Electricity Storage

1. THE TRANSITION TO RENEWABLE ENERGY

The UK government wants all energy to be generated renewably by 2050. This will be necessary when we run out of the fossilised biomass (coal, oil and gas) that has (literally) fuelled our economy since the industrial revolution. The government is forcing the pace because burning fossil fuels increases the net amount of carbon dioxide in the atmosphere, which risks changing the climate in potentially hazardous ways.

Liberal democracies usually rely on market forces to drive transitions like this, but if action is necessary before it becomes an economic imperative, market forces alone may not be enough. But government initiatives have a mixed record, and tend to be resented by those who feel that government should be limited. So democratic governments have to rely on regulation, taxation and subsidy to create the necessary incentive for market investment.

2. THE PROBLEM OF RENEWABLE ENERGY.

Most renewable energy – wind, sun, falling water and tide – is variable and intermittent. It does not respond directly to demand, which, though predictable, has daytime and seasonal peaks and troughs. There is enough renewable energy to meet our current and future needs, but it is not available when and where we need it.

So though we might over the course of a year generate renewably all the energy we consume we cannot meet local peak demand renewably. For centuries we have relied on (and have been rapidly depleting) the solar energy stored in fossil fuels. We must find ways to store *today's* solar-derived energy if we want it to be available whenever and wherever we need it.

3. THE PROBLEM OF FOSSIL FUEL GENERATION.

The inability of renewable energy to cope with peak demand is a barrier to any renewable energy transition. Coal, gas and nuclear power stations generate around the clock and do so when the sun is not shining and the wind is not blowing. But precisely because energy demand varies with the time of day and year, nuclear and fossil fuelled power generation has to have the capacity to cope with peak loads and the efficiency to meet trough demand economically. This leads to inefficiency and waste and distorts the market.

In a free market, products in low demand are supposed to cost less to buy and therefore need to cost less to produce. Given the nature of electricity generation it actually costs more (net) to meet low demand. This makes it hard for the free market to deliver a reliably continuous supply of power, without which public safety and many necessities of modern life would be threatened.

So nuclear and fossil fuelled generation pose commercial challenges in a free market. There is little incentive to invest in capacity, because new capacity – unless it creates new demand – simply reduces the return for everyone. Power station efficiency and economics are sensitive to load, and few can operate economically below their rated capacity, let alone turn on and off with demand.

In practice, therefore, the electricity market cannot be entirely free in the sense of encouraging investment and supply competition. The UK government has to subsidise a guaranteed (and inflated) price for nuclear power, while most other governments (as did the UK, originally) publicly own their nuclear power stations.

Nuclear and fossil fuel generators have reason to resent renewable energy. It has no fuel cost, yet is subsidised by governments desperate to produce as much renewable power as possible. It makes traditional generation uneconomic while not offering a completely viable alternative. Renewable energy generators may be at the mercy of the elements but when they *are* producing they are doing so cheaply and reducing the price of electricity for nuclear and fossil generators. This is obviously not a stable situation.

A COMMON SOLUTION?

We need the market in electricity production *and* consumption to encourage competition and investment in both. The playing field the government has created is currently stacked in favour of renewable generation, but even those of us who agree that a transition to renewable energy is both inevitable and desirable must recognise that current technology cannot deliver timely or continuous renewable energy, but does damage the commercial viability of non-renewable generation.

Since imbalance between supply and demand affects the efficiency of non-renewable generation, the market price of electricity reflects the spot value of the commodity over very short accounting periods, and wholesale consumers and producers of electricity compete in their response to the price. This is difficult for electricity because – unlike other commodities – it can't be stored or generated for stock.

The answer, therefore, is for both consumers and producers to learn how to store energy. Consumers with storage reduce their peak demand and avoid having to buy at peak prices. Non-renewable generators with storage can operate at optimal efficiency and renewable generators can save their excess production to sell later, rather than having to throw it away as happens today.

Furthermore, given the UK's particular expertise in financial engineering, storage technology creates space for the so-called Non Physical Traders in the electricity market to go beyond just trading energy futures, derivatives and hedging, and enable them to "take a position" in real, present, electricity.

