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Renewable Alternatives To Nuclear Base-load Power Generation

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Executive Summary

Nuclear power has both advantages and disadvantages. This paper suggests alternative sources of low/ zero carbon generation, that could supply base load, should be developed in preference to new nuclear.

Analysis suggests that the base-load alternatives could provide between 30% and 45% of the UK's electrical energy needs from domestic renewable resources. In addition these sources have greater capacity to flex supply to match demand.

The alternatives can supply base load at comparable or lower levelised costs, while providing diversification for local economies with greater opportunities for local employment and participation.

Timescales for large-scale deployment are comparable (some capacity, faster) with new nuclear, providing that similar levels of political will to progress are available.

The principle arguments set out in this paper, is that 21st Century society should not be imposing liabilities and costs on future generations from new nuclear, especially as there are alternatives available.

The advantages of nuclear are:

Low Carbon. The argument goes that CO2 and Climate Change are a bigger risk than nuclear, an argument that is supported by the authors of this document. However the authors also suggest that alternatives to nuclear are available at similar levelised costs of energy and these should be developed in preference to new nuclear.

Low marginal costs of operation.

Availability of fuel from multiple countries.

Reliability, utilisation rates of over 80% are achievable.

The disadvantages are (listed in order of the author's view of importance):

The legacy of nuclear is imposed on future generations when these future generations, whom have no say and do not benefit directly from the energy nuclear provided.

Nuclear waste. A small proportion of the waste will be highly radioactive for thousands of years, even the waste with shorter half lives will require on-site containment for several generations. Too many countries act irresponsibly in their disposal of waste. Thus it's a technology that should be discouraged.

Mining practice. The history of mining (nuclear and other raw materials) shows that too many countries ignore the environment, long-term impacts and their own peoples' health. If alternative sources of generation exist, environmental abuse can be avoided.

Carbon emissions. Nuclear is a low carbon rather than zero carbon source of power, as there is unavoidable CO_2 generated throughout the supply chain.

Energy Costs. Analysis suggests that with commitment to the alternatives a Levelised Cost Of Energy[1] comparable or lower than nuclear at £92.50/ MWh is achievable.

There are a number of other arguments, which, in the views of the authors, individually are either relatively low risk or relatively low cost (at least in the grand scheme of things). However collectively they add further weight to the argument that the alternatives are in fact a preferable pathway. These include, **socialised costs, decommissioning costs, reliability, fuel supply uncertainty, transmission infrastructure, stranded assets, insurance, transportation, infrastructure projects, balance of payments, radiation, natural disasters** and the unexpected.

[1] **LCOE** is the total **cost** of installing and operating a generator over its life, expressed in kWh

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The energy conundrum: Achieving ultra-low carbon base-load without recourse to nuclear power generation.

This paper examines reasons to avoid nuclear power and suggests alternatives for base-load electricity supply. The advantages and disadvantages are listed in the author's view of relative importance.

It is argued nuclear is a preferable source of energy than fossil fuels as carbon emissions are low, that it is therefore a 'renewable' power source and that transition to a low carbon future will require nuclear. However these arguments only hold if there were no alternative solutions.

Arguments in favour of nuclear are understood. To explain certain disadvantages one must provide some background information. This document is therefore disproportionate in discussion of the disadvantages verses advantages.

The Advantages of Nuclear power

Low Carbon: Nuclear is a low carbon energy source with the potential to lower CO2 emissions if the alternatives are only coal, gas and other hydrocarbons (collectively the greatest threat to biodiversity, sustainability and health).

Low Operational Costs: Nuclear has low marginal costs to supply electricity. Fuel is a small percentage of overall costs. A rise in Uranium prices would not make a substantial difference to the wholesale energy cost (though limited supply might).

Available Fuel Supply: At current use rates, Uranium supply is predicted to be available for 60+ years, i.e longer than the life of the reactors (around 40 years). Friendly countries have good levels of Uranium reserves.

