Energy Solutions for Sustainability, v9l **Gordon Taylor, C.Eng., M.I.Mech.E.** **2016-12-01**

Introduction

This note reflects Danish and German precedents on energy solutions, from which I have learnt the underlying principles. Humankind requires not energy but energy services such as illumination, movement and thermal comfort. Germany realises that it is not enough to set targets for reducing carbon emissions; policies, plans and actions are also required. It has adopted the 'Energiewende' energy transition plan for 80 to 95% carbon reduction by 2050. [1] Solutions for sustainable energy services can be determined by following a few fundamental principles and metrics, enumerated below.

1) All energy services can be expressed as energy-using devices, each with thermodynamic and practical minima.
The best work on this has been done by Cullen and Allwood et al at Cambridge University.
In 'Theoretical efficiency limits for energy conversion devices', [2] the Abstract includes: 'The result estimates the overall efficiency of global energy conversion to be only 11 per cent; global demand for energy could be reduced by almost 90 per cent if all energy conversion devices were operated at their theoretical maximum efficiency'.

Experience shows that, given the chance, engineers can design and manufacture affordable and durable devices that achieve within factor two of the thermodynamic minimum energy consumption. For example, working between the same top and bottom temperatures, the thermal efficiency of real internal combustion engines is about half that of the ideal Carnot engine. Taken with the above, this suggests that global energy demand could be reduced by about 45% if all energy conversion devices operated at half their theoretical maximum efficiency.

In 'Reducing Energy Demand: What Are the Practical Limits?' [3] , the Abstract includes: 'The result demonstrates that 73% of global energy use could be saved by practically achievable design changes to passive systems'.

These two papers, the latter with Supplementary Information, are complementary as most energy-using devices involve both energy conversion (Second Law of Thermodynamics) and energy losses from passive systems (First Law of Thermodynamics). For example, a refrigerator consists of an (active) electric heat pump and a (passive) insulated box.
Taken together, the above implies that global energy use could be reduced by about 73% + (27% x 0.45) = 85%.
Moreover such solutions are sustainable, as end-use equipment can be re-cycled at end-of-life, and successive generations can be more energy-efficient - at least to the factor two level. In Japan, this is encouraged by the 'Top Runner' Program. [4] [5]
More recently, Germany has adopted a general 'Efficiency First' energy policy. [6] [7]

2) When choosing energy supply and savings measures, important metrics are the Energy Return on (Energy) Invested (EROI) and the carbon or GHG intensity (e.g. CO2e/kWh).
An excellent reference is 'False solution: Nuclear power is not 'low carbon', Professor Keith Barnham. [8]
For example, the EROI of nuclear power plants is about 5. [9]
For comparison, the EROI of a Vestas wind turbine in medium wind conditions is about 38 and in high wind conditions 44. [10] and the EROI of an Enercon wind turbine for inland sites is about 35, near-coastal sites about 41 and coastal sites 51. [11]

So for equal energy invested, the electricity yield from wind turbines is at least seven times that from nuclear power plants. Moreover, nuclear plants need refuelling with energy-intensive fuel throughout their lifetime, where wind turbines do not. The construction times for wind farms onshore are about one year [12] and offshore about two years [13] , compared with nuclear power plants at 5 to 10 years. [14] Furthermore, the UK could manufacture most or all of wind farms, but much less of nuclear power plants, leading to far greater import costs. As reducing carbon emissions is most urgent, these are crucial differences. In any case, the Conclusions below show that all nuclear plants must be decommissioned by 2050. If construction started in 2020, it might be commissioned by 2030, but would need to be shut down in 2040 to allow 10 years for decommissioning.

