Centre for Alternative Technology
Canolfan y Dechnoleg Amgen

Keeping the lights on without fossil fuels

Opening statement to the Joint Oireachtas Committee on Communications, Climate Action and Environment, detailed scrutiny of the Petroleum and Other Minerals Development (Amendment) (Climate Emergency Measures) Bill 2018.
This work is drawn from Zero Carbon Britain: Rethinking the Future.
The full report can be downloaded for free from www.zerocarbonbritain.org

Primary authors: Paul Allen, Laura Blake, Peter Harper, Alice Hooker-Stroud, Philip James and Tobi Kellner.
Contributing authors: Vijay Bhopal, Guppi Bola, Isabel Bottoms, Julie Bromilow, Louisa Casson, Richard Hebditch, Ling Li, Nuria Mera-Chouza, Lucy Neal, Darcy Pimblett, Sophie Wynne-Jones, Liz Zeidler and Mike Zeidler.
 Machynlleth, Powys SY20 9AZ, UK Tel. 01654 705950 • Fax. 01654 702782 info@cat.org.uk www.cat.org.uk ISBN: 978-1-902175-69-0

Zero Carbon Britain: Rethinking the Future describes a scenario in which the UK has risen to the challenges of the 21st century. We have acknowledged our historical responsibility as a long-industrialised nation and made our contribution to addressing climate change by reducing UK greenhouse gas emissions rapidly to net zero. Our research shows that we can do this without relying on promises of future technology, but by using what exists now. By making changes to our buildings, transport systems and behaviour, and by investing in a variety of renewable energy generation technologies suited to the UK (without a nuclear component), we can provide a reliable zero carbon energy supply without negatively impacting on quality of life. Smart demand management, plus the intelligent use of surplus electricity in combination with biomass to create carbon neutral synthetic gas and liquid fuels, mean that we can meet our entire energy demand without imports, and also provide for some transport and industrial processes that cannot run on electricity.

Introduction to why *(ref 2.3.2 The physics-politics gap, page 27)*
Physical problems have physical solutions and no amount of talking will make them go away. This is not to say that talking is not important; it is essential. But it is best to get the physics right first. Virtually everybody agrees that rapid decarbonisation is the cornerstone of any solution to climate change, and we have adequate ways of measuring how much decarbonisation is required, plus how fast it is required. However, if we analyse these physical requirements and work out a physically credible plan based on our scientific knowledge of the situation, we find it does not fit comfortably into the frame of normal politics and economics.

On the other hand, if we work out a plan that does fit the politics, we find it does not meet the physical requirements. In fact, a huge gulf between what is physically demanded by science and what is seen as politically possible is revealed. This is reflected in the difference between our projected emissions 'spend' above (15,800 MtCO2e), and the UK's portion of the global carbon budget in line with a good (80%) chance of avoiding a global temperature rise of 2C (8,400 MtCO2e). That's a difference of 7,400 MtCO2e.

We can call this the ‘physics-politics gap’. Most current efforts attempt to build bridges from the now, working forwards within current political, economic and social boundaries to try and meet the challenge of rapid decarbonisation. There are plenty of ‘half bridges’ built on foundations in the politically realistic perspective, none of which quite reach where we need to go from the physically realistic perspective.

Another approach is to instead ask, ‘what is the end point?’ A physically realistic perspective based on this line of question shows us where we need to get to in order to successfully meet the challenge of climate change. We can explore the possibilities for physically realistic worlds and consider what needs to change (from lifestyles, to infrastructure, to politics and economics) for us to get there, plus how fast we need to change, and the alternative routes that we can take. Once we have worked out where we need to get to, we can work backwards to find out how we get there. Zero Carbon Britain focuses on the questions involved in this process and sets out such a physically realistic scenario – laying foundations on the ‘right’ side of the physics-politics gap.

Keeping the lights on without fossil fuels
The section is referenced from *Chapter 3.4.2 Balancing supply and demand, page 63*.
It describes how we can balance fluctuating energy demand and supply by managing our demand, and creating a back-up system with carbon neutral synthetic gas.

Summary:
• As most of the energy in our scenario is from variable (fluctuating) sources, there is often a mismatch between supply and demand, with both large surpluses and shortfalls.

• Adding more electricity generating capacity (for example, more wind turbines) would increase surplus electricity production without significantly reducing the problem of shortfalls.

• Shifting certain energy demands to times of high energy supply and combining different renewable sources of energy helps, but it doesn’t completely solve the problem.