Reliable: UK nuclear has historic utilisation rates around 70%, i.e. providing 70% of its theoretical maximum if running constantly (elsewhere, e.g. US, utilisation rates are higher at 83%). The 70% figure is comparable to the achievable utilisation rates of other base-load generation (coal, gas). Fossil fuel base-load generation has been declining in the UK due to lower marginal cost energy from renewables (wind, hydro, PV) and declining maintenance on older power stations.

The Disadvantages of Nuclear power

The Legacy of Nuclear Power on Future Generations: There is general understanding about the potential risks from nuclear facilities and the legacy imposed on future generations. At any point in time the risks are low but the timescales are very long. Nuclear power knowingly imposes substantial, on-going costs and risks on future generations.

Nuclear Waste: Highly radioactive, Plutonium-239's half-life (half of the total radioactive decay) is 24,000 years (5 times the elapsed time since the building of the pyramids at Giza). Some nuclear wastes have shorter half-lives, Strontium-90 and Cesium-137 are 30 yrs. It takes the duration of several half-lives before the waste decays to a safe level.

The storage of spent fuel (civil and military) is the most pressing unresolved problem (there is still no storage site available for the waste from the 1950's). The current proposals for Hinkley Point-C are 100+ years of storage on-site in ponds, prior to removal to a yet unknown long-term underground storage facility.

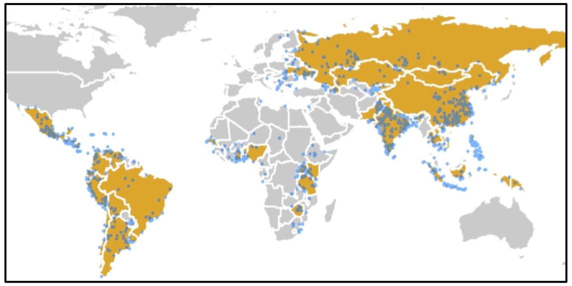
There are no long-term storage facilities for high-grade waste anywhere in the world. No site has been identified in Europe. In the US the single identified site has been deemed unsuitable. The onus should be on the nuclear industry and governments to agree waste storage before building a new generation of reactors.

Governments should consider and demonstrate alternative sources of base-load generation as the track record of environmental damage from the development of nuclear power (and other mining / industrial processes) provides ample reason for concerns about nuclear consequences beyond our boarders. Too many countries show too little regard for the environment, worker protection, public safety, health, construction standards, facilities maintenance, waste disposal etc.

The UK should take no part in the promotion of a technology that presents relatively low risks domestically (at any single point in time) but current and on-going high environmental and social risks elsewhere.

In the former Soviet Union the environment and public safety were ignored as the development of nuclear power and weapons outweighed all other considerations: The Kara Sea (Disposal site close to Norway) has 17,000 containers, 19 vessels with radioactive waste, 14 nuclear reactors of which 5 have hazardous spent fuel; Lake Karachay and surrounding areas are the most polluted places on Earth.

The Toxic Site Identification Program shows the disregard for the environment (all industrial processes), how the toxic problems are endemic and stretch across the globe, from China to Pakistan, African to the Americas, Russia and Central Asia. 91 sites on the map involve nuclear mining, disposal or processing.



Mining: Mining of Uranium is a dirty business. Pure Earth estimate over 800,000 people at risk of exposure from disused nuclear sites and Yablokov[2], that over 10 million nuclear personnel exposed to anthropogenic ionizing radiation. Yablokov's figures are probably inflated, however the problem exists. The UK should remove itself from an industry that does extensive social and environmental harm.

Carbon: The production of electricity from nuclear is low carbon, however the extraction of Uranium is not. The carbon cost of mining (and transport) does not appear on the UKs figures, as the fuel (mainly diesel) used during extraction, processing and transportation are added to the emissions of the producer country. The largest producers are: Kazakhstan (33% world supply), Canada (18%), Australia (11%), Namibia (8%), Niger (7%), Uzbekistan (5%).

Nuclear facilities are extensive projects, taking years to complete, with all the associated construction and eventual de-commissioning emissions, throughout the supply chain.