3) When choosing energy carriers to supply energy end-uses, an important metric is their thermodynamic energy quality or exergy.
Electricity, gas and hot water have high, medium and low exergy respectively. To minimise losses of exergy and energy, the chosen energy carrier should have exergy that matches that of the energy end-use. *In the UK, like most developed countries, electricity accounts for about 20% of delivered energy, transport for about 30%, and heat at < 100 C for about 50%.* So reject heat from Combined Heat and Power plants and renewable Power-to-Gas etc. synthesis plants could be cascaded to heat loads and save approaching 50% of the total input energy. But this is only possible by choosing hot water as the energy carrier, supplied via heat networks to most urban buildings and some industry heat loads.

4) Electricity is the most costly energy in exergy and money, but also the easiest to measure and so to control and save.
Electricity accounts for about 20% of delivered energy. One demand for electricity is lighting. The first electric lamps were incandescent, followed by fluorescent saving about 80%, and now LED saving about 90% for comparable light output. Because LEDs are also much longer-lived, at up to 30,000 hours, replacing incandescent and fluorescent lamps is highly cost effective. Historically, lighting accounted for about 20% of electricity, but such consumption is falling with the changeover to LEDs.

Another demand for electricity is pumps and fans in industry, commerce and homes. Pumps and fans have a 'duty', the product of the flowrate and the pressure rise. Originally the drive motors had single fixed speeds and flow control required throttles or bypasses, incurring losses. Now electronic variable speed drives (static converters) are ever more affordable, that enable flow control by speed. The saving closely follows a cube law – e.g. half the speed, about one-eighth the power. For example, measurements show that a typical Central Heating Pump has a duty requiring an ideal 'hydraulic' power of 1 to 2 Watts. I have fitted a 'best practice' pump with electronic speed control. At the (adequate) minimum setting, it takes not 50 or 30 but 5 Watts, saving up to 90%. A later version of the same pump at minimum setting takes 3.5 W, only about three times the ideal 'hydraulic' power of 1 W. Historically, pumps and fans may have accounted for about 30% of electricity, but such consumption is falling with the increasing adoption of electronic variable speed drives.

Energy saving measures for electrical and other end-uses are discussed in the above papers by Cullen and Allwood.
I discussed saving electricity in: 'Saving Electricity in Appliances and Lighting'. [15]
Changing my 13 Compact Fluorescent Lamps to LEDs reduced the power by 56%. [16]
Yet where Germany expects electricity consumption to fall 25% by 2050, the UK expects it to rise by up to 80%.

5) Transport energy is almost all supplied as fuels, with electric vehicles (trains, trams and cars) being maybe 1 or 2 %.
Transport accounts for about 30% of delivered energy. About half is for Heavy Duty Vehicles (HDVs) - i.e. trucks, non-electric trains, ships and aircraft. These use fossil oil-derived fuels, with high energy densities (volumetric and gravimetric) that enable long ranges without re-fuelling. This is essential for ships and aircraft. Moreover in the case of aircraft, the reliability of the engines, nowadays turbo-jets, is of supreme importance. Thus approval and availability of any new fuels, which would probably also require new aircraft, would take decades. For trucks and non-electric trains, if the fuels were replaced by electricity stored in batteries with energy densities lower by 100- or 10-fold, either payloads or ranges would be much lower, which would adversely affect the capacity of these vehicles. However, existing fuels could be replaced by equivalent 'drop-in' fuels with equal energy density but lower carbon intensity. Two possible options are biofuels and renewable synthetic fuels.

Germany has recently launched a 'Power-to-X' project, covering Power-to-Gas, Power-to-Liquids, and Power-to-Chemicals. [17]
This will enable the use of wind and solar power in the transport and heat sectors that together account for about 80 percent of energy consumption, as well as in the the electricity sector of about 20 percent.

HDVs are vital in that ships, aircraft, heavy trucks and electric freight trains carry the food that is imported, 40 to 50% for the UK, and tractors and farm machinery help to produce food in UK farms. Also trawlers bring fish to UK ports. Heavy trucks and freight trains then carry almost all food from the ports, container ports and farms to the supermarkets and shops.

