 8.5GW of wind power and 150MW of solar farm. Since these farms are typically spread over a wide areas, they're also responsible for 1000km of their own power lines. They have, he said, 8MW of storage, but he didn't say (and I didn't ask) whether that was the power output of his storage system in watts, or whether he meant he had 8MWh of storage.

John's interest in storage is obvious and ancillary to their main business. He referred to "fast balancing" which I took to mean the need they have to match output to demand where both can vary rapidly. A storage system buffering a wind farm from the grid can effectively turn off quickly while not losing the energy it has generated, and can switch back on quickly as soon as there is demand to maximise revenue. Batteries also help with grid integration and may even relax the need for new power lines. A raw connection to the grid must be able, today, to take the entire instantaneous output of the generator. With a storage buffer, it only needs to be able to take the average output. Since the capacity factor of a wind turbine is between a fifth and a third of its rated output, this must make quite a difference to the cost of connecting a wind farm.

At the moment, RES is only using storage in its U.S. projects, There they use Lithium Ion batteries able to generate between 4 and 20 megawatts over 4 to 6 hours - the largest one they have holds 7.8MWh of electricity. As well as lithium ion they are also looking at so-called flow batteries.

Next up, Mike Pedley of Welsh Water (DCWW). Mike is Head of Energy for DWCC, which (I guess) shows that they consider themselves serious energy producers as well as a water supply company. This makes sense because a water company is a heavy electricity consumer (450GWh a year in DWCC's case) and indeed has 50 sites where they generate 90GWh a year.

The title of Mike's pitch, though, was "the gas network as storage for an energy park". The focus was his show-piece installation on a sewage works and water treatment plant in Wrexham. Here they need a lot of electricity but have a useful source of promising biomass in the shape of the sewage output of 96,000 Wrexham residents.

This is partially processed by an anaerobic digester to produce Bio-Methane, which is, in turn used to power a CHP (combined heat and power) electricity generator, making the site more energy self sufficient. They have 2MW of solar PV installed and are planning some wind power. It's unlikely that the plant is sited in an AONB, so that will probably go through. They also have a 50 metre drop for the treated water into the River Dee, which offers some (largely symbolic) hydro capacity - though Welsh Water also have significant hydro installations on their many reservoirs, including the impressive Elan Valley reservoirs (2MW) and Llyn Brianne (4.3MW).

The anaerobic digestion feeds a thermal hydrolysis plant with the heat and electricity to further process the sewage into solid waste and clean water. The solid waste can itself be burned directly or gasified to fuel further power and heat generation, or used directly as a fertiliser.

In the last talk of the session, we heard from Professor Jon Maddy of the University of South Wales who is an expert in the generation, storage, and use of hydrogen. He was posing the somewhat loaded question: "is it time for hydrogen?".

It's good to hear that UoSW has two sites doing hydrogen research, at Baglan and Pontypridd. They are looking into new production methods, of which fermentation of biomass - which also has a by-product of bio-plastic material - is one of particular interest. The simplest (but not the cheapest) way to make hydrogen is by hydrolysis of water, and while that doesn't make much sense compared with the alternatives if electricity is expensive, it might make sense if you are trying to store electricity you already have that you would otherwise have to throw away because there is no current (see what I did there!) demand for it.

There are also several industrial processes that have hydrogen as a by-product so we need better methods of capturing it, storing it and distributing it. Hydrogen poses some problems in this respect if you're storing a lot of it because it is famously as light as the lightest imaginable thing. So we also need better techniques for storing is under high pressure so we can store more in a given space. Unfortunately, there is eventually a trade-off between how much hydrogen by weight you can, if you compress it, store in a container of a given weight.

Still, once you have it, hydrogen can be moved around the gas grid in small concentrations. Before the advent of natural gas, town gas was typically composed of 50% hydrogen, 35% methane, 10% carbon monoxide and 5% ethylene. Natural gas, which is what we use in the gas grid today, is typically 95% methane. At atmospheric pressure, natural gas has over twice the calorific value per cubic metre of town gas or hydrogen, and its production costs are much lower because it doesn't require much further industrial processing after it has been brought to the surface. By weight, of course, the calorific vale of hydrogen is much higher than methane, and hydrogen is the preferred fuel for so-called fuel cells.

