2023-06-06 Nuclear Power Has No Future **Gordon Taylor**

Summary

The first section shows that nuclear fuel may be effectively exhausted before 2050, when the climate targets should be met. The second section shows that the costs of nuclear power have risen over time, and are now uncompetitive. So nuclear power must be replaced by sustainable and affordable options such as energy savings and renewables like wind, solar and storage. The third section shows that nuclear power conflicts with energy savings and renewables, so impairing the business case and deterring investment. So the UK should phase out nuclear power and join the rest of the world in deploying energy savings and renewables.

1) Nuclear fuel is running out

The UK has formed a nuclear fuel alliance with US, Canada, Japan and France. [1] This recognises that the world uranium fuel supply stands to lose the 58% that came from Kazakhstan, Uzbekistan and Russia in 2021. [2] The West is still scared to apply sanctions on Russian nuclear fuel. [3] [4] But they cannot prevent Putin from embargoing it. Nor can they affect the amount or distribution of uranium ore in the earth's crust.

As uranium is depleted, extraction moves to the remaining ores, which are almost always leaner. This requires more dirt to be moved to access the uranium ore by surface or deep mining. It also moves from soft to hard uranium ores, which require more energy to mine and to refine by crushing to dust, for separation. Uranium can also be extracted by chemical leaching, but this can take several years. It can also leave severe environmental problems. [5]

The world uranium supply is documented in periodic ‘Red Books’ but the quantities are highly uncertain. [6] [7] ‘More than 85% of uranium is produced in six countries: Kazakhstan, Canada, Australia, Namibia, Niger, and Russia’. [8] After mining and refining to ‘yellowcake’ in the country of origin, this is converted to a gas and enriched in U235, from 0.7% to between 3% and 5% for most reactors. The UK has an enrichment capability at the jointly owned Urenco plants at Capenhurst. [9] The fuel is then formed into cylindrical pellets and enclosed in metallic ‘cans’ or fuel rods, at the Westinghouse-owned plant at Springfields for loading into the nuclear reactor. [10]

Storm van Leeuwen found that with no growth of nuclear power, the decreasing ore grade of uranium would cause the CO2 emissions of nuclear power to exceed that of gas-fired power by about 2075. [11] If the world uranium supply is reduced by even 50% by sanctions or embargos, this point would be reached before 2050, and the West could lose all nuclear electricity.

All the nuclear power plants in use and under construction would become stranded assets, incapable of servicing their debts. For those in use, much of the steel and concrete would be radioactive, and could not be recycled. Instead they would add to the nuclear waste that requires storage away from humans, some for a very long time.

The proven technical options for extending or alternative nuclear fuels are very few.
One is to increase the burnup of uranium fuel. Current practice is about 45 Gwd/MtU, and fuel vendors offer about 62 Gwd/MtU. [12] However, fuel for higher burnup requires higher enrichment, and thus more uranium resource. The overall effect of raising the burnup from 50 to 100 Gwd/MtU ‘has only a modest impact on natural uranium requirements’. [13]

Another is to recycle spent fuel to produce plutonium oxide. This is added to uranium oxide fuel, to produce Mixed Oxide fuel (MOX). Spent fuel contains over a hundred radionuclides and is highly radioactive. This makes reprocessing it very dangerous. The plutonium oxide is also very dangerous to humans, both chemically and radiologically. Sellafield (UK) used to operate a Thermal Oxide Reprocessing Plant (THORP), but this leaked, lost very considerable sums of money and was shut down. [14]
The fuel cycle cost with MOX was five times higher for US conditions, but parity is possible under other conditions. [15]
Mixed oxide (MOX) fuel provides almost 5% of the new nuclear fuel used today and fuels about 10% of France's fleet. [16]

Assuming that the UK could build one 3 GW nuclear power plant every five years, building Sizewell C and six more to total 24 GW as proposed in ‘Powering Up Britain’ [17] , would take until 2058. They should operate for up to 60 years, requiring uranium fuel until 2118. Yet the UK could never outbid the US, China and India, or even France who is, and Japan who wants to be, highly dependent on nuclear electricity.

Due diligence demands that enough uranium nuclear fuel for the design operating lifetime of every nuclear power plant – including in the UK - be verified before ordering. Otherwise the sustainable options of energy savings and renewables, notably wind and solar power and long duration storage, should be adopted.