• Our scenario combines various short-term energy storage mechanisms (hours to days) with the capacity to store up to 60 TWh of carbon neutral synthetic gas for months or years.

• On average, we would be producing 27 TWh of synthetic gas every year, which would be used only as and when required.

• Although overall synthetic gas covers only a very small percentage of our total energy supply, it plays a critical role at times when demand is high and supply from variable renewable sources is low – for example in the cold, windless December of 2010.

Chapter 3.4.1 Renewable energy supply, Page 56 explains how in our scenario the total amount of renewable energy produced in an average year (about 1,160 TWh) is more than enough to meet a ‘Powered down’ energy efficient demand (about 770 TWh per year on average). However, as both demand and supply of energy in our scenario are variable (fluctuating) it is still a challenge to make sure that the supply always meets the demand.

Energy demand is variable

The amount of energy we use changes all the time. Currently, our electricity consumption increases rapidly between 5 a.m. and 9 a.m. on a weekday; it reaches its peak in the evening when we come home from work and switch on lights, cookers and televisions. Electricity demand can rise sharply when thousands of kettles are switched on during a TV advertising break or when clouds move over the skies of a big city and lots of people switch on the lights. Also, our demand for heating increases sharply when it gets colder. The distribution infrastructure for gas and liquid fuels has a number of built-in buffers – petrol stations and refineries have large fuel tanks and the gas grid has various stores, including the pipelines themselves. In contrast, the electricity system has much less built-in buffer capacity, hence the supply of electricity always needs to closely match demand. If in the future electricity plays a larger role in heating (heat pumps) and transport (electric cars) then dealing with demand variability will become more challenging.

Renewable energy supply is variable

The energy supply (or 'output') from most forms of renewables is variable. Whereas a nuclear power station might produce the same amount of energy whatever the weather, renewables produce different amounts of energy depending on how fast the wind is blowing, or how much sunshine there is – factors that are beyond our control. With wind power, the changes in energy output can be very sudden. Even with thousands of wind turbines spread around the whole of the UK, it is possible that energy production can near its maximum on one day and be close to zero the next. Moreover, we cannot change these things according to our needs. This does not mean that renewable energy supply is unpredictable. We can predict the tides centuries ahead, and even predict wind speeds reasonably well a few days in advance. Combining a diverse mix of different renewable energy sources can help 'smooth out' energy supply. However, our research shows that even when we combine all the renewable energy sources available in the UK, the energy supply will fluctuate significantly, for example, between a windy, sunny day (lots of energy) and a calm, dark night (little energy). And just adding more generating capacity, for example building more wind turbines or solar panels, is not enough to solve the issue, either. Our calculations suggest that, beyond a certain point, adding more generating capacity will primarily increase the amount of energy that is surplus to requirements without making much difference at times of low renewable energy supply.

Supply does not match demand

Unfortunately, our variable energy demand and variable energy supply don't necessarily 'match-up' – they don't go up and down in step. Energy demand also fluctuates – it is typically higher during the daytime, and higher still on cold days because of the demand for heating. Sometimes renewables supply much more electricity than there is demand for, but at other times wind, waves, tides and solar combined do not produce enough to supply the energy required. Our research shows that there are significant differences over hours, days and even years. For example, 2010 was a year with very cold winters at each end (high heat demand) and unusually low wind speeds (low renewable electricity supply), whereas 2011 was a warmer year with stronger winds. Finding ways to deal with these fluctuations is one of the biggest challenges in powering the UK on 100% renewable energy. We need to ensure our lights stay on and our houses stay warm even during a dark windless night, or during a year with low wind speeds and cold winter months.

What’s the solution?

The infrastructure of a renewable energy supply must incorporate some way of ‘balancing out’ this potential mismatch in supply and demand that is flexible and responsive to fast-changing weather. There are two main methods that can work in conjunction.

1) Shifting demand to match supply (demand management)

One way to balance supply and demand is to change our energy consumption patterns so that we consume more energy when supply is plentiful, and need less when it is scarce. Industry and some households already pay less for energy during the night when demand is low. It is not difficult to imagine a future in which electricity will be cheaper when it is windy and demand is low, and more expensive when it is calm and demand is high. This could provide an incentive to consume more energy at times when supply exceeds demand and to reduce consumption when energy is in short supply. ‘Smart’ appliances (such as washing machines and freezers, as well as industrial processes) will automatically run more when electricity is cheap – at times of high supply and low demand – in order to minimise energy consumption when electricity is expensive and in short supply. ‘Smart’ car charging of millions of electric vehicles could play an important role. Their very large electricity demand can very easily be ‘shifted’ to times when there is a surplus in the supply of electricity, for example at night or during windy periods.