As a hydrogen expert, Prof Maddy would obviously prefer to deal with the pure gas, but pragmatically - if we are going to start to store energy as combustible gas, it makes sense to use natural gas which we already know how to store, transport and pump in liquefied form and large quantities. And while most industrial hydrogen is produced today from methane (rather than water) converting hydrogen to methane is chemically straightforward.

So in case this thread is not yet clear, the idea being mooted is the use of the gas grid for energy storage and transport. And Prof Maddy would obviously like us to be using that grid to transport hydrogen - which would require some upgrading, although the same grid used to transport town gas when it was predominantly hydrogen, so hopefully to upgrade wouldn't be ludicrously expensive. We would then have a readily available source of energy which we can use to generate heat energy by burning it, mechanical energy by internal combustion, electricity using internal combustion or fuel cells, and transport using fuel call cars.

There's only a couple of (admittedly quite major) obstacles:

1. Hydrogen produced isn't produced renewably and

2. The gas grid only covers urban(ised) areas of the country.

I guess these could be addressed. We can produce renewable hydrogen by hydrolysis of water using spare renewable electricity capacity. We could even produce renewable methane from it by "methanisation" using atmospheric CO2. And we can presumably deliver either hydrogen or this "green methane" in gas canisters to rural areas.

Hydrolysing water to make hydrogen is now much more sophisticated than simply running a current though water and capturing the bubbles from the cathode. Nowadays they use either alkaline electrolyzers or Proton Exchange Membranes (PEM) - the ones they use in fuel cells. Membrane electrolysers are particularly attractive because they can cope with large fluctuating currents that a typical wind turbine or solar panel might generate, and the technology scales down much better than more common large scale alkaline electrolyzers which require more industrial installation.

The Energy Storage Association is now predicting conversion efficiencies of 65% to 70% for modern electrolysis offering a so-called "round trip" efficiency using fuel cells of about 50% - in other words, we would get back about half the electricity we put in. If we had had an immediate use for that electricity, this would be a stupid thing to do, but once we start generating all the electricity we can, when we can, rather than when we need it, we can "go to town". Inevitably, in this scenario, we will start to build wind farms in remote areas that simply make hydrogen which we ship out by tanker or through the gas grid.

To give an example, Professor Maddy cited an operating Power-to-Gas system that is high capacity and offers 77% efficiency. If the hydrogen produced was just burned it would produce about 77% of the energy needed to generate it. If instead of just burning it you did so with a combined heat and power system (CHP) you could achieve 86% efficiency. If you simply generated electricity directly with a fuel cell - say in a hydrogen car - you would still get about 60% back.

So what they're talking about initially is "peak lopping" current renewable supply - converting surplus renewable electricity to hydrogen instead of wasting it. Any country that can generate, over the course of a year, the same amount of electricity as it uses in a year could in this way supply all its electricity renewably - even though its renewable generators could not cope with peak demand or (sometimes) generate any electricity at all. Some countries in Europe are in a position to do this today, apparently. The UK probably would be one of them if it were able to fully exploit its winter wind capacity. The UK wasted (curtailed) 483GWh of renewable electricity in 2013/4 because it was surplus to demand at the time.

The government (DfT via OLEV) is funding an experimental hydrogen generator in the form of a wind turbine producing 80kg of hydrogen a day at the standard 700 bar pressure that hydrogen fuel cell cars tend to need. Since wind turbines that produce hydrogen for local transport won't need pylons - which a grid-powered motorway refuelling station for 20 Tesla electric cars certainly would - they may become more popular.

In short, electrolysed hydrogen in the gas grid could offer a very long-term season-to-season energy storage and distribution system that makes full transition to renewable energy generation feasible.

SMART GRIDS

The first session of the afternoon was chaired by Simon Roberts from the Centre for Sustainable Energy a charity that "shares our knowledge and experience to help people change the way they think and act on energy".