The other half of transport fuels is used by Light Duty Vehicles (LDVs), mainly cars and light vans. If renewable 'drop-in' fuels were available at the scale required for HDVs, more could be produced for LDVs.

Many have proposed that conventional cars be replaced with battery electric vehicles (BEVs). However their large-scale deployment would require an elaborate and expensive charging infrastructure – plug-points, distribution, transmission and generation. Also BEVs with ranges acceptable to private buyers are expensive, largely due to the batteries which have high embedded energy of manufacture. Yet such high prices are hard to justify, whether at individual or societal level, when the vehicles are typically stationary for 94% of the time, and thus not earning a return, whether of energy (EROI) or money (ROI).

Also, many large and/or poor countries lack an electrical infrastructure capable of charging many electric vehicles. So these will still require internal combustion engine vehicles and liquid fuels - i.e. low-carbon biofuels and renewable synthetic fuels.

6) Heat services for buildings may be divided into existing and new-build.
Heat at < 100 C accounts for about 50% of delivered energy. Due to low rates of building replacement and increase, the UK building stock in e.g. 2050 will be mainly existing, with only a minority being new-built between now and then. The former are thermodynamically best heated via a low-exergy carrier – piped hot water in networks, known as District Heating (DH). The latter are thermally best heated by building to Passive House (PH) heat loss criteria.

The Passive House criteria include net peak heat loads of 10W/m2 and net annual heating energy of 15 kWh/m2 floor area. These can be achieved by using free heat gains from solar via the windows, appliances and occupants, and enough insulation to avoid the need for a conventional heating system. The remaining heat is supplied via a ducted ventilation system that has a heat exchanger recovering at least 75% of the heat from the exhaust air. Also PH design and construction minimises the 'thermal bridging' and air leakage that is so prevalent in conventional construction, so that the criteria are achieved in practice. [18]
Compared with current UK building standards, building to the PH criteria gives a saving in paid-for energy for space heating of about 90%.

Heat services in new build are best addressed with Passive House design and construction, of which many thousands of examples have been built - notably in Germany - and proven highly effective. They range from single-family houses to multi-family blocks, office-blocks, schools and gymnasia etc. Indeed the PH criteria are generally easier to meet with larger buildings. These typically have lower surface to volume ratios, due to the 'square-cube' law - i.e. the outside surface area increases as the square, but the volume increases as the cube. Also such larger buildings often have more occupants and electrical equipment, providing more 'free' heat, per unit of floor area.

For heat services in existing buildings, renovation to near Passive House standards is possible, and is done in Germany. But it can be expensive and if the additional insulation required is external, may change the appearance unduly. This may not be acceptable for the many 'heritage' buildings in cities, town and villages. In these cases, renovation might be confined to those aspects that strongly affect thermal comfort, including better insulated windows and doors, draught-stripping and controlled ventilation. This may reduce the space heating energy requirements by 30%, so substantial heat would still be required.

7) Heat at < 100C should be supplied via heat networks for the highest thermodynamic efficiency and the lowest GHG emissions.

Compared with electricity and gas as energy carriers, hot water has the best exergy match to building space and water heating. Moreover, like the networks for electricity, gas and water, heat networks need not be designed for the full theoretical load, but only a fraction, due to 'diversity' of the individual loads. For example, for heat networks serving more than 200 homes, the 'diversity factor' is 0.47. [19] So compared to many individual heating plants, the central plant is smaller and less costly, with higher returns for the energy (EROI) and money (ROI) invested. It also operates nearer to full load more of the time, and thus often more efficiently.

