Energy Transition Technologies **Gordon Taylor** **2022-06-14**

1) Energy Savings and Increased Energy Efficiency

This is prompted by the Energy Hierarchy of the Institution of Mechanical Engineers. (See: The Energy Hierarchy: a powerful tool for sustainability, https://www.imeche.org/news/news-article/the-energy-hierarchy-a-powerful-tool-for-sustainability). From most to least sustainable, Tier 1 is Energy Demand Reduction, Tier 2 is Energy Efficiency, Tier 3 is Utilisation of Renewable, Sustainable Resources, Tier 4 is Utilisation of Other, Low-GHG-Emitting Resources, and Tier 5 is Utilisation of Conventional Resources as we do now.

Here are some observations based on it and my own work.

The potential demand-side energy reductions are estimated in two major papers by Cullen and Allwood et al. at Cambridge:

1.1) 2011-01-12 Reducing Energy Demand: What Are the Practical Limits ?, Cullen, Allwood and Borgstein,
https://pubs.acs.org/doi/pdf/10.1021/es102641n
The Abstract includes: ‘The result demonstrates that 73% of global energy use could be saved by practically achievable design changes to passive systems’.

1.2) 2010-03-05 Theoretical efficiency limits for energy conversion devices, Cullen and Allwood,
https://www.sciencedirect.com/science/article/abs/pii/S0360544210000265
The Abstract includes: ‘global demand for energy could be reduced by almost 90 per cent if all energy conversion devices were operated at their theoretical maximum efficiency’.

1.3) When checking the links for the above, I found a later paper:
2019-08-22 Technical limits for energy conversion efficiency, Leonardo Paoli, Jonathan Cullen,
https://www.repository.cam.ac.uk/bitstream/1810/298904/1/LP_technical_limits_revised2.pdf
The Abstract includes:
‘The UK's final energy demand could be reduced by 25 % if conversion devices were operated at their technical limit and two thirds of these savings are in transport. The analysis suggests that a) improvements in conversion efficiencies are insufficient to reach energy reduction targets, except in transport and b) that for most technologies it is more important to focus on converging towards the efficiency level of the best available technologies rather than on research pushing the boundaries of conversion efficiency'.

Combining 1.1) and 1.3) would reduce the global demand for energy by 100-(((100-25)*(100-73))/100) = 80%.

1.4) A wider-ranging paper from the Allwood group is:
2019-11-29 Absolute Zero, by J.M. Allwood,
https://www.repository.cam.ac.uk/bitstream/handle/1810/299414/REP_Absolute_Zero_V3_20200505.pdf
Pages 6 and 7 show a set of measures deemed necessary to meet an Absolute Zero target.
Many are highly contentious, but luckily other options are available and emerging.

1.5) Examples of Energy Savings (Tier 1) and Increased Energy Efficiency (Tier 2) include:
- reduced transport volumes.
- modal switching of transport from cars and aircraft to buses and trains.
- proper use of electric appliances and lighting (choosing the best of those at hand).
- increased efficiency of electric appliances and lighting.
- the insulation of buildings.

Most can be implemented swiftly because the alternatives are either in place, or have short working lifetimes and so can be renewed in 5 to 15 years. The insulation of buildings can best be done by measures procured by local governments using low-cost capital, and rolled out complete with quality control street-by-street in every city, town and village.

These are summarized in the following table:

Energy Measure	Size of GHG Impact	Speed of Roll-out
Reduced transport volume	e.g. 70% reduction	Immediate
Switch transport mode	e.g. halved	Immediate and onwards
Best appliance use	e.g. halved	Immediate
Increased appliance efficiency	e.g. halved	5 to 15 years
Insulation of buildings	e.g. 30% reduction	e.g. 30 years

2) Energy Supply Technologies

This is prompted by the paper: 2021-09-14 Empirically grounded technology forecasts and the energy transition, Way et al, https://www.inet.ox.ac.uk/files/energy_transition_paper-INET-working-paper.pdf and https://www.dropbox.com/s/fwlsys15aa4l5b9/Way_et_al_2021_energy_transition-INET-working-paper-SI.pdf
Here are some observations based on it and my own work.

2.1) They have shown that conventional nuclear power would be much more costly in money. I believe that this follows from being far more costly in energy and GHG emissions, due to the energy for construction of the plant (from e.g. concrete and steel), and the energy for mining, refining, enrichment and manufacture of the (uranium) fuel and the removal, decommissioning and long-term storage of the nuclear waste.