Cost of Electricity from Nuclear Power Production (UK): The proposed minimum wholesale cost of energy from nuclear (under the Contracts for Difference) is £92.50/ MWh. Wholesale costs represent around 50% of the price to commercial consumers. What point are you making? The shortfall has to be Govt funded?

Socialised generation costs: There are additional operational costs imposed on the consumer, via grid operating charges. These charges are likely to increase as a result of new nuclear generation (all generation types have socialised costs).

The grid requires reserve power to cope with a generator going off-line at short notice. Currently the UK's system ensures sufficient operational spinning reserve capacity for two large generators to go off-line in short succession

Some power stations are designed as arrays that collectively supply the peak generation capacity (coal, gas, renewables, biomass, etc), so a fault in one generator is less likely to shut down the whole plant. However nuclear is different as it has a single source of power – the reactor. A nuclear station shut down event creates the single largest stress on the grid of any generation facility.

New nuclear, due to its larger capacity will require additional reserve, as the larger the generator, the larger the reserve required and the greater the socialised costs.

Spinning reserve provision is mainly provided by thermal plants (there are other options) either running below peak capacity or by generators with fast ramp rates. It is supplied via two market mechanisms, Mandatory Frequency Response and Reactive Power, these have annual socialised costs (2015), of £48m and £72m respectively. To provide context other balancing services include Fast Reserve at £130m, STOR at £62m and Commercial Frequency Response at £126m. Nuclear's inflexible supply profile also requires use of other grid balancing services as it cannot react to rapid demand changes.

Decommissioning Costs: The UKs current nuclear fleet were state owned when built, but they were privatised during the 1980's. However the liabilities were retained as the sale would have been impossible with unknown future liabilities. This means that the resulting energy price from existing nuclear does not include provision for decommissioning. Estimated at £53.7 billion in 2012 plus, reprocessing or disposal of waste at £2.4bn/year.

New nuclear contracts, such as Hinkley Point-C, place decommissioning and disposal liabilities (though not the provision of the underground disposal facility) with the operator, therefore there is some provision within the costs of the electricity sold. However at the time of decommissioning (or before) there is always a risk that the owners (EDF with Chinese finance) can't pay / refuse to pay in part or in full. Under this scenario the state (taxpayer) still holds all liabilities.

[2] (Journal of Health Pollution 2014;4(7):62-74)

It would be more honest for government to keep the liabilities (as it ultimately has them anyway) and to be intimately involved in the process of managing assets and disposal (government must do this anyway, via the regulators & waste site identification processes).

Reliability: Nuclear is presented as the most reliable source of generation, giving the impression it operates nearly all the time. However Dukes 5.9 (plant load factors) shows UK nuclear operating at 66% load factor (2014). This compares to other more flexible technologies such as gas turbines at 30% (this was around 65% in 2010), pumped hydro storage at 12%, conventional thermal 46%, Coal 48% and variable sources such as, on-shore wind 27%, off-shore wind 37%, hydro 38%. It should be noted that both nuclear and most renewables require various grid services to provide flexibility to match supply and demand.

Fuel supply certainty: The current price of mined Uranium (prior to processing) is around $75/kg. Energy Watch[3] [EW] predict global nuclear capacity will grow to between 540 GW and 746 GW by 2035, giving a central scenario of 643 GW, requiring 112,000 tonnes of Uranium annually.

By 2020 EW anticipate global extraction capacity of 100,000t/ annum costing $260/kg (including both 'reasonably assured reserves' and 'inferred resources'). This is 12,000t short of the central scenario requirement. EW predict that production levels are sustainable for around 30 years (to 2050), before supply starts to fall (or the fuel becomes more expensive as more marginal supply is introduced).

Based on EW predictions on resource availability, Hinkley Point-C (40 year operational life) if commissioned in 2026 could experience 16 operational years with increasing fuel supply scarcity. We should question the wisdom of investment into nuclear power from Uranium, as it would appear to be a dead-end technology, potentially before the end of the operational life of the proposed plants.