One source of supply for heat networks is that co-generated in large Combined Heat and Power (CHP) plants, fuelled with fossil fuels, municipal waste, and increasingly biomass. District heating from CHP plants has been practiced in Denmark since 1906 and DH now supplies over 60% of space and water heating. [20] [21]

Large (~ 400 MWe) Combined Cycle Gas Turbine (CCGT) combined heat and power (CHP) plants supply power at very high efficiency (e.g. 50% on the HHV) and co-generated heat at very high Thermodynamic Heat Efficiency (THE) (e.g. 400%). Such plants have a gas turbine, with exhaust heat recovered in a steam boiler, supplying a steam turbine. The gas turbine allows the top temperature of the power and heat cycles to be higher than the combustion chamber wall, which is limited by material durability and cost. The heat cycle is a 'virtual heat pump', with an output temperature high enough for space and water heating. This may be up to about 90 C, with an annual average of about 70 C. With losses in the heat network, heat reaches the buildings at up to about 80 C, with an annual average of about 65 C. The heat network temperatures are controlled with 'outside temperature compensation' and other strategies. To encourage economical use, network heat charges are divided between the users, often according to heat meters much like electricity, gas and water meters.

Large CHP plants require heat networks to aggregate the heat loads, but the large scale brings gains in Thermodynamic Heat Efficiency that far exceed the network heat losses. [22]

Other sources of supply for heat networks are large arrays of solar thermal collectors (much cheaper than individual house arrays), deep geothermal heat wells (only affordable for large heat loads) and surplus renewable electricity (in winter, mostly wind power), via electric boilers or large central heat pumps. All have near-zero carbon intensities.

District heat can be piped over distances of 10's of km, and stored for hours to days in cylindrical ground-mounted tanks and for days to months in surface reservoirs. Such storage also benefits from the square-cube law, whereby the heat loss scales as the square of the linear dimension, while the heat stored scales as the cube.

Heat networks are widespread on the European continent, as shown in 'The Case for District Heating: 1000 Cities Cannot be Wrong'. [23] They enable all fossil-fuelled heat to be replaced with renewable heat. That serving Copenhagen should be carbon-neutral by 2025. [24] Yet in the UK, heat networks so far supply only about 2% of the building heat energy.

Conclusions

The consequences of severe climate change would be many millions of lives lost and huge economic costs. So fossil fuel use must be reduced much faster, in line with the best evidence. In 'Some Comments on IPCC AR5 and the omissions of significant 'Feedback Effects' from the Climate-Models used in its preparation' [25] , Page 12 includes: 'Global emissions contraction must be fast enough to achieve the objective of the UN Framework Convention on Climate Change [UNFCCC] on a precautionary basis [for example 100% contraction by 2050]'. Page 12 says in effect that to avoid severe climate change before 2100 requires not Convergence (of all countries' carbon emissions) by 2050 and Contraction (to zero) by 2100, but Convergence by 2020-2030 and Contraction by 2050.

The energy solutions for sustainability must be chosen according to the thermodynamic principles and score highly on the important metrics above. According to the major studies by Cullen and Allwood et al, energy savings and increased energy efficiency alone could reduce energy consumption across all sectors by up to 85%. Such measures would be both near zero carbon and sustainable.

Car-commuting has long proved costly in time and energy in all cities and many towns, especially in Europe, due to limited road space and parking. Also both residents of and visitors to cities now demand cleaner air, while combustion-engined vehicles emit noxious gasses and particulates, and all including electric vehicles emit particulates from tyres and brakes. So for the sustainable 'end-game' scenario, car-commuting in cities and towns, even with battery electric vehicles, should be largely replaced by public transport, cycling and walking. In Denmark, this is encouraged by high taxes on cars and motor fuels.

To be ready for the increased stresses caused by climate change, the UK must become far more self-sufficient in food and biomass. So biomass should not come from imports, or from home-grown energy crops which would compete with food crops, but only from wastes, both dry for combustion and wet for anaerobic digestion to biogas. Likewise solar power arrays should not be installed on arable land, but only on buildings and waste ground - e.g. in urban areas.