Producing and using energy the way we do today will become increasingly challenging, and while we must tackle the problem of how to generate all of our energy sustainably, we can also change the way we use energy to use less of it, and use it in a more easily sustainable way.

First speaker was Laurence Carpanini from IBM, talking about how to make smart grids work. He didn't bother to explain what a smart grid is, but it emerged that what he's talking about is a producer-consumer network where information about production and (potential) consumption is available to both consumers and producers in a manner that enables optimum production and consumption.

For example, we could have electrical appliances that shift their load in space (I didn't understand what that meant) and time (which is more easy to see). To do that, the appliance needs to "know" what the current production capacity is (which might be expressed as a price-per-unit, for example), what goals it has been set by the consumer (e.g. when the washing has to be dry) so that it can turn itself off and on at the optimum period.

There will have to be something in this for consumers, because they'll be required to invest in new appliances and plugs. The key word here is ENGAGEMENT - consumers will need to be positively involved in better understanding and managing their energy use. The days of too-cheap-to-meter energy (which never really arrived) are definitely behind us now!

One way forward, currently the subject of widespread publicity, is the concept of an "internet of things". But (and remember, Laurence is from IBM) this will depend on Big Data, in the Cloud.

Data, as distinct from energy and material, has become the new resource we'll all be buying, selling and competing for, and the trick is to ensure that the right data is made available to the right people to use in the right way.

The first step on what will be a long road are Smart Meters. The government is committed to rolling these out to the whole of the UK by 2020. This is going to be very costly, and the main beneficiaries initially will be the so-called "energy companies" - retailers who buy it wholesale and sell it to consumers with a bewildering array of contract types designed to ensure that the consumer never pays as little as possible for their energy. So we can expect a hard sell.

The consumer benefit of smart metering will initially be limited to more accurate billing without the need to "read the meter". Your energy supplier will know, in real time or on a 30 minute by 30 minute basis what your energy usage is. This information will also be available to you via an indoor display of the kind you've been able to buy for 5 years.

In the US, the Pacific Northwest Laboratory of the federal government Department of Energy has been conducting a long range study in 5 states and 60,000 premises in North West Pacific areas. They're looking into the effects of a more decentralised grid where end users both produce and consume electricity, and prices fluctuate in real time.

Next up, Simon Power from Arup, on "learning from smart energy in Cornwall". One of the common questions about sustainability and the environment is "Yes, but what can *I* do about any of this". In Cornwall, they've been thinking about it, and are looking at ways in which individuals and communities can take more of the initiative.

They start with the observation that power generation is moving from centralised to a distributed model - for which the current grid (and indeed the energy market) are clearly not designed. Cornwall has tended to view itself, and to have been treated, as a not terribly affluent consumer of power, delivered to it from parts of the country where there is more demand and more generation capacity.

But now, Cornwall is starting to see serious energy generation locally in the form of solar and wind, and while none of the generators are massive multi-gigawatt stations, they can achieve electrical self-sufficiency with large numbers of small individual and community owned power schemes.

They'd like this revolution in power generation to be an opportunity for urban and rural renewal in Cornwall, creating local jobs and wealth. And they don't see this (or at least present it) as a carbon-saving planet-preservation exercise at all. They see it as being about money earned and saved, and about self-reliance. This might be a better renewable energy pitch to give to the "Tea Party" faction of the UK right-wing, too.

So the goal is a "fully integrated, smart energy network providing jobs, wealth and a prosperous resource efficient future". I expect the Welsh Government would be happy to lead Wales in a similar direction. It's not a "Hinkley C" story by any stretch of the imagination.

They're looking at ways to encourage local energy generation and the development of a local energy market where consumers buy their energy from local suppliers and/or community-owned generation capacity. To work within the current energy market, you can see that they're likely to form local energy supply companies that are at least partly community-owned. "Community-owned" energy companies are not, of course, to be confused with "publicly owned" energy companies which would be anathema to current UK government. But anything that breaks the perceived stranglehold of the "Big 6" is likely to be welcomed by both government and consumers.