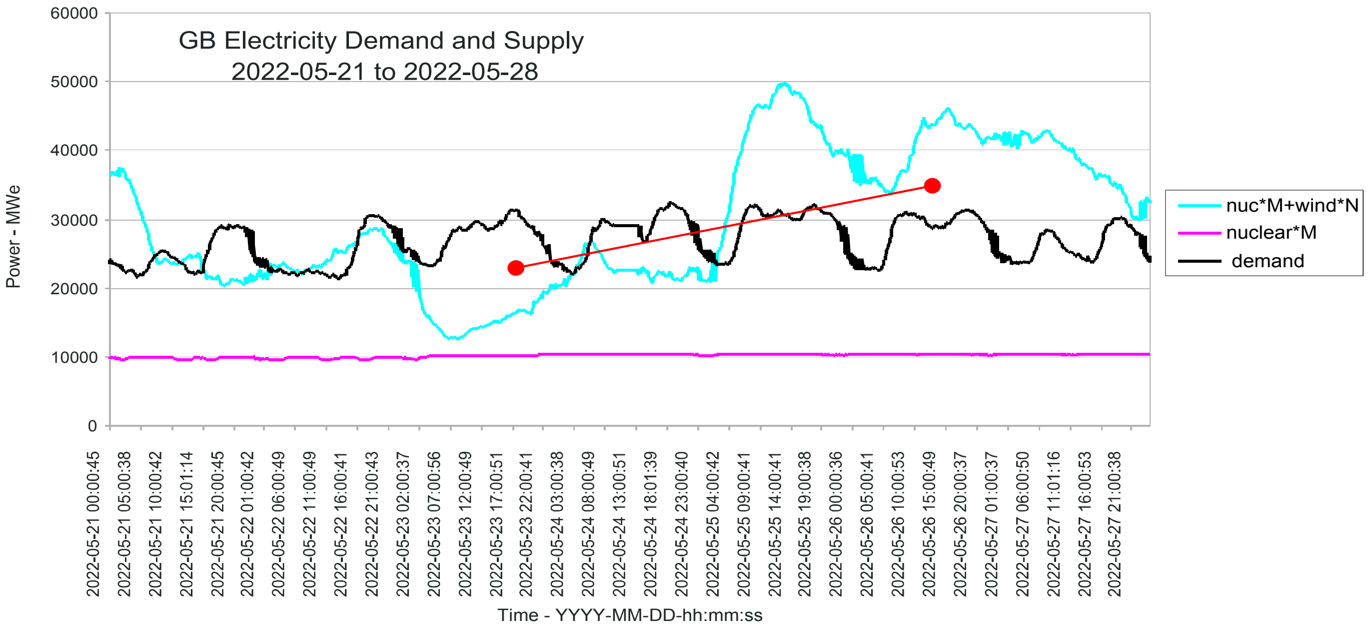
2.2) They have shown that Fossil Fuels with CCS would have a much higher money cost and a much higher energy and GHG cost, due to the high and rising costs of the fossil fuels.

2.3) Small Modular Reactors do not yet exist. However experience with chemical plants is that the specific capital costs (per unit of output) vary as about the 0.6th power of the unit output. Also smaller plants suffer proportionately higher losses due to the square-cube law and lower elaboration (e.g. in feedwater heating), and hence lower efficiency in converting heat to electricity. Moreover, the costs for security are less dependent on plant size. So smaller nuclear plants suffer from adverse scale effects.

2.4) Fusion power plants do not yet exist, and may never be feasible on Earth. As the pressures prevailing in the Sun cannot be achieved on Earth, far higher temperatures are required, along with different reactants Deuterium and Tritium. The latter is radioactive, with a half life of only 12.3 years. So any plausible fusion plant has to be able to produce it's own Tritium, via a Tritium Breeding Ratio (TBR) sufficiently above one to counter multiple loss mechanisms and allow the replication of plants. ITER is not due to be completed until 2037 and even then, may not be able to demonstrate a sufficient TBR. Also, it lacks any power cycle so a successor DEMO would be required to produce any output power, and to offset all the input power, with a Q of well above one. (See: 2021-06-09 The Futility of Fusion – A Dream Too Far, http://cms.energypolicy.co.uk/nuclear/348). Yet such fusion power may never be competitive, making the final cost of power infinite.

2.5) Space Solar Power plants do not yet exist, and even with many billions in public funding would be unlikely before 2042. (See: 2021-09 Space Based Solar Power—De-Risking the Pathway to Net Zero, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1020631/space-based-solar-power-derisking-pathway-to-net-zero.pdf). The money, energy and GHG costs would include not only those for the space power plants and the earthbound power receivers, but also those of the rockets and fuels needed to lift these into orbit, and to maintain them. Yet such space solar power may never be competitive, making the final cost of power infinite.