So the main renewable energy resource in the UK, which has little hydro-electricity, is wind power, both onshore where the towers occupy minimal land, and offshore where the UK has the best wind resource in Europe. Wind power should increase to some 75% of electricity, with backup from gas-fired CHP plants fuelled initially with fossil natural gas then with biogas purified to 'pipeline quality' methane and renewable methane produced by 'Power-to-Gas' processes (electrolysis producing hydrogen, then methanation), so becoming near-zero carbon. Such gas would continue to be stored in underground caverns with capacity equivalent to up to months of demand. Once most renewable sources are in place, they require no fuel supply that might be blockaded, whether internally or externally, and thus are resilient.

On 2011-03-08, I showed that for the UK, 100% of all energy could come from wind. [26]

On 2013-10-09, I showed that for the UK, wind power alone could reduce the fossil gas required for gas-fired power plants by about 75% before significant long-term storage of synthetic gas made with surplus renewable electricity was required. [27]

In 'Carbon Budgets and Switching to Renewables', dated 2013-07-22, [28] , I assembled evidence leading to the conclusions:
a) 'For an 80% chance of limiting global warming to 2 C, only 565 GtCO2 can be emitted (up to 2050). With carbon emissions increasing at about 3% a year, this would be reached in about 16 years, i.e. by 2028'.

b) 'The EROI of high-carbon conventional oil is about 15, ultra-deepwater oil 7 to 4, tar sands oil is from 7 to 3, and shale oil is from 2 to 1.5. However, the EROIs of low-carbon Wind Turbines producing electricity are around 50 to 35, and with Power-to-Gas conversion producing methane, may be about 10, and with further conversions producing gasoline, may be about 7. As the high-carbon sources are replaced by low-carbon sources, the carbon intensity of energy would reduce, eventually to zero. Such zero-carbon sources would impose zero risk to the climate so such investments would incur zero climate risk'.

Most of the money wealth in the world is based on property. Much of this is located in low-lying coastal and riverine cities, such as in Florida, New York, Tokyo, and London, etc. The effects of severe climate change such as hurricanes, storm surges and sea level rise will render this valueless. Many poor countries are also at risk from loss of land, livelihoods and food. So for both developed and developing nations, the economic and human costs of severe climate change are almost incalculable.

As a consequence of having left fossil fuel reduction so late, severe climate change this century, leading to widespread poverty, starvation, social breakdown and warfare, is all too likely. While many earlier civilisations have collapsed, humankind could recover because the damage was not worldwide. This time would be different.

Professor Johan Rockstroem et al published in Nature, 2009-09-24, ‘A safe operating space for humanity’. [29] This sets out nine planetary boundaries that must not be transgressed to prevent human activities from causing unacceptable environmental change. But Biodiversity Loss and Nitrogen Cycle have already been exceeded, and Climate Change may be exceeded soon.

Professor Peter Wadhams gave an interview in 2013-11, published on video: [30]
When asked whether he thought that civilisation could survive a further 50 Gt of methane, he said:
‘No, I don’t think it can. If you look at the existing predictions of global warming rates, what’s kind of eerie is the fact that the business as usual projections, even the cautious ones, produced by IPCC, are still giving us about 4 degrees of warming by the end of the century. And with 2 degrees has been taken arbitrarily as the level beyond which nasty things happen; I don’t know why 2 degrees, but that will be reached by the middle of the century, and 4 degrees by the end of the century. Now 4 degrees, people who calculated what that would do to food production, die off of forests, to acceleration of warming due to various extra feedbacks that kick in, the general conclusion is pretty dire, that if you get to 4 degrees of warming, then collapse of civilisation is what’s going to happen because the world won’t be able to sustain anywhere near it’s present population. So the result will be chaos and warfare. So that’s just...the eerie thing is that that’s predicted by the IPCC report, the projection of warming by the end of the century is 4 degrees, but nowhere do they state at all that 4 degrees is a catastrophe economically and socially but for the planet and now, with this Arctic methane you’re simply adding another element to warming, even if it’s only an extra 0.6 [degrees], that brings forward the date at which catastrophic warming is achieved by maybe another 20 years, so that we’re going to get into a state where the warming rate is giving us something that would cause society to break down, and we’re going to get to that state quicker because of offshore emissions of methane...’.

