'A Smart, Flexible Energy System'

https://www.gov.uk/government/consultations/call-for-evidence-a-smart-flexible-energy-system

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AECB Submission to BEIS

Overview

A significant problem with the drafting of this consultation is that it confuses 'energy' with 'electricity'. This tends to promote confusion. It needs to be corrected if this consultation is to be of value.

Approximately 88% of the UK's energy which is delivered to final consumers - i.e., households, non-domestic buildings, transport, industry - is needed as heat or portable transport fuels. Around 12% is needed specifically as electricity. Some 18% today is provided as electricity. [1]

In recent decades, the UK has used the energy delivered to final consumers roughly as follows:

- 12% - for essential electricity; i.e. internet, lighting, appliances, controls, pumps, fans, mainline railways, etc [2]
- 46% - for low and high-temperature heat
- 42% - for portable transport fuels.

. [3]

We are concerned over what led BEIS/OFGEM to conflate 'energy' with 'electricity'. BEIS has made a number of illogical and nonsensical assumptions and statements in its call for evidence.

Muddled thinking should have no place in an *official government* consultation document. Yet a policy has emerged since 2008 that is based on significant fallacies. We regard it as verging on 'group-think'.

The former DECC Chief Scientist, Professor Sir David MacKay, pointed out late in his life the implications of the Second Law of thermodynamics and the 10-fold difference in *exergy* content between 1 kWh of warm/hot water and 1 kWh of electricity. He discussed at length virtual and conventional electric heat pumps.

He acknowledged that some of his early statements favouring heat pumps versus CHP and heat networks [4] had been somewhat in error. The COP of virtual heat pumps is higher than that of small electric heat pumps in buildings. It is vital that BEIS do not forget the matter, relatively soon after Professor MacKay's term of office ended in October 2014.

Transport and Heat

Infrastructural Change

The document cites 'electrification of transport and heat' as if the idea has been proven in practice. It presumes that the UK can undertake this change to its 8,500 filling stations, 30 million buildings, high-voltage overhead electric lines and local low-voltage networks at reasonable cost, effort and difficulty and without disrupting the economy.

To be charitable, this seems pretty unlikely. No country has done this, certainly not in the 'mere' 33 years left before 2050 and the 80% legally binding CO_2 reduction target.

The concept of 'electrification of heat and transport' is largely based on erroneous assumptions and discussions between the Secretary for State for Energy and DECC Chief Scientist around 2008. Many points were later modified or withdrawn, as all parties slowly reached a better understanding of the underlying issues. [5]

Germany, the EU's most successful industrial economy, has said that it expects its electricity usage to *decline* 25% by 2050. [6] But since 2008, the UK has posited a considerable *rise* in electricity consumption by 2050. On some occasions, a more than doubling.

The technologies available to both countries are identical. [7] It is unlikely that both can be correctly pursuing cost-effective options to give these divergent forecasts. Given their relative records of engineering and economic success since 1945, which country is perhaps on balance more likely to be 'right'?

Electric Transport

Electrification of non-rail transport encounters fairly well-known limits to battery system life, cost and weight. Above a certain percentage of car-km., it also starts to encounter range and refilling restrictions.

In Norway, there has been a trend for owners of electric cars to retain long-range/conventional cars. [8] That is, one-car households have changed to two-car households.

Does the UK have the space for households to store extra cars? Possibly not. In some new housing estates, the local roads are already obstructed by parked cars, due to small plots and limited off-road parking.

Also, do lower-income households have the access to capital to buy an extra car? Possibly not.

Indeed, the need to replace battery banks over a car's 16-20 year lifecycle could make the lower end of the second-hand car market unviable. The households concerned do not have access to the potential capital needed and may have a poor credit rating. That is usually why they buy a £1-5k, not a £10-20k used car.

It is not sensible for UK PLC to continue paying a net differential subsidy of c.£10,000 per electric vehicle [9] if renewable energy options of potentially similar or higher value receive by comparison £0 per vehicle. The situation is best described as a playing field that the government has deliberately tilted. It has zero to do with 'cost-effectiveness'.