2.6) System Impact
This is expressed for nuclear power, but the same would apply to all technologies claiming near-continuous power.
The chart below shows the GB Electricity Demand for seven days (2022-05-21 to 2022-05-28) taken from https://www.gridwatch.templar.co.uk/download.php The other two variables are the Electricity Supply from Nuclear and from Wind (stacked) for the same period, each scaled by arbitrary factors (N and M) in order to illustrate the points below.
Similar behaviour occurs over weeks, months and years. Over longer periods, stores can be first charged then discharged.



The GB grid system already has a large share of electricity generated by existing variable renewable plants. Therefore:

2.6.1) Existing and new nuclear power plants would conflict with the renewable plants and reduce their utilization and business case. This is shown above by the large areas of potential wind electricity output that would be curtailed in favour of nuclear electricity. Developers of renewable plants, which nowadays have the lowest cost of electricity and can be funded by the private sector without subsidies, may sue for compensation and would refuse such terms. They are already compensated if their output is curtailed due to e.g. transmission bottlenecks. Yet nuclear power is not competitive with variable renewables such as wind power and can only be funded with large subsidies from government for almost all the 'unquantifiable' risks of nuclear accidents as well as the costs of decommissioning and radioactive waste storage. (See: Supplementary Estimates 2011-12, Department of Energy and Climate Change, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/220724/supplementary_estimates1112_decc.pdf pp 419, 1). An alternative that has been proposed is to charge all electricity consumers on a Regulated Asset Base without even asking them. Also nuclear power depends on imported fuel, half from or via Russia, and has a high and increasing carbon intensity. (See: 2016-08-09 Nuclear Insecurities, http://cms.energypolicy.co.uk/nuclear/247).

2.6.2) Moreover, nuclear power could not guarantee to meet even the minimum load - the low points of the demand curve. The grid requires storage to cover possible outage of the largest unit on the system. This must last for the start-up time of 'thermal' plant fuelled by gas or coal in order to avoid them being kept on 'hot standby'. So far this been met by the Dinorwig pumped hydro storage plant of 1728 MWe with some smaller plants, but this would not suffice for nuclear plants such as Hinkley Point C and the proposed Sizewell C, each of 3200 MWe. So additional storage of around 1000 MWe would be required.

2.6.3) Furthermore, nuclear power could certainly not meet the maximum load - the high points on the demand curve. Operating nuclear power plants at varying load ('load following') as in France, requires special equipment and procedures. Also, as the nuclear capacity increases from the minimum to the maximum demand, the incremental utilization falls to zero, and the cost of electricity rises to infinity. So in practice other plant is used, including storage, or incentives are offered to users to reduce their demand.

So existing and new nuclear power is uncompetitive in itself, yet would reduce the business case of existing renewables.

2.7) Conversely, adding storage would complement the variable renewable plants by increasing their utilization and business case. This is shown by the red line above, 'charging' the storage when the output exceeds the demand and 'discharging' it when the demand exceeds the output. Increasing the utilization of the renewable plants would be attractive to existing and new developers in the private sector.

Depending on the required duration, such storage could be pumped hydro, high temperature heat, hydrogen or methane – all from renewable electricity. (See: 2020-01-22 Development of a Global Atlas of Off-River Pumped Hydro Storage http://cms.energypolicy.co.uk/electricity/337, Stiesdal 'GridScale' Storage https://www.stiesdal.com/storage/, 2013-10-09 Electricity from Wind and Storage, http://cms.energypolicy.co.uk/electricity/241).

So adding storage has a positive business case in itself, and would increase the business case of existing renewables.

The above are summarized in the following table:

Energy Supply Technology	**Money Cost**	**Energy and GHG Cost**	**System Impact**
Conventional Nuclear Power	The above paper	Follows from the paper	Reduce business case of renewable electricity
Fossil Fuels with CCS	The above paper	Follows from the paper	Reduce business case of renewable electricity
Small Modular Reactors	Adverse scale effects	Adverse scale effects	Reduce business case of renewable electricity
Fusion Power	Huge to infinite	Huge to infinite	Reduce business case of renewable electricity
Space Solar Power	Huge to infinite	Huge to infinite	Reduce business case of renewable electricity
Storage	The above paper	Follows from the paper	Increase business case of renewable electricity

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