All the present nuclear power plant sites in the UK are coastal, to enable the use of seawater for cooling. So all are vulnerable to storm surge and sea level rise. For Hinkley Point, this is aggravated by the convergent mouth of the Severn estuary and the largest tidal range in the UK. All nuclear sites are polluted with radioactivity from ‘operational’ and accidental releases, and as nobody wants to pay for it or a waste repository, the nuclear plants are unlikely to have been decommissioned, even by 2050.

Climate change may cause sea levels to rise by 0.5 to 1.4 m by 2100 [31] , and – if severe - up to 7 m in 1000 years. [32]
So rising seas, together with storm surges, could lead sooner or later to flooding of coastal nuclear sites. These effects and much higher global temperatures, affecting fresh water supplies and crop yields, could lead to social breakdown and the loss of electric power, resulting in overheating of spent fuel pools and other stores of nuclear material. The seas and winds would then spread radioactivity worldwide.

Evidence from the A-bombs and later nuclear bomb tests, nuclear workers, and releases from Windscale, Three Mile Island, Chernobyl and Fukushima etc shows that radioactivity in the environment is ingested by humans and damages DNA. [33] This can cause abortions, deformities and sterility so, if severe climate change were to cause a major extinction of human life, it’s chance of recovering would be near-zero. [34]

Therefore all nuclear fuel and power plants must be shut down promptly, and all nuclear weapons must be dismantled without delay. All reactors and spent fuel pools must be emptied as soon as the fuel rods are cool enough, after about 5 years, and all plants decommissioned. All the ‘high-level’ nuclear material must be put into repositories secure against a sea level rise of 70 m, that for an ‘ice-free’ earth, [35] before 2050, the date from which climate change may run out of human control. [36]

Appendix on Policy

Building new transport infrastructure is unhelpful, as in addition to being carbon-intensive, it invariably generates additional traffic. Yet traffic volumes must fall, and will as transport energy and fuels become more costly and then near zero carbon.

Even more unhelpful is the building of armaments, such as aircraft carriers, destroyers, and military aircraft, all requiring massive amounts of oil fuel, and nuclear submarines, which along with their nuclear weapons are massively energy-intensive. They also incur very high ‘opportunity costs’ in the UK’s limited engineering design and manufacturing capability, as well as requiring very considerable foreign currency for imports. Military expenditure for 2015 by the UK was $ 55.5 billion, 2% of GDP, while that by Germany was $ 39.4 billion, 1.2% of GDP. [37] These make the UK substantially poorer and far less well-prepared for the real challenge that is climate change and its consequences.

Instead, UK design and manufacture should make equipment for energy saving, energy efficiency, and renewable energy supply. As well as meeting the needs at home, it would be in demand worldwide, and – unlike armaments - could be exported without restriction. Also the UK must maximise repair, re-use, and recycling, as mineral and material imports may become unaffordable or unavailable as world tensions increase.

As an engineer, I have long been concerned that nuclear power posed unacceptable risks.
On 2011-03-11, the Fukushima Daiichi nuclear power plant in Japan was damaged by a major earthquake and tsunami. The three operating reactors overheated, leading to hydrogen explosions and radioactive releases, which necessitated progressively wider evacuations of the populace. In the weeks that followed, it became clear that Reactors 1 to 3 and the spent fuel pools of Reactors 1 to 4 had the potential for far greater radioactive releases. However, without visiting Japan or waiting for events to run their course, the U.K. Nuclear Installations Inspectorate reported that there was no need to curtail nuclear power. [38] Moreover, the then Energy and Climate Secretary, Chris Huhne, said that the report 'provides us with the basis to continue to remove the barriers to nuclear new build in the UK'. This was patently unjustified so I produced several documents on the dangers of nuclear power - especially in the light of Fukushima:

a) a 15-page study 'The Case Against Nuclear Power', dated 2011-06-06, based on the evidence from nearly 90 references. [39]
b) a 73-page study 'The Real Lessons of Fukushima', dated 2012-04-11, based on the evidence from over 230 references. [40]
c) a 10-page summary 'Nuclear Power's Fatal Flaws: the Real Lessons of Fukushima', dated 2013-11-01, explaining how nuclear releases arise. [41]