It is usually agreed that air, sea and long-distance road freight or passenger transport have little prospect of being successfully electrified. Air, sea and bulk road freight account for about 50% of sectoral energy use.

Climate change has to be tackled with these transport modes *continuing to run on portable fuels*. That is, we cannot do without renewable transport fuels. The economy is in acute need of chemical, not just electrical energy.

Exclusively short-range passenger road transport probably consumes ~25% or less of sector's energy. [10] After oil has gone, or after the rest of it is left in the ground to save the climate, the other ~75% of transport sector usage may need synthetic fuels anyway. [11]

So, why spend so much effort electrifying only 25% of the transport sector? [12] Some scarce resources might be better devoted to building and improving synthetic fuel plants, or state aid to companies developing ultra-lightweight car bodywork for use in liquid-fuelled cars. [13]

Power-to-gas has been ignored in the UK. It is taken more seriously abroad. Power to liquids, ditto. [14] Being slow at picking up technologies and taking them through the many difficult stages from 'ivory tower' to universal commercial practice appears to sum up the UK's poor industrial performance over the last 50-100 years. Significant opportunities would arise from a change of approach.

An area where by contrast more displacement of liquid fuels by mains electricity *might well* make sense is the trunk rail network. Electric trains need no batteries, the motors take less maintenance than internal combustion engines and they produce no fumes when standing in stations. [15]

So why has around 50% of GWR electrification been paused/delayed/cancelled? [16] Why are the UK percentages of electric traction, measured by passenger-km. or route-km., among the lowest in the EU? There has been little progress in the last 20 years and apparently no schemes are planned post-GWR.

Electric rail [17] deserves higher priority than electric cars. Rail travel is growing faster than car travel. More young people have chosen not to own cars than in their age group 20-30 years earlier. With overhead wires, no battery-related difficulties arise.

Electric Heat

Electrification of space heating poses real problems. One is that substantial parts of the national grid would have to be replaced.

The existing GB electricity network has a total capacity of 60 GW, although by 2015 the peak demand on it had fallen to 53 GW. The bulk of this capacity is taken up by lighting and other essential electricity uses, although some is devoted to electric space heating. Some capacity may possible be spare, owing to the 14% fall in domestic electricity consumption since 2008 from 126 to 108 TWh/y.

The gas network has an estimated capacity of 200 GW. It heats just under 80% of UK buildings.

Oil and LPG heat most large rural properties. A fair estimate of the extra capacity needed if these loads were electrified would be roughly 20-25 GW. [18] So, to electrify space heating, it seems that the national grid might have to add about 220 GW of thermal generating plant, transformers and cables to its existing 60 GW. [19]

If BEIS/OFGEM consider and cost this modification to the UK electricity network, the implications may become painfully clear. Going from 60 to 280 GW is no trivial matter.

We wonder if BEIS/OFGEM or others may have confused two distinct numbers:

- the **14-24 kW** (60-100 amps) capacity of the electric cables entering a house, and the similar rating of the consumer unit;

  versus

- the **1 kW** per house capacity of the cables near the local substation, the transformer itself and the cables just upstream of the substation.

Why are the two capacities so different? Largely because the peak demands of individual light bulbs, appliances, et al are so strongly diversified. [20]

The existing 500 kW substations *cannot* support the peak load on the national grid which would arise if the UK implements its plans to 'heat and drive electric'. The difficulties arising with the French electricity system in the last 15 years have already been described by others.

Before the UK proceeds further, we counsel BEIS to take professional advice from experts who understand the electricity transmission and low-voltage distribution systems. The main points appear to be that:

- the electricity network has a capacity of 60 GW
- the gas network that BEIS plans to replace by an enhanced electricity network has a capacity of some 200 GW
- the liquid fuel delivery system that BEIS wishes to replace by electricity sells fuel at a rate of 53 GW; i.e., if averaged 24 h/day, 365 days/year [21]
  and
- there appear to be viable ways forward which would not entail significantly electrifying heating or transport. [22]

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Cost-Effectiveness

The document states in para. 18, pp. 10-11

'Consumers will benefit most from an energy system and markets that can match the system need with the most cost-effective solution, in both the short and the long-term.'