2) Storing energy

There are a number of options for storing energy during times of surplus supply so as to make it available at times when more energy is needed. Different types of storage can perform different roles. Sometimes we only need to store energy for short periods – hours or days. At other times, over a very cold and calm winter period for example, we need to be able to build up energy stores for longer periods in advance, in order to make sure we have enough energy to last. What is crucial for any energy storage solution working with a variable renewable energy supply, is that the ‘building up’ or the ‘emptying’ of a store is flexible and, if necessary, relatively quick. We need a dispatchable energy store that can be called upon whenever demand requires it.

For hours or days:

There are a number of energy storage options that can help balance out supply and demand over timeframes of a few hours or days.

• Pumped storage is used today to store electricity by pumping water uphill into a reservoir at times of surplus energy supply and then letting the water flow downhill through a hydropower turbine when energy is needed. This form of energy storage can be activated very rapidly, but the total amount of energy that can be stored is small. The UK consumes far more than 1,000 GWh of energy on a single cold winter day. The UK’s largest pumped storage station, Dinorwig in North Wales, can only store around 10 GWh of electricity.

• Batteries in electric vehicles can help shift some electricity demand (as described above). But with today’s battery technology, dedicated battery storage – batteries installed exclusively for the purpose of storing surplus grid electricity – is not yet as cost-effective as some other ways of storing energy.

• Heat storage offers an attractive solution in the UK where a large proportion of electricity would be used for heating. Heat can be stored over a few hours or days without significant losses in well insulated hot water tanks (those required, for example, in solar thermal systems). Two hundred litres of storage per household – either individual hot water cylinders, or large external heat stores connected to district heating systems – can store around 100 GWh of heat. This allows heat pumps to play an important role in demand side management as they can be run at times when electricity supply exceeds demand.

• Hydrogen can be made by the electrolysis of water – splitting H_2O into hydrogen (H) and oxygen (O) using electricity. Electrolysers can use electricity at times when there is abundant surplus of electricity, to create hydrogen gas for storage. In principle, hydrogen can be stored and then used directly to produce electricity using gas turbines or fuel cells. However, hydrogen is a very light gas that needs to be highly compressed for storage. It is also quite explosive and can even corrode metal. It is possible to store relatively large amounts of hydrogen (a few 100 GWh) over long periods of time, for example in salt caverns. However, compared to natural gas (primarily methane), hydrogen is difficult to store and transport and there is almost no existing infrastructure suitable for it.

For weeks or months:
Storing enough renewable energy for, say, a cold, dark winter week with low wind speeds is technically very challenging. Realistically, solid, liquid or gaseous fuels are the best option to store the very large amounts of energy required (a few 10,000 GWh). Their high-energy densities mean that vast amounts of energy can be stored in relatively small spaces over long periods of time.

Biogas and synthetic gas are both produced from renewable sources. Biogas, a mixture of methane and carbon dioxide, can be produced by anaerobic digestion (AD) – the decomposition of biomass (for example, grass, animal manure or food waste) in an oxygen-free environment.

Carbon neutral synthetic gas is made via the Sabatier process. Here, hydrogen (made by electrolysis) and carbon dioxide (from burning biomass, or from biogas) are combined to produce methane. Methane is easier to store than hydrogen. The Sabatier process can be seen as 'upgrading' hydrogen to a gas that is easier to handle. The process of using electricity to produce gaseous fuel is sometimes referred to as 'power to gas' (GridGas, 2012). Methane gas is also the primary component of today's fossil fuel natural gas. The methane in biogas and synthetic gas can be stored in very large quantities just as natural gas is currently.

The UK today has a highly developed gas infrastructure that includes storage facilities, such as the Rough gas store off the coast of Yorkshire, which has a capacity of 35,000 GWh. However, methane is a powerful greenhouse gas, so it is very important that any escaping from pipelines or storage is kept to a minimum. Biogas and synthetic gas, once stored, can be burned in power stations (again, like natural gas today) to provide energy when electricity supply from renewable sources is insufficient to meet demand. Gas power stations burning biogas or synthetic gas can be flexible – we can turn them on or off quickly. We can use them as 'back up' generation to meet demand when electricity supplies from variable renewables fall short.