Among many television programmes on the Fukushima disaster, NHK has produced three 'Meltdown' documentaries in English, first broadcast on 2012-01, 2012-08-18, and 2013-03-05. These are based on some 300, later 400, interviews of those involved and outside experts, which enabled realistic re-enactments. They thus go far beyond the reports of the IAEA, UK ONR, NISA, and TEPCO, which are self-serving, and of the Japanese Cabinet Office (Hatamura Panel), the independent Kitazawa Panel and the Japanese Diet (parliament), which were completed earlier. The second and third NHK 'Meltdown' documentaries are available on YouTube. [42] [43] I also produced transcripts of these two documentaries, dated 2014-01-13, and a summary of the main findings. They reveal design and operational deficiencies additional to those in the official reports. [44]

2016-08-08. I produced a three-page document ‘Nuclear Insecurities’. [45] This outlines ten insecurities that result from existing nuclear power plants and would result from any new plants such as Hinkley Point C.

One (No. 2 in my document) is ‘Fuel Supply Insecurity’. Some have advocated nuclear power, including that based on thorium, or even nuclear fusion. [46] Even if it runs for the design life, as noted above, nuclear power is not low-carbon and the EROI is at most one-seventh that of wind power. While the fuel energy cost is assumed to be constant, it must rise as uranium is depleted, and the decommissioning and long-term waste storage energy costs, if included at all, can only be guesses, often by interested parties. Hence the EROI of nuclear power must fall and the carbon intensity must rise, so it cannot be even part of a sustainable solution. Also, in a mix with renewables, nuclear power would compete with the deployment of renewables, due to mindshare, money cost and embedded energy, and because it is inflexible, cause frequent curtailment of renewables, thus increasing carbon emissions.

In most developed countries, electricity accounts for only about 20% of delivered energy, and in most ‘nuclear’ countries, nuclear power accounts for only about 20% of electricity. France is the exception, with about 75% of electricity from nuclear, but the demand varies by about factor two, for which nuclear plants are hard to control. As nuclear power accounts for only about 20% x 20% = 4% of the UK delivered energy supply, to become ‘the answer’ it would have be scaled up by 25 times. This would incur a huge debt in embedded carbon for the steel and concrete, be completely unaffordable, and take far too long to build, by which time uranium depletion would cause the EROI to fall below 1, the ‘point of futility’. [47]

For fusion, unlike in the sun, exceeding the Lawson criterion for energy break-even may well prove impossible in a power plant, as the inevitably lower pressures on earth have to be compensated for by temperatures far higher than inside the sun. [48]

In ‘Flexibility concepts for the German power supply in 2050’, [49] Footnote 5 includes: ‘Power generation based on nuclear fission was ruled out with view to the German Federal Government’s decision to phase out nuclear energy – a resolution which is backed by broad public support. However, even assuming the power generation costs currently presumed in the United Kingdom in a feed-in law for new nuclear power plants, this technology would, for economic reasons, still be ruled out. Power generation by means of nuclear fusion was not considered an option, as experts agree unanimously that even by 2050, no fusion power plant will have reached technical and economical operability’.

So no new nuclear technology, whether fission based e.g. on thorium, or fusion, could be developed and deployed sufficiently rapidly to reduce the severity of climate change. In any case, as noted above, all sources of ‘high-level’ radioactivity must be in secure storage at more than 70 m above the present sea level by 2050. The only solutions that are ready now, inherently safe, climate-friendly, resilient and sustainable are energy savings and renewable sources. The latter are mainly hydro, wind and solar, and derivatives such as biogas, waste biomass, and synthetic gas and liquid fuels, along with geothermal for heat.