THE UK ELECTRICITY MARKET TODAY

Electricity is in most respects a classic commodity, but because it can't be stored, sales contracts have to be for short duration – in the case of the UK, 30 minutes. The UK market has 3 types of participant, connected by the publicly owned National Grid:

1. Generators – who physically produce electricity.

2. Suppliers – who buy it to sell to consumers. As with other commodities large consumers can also act as "suppliers".

3. Non physical traders - who do neither but simply buy and sell electricity from and to the others for a profit.

As with any wholesale market, domestic and small commercial consumers do not participate directly. Consumers tend to have year-long contracts with electricity suppliers for an unspecified amount of electricity that they pay for in arrears. Only very large consumers of electricity, who can predict their demand in terms of both power (watts) and energy (watt-hours) for every half-hour trade directly in the wholesale market as "self-suppliers".

And like other stock and commodity markets there is also an electricity "exchange" where generators and suppliers can buy and sell anonymously at a spot price which fluctuates with immediate and future supply and demand.

Most electricity contracts are established between generators and suppliers months or years ahead of time, although the actual deadline for confirming a contract is one hour before it is has to be fulfilled. This gives the National Grid time to tell each generator how much they need to produce to fulfil their contracts and each supplier how much they have contracted to take.

There is then a short “balancing” period during which generators and suppliers make arrangements to deal with any discrepancy between what they have agreed and what they now want. This involves generators stating the price at which they are willing to generate more power than they are contracted to, or the revenue they are prepared to forgo to generate less. For suppliers it involves stating how much they are willing to pay for additional power or how much they expect to be compensated to take less.

As with other regulated markets and stock/commodity exchanges, payments are aggregated over accounting periods of a day or two.

The National Grid uses physical and statistical metering to determine and predict actual flows of electricity and can put in place exceptional measures to call for increased or reduced generation, or reduced take-up of supply, providing compensation to the generators and suppliers involved, at a price shared by all. This is regulated by government agencies and authorities.

Should actual demand exceed supply, the AC frequency of the grid will drop and if it goes below statutory limits steps have to be taken to connect additional supply, or turn off some of the demand. If supply exceeds demand, the AC frequency may rise above the statutory limit and supply then needs to be shut down[1]. Generation capacity that can produce power instantly and on demand is therefore very important to the Grid, and will command high prices. Similarly, large users of electricity who can quickly shut down can negotiate a better price for their electricity.

Domestic and small commercial users, on the other hand, have annual contracts with suppliers and no way to moderate their demand (or supply) to minimise costs (or maximise revenue). This could be about to change.

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[1].. though as far as I'm aware, there doesn't seem to be any provision for turning *on* additional demand at times of over-supply!

SMART METERING

The UK government is also committed to smart metering by 2020. The main benefit of smart metering in the short term is to allow domestic and commercial meters to be "read" remotely, potentially at 30 minute intervals. Smart meters also provide the consumer with immediate access to current usage, although that has been possible for some time with an auxiliary energy meter.

One immediate effect of Smart Meters will be that domestic consumers can opt for an "Economy 7" tariff without needing to change their physical meter, which will already be recording the electricity they use, and when. Innovative suppliers may offer a range of different tariffs with time-variant prices. Smart Meters can also measure energy generation – e.g. PV – in the home.

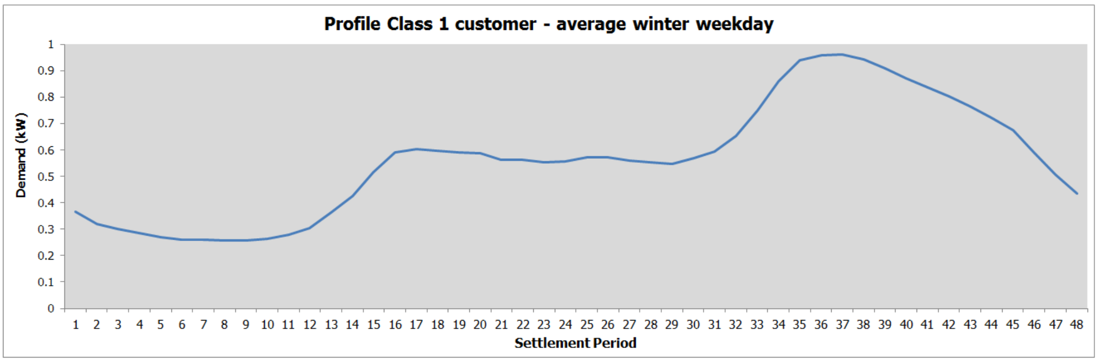
Smart metering therefore allows suppliers to offer a more flexible set of tariffs which – modulo the inevitable blossoming of a new raft of arcane tariffs by suppliers anxious to evade price comparison – might help move us toward more rational and responsive power consumption pattern, and a freer market.