We disagree. The proposal to electrify heat and transport has not been adequately analysed to show it to be the most cost-effective route, given current costs of various technologies and cost ranges foreseen by, say, 2035-50.

The statement is only explicable to us if, after internal discussions, DECC (now BEIS) made a formal decision in 2007-08 to electrify heat and transport whatever the cost. We presume that this was minuted as 'policy' at the highest level, becoming politically unchallengeable in the short term, no matter how flawed.

Bodies such as the Climate Change Committee, which was created to assist with the 80% reduction goal, 'bought into' this flawed position. The CCC has incorrectly focussed for 8 years on 'electricity decarbonisation'. The correct policy to focus on is 'overall net decarbonisation'. UK PLC might benefit by adopting a methodologically more defensible position.

Flexibility

If the UK energy system is not further electrified, 'flexibility' remains irrelevant. Its main value is where it can help the grid operators by making some loads contributing to the regular 17.00-18.00 h winter peak interruptible, or systematically displacing these loads to other times of day; e.g., 15.00-17.00 h, 19.00-21.00 h.

However, this 17.30 h peak has been present on the UK daily winter load curve for at least the last 40 years. Other developed countries have similar demand profiles. Arguably, countries should be used to meeting it after that time.

Given that the electricity network at present has a capacity of 60 GW and incurred a maximum demand in 2015 of 53 GW, [23] we cannot see that it is a priority.

It helps grid operators too if loads such as refrigeration are fitted with sensors to respond to price signals and react to unwanted surpluses or deficits of renewable electricity, providing useful frequency control. However, this approach is not mentioned, although it may only need a request to/agreement with manufacturers to fit them to new 'cold appliances'.

Not mentioned either is the option of using dimmable lighting ballasts. In a national grid emergency involving an unforeseen loss within say ten seconds of 5 GW of generating plant, the lights would dim but not go out. [24]

Energy Storage Costs

The costs of bulk energy storage are approximately in the ratios of:

- Fuel: 1
- Heat: 100
- Electricity: 10,000

In summary, BEIS appears to be focussed on converting UK delivered energy from

- 82% in the form of easily- and cheaply-stored energy
  to
- nearly 100% in the form of expensive-to-store electricity.

We cannot understand the reason behind this policy decision. We have seen no supporting analysis.

The fraction of delivered energy that *must* be supplied as electricity is near 12-13%. Had BEIS focussed also on difficulty and expense of energy storage, it might be trying to *reduce* the electrical fraction of delivered energy, to help keep the national grid stable as society becomes increasingly dependent on a small trickle of 'essential electricity'. [25]

Heat below 100°C can be stored for a whole year if needed, i.e., held in 50,000-250,000 m^3 or more of water (4-20 GWh upwards). Heat above 100°C can be stored for days or maybe weeks, as in concentrated solar power plants in Morocco, USA et al.

There seems little prospect of electricity storage being brought down to match the cost of bulk hot water storage. Parity would need a 100-fold fall in cost. Yet policy seems to be based on the fiction that the two have roughly reached parity!

To sum up the means for storage of non-electrical energy:

- as today, liquid fuels are stored in tanks
- as today, gaseous fuels are stored in underground caverns or occasionally in above-ground gasholders
- as today in Denmark, hot water can be stored cheaply in bulk in excavated pits
- at somewhat higher cost, as today in Denmark, hot water can be stored in above-ground insulated steel stores similar to gasholders
- as today in the USA, Spain and Morocco, high-temperature heat can be stored short-term in rock stores
  etc.

We believe that BEIS would benefit from familiarising itself with the full range of technologies developed and used abroad. In principle, we would be happy to assist BEIS. Given the errors and inaccuracies that have accumulated and are evident here, it might be worthwhile and helpful for BEIS to commission further input on this subject. If so, it should consider engaging on a professional basis the authors of this submission or other experts who understand the wider subject of energy as a whole; i.e., *not* just electricity. It is crucial to make policy on the basis of scientifically sound documents.