Another (No. 3) is ‘Physical Insecurity’. All fission nuclear power plants give off 'decay heat' after shutdowns, whether operational or emergency. If it loses both the grid connection and the standby generators, the batteries would last only 4 to 8 hours before decay heat causes the reactor cores and spent fuel pools to overheat and all containments to be breached in hours to days. This happened at Fukushima, where three reactors discharged major radioactive releases to the air, land and sea.

Spent (nuclear) fuel pools are nowadays often subject to ‘re-racking’, to increase their fuel rod capacity beyond the original design. This is done by operators to defer the expense of more secure dry cask storage and final repositories. It is widespread in the USA and is also the case for the Fukushima plants. But it also increases the total decay heat in the spent fuel pools, so that cooling - which already requires pumps - becomes even more demanding. Water is both a coolant and a neutron absorber, so if it is lost e.g. by leakage or boil-off, the spent fuel will certainly heat up, may catch fire and/or could become critical again.

One way of suppressing nuclear reactivity is to use 'borated' water, but this would still fail if the water was lost. Another way is to fit neutron absorber plates between the racks. But even if they prevented criticality, the fuel rods of BWRs, PWRs and EPRs, the vast majority, are clad in Zircaloy, so if the water was lost, the spent fuel rods could well catch fire. [50]

In ‘What about the spent fuel pools ?’, [51] , Page 2 includes: ‘If a fire were to break out at the Millstone Reactor Unit 3 spent fuel pond in Connecticut, it would result in a three-fold increase in background exposures. This level triggers the NRC’s evacuation requirement, and could render about 29,000 square miles of land uninhabitable, according to Thompson. Connecticut covers only about 5,000 square miles; an accident at Millstone could severely affect Long Island and even New York City’.

In '600 tons of melted radioactive Fukushima fuel still not found, clean-up chief reveals', [52] , the third comment is:
'600 tons. There are 451 reactors in the world. That's 90,000 tons of core fuel in use at any given moment in time. The average ICBM contains a few hundred pounds. And we worried about nuclear war. It's a joke. The spent fuel pools around the world (all adjacent the reactors) can easily meltdown (takes up to 3 years to cool down). Current estimates put spent fuel at 225,000 tons!! If any global or even national catastrophic event occurred such as a pandemic or a huge solar flare, it would be an extinction level event. Reactors take years to cool down and require power to run the ECCS cooling systems'.

Another (No. 4) is ‘Human Insecurity’. Chernobyl resulted in fallout over 40% of western Europe, while 2400 km away in the UK, the fallout on hill farms in Scotland and Wales resulted in compensation being paid for 25 years. Fukushima caused the evacuation of some 100,000 citizens, the loss of many livelihoods including farming and fishing, and of up to 8% of Japan for decades. So the human and economic consequences of major radioactive releases are such that the populace experiences life-threatening human insecurity and demands immediate shutdowns of all nuclear power plants. This happened in Japan after Fukushima, and even five years later, hardly any have been re-started, while the cleanup is expected to take at least forty years.

Another (No. 5) is ‘Energy Insecurity’. The consequences of the Chernobyl and Fukushima nuclear releases are horrendous. Yet the 'worst-case' nuclear releases are 100 times greater, with far worse consequences. This is shown by three reports originating from within the nuclear community. [53] For example, the Japanese Kondo Report says that a ‘worst-case’ release would require ‘voluntary’ evacuation over a distance of 250 km. [54] Applying this to the eight nuclear sites in the UK shows that almost all those living in Britain are threatened. [55] In the words of Dr John Gofman, this is 'licensing random premeditated murder'. [56] Moreover while nuclear fuel and power plants operate, such releases are inevitable. So all the existing plants must be phased out forthwith and any proposed new plants abandoned.

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