Ultimately, a domestic tariff could even track the wholesale spot price of electricity – which changes in principle every 30 minutes – so that consumers (and their appliances) can adapt consumption to the current price. An intelligent freezer might lower its temperature when electricity is cheap to reduce its peak demand. An electric vehicle could customise its charge rate to take advantage of varying prices, and local generation.

If electricity were a "normal" product, suppliers would want to sell as much of it as they can for as much as they can get. However, given the nature of electricity and the particular problems of matching supply and demand for it in real time, generators have no incentive to sell more than they can economically produce and are limited in how quickly they can increase supply when necessary. For better or worse, the electricity supply industry is bound to move towards more efficient production and balancing supply and demand better. Flexible domestic tariffs will encourage that, which is (hopefully) why the government is so keen on their introduction.

CONSUMER POWER STORAGE

So does smart metering and a variable domestic tariff changing the price every 30 minutes offer the consumer any incentive to invest in domestic electricity storage, and would the power supply system benefit? The answer is yes, though as ever it depends on the price.



This graph, from Elexon, shows the average daily power demand of a UK house in winter. It's broken down into the 48 half-hour power periods that feature in UK electricity wholesale market contracts, starting at 12 midnight. As you can see, this average UK house consumes about 15% of its electricity between midnight and 7am, which is the Economy 7 "night" time during which electricity retails at about half price. With enough battery to store the power needed for the rest of the day (about 10kWh) a house could purchase all its electricity at Economy 7 rates. And since suppliers are not stupid, the Economy 7 rate should still return the same margin over the wholesale price at night which should also work out at about half the average day-time price.

In a free *market*, if "everyone" did this, night time prices would rise, and day time prices fall. Until then, the effect would simply be to smooth grid demand, chopping a peak and filling a trough. More importantly for the government's long term goal, it would provide more revenue for renewable generators who otherwise might have to shut down at night when demand is low.

Economy 7 is a crude tariff designed originally to provide a night time load for nuclear power stations that would otherwise need to moderate their output, something that is expensive for them to do. In reality, the grid experiences several peaks and troughs in a day, most of them predictable. Smart domestic storage, installed on consumer premises with a constantly varying tariff, can modify its charging to adapt to the price. The effect of this, if widely adopted, would be considerable and positive.

Today's energy traders negotiate contracts for a huge amount of power for a 30 minute interval some time in the future. Buyers can take advantage of fluctuating prices, where they are predictable.

What they can't as easily do, even at the 30 minute interval, is take advantage of unpredictable peaks, which is why the grid needs to perform its sophisticated last minute “balancing act”.

So a significant number of domestic consumers with storage systems stocking up on electricity in times of plenty to use in times of scarcity would collectively provide a responsive load on the grid, smoothing its demand curve. Today, when a gale is blowing in the Scottish night, wind turbines produce electricity no-one wants, and it is simply wasted. In future, this over-supply could simply cause a sufficient drop in price that thousands of domestic and industrial batteries could start charging at maximum power creating responsive demand to the excess supply. And though it grieves me to say so, this feeding frenzy might be led by bank-owned batteries keen to make a killing at the next demand peak.

Today domestic batteries are sold to consumers with PV panels to carry surplus daytime power for use after sunset, instead of exporting it to the grid for a pittance. If these batteries are also able top up at night from cheap electricity they would reduce electricity costs for the consumer even on days when his PV does not generate his entire load.