This was followed by Steve Edwards of Wales and West Utilities who are the gas equivalent of Western Power Distribution, operating in much the same area. Their grid serves 2.5m homes and 7.5 million consumers through a grid of 35000km of pipe. Unlike WPD, I fancy, they wouldn't have any technical problem accepting more gas generation, since gas mains are essentially “squashy”.

Gas tends to be ignored in talk about renewable energy because as everyone knows, gas is a fossil fuel which isn't renewable and would have finite supply even if it were a good idea to burn it all. But we do need to remember that gas currently provides 80% of the energy used by households and industry, and so even if we had a completely renewable electricity supply we'd still be some way from having a renewable *energy* supply.

As has already been pointed out, short term electricity storage in batteries and pumped hydro schemes can balance supply and demand over short periods, making up some of the discrepancy between when and how much energy we can generate renewably and when and how much of it we use. If we want to extend the storage period to months or years - to use solar energy over production in summer to deliver the higher demand we have in the northern winter, say - we may need to do so in the form of hydrogen or synthetic methane.

And this is an urgent problem as we tackle the issues of moving to renewable energy at the same time as our population is expanding and ageing. Changes like that, in the past, have taken a long time, and we may not be able, as a society, to move away from gas as a primary energy fuel as quickly as we'd like.

One approach, therefore, is to progressively "de-carbonise" the gas supply, continuing to use the gas grid as both a store and a distribution network for renewable energy. One big advantage of gas is that it can provide storable energy for transport. Cars and trucks that run on gas can be refuelled as quickly as current vehicles, and from much the same outlets.

Finally, we heard from Nigel Fox of the National Grid, about smart grids and what they mean for the National Grid. The National Grid operates the high voltage lines that span the country connecting large scale generators like nuclear power stations to local distribution networks. Their job is (largely) to balance the rest of the grid, and unlike local distribution networks they are better geared up for bi-directional flows.

The National Grid does scenario planning where they look at the requirements that will be placed on them by the different futures suggested by government policy, society, technology, and demographics. They have to plan for situations where we make either a lot of or very little progress in our ambitions to move to a renewable energy system while either continuing on the current downward trend in consumption (likely to reverse as the population rises) versus starting to increase our energy usage to US or Australian levels.

That's not a task that many would thank you for, but interestingly all scenarios require a more distributed grid - with the bulk of the power necessarily being generated at or near the periphery as distinct from at the centre. The role of the national grid will then be more and more about balancing supply and demand between different parts of the country.

So, for example the National Grid predicts that by 2035, in the middle of a sunny day, hardly any power will be moved over the national grid. This will be because all domestic and local industrial power will be provided close to or on the premises. Hmmm.

They do have some technical challenges to cope with. Solar and wind generators cut in and out very quickly and today they have to be "curtailed" - i.e. told to stop generating and switched off. The long term solution must be that generators buffer their output until they can economically export it - but if the grid gets to the point of being able to signal the current price it will still have to cope with very high speed cut-in and cut-out times that renewable systems provide, compared with the much slower start-up and shut-down times of conventional and especially nuclear power stations.

Aside from that, however, the National Grid is far better set up to cope with "flow reversal" than the local DNO (distribution network operator" - e.g. Western Power) grids.

SMART LIVING.

The final session, chaired by Fflur Lawton of British Gas, was about "smart living".

The first speaker was Professor Elizabeth Shove of Lancaster University who talked about "the dynamics of energy, mobility, and demand". Prof Shove heads a research programme called DEMAND looking into the **D**ynamics of **E**nergy **M**obility **AN**d **D**emand which focusses on the interesting and oft-overlooked question of what energy is for.

First up, she reminded us that energy demand is an *outcome* of social behaviour and practice - rather than a *driver*, as technologists might prefer. So if, for the next few generations, we're going to have to change energy demand to better match our ability to supply it, we're going to have to do so by manipulating those practices. We can do that partly, but only partly, by changing the appliances which mediate demand. So far, so good - if a bit scary.