2) Nuclear Power is Uncompetitive

The UK has long proved itself incapable of building power plants to time and cost, especially nuclear. [18] Yet the UK is faced with a poor choice of nuclear power plant suppliers. Russia and China are presumably excluded. [19] Westinghouse went bankrupt in 2017, and the AP1000 line came under Chinese ownership. [20] The ABWR has a record of cost overruns and poor availability. [21] EdF built an EPR as Hinkley Point C and is due to build another as Sizewell C, but has problems in Finland and France. [22] There are twelve South Korean OPR-1000 plants, and variants that have yet to be built. [23] So the ABWR is unlikely, the EPR is very costly, and the OPR-1000 family uncertain. [24]

Nuclear power plants are very complex, subject to weather and component delays, with little opportunity for learning from series production. Instead they are liable to specification creep due to safety concerns arising after the design and evaluation. This causes negative learning, where costs increase even as deployment increases. [25] So most new nuclear power plants exhibit huge delays and cost overruns. EdF has already shown this with the EPRs in Olkiluoto, Finland, Flamanville, France, and Hinkley Point C, UK. [26]

Professor Bent Flyvbjerg of Oxford University has found that nuclear power and nuclear waste projects are amongst the worst for time and cost overruns and for performance not being achieved. 'Such projects must be 100% complete before they can deliver benefits: Even when it's 95% complete, a nuclear reactor is of no use'. [27] 'Nuclear power plants are one of the worst-performing project types in my database, with an average cost overrun of 120 percent in real terms and schedules running 65 percent longer than planned. Even worse, they are at risk of fat-tailed extremes for both cost and schedule, meaning they may go 20 or 30 percent over budget. Or 200 or 300 percent. Or 500 percent. Or more. There is almost no limit to how bad things can get, as Monju demonstrated so spectacularly'. [28]

Nuclear power is now so costly that almost no-one will finance it except autocratic states like Russia, China and India. The funding problems for Hinkley Point C are far from over. [29] Also, the UK will have trouble funding even Sizewell C beyond the £ 700 million already promised by the government. [30] Yet the UK government is proposing to impose more nuclear power and to finance it via a so-called 'Regulated Asset Base' model, charging all electricity consumers without their being asked. [31]

That Hinkley Point C could provide 3,200 MW is not a virtue, but 'too many eggs in one basket'. With two generators side by side, many common-mode failures could occur. So the UK Short Term Operating Reserve (STOR) should be increased to 3,200 MW. But Dinorwig of 1800 MW was built with the penstock pipes and turbine hall inside a mountain, and took 10 years. [32] Without a STOR of 3200 MW, any unplanned outage of Hinkley Point C would subject the GB grid to massive blackouts. So an increase in UK STOR capacity to 3200 MW is part of the cost of building such large nuclear power plants.

Small Modular Reactors

The government has great hopes for Small Modular Reactors. [33] However, Michael Barnard has noted: "They don't solve any of the problems that they purport to while intentionally choosing to be less efficient than they could be. They've existed since the 1950s and they aren't any better now than they were then." [34] "Data on the current costs of small modular nuclear reactors (SMR) is starting to roll in. As a result, it's now possible to make some projections of how long it would take for their costs to drop to the level of renewables today. The results aren't good for SMRs." [35]

Moreover, Krall et al have found: 'SMRs will not reduce the generation of geochemically mobile 129 I, 99 Tc, and 79 Se fission products, which are important dose contributors for most repository designs. In addition, SMR spent fuel will contain relatively high concentrations of fissile nuclides, which will demand novel approaches to evaluating criticality during storage and disposal. Since waste stream properties are influenced by neutron leakage, a basic physical process that is enhanced in small reactor cores, SMRs will exacerbate the challenges of nuclear waste management and disposal.' [36]

The laws of physics, chemistry and thermodynamics show that SMRs would cost more money and carbon emissions than current nuclear power plants and their electricity would be more expensive.

UK electricity consumers and tax-payers must receive a full prospectus on nuclear power, and on renewable alternatives, before being asked to invest. Due diligence requires recognition of the respective risks of cost and time overruns, and of performance shortfalls, including that due to nuclear fuel depletion.