A consumer with PV panels, however, also exports to the grid, and with smart metering and storage, it should be feasible for him (or his software) to choose when to do that based on the current export price, if there is a variable export price. Power suppliers should offer flexible export tariffs, and if they are reluctant, a government committed to the free market would surely demand that they do. Suppliers should compete to sign up domestic generators even if they don't buy as much as they did, or pay as much for it.

GENERATOR STORAGE

As the combination of storage, smart meters and flexible consumer tariffs smooths out grid demand – cutting peaks and filling troughs – non-renewable generators will benefit by being able to operate more of the time at optimum capacity – the one that is cheapest for them. This will ensure that biomass and fossil fuel are burned for power generation as efficiently as possible.

Since peak electricity will still command higher prices, there is market opportunity for a storage technology optimised for short (half-hour to one hour) high power output which can offer massive power, instantly, for a short period. This is what the pumped hydroelectric storage systems do today. They use cheap power to slowly fill a large store – a high altitude water reservoir – generating massive power quickly when it is expensive.

However, storage technology has most to offer the *renewable* energy generator, because it enables him to contract reliably for a given time slot. He would normally do that by storing his own excess power, but he can just as easily buy it cheaply from another generator – perhaps one who has no storage. Today, a contracted renewable energy generator would have to buy in power he cannot supply at the last minute, at a price over which he has less control.

Future wind turbines and solar panels may even come with built-in storage to make them (up to a point) reliable and dispatchable energy generators. The same effect could be achieved via a storage cooperative taking the surplus power of a group of renewable generators, and there is also room for third party speculators with money to invest in storage to buy power from renewable generators at a favourable forward price for both parties, with a view to reselling it at a premium price later.

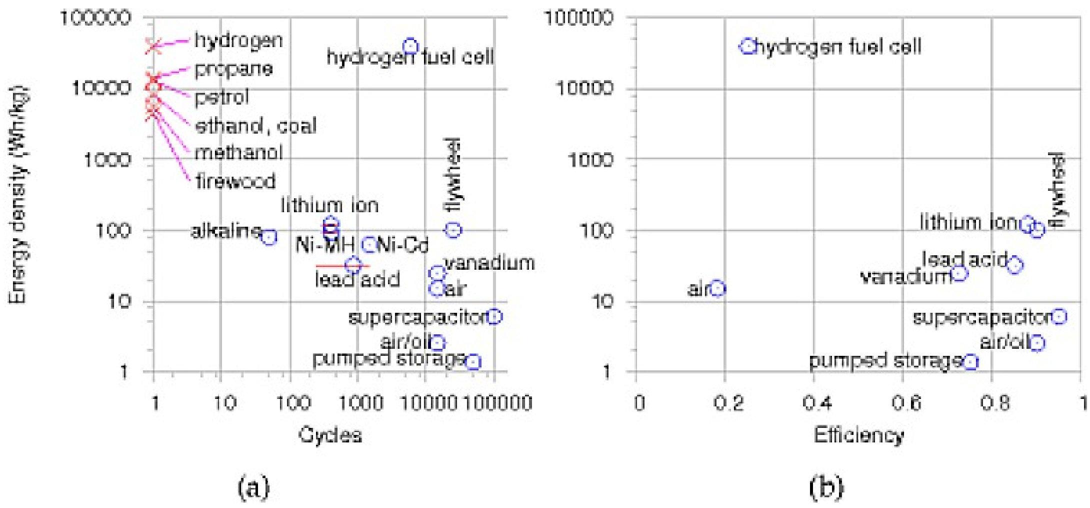
SEASONAL STORAGE

Over a period of a week or ten days, battery storage by both consumers and generators end can smooth power demand and supply, reducing wastage and increasing efficiency. Energy demand, however, shows *seasonal* fluctuations, as does a lot of renewable energy generation. In cooler climates we generally need more energy in winter and less in summer, but generate more solar energy in summer and more hydro and in some cases wind and wave power in winter. To smooth *that* out requires energy storage able to hold a massive amount in a small space for a long time.

The gas network has always been able to this, and gas can also be transported long distances efficiently by tankers and pipelines. An obvious seasonal storage candidate is therefore hydrogen gas, produced by water hydrolysis, perhaps converted to methane. The gas can be burned for heating and to drive turbines and reciprocating motor generators, converted to synthetic liquid fuels chemically similar to diesel and petrol, or converted directly to electricity using fuel cells.