Notes and References

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[1] This reflects the fact that almost a third of electricity is used for bulk thermal purposes; e.g., space and water heating and industrial process heat. The amount used this way could be significantly reduced if UK policy was changed.

[2] *LESS IS MORE: Energy Security After Oil*, AECB (February 2012).

[3] We adopt a convention that the UK ambient temperature is +10 degC. With this reference point, 1 kWh of heat at 70 degC; i.e., warm enough for most radiators, or for producing domestic hot water via a typical heat exchanger, contains 0.17 kWh of exergy. 1 kWh of hot water at 30 degC; e.g., swimming pools, contains 0.06 kWh of exergy. 1 kWh of electrical or chemical energy contains 1 kWh.

[4] Thermodynamically, CHP is a virtual heat pump.

[5] BEIS is using incorrect conventions which signal the wrong emissions for electric heat pumps, versus other methods of heating the UK. The methodologies used are not in line with the Second Law of thermodynamics and cannot be

defended by reference to 'sound science'. The outcomes of a process of good governance can. We would appreciate the use of the correct ones before BEIS launches further consultations.

[6] Implicitly retaining the heavy industry which gives Germany a higher per capita electricity usage than the UK, France, Italy or Spain.

[7] Given the Single Market and the laws of physics. If anything, Germany could possibly encounter fewer difficulties than the UK in any attempt to electrify heat. This reflects the greater interconnection of its electricity network with those in adjacent countries and the ability to import electricity at the times of peaks caused by electric space heating - always assuming, of course, that surrounding countries do not also electrify their space heating.

[8] This might still be a hybrid vehicle. Hybrids should not be classified with pure battery vehicles. Hybrids can be a) refilled quickly when on the move b) heated in winter by waste heat from the engine.

[9] Reference to a differential subsidy of £10,000 comprises a direct subsidy of £5,000/car plus the ~£5,000 NPV of the loss to UK PLC per vehicle over its lifetime in motor fuel tax revenue and duty. Unlike electricity, the renewable fuel mixed with petrol and diesel carries 20% VAT and full duty. There is also a tendency for UK PLC to subsidise battery vehicles via differential rates of vehicle excise duty. This has perverse effects on the car market.

[10] This is a rough estimate of what fraction of transport energy might convert to battery operation without major loss of convenience. There are many factors to take into account, though.

[11] Our position is that imported or indigenous bio-energy cannot be relied on to provide all transport fuel. We should focus on synthetic fuel as the source of portable fuel; i.e., at the margin. There are too many bio-energy schemes with higher CO_2 emissions than claimed.

[12] Some small electric vehicles are attractive, e.g. electric mopeds need less maintenance than petrol ones and can travel 50 km on a small battery, with only a modest increase in vehicle weight. However, beyond these specifically short-range vehicles, electricity rapidly becomes unattractive to UK PLC, due to the range and the inability to refill quickly, although today's taxation differences may have perverse effects.

Fewer range and refilling difficulties emerge if most future cars and vans are fuelled by renewable methane or methanol. The former is clean enough to use fairly freely in cities. Both can be refilled at the normal speed and have a near-normal range, avoiding the need to buy or rent a second car.

[13] For example, the pioneering 1999-2005 aluminium Audi A2. For lack of shared-cost state aid - it is illegal in the EU, although the USA has some - Audi later reverted to cheaper, less fuel-efficient steel bodywork. Similarly-sized 'fuel-efficient' cars *in 2015* consumed *25% more fuel* than the A2 in 2005. Many weight- or drag-saving innovations that are now applied to battery-electric cars should and could be applied to liquid-fuelled vehicles.

[14] http://fz-juelich.de/SharedDocs/Pressemitteilungen/UK/DE/2016/2016-10-13-kopernikus-power2x.html.