3) Nuclear Power Would Block Our Renewable Future

There is a fundamental conflict between nuclear and renewable power on the same grid system. Nuclear power is usually funded by public monies in authoritarian states, by private companies operating in monopoly markets e.g. in the US or by overseas companies e.g. in the UK. It is very costly, so to recover the money and energy outlays, it is run as often as possible. As the electric load varies but is finite, this would lead to curtailing of renewable power. But this would destroy the business case of renewable power, which is usually funded by private companies, either indigenous or overseas. So they would be deterred from funding renewable power, which – apart from energy saving – is the lowest cost and fastest scalable option for meeting climate change targets. This would raise energy costs and increase carbon emissions.

Professor Bent Flyvbjerg has written '… the best-performing project types in my database, by a comfortable margin, are wind and solar power'. [37] Michael Barnard has noted: 'The natural experiment of renewables vs nuclear continues in China, and it continues to unfold in renewables' favor'. [38] The Flyvbjerg database of over 16,000 projects provides powerful evidence in favour of renewables, with which this 'natural experiment' is consistent.

Adding any nuclear power when significant wind and solar power is already present would be counter-productive. Wind farms in the UK already receive compensation when their output is curtailed due to lack of transmission capacity. 'The cost of curtailing wind generation in 2021 hit a record high, costing Britain £507 million. This is up from £299 million in 2020, bringing the total cost of curtailing wind over the last two years to £806 million'. [39] So wind and solar farms would require similar compensation if curtailed due to nuclear power.

Curtailing of wind and solar would be even more counter-productive when they are expected to provide three-quarters of UK electricity, as well as much heat and transport fuels, and to be privately funded, largely from abroad. Nuclear power plants are much harder to fund because the projects are larger, they take much longer to build, and as Flyvbjerg has noted, are at great risk from cost and time overruns. [40] Yet the government hopes nuclear power will provide a quarter of UK electricity by 2050. [41]

24 GW of nuclear power would require the UK to build Sizewell C and six more of 3 GW, and with construction times of five years would take until 2058. So for 'True Zero' by 2050, wind and solar would then have to provide more than three-quarters of UK electricity. Storm van Leeuwen found that with no growth of nuclear power, the decreasing ore grade of uranium would cause the CO_2 emissions of nuclear power to exceed that of gas-fired power by about 2075. [42] If the world uranium supply is reduced by even 50%, this point would be reached before 2050 and wind and solar would have to provide all UK electricity thereafter. If the UK opts for 'Net Zero' by 2050, the GHG emissions of any gas-fired electricity would have to be offset by Carbon Capture and Storage. This has yet to be proven at scale, and would certainly be costly.

The modelling for 'Powering Up Britain' shows two scenarios – High Nuclear and Low Nuclear. [43] But using only end points is not sufficient as populations, energy demand and depletable fuel supplies continually change. Instead, system dynamics should be used to represent the transition, as was done in the seminal Limits to Growth study of 1972. This remarks: 'As resource prices rise and mines are depleted, more and more capital must be used for obtaining resources, leaving less to be invested for future growth'. [44] Thus the provision of uranium nuclear fuel would require significant outlays by the UK, either as capital invested directly beforehand, or for later purchases of nuclear electricity at premium prices as for Hinkley Point C. [45] Yet while the 'Powering Up Britain' modelling included considerable wind and solar power, it excluded long duration storage. [46]

In the Ministerial Foreword to Powering Up Britain, Grant Shapps said: 'Revenue models, financing mechanisms and market frameworks: in emerging sectors we are establishing clear market frameworks (including through the Energy Bill), so the private sector can invest with confidence. This includes revenue models that give investors more certainty about the returns they will make: from CfDs and business models for hydrogen, through to the Nuclear Regulated Asset Base (RAB) model and models for CCUS. To complement this, our green finance policy framework seeks to ensure sufficient private capital is available to finance our net zero objectives'. [47]

However, this fails to take note of Flyvbjerg's evidence that nuclear projects are far riskier than wind and solar. They would also add to the costs of the liabilities of nuclear power, and of nuclear decommissioning and waste storage, that are already borne by the public purse. [48] [49] Following the nuclear disaster at Fukushima, a German study found the hypothetical mean total payable sum insured for a nuclear disaster to be around 6090 billion euros. [50] Also Chancellor Merkel of Germany set up an Ethics Commission for a Safe Energy Supply. [51] So Germany, with it's large and successful manufacturing sector, has phased out nuclear power. [52] It has joined the vast majority of states worldwide that are non-nuclear and deployed even more wind and solar power.