The round trip efficiency of hydrolysis to hydrogen to fuel cell recovers only 30% to 40% of the original electrical energy. Whether this makes sense financially depends on how you cost it. Chemical batteries are perhaps 80% efficient, but use a lot of energy to build and have a limited life span. If you sum all the energy that goes into them over their lifetime, they don't scale as well for seasonal amounts of energy, which is what we will need.

Day to day storage, designed to smooth the daily or weekly demand curve, only needs to store a day's (or a week's) worth of energy. But seasonal storage needs to be able to hold months, and the chemical batteries to do that would require orders of magnitude more space. The graph(s) below, copied from Professor David MacKay's book[2] show the energy densities of various storage media:



....and as you can see from graph (a). hydrogen holds a theoretical[3] 39kwh of energy per kilogram while a lithium battery holds about one tenth of a kWh per kg of battery. Hydrogen itself doesn't have a life cycle, but graph (a) shows that a hydrogen fuel cell lasts an order of magnitude longer in terms of throughput than a battery.

Graph (b) shows the efficiency of the storage mechanism as a ratio of energy in to energy out. Hydrogen fuel cells don't compare as well with batteries, but when you consider the investment you have to make per kWh of throughput on a store you are going to fill and empty once a year, efficiency may matter less than capacity. Furthermore, the energy being stored would by definition be surplus to demand at the time. It would therefore have no value on the wholesale market and is effectively thrown away today. If the UK

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[2] "Sustainable Energy without the Hot Air", available from UIT Cambridge as a paperback or free on the World Wide Web at http://www.withouthotair.com/

[3] theoretical, because any container for hydrogen weighs many times more than the gas, though this thankfully doesn't scale linearly!

had renewable energy capacity able to meet its peak demand, there would be substantial energy surpluses most of the rest of the time.

Today, there is a limit to how much renewable energy capacity the country can afford to build, given that energy produced beyond current demand is worthless. This gives a free market no incentive to build renewable capacity that could come close to meeting peak demand. If it is our goal to have all our power generated renewably by 2050, then unless we can meet peak demand renewably, we will need to store energy for extended periods. And when we realise that electrical energy only represents about a fifth of our domestic energy consumption, we need to start learning how to store it – regardless of efficiency. The only widely available renewable heat source, for example, is biomass. Biomass comes with built-in storage, but *its* efficiency is much, much poorer than hydrolysis.

CONCLUSION

There is no way we can, as a country, meet our current real time electricity demand – let alone our *total* energy demand – from renewable sources in the UK. This is because renewable energy is intermittent and cannot respond to demand. Even if we had sufficient capacity to meet our year-long demand, renewable energy cannot cope with peaks no matter what its rated capacity is.

The answer – unless and until we develop a global, or at least a continent-wide grid – is to increase renewable energy capacity to cope with yearly demand but match it with storage to cover peak demand. Our best hope of achieving the investment necessary is to encourage decentralisation and localisation of energy generation and storage together with a grid that supports a truly free market in electricity. In such a market, price alone can determine production and demand levels.

Consumer energy storage and renewable generation can already modulate demand so that individual households can meet their own energy needs without peak loads. Businesses of all sizes can do the same, and both should be allowed to trade any surplus they generate. Very large consumers of electricity can trade with very large producers in a free market, each adapting to the needs of the other via the dynamic price mechanism.

Smart metering of energy flows into and out of the distribution network will enable and encourage producers and consumers at all levels to adapt their supply and demand to the market. Intelligent domestic appliances and industrial machinery can accelerate this process if there is a financial incentive to invest in them. They should have the effect of reducing the aggregate and the peak amounts of power we use and therefore when and how much we need to generate as a nation. Total UK demand, at the time of writing, appears to have peaked, although electrification of the transport system may still create additional demand in the future.

So storage is an essential component, as far as I can see, to any transition to renewable energy, and the good news is that investment in it can be led by the demand side – domestic and industrial power consumers seeking to minimise their electricity bills and make best use of whatever generation capacity they have. Grid level storage might not even be necessary, which given the massive investment involved, and the poor commercial incentives to make it, may be just as well.