They can also supply industry for very energy intensive processes which would be difficult to run on electricity (see chapter 3.3.1 Buildings and industry). It is important to remember that burning methane is only carbon neutral when it is produced using biomass and/or renewable electricity. When methane gas is produced from biomass, the amount of CO_2 released by burning it is reabsorbed when new biomass plants are grown, resulting in no net increase of GHGs in the atmosphere. Synthetic gas is carbon neutral when the hydrogen used is produced using renewable electricity, and the CO_2 used is from non-fossil fuel sources (like biomass). The processes involved in creating a significant biogas and synthetic gas back up system have many losses associated with them. As energy is converted between forms (electricity and biomass to gas, and back to electricity), we lose energy in the process – about 50%. However, the ability to store energy in this way forms an integral part of an energy system powered by renewables, and is a good way of using electricity which would otherwise be surplus to requirements.

Our scenario
In developing our scenario, we used real hourly weather data (solar radiation, wind speeds, temperatures, etc.) for the last ten years – a total of 87,648 hours – to simulate patterns of supply and demand. In other words, we looked at how well the technical solutions we propose for a zero carbon future would have fared hour-by-hour under the weather conditions observed in the past decade. In our scenario:

• 82% of the time, the supply of renewable electricity exceeds the direct demand for electricity (including electricity for heating and transport) required at any one moment. Due to the very large number of wind turbines and other renewable electricity producers, almost half of the total electricity produced (about 354 TWh per year) is surplus to what is directly required at the time of production. However, 18% of the time, electricity supply does not fully meet demand.

• Short-term storage mechanisms, such as pumped electricity storage (25 GWh storage capacity), 'shiftable' demand from smart appliances and electric car charging (25 GWh), and heat storage (100 GWh heat) reduce the proportion of time during which electricity supply does not meet demand from 18% to 15%. This reduces the amount of surplus electricity to about 345 TWh per year. Crucially, by 'capping the peaks' of unmet demand, these mechanisms significantly reduce the back up power station capacity required (see below). So, short-term storage reduces not only the number of hours during which back up is needed, but also the number of gas power stations required.

• Electrolysis units, with a maximum power consumption of 35 GW, use around half (180 TWh per year) of the surplus electricity (the rest is exported). The hydrogen produced (126 TWh) is stored mostly in large underground caverns with a capacity to store 20,000 GWh of gas. A small proportion of this hydrogen is used as fuel for hydrogen vehicles (11%) but most of it is used to produce carbon neutral synthetic gas (35%) or synthetic liquid fuels (54%), as explained below.

• Biogas and carbon neutral synthetic gas are burned in gas power stations to supply electricity during the 15% of the time when electricity demand would otherwise exceed supply. In our scenario, we need to produce on average 27 TWh of biogas or synthetic gas as back up every year, to be used as and when required, which in turn produces an average of 14 TWh of electricity per year. We incorporate a large number of (renewable) gas power stations (45 GW maximum output, comparable to the capacity of all gas power stations we have today), but these power stations are inactive most of the time, turned on only when electricity demand would otherwise exceed supply.

Overall, these gas power stations only produce 3% of the electricity in our scenario. But our simulation shows that in weather conditions such as those experienced in December 2010, with very low temperatures and very little wind, such back up power stations would play a critical role, supplying more than half of all electricity on some days. To store enough biogas and synthetic gas for these periods, our scenario includes 60,000 GWh of methane gas storage. Today the UK already has one gas storage facility with a capacity of 35,000 GWh.

In section "3.4.3 Transport and industrial fuels" (Page 70) we describe how we can provide carbon neutral synthetic liquid fuel to meet transport and industrial energy demands.

Additional Research from CAT:

Toward understanding the challenges and opportunities in managing hourly variability in a 100% renewable energy system for the UK
Alice Hooker-Stroud, Philip James, Tobi Kellner & Paul Allen
Carbon Management (2014)

Overview
One hundred percent renewable energy systems have the potential to mitigate climate change, but large fluctuations in energy supply and demand make ensuring reliability a key challenge. A hypothetical future energy system developed for the UK features reduced total energy demand, increased electrification and 100% renewable and carbon-neutral energy sources. Hourly modelling of this system over a 10-year period shows that even in an integrated energy system there will be significant electricity surpluses and shortfalls. Flexible demand and conventional electricity and heat stores reduced the extremes but could not provide the capacity required. Carbon-neutral synthetic gaseous fuel could provide a flexible and quickly dispatchable back up system, with large storage and generation capacities comparable with those in the UK today.

Available from www.zerocarbonbritain.org