Transmission infrastructure: Nuclear is deliberately sited at considerable distances from people and demand, an acknowledgement to the fact there are risks. The facilities require transmission infrastructure (60 year life, why when the plant has only 40 years?) from these remote sites to consumers. Currently much of the UKs transmission infrastructure is due for replacement (one? decade timescale). The cost of the new 55km (47km over-ground, 8km under-ground) of transmission for Hinkley across Somerset is mostly socialised[4]. There is the potential for both the nuclear plants and transmission infrastructure to become stranded assets.

There are other consequences arising from Hinkley. Grid capacity (that could be used for shorter timescale projects) is being reserved for Hinkley, on the assumption it will progress. This is preventing other (renewable) energy projects from progressing, lowering potential capacity margins. In addition the scale of nuclear projects divert grid and transmission operators' resources from other smaller issues that tend to sit in the queue waiting for resolution.

Insurance: The nuclear industry pays a fraction of the insurance costs associated with nuclear clean up (in the unlikely event one occurs). It is the taxpayer that ultimately holds the insurance and clean up risks. The potential scale and costs of a disaster are too large for the nuclear insurance market and industry combined.

> *"Worldwide, nuclear risks generate an overall amount of premium which is disproportionately small in comparison with their political, sociological and economic importance and the size of the risks assumed by insurers"* **Source: Nuclear Pools**
>
> *"it was realized that nuclear power makes a valuable contribution to meeting the world's energy demands and that in order for it to continue doing so, individual operator liability had to be curtailed and beyond a certain level, risk had to be socialized"* **Source: World Nuclear Association**

Since 2004, the OECD Paris and Brussels conventions provide for €1.5bn (£1.1bn) compensation per facility (operators contribute €700m (via insurance), nation states (public funds) €500m and Brussels (EU) institutions €300m.

To put into perspective, Japan's Government advise direct costs of Fukushima will be ¥11tr (£64bn) over 40 years (source: World Nuclear Association) with nearly half as compensation payments. Forbes.com (03/2016) advise a further $200bn (£125bn) has been spent on fuels to replace the nuclear production taken off-line.

Clearly not all costs associated with Fukushima are insurance related, some are government decisions (such as evacuation area), others will be consequential losses. However there is clearly a substantial difference between the £1.1bn insurance available and the scale of potential liabilities and consequential costs.

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[3] Fossil & Nuclear Fuels Supply Outlook 2013 report, based on Nuclear Energy Agency's 2011 forecast

[4] Socialised means shared across all energy users bills

Transportation: Nuclear containers in the UK are well designed & the risks of accidents, theft or terrorism small, as are the risks from the mine to the processing facility, as unprocessed fuels have relatively little value or use.

Infrastructure Projects: Governments tend to steam-roller through major infrastructure projects, ignore local concerns, planning procedures and even certain pre-agreed requirements. For example Hinkley-C is supposed to have (but does not) solutions to waste disposal, discharges and a decommissioning payment system in place prior to planning being granted. At Hinkley there has been a presumption of approval in tandem to an imposed severe limitation on external groups' ability to present counter arguments. At Hinkley this has lead to a vast area of natural habitat being removed (part of enabling works) before planning was even granted.

Balance of Payments: The UK is increasingly dependant on imports for its energy (fossil and nuclear fuels or via interconnectors). The trade deficit in goods is a particular issue for the UK. Utilising local energy sources rather than imports is therefore desirable. The UK imports 2000 tonnes of Uranium/ annum, costing around £100m/ annum at today's prices (£400m/annum by 2035!).

Nuclear radiation: Naturally occurring background radiation is common in many places, having little or no adverse effect on human health. In many places natural background radiation is higher than permitted exposure levels set for some of the evacuated areas around Fukushima.