To get a more concrete handle on what's happening here, we need look no further than the widely understood notion of "room temperature". What constitutes room temperature is actually a social construction. It would have been driven to some extent in the past by what was achievable, though it's now largely culturally constrained in developed societies.

[Despite that, we have developed "scientific" measures of what can be expected to constitute "thermal comfort". The Fanger equations are derived from empirical studies of groups of people subjected to particular conditions of air temperature, mean radiant temperature, relative humidity, air flow, metabolic rate, and clothing insulation. From this it is possible to calculate the energy input required to maintain an air temperature that would maximise the number of satisfied people and minimise the dissatisfied].

But does that help us plan present and future energy generation and demand? When we analyse peak demand, for example, we find that it is dependent on many things. In the workplace, it depends on employment policies - the proportion of women in the work force, for example - which vary from country to country. In the home, it depends on the demographics of the occupants - working age occupants having a more chaotic energy usage pattern than retired people.

The DEMAND team has looked at cars, and the role they fulfil in personal transport. It emerged that it is cargo carrying that determines the necessity and use of a car for most of us, and Western society has now adapted itself to the availability of cars in its design of transport infrastructure and retailing, for example. To persuade people not to use their cars so much, we would need to understand that before we could present adequate alternatives or design different support infrastructure.

Appliance designs - for freezers, TV's or cars – tend to focus on efficiency, relative to the status quo, of a particular technology. This wasn't what drove the adoption of the technology in the first place, and tends to treat the technology in isolation. But there is now a link between, for example, refrigerator capacity and car carrying capacity.

Professor Shove has also been looking into the social psychology of climate change policy. She is a critic of the Civil Service's conventional "ABC" approach to policy implementation. Here ABC stands for Attitude, Behaviour, Choice, and the idea is that we start with people's attitudes, which condition their behaviour and hence drives the future choices they will make. This sounds logical and credible, but people don't actually work that way.

Professor Shove tends to the view that, more often, available choice determines or otherwise constrains behaviour which in turn determines attitude. She claims that there is ample evidence from all branches of social science that human behaviour, particularly social behaviour, and its determinants are complex and interconnected in ways that will typically defeat our attempts to predict it. But understanding it better can help us change it.

Next up, a more pragmatic pitch from Lynda Campbell of British Gas on their implementation of the smart meter roll-out. She called her talk "innovating from the customer upwards".

She explained what smart meters are, why they are good for us, what British Gas is doing to engage its customers about the benefits and the kinds of customer programmes that smart meters enable.

Basically, a smart meter provides a real-time reading of current energy usage in the home (or customer premises). One immediate benefit to both customer and supplier is that there will no longer need to be a meter-reader and the bills will be accurate. An additional, customer benefit is that they can now have a real time display of current energy usage in the home (in British Gas's case this will include gas as well as electricity), enabling better control. In addition, or as an alternative, the customer will (eventually) have access to this information and historical usage information on-line.

The charging flexibility that comes from knowing when the energy is being used opens up interesting billing alternatives. British Gas could, for example, manipulate demand (though they might not put it like that) by offering free electricity on Sunday in exchange for a slightly higher tariff at other times. Lynda also mentioned the possibility of smart prepayment meters, and the possibility that more customers might choose to have a prepayment meter - presumably "fed" by a credit card - to control their energy expenditure themselves rather than be stuck in the strait-jacket of an annual contract tariff.

Smart meters allow energy suppliers to add different time-dependent tariffs remotely - they don't need to change or adjust the meter in the home. Further out, British Gas expects to see smart appliances that only operate at low tariff periods, signalled by the smart meter. She mentioned the HIVE thermostat which is being deployed to control home heating and hot water by signalling through the mains. This approach will be generalised in the longer term to universal control of all sorts of other things.

Lynda played a scary vision video of the future of the smart metered and HIVE'd home which included a solar PV charging a battery which would be aiming to minimise imported electricity. It featured the working homeowner remotely checking the credentials of a British Gas engineer calling to fix the boiler and unlocking the front door. Good luck with that!