[15] Typical diesel train emissions appear less well-controlled and more noxious than modern diesel car emissions. Possibly the stress should be on changing diesel engine fuels, on those rail routes that cannot be electrified. This can reduce PM-2.5s and NO_x.

[16] It seems that the line from Paddington via Reading, Swindon, Bristol Parkway and Cardiff to Swansea will be electrified but routes to Henley, Windsor, Newbury, Oxford, Worcester, Malvern, Hereford, Stroud, Cheltenham, Gloucester, Bath, Bristol Temple Meads, Exeter, Plymouth, Truro, Penzance and west of Swansea may never be. Some other trunk routes may be candidates for electrification including a) Reading to Gatwick Airport, b) Penzance to Aberdeen, c) Reading to Basingstoke and d) London Marylebone to Birmingham. Owing to its lower speeds, d) could possibly provide as much extra capacity to Birmingham as HS2 at lower cost. Trains operating at top speeds of 150-200 km/h give lines a higher capacity than trains operating at 300 km/h as with HS1 in Kent.

[17] Also trams and trolley buses.

[18] 8% of 27 M dwellings, with a mean peak demand of 10 kW(t), gives a peak heat demand of 21.6 GW. If peak losses are 17%, demand at the power plants is 21.6/0.83 = 26 GW. The peak of ~10 kW arises because oil-heated dwellings are larger than the UK average and are located in more wind-exposed areas.

[19] Heat pumps could reduce the peak if they are sized to provide the whole load at just below normal design temperatures without resistance backup. If their peak COP is 1.5-2.0, the added grid capacity needed might be nearer 220/1.5 to 220/2.0 = 110-150 GW(e).

[20] However, those for space heating are not. The demands coincide. They would peak in cold weather at around 6 kW(t) per dwelling, or somewhat less if insulation and draughproofing standards are improved.

[21] The speed of refilling a liquid-fuelled vehicle can be 40-80 litres per minute, a rate equivalent to filling it at a rate of 24 to 48 megawatts. This cannot be replicated if filling a battery with electricity because of a) limited network capacity b) the batteries would not cope. Unless the national grid is reinforced, the capacity available, say, on winter afternoons, after deducting other demands on the system, is probably a coincident peak demand of 0.2-0.3 kW(e) per dwelling, or 7 GW(e) nationwide.

The electricity system could not easily level the demand over the days, weeks and year in the way that the liquid fuel system does. Electricity networks and battery-electric vehicles contain energy storage only in a) the vehicle batteries and b) the fuel store at the power station(s), if any.

Coal-fired power stations have substantial amounts of local fuel storage. But they are being phased out. Most gas-fired power plants have no backup fuel storage tank, although they could have one.

In short, the electricity network cannot easily match the energy storage inherently contained in the UK liquid fuels supply system. This storage takes the form of a) large storage tanks, b) national pipelines system, c) smaller tanks at depots, d) delivery lorries, e) filling station tanks, f) vehicle fuel tanks and g) building heating oil tanks.

[22] Some are set out in reference 2.

[23] The cables have this capacity of some 60 GW. We are currently short of *power generating* capacity; i.e., due to the planned closure of coal and nuclear plants and the lack so far of replacement CCGTs or other options like very large diesels - which have advantages over CCGTs for mid-merit order plant and meeting unexpected demands.

[24] Assumes that the GB peak of 53 GW includes about 6 GW of lighting. Dimming fluorescents or even LEDs as low as 5-10% of their peak output is potentially straightforward these days. Although it is noticeable if it is done as an emergency measure in a matter of seconds, it still does not produce the alarm/drama/bad publicity of the lights going out.

[25] Independently of the shift to renewables, we increasingly need very modest amounts of electricity to provide what society now regards as essential services, including a) the internet, b) mobile telephones, c) landlines, d) energy-efficient lighting, e) A+++ domestic appliances, f) ventilation, g) heating pumps, fans and controls, h) supermarket tills, i) fire and other security systems, etc.

The lower the total consumption, the higher the percentage of it that can come from despatchable sources; e.g., tidal double lagoons, hydro. These sources normally do not need backup plant except to cater for outages.

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