The risks associated with low levels of radiation following a disaster appear to be small. However, we must acknowledge there is a huge difference between scientifically assessed risk (how insurers would wish to pay) and how the public and/or governments might decide to react to a disaster, for example, it took 30 years for the sheep grazing areas in the UK Borders region to be declared free of contamination following Chernobyl.

Regardless of evidence on risk, the reaction by people and government is likely to be extensive evacuation, potentially for decades with considerable losses both economically & socially. Extensive costs to the health service and productivity loss from the impacts of stress, relocation and fear. These cost would initially be borne by individuals and as time passes becoming increasingly socialised.

Natural disasters & infrequent geological events: There have been a number of (rare) natural disasters effecting the UK, as it is geologically stable. There is evidence of events beyond the UK's continental shelf affecting the coast. Some events are disputed and we benefit from monitoring systems. However we should acknowledge that the unexpected does occur (however small the risk). Fukushima is a good example where risks were understood but underestimated. The earthquake & tsunami were larger than the predicted maximum!

Some UK examples: The 6100 BC Storegga Slide (21m high waves in Scotland); 1014 Tsunami (Kent to Cumbria); 1580 Dover Straights earthquake; 1607 Bristol Channel Tsunami; 1755 Lisbon Earthquake (3m high wave in Cornwall).

Within the operational life of a nuclear facility (and the further 100 year on-site waste decommissioning period) a natural disaster affecting the site is small. However when the consequences are potentially so large unforeseen events should be given extra weight when deciding on new nuclear or alternatives.

Options for Replacing Nuclear Base Load

There are a number of renewable technologies that can provide base-load generation, some already used in the UK. New base-load potential sources include tidal current, tidal lagoon and geothermal, while existing technologies include biomass[5] (various forms) and energy from waste, currently provide 8.5% and 1% of the UKs electricity respectively. Energy from waste will be limited due to availability of feed-stock, while bio-mass requires either a reliance on imports or a repurposing of some land to forestry.

Other renewables (2015) provided 16.5% of UKs electricity (12% wind, 2% Solar, 2.5% hydro). The proportion of generation from renewables continues to rise. Further renewables coupled with storage and demand management has the potential to provide the majority of electrical power for the majority of the time.

Base-load generation options, which can also adjust supply during demand peaks (unlike nuclear), are: Geothermal; Tidal Lagoons (tidal barrages might be an option but to date the environmental cost appears too great) and Tidal Current technologies. A brief summary on their potential is provided below:

[5] Biomass is a net CO_2 emitter and at a large scale will require extensive UK reforestation to avoid even more extensive imports.

Geothermal

Potential	7.5%-12.5%[6] (UKs total electrical energy needs)
Load factors	>90%[7]
Levelised cost of energy[8]	£63/MWh to £102/MWh (electricity only)
	£9/MWh to £55/MWh (combined heat and power)
Maturity of technology	11.5GW globally, used widely in a few countries. Skills gap is small for early projects.
Other benefits	Provision of heat for industrial/ domestic demand.
Risks	The risks are small, localised, similar/ lower than gas power without storage and transport risks.

Tidal Lagoons

Potential	5%-8%[9] (UKs total electrical energy needs)
Load factors	20%-24%[10]
Levelised cost of energy	£100[11]
Maturity of technology	Low technology risks, hydro is a mature industry. First commercial hydro was 1879, thousands plants globally. Construction of dams, sea walls, etc. established, skills readily available.
Other benefits	Lagoon infrastructure 120+ year service life. Low cost energy for 85+ years beyond the CfD??.
	Lagoons can provide new jobs in other industries, e.g. fish and oyster farming, leisure and tourism.
Risks (Tidal lagoons)	Environmental concerns such as, animal habitats, requiring careful site selection and mitigation measures for fish, marine mammals and birds.

Tidal Current [12]

Potential	7.5%-10%
Load factors	25%-30% [6]
Levelised cost of energy	£200/MWh (2017) falling to £120/MWh (2025-30)[13]
Maturity of technology	Early in cycle, 3-5 year operational history. Next step is small arrays. Confidence achievable over 3-5 years. Mature cost timescale 10-15 years.
Other benefits	Siting in proximity to lagoons, potential to share grid infrastructure (tidal current generates in high flow, while lagoons generate at high and low water, i.e. they have counter cycle.
Risks	Environmental, marine mammals, fish, fishing leisure activities, shipping. Manageable with care.