There was some discussion about the shift an energy retailer like British Gas has to make to change its business goal from selling more gas is to helping the customer use as little gas and electricity as possible. She cheerfully admitted that this would be a difficult transition to make, one to where superior customer service would be what they (British Gas) would be selling. It means employing a different kind of customer-facing staff, and we were all delighted to learn that BG's recruitment policy is now:

"hire the smile, train the skill".

Finally, we heard from Hugo Spowers, the CEO of Riversimple, a company that is developing (and has been developing for many years now) a hydrogen fuel celled car. This is about to launch next year, although that has been the position for some years.

Riversimple's research arm (at least) is now based in Llandrindod Wells, supported by a Welsh Government grant. It is proposing a quite different and more environmentally aware model of car production and use. You will not be able to buy a RiverSimple car from the company. Instead you will buy so many miles of personal transport, and they will provide the vehicle and the fuel for you to do that for (say) £500 a month.

The cars are technically 4 seater light vehicles (quadricycle class) with an 8kW fuel cell and a range of 300 miles. Despite the quite respectable range, they are targeting the local travel (50 miles a day) niche, which means you'll expect to fill the tank (1kg of hydrogen at 350 bar, which is about 33kWh of energy) about once a week. The car itself is effectively zero emission (it does produce water).

The business model is a novel one, and as Hugo pointed out, means that it is in Riversimple's interests to make the car as reliable and long lasting as possible, and to upgrade it to run as cheaply as possible throughout its "life" which could effectively be very long.

One short term issue is that there is no hydrogen fuelling infrastructure to speak of, and it would only make sense to rent one of these cars if you lived within a short distance of one. For next year's trial, Riversimple will be providing the fuel station and the first trial batch of cars will presumably have to be rented by subjects who live within range of it. The hydrogen fuel stations the government is expecting to roll out for full size hydrogen cars from Toyota operate at 700 bar, but I assume that these would be accessible to a Riversimple car. A 350 bar fuel station might be cheaper, and we might in the next couple of decade see small renewable electricity hydrolysers generating hydrogen for local use.

The interesting thing about the Riversimple design is (or was) the way it optimises the fuel cell so that it only has to provide the average rather than the peak current an electric car requires. Riversimple uses super-capacitors which don't hold a lot of power, but can charge and discharge very quickly and at high power. This is particularly useful for energy recovery from braking, for example, and means that hard braking can produce the energy needed for subsequent acceleration, so evening out the demand from the fuel cell, which otherwise charges the super-capacitors at constant rate. I don't know what it would be like on a long hill climb, though.

TAKEAWAYS

The conference was much more interesting than we thought it would be, providing us with a much broader perspective on energy storage and how critical it is to a feasible transition towards an economy powered by renewable energy. In summary, we learned:

- because renewable electricity is not continuously produced, storing electrical energy is an essential component of any transition to a fully renewable energy system.
- in the home, we use 4 to 5 times more energy heating space and water than doing anything else.
- the electricity grid only balances inputs and outputs, it doesn't, itself, *store* energy.
- the gas grid balances and stores energy for months.
- if we want all our energy to be renewable we're going to have to learn to store renewable energy in a different form (e.g. gravitational, chemical, or heat) for long periods.
- despite the losses involved we could store most of our energy on the gas grid in the form of hydrogen
- we still need sufficient renewable electricity capacity to provide all the energy we need over a year

- that capacity may not cope with demand peaks, but will generate a substantial surplus during demand troughs

- we can store that surplus to get us through the minute-to-minute, hour-to-hour, day-to-day, month-to-month and seasonal demand peaks

- by converting surplus renewable electricity to hydrogen and injecting into the gas grid, we can exploit its huge energy storage capacity

- the Bad News is that none of this is possible with the kind of centralised energy production and distribution system we have today

- the Good News is that most of it can already be done by moving to a more distributed energy network where large numbers of consumers and producers aim to be as energy self-sufficient as possible, but trade energy surpluses and buy energy when they need it from commercial energy producers.