Combination of: Biomass; landfill and sewer gas; waste to energy; AD[14]

Potential	10%-15% from domestic resources - requires investment in forestry.
Load factors	>70%, similar to thermal plants achievable.
	Or biomass etc. could be used for power system balancing (lower utilisation, higher value).
	Has potential to provide renewable local heat.

6 Based on DECC's October 2013 study and Atkins' Deep Geothermal Review Study Final Report, 2013
7 In Iceland load factors are around 95%, technology provides 25% electrical energy
8 Information source: DECC's 2012 report "Electricity Generating Costs" using low to central CAPEX examples and assuming a mature industry can be developed reasonably rapidly.
9 Potentially higher but finding sites without environmental impact may limit opportunities.
10 Individual lagoons do not provide base load, it requires distribution of lagoons around the coast taking advantage of the changing tides times.
11 Volume weighted over three projects, 35 year CfD. Energy cost for later projects £92/MWh (close to new nuclear). Source: Poyre "Levelised Costs of Power from Tidal Lagoons" March 2014; DECC Wiki calculator.
12 Information source: Various manufactures, DECC Wiki calculator.
13 Cost reduction will depend on rates of deployment and commitment to the technology.
14 Anaerobic Digestion

Levelised cost of energy[15]	Amalgamated rate of around £100/ MWh. £65/ MWh for landfill & sewer gases. up to £120 for dedicated biomass.
Maturity of technology	Mostly reasonably mature technologies. On-going innovation in many areas.
Other benefits	Reforestation, biodiversity and some decarbonisation (as the forests grow). Alternative revenues for rural economies. Reduction of waste going to landfill. Reforestation has benefits & the fuel could be used for alternative energy uses such as heat, CHP or electricity peaking plants, replacing extracted hydrocarbons.
Risks	Commensurate with traditional thermal generation. New growth forest used for biomass generation is not a zero carbon cycle. Carbon emissions from biomass generation will make an ultra low carbon economy more difficult. Further carbon emissions created from forestry, transportation and processing.

[15] Information source – Various including DECC

Summary

There are alternatives to new nuclear to provide base-load generation in the UK from renewable sources at a comparable levelised cost of energy.

The timescales to bring alternative base-load generation on-line are comparable or shorter that new nuclear, with the exception of reforestation.

21st Century society should not be imposing costs on future generations, nor should we be part of the system that imposes environmental damage elsewhere.

Larger nuclear generators will increase the requirements for spinning reserve and other grid services adding to socialised costs and CO_2.

The renewable base-load technologies (existing or achievable) have the potential to supply between 30% and 45% of the UK's electrical energy needs. Power from these sources is dispatchable and all have some ability to manage demand peaks.

The technologies can share infrastructure, such as grid connections, to lower costs. Some (geothermal and biomass) provide opportunities to supply heat locally (an often overlooked aspect of the decarbonisation problem).

These energy sources will be more distributed than super-sized nuclear facilities, providing opportunities for greater local involvement including investment, supply chain and employment.

All energy sources have their strengths and weaknesses, so policy development is about the relative risks and benefits of the technology types and the mix. The UK has the resources to become a net exporter of energy, where the resources used are almost entirely renewable. Interconnectors and demand management will play a role in balancing the system in a highly cost effective manner.

Biomass would result in the requirement to alter some land use from food potential to forest. However currently 5% of agricultural land is set aside, i.e. maintained as agricultural land but not used for crops. It would therefore appear that there is some headroom on land availability for biomass production without affecting food production, with the additional benefit of increasing total UK biomass, meaning the extraction of some CO_2 from the atmosphere.

However small the probability of a major disaster we should not ignore the fact that there is the potential for massive environmental and social harm.