4) Conclusions

The UK must plan properly for a secure and sustainable energy and climate future. This requires modelling using system dynamics and funding based on full disclosure of the risks and costs. The evidence shows that wind and solar power and long duration storage can meet the short-term security and long-term sustainability targets, but that nuclear power cannot.

Gordon Taylor, B.Sc., M.Sc., M.I.Mech.E.
Chartered Mechanical Engineer
19 The Vale, Stock, Ingatestone, Essex, CM4 9PW
Tel: 01277 840569
Email: gordon@energypolicy.co.uk
Web: http://www.energypolicy.co.uk

1 2023-04-16 UK forms nuclear fuel alliance with US, Canada, Japan and France, https://www.independent.co.uk/business/uk-forms-nuclear-fuel-alliance-with-us-canada-japan-and-france-b2320708.html
2 List of countries by uranium production, https://en.wikipedia.org/wiki/List_of_countries_by_uranium_production
3 2023-02-16 EU Commission scratches Russia nuclear sanctions plans, https://www.politico.eu/article/rosatom-russia-ukraine-volodymyr-zelenskyy-vladimir-putin-eu-executive-scratches-russia-nuclear-sanctions-plans/
4 2023-03-07 The West hasn't gone after Russia's nuclear energy. Here's why, https://edition.cnn.com/2023/03/06/energy/russia-nuclear-industry-no-sanctions/index.html
5 2023-04-13 Uranium mining, https://en.wikipedia.org/wiki/Uranium_mining
6 2009-09-08 The Future of Nuclear Energy: Facts and Fiction, Chapter III: How (un)reliable are the Red Book Uranium Resource Data?, https://arxiv.org/pdf/0909.1421.pdf
7 2023 Uranium 2022: Resources, Production and Demand, https://www.oecd-nea.org/jcms/pl_79960/uranium-2022-resources-production-and-demand?details=true
8 The Mining of Uranium, https://world-nuclear.org/nuclear-essentials/how-is-uranium-made-into-nuclear-fuel.aspx
9 Urenco UK, https://www.urenco.com/global-operations/urenco-uk
10 2021-08-24 Nuclear fuel manufacturing in the UK, https://commonslibrary.parliament.uk/research-briefings/cdp-2021-0134/
11 2017-10-23 Climate change and nuclear power: An analysis of nuclear greenhouse gas emissions, Storm van Leeuwen, https://wiseinternational.org/sites/default/files/u93/climatenuclear.pdf Fig. 10
12 Higher Burnup, https://www.nrc.gov/reactors/power/atf/burnup.html
13 2003-09 Nuclear Fuel Cycles for Mid-Century Deployment, Etienne Parent, http://dspace.mit.edu/bitstream/handle/1721.1/17027/54495851-MIT.pdf Page 15
14 Thermal Oxide Reprocessing Plant, https://en.wikipedia.org/wiki/Thermal_Oxide_Reprocessing_Plant
15 2003-09 Nuclear Fuel Cycles for Mid-Century Deployment, Etienne Parent, http://dspace.mit.edu/bitstream/handle/1721.1/17027/54495851-MIT.pdf Page 116
16 Mixed Oxide (MOX) Fuel, https://world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/mixed-oxide-fuel-mox.aspx
17 2023-04-04 Powering Up Britain, https://www.gov.uk/government/publications/powering-up-britain/powering-up-britain
18 2017-11-07 Why does Britain struggle to build power plants?, https://citymonitor.ai/community/why-does-britain-struggle-build-power-plants-3311
19 2022-02-21 China and Russia cannot be trusted on UK nuclear projects, Parliament told, https://www.gbnews.com/news/china-and-russia-cannot-be-trusted-on-uk-nuclear-projects-parliament-told/231242
20 AP1000, https://en.wikipedia.org/wiki/AP1000
21 Advanced boiling water reactor, https://en.wikipedia.org/wiki/Advanced_boiling_water_reactor
22 2022-01-12 Hinkley Point developer hit by new setback with French nuclear reactor, https://www.telegraph.co.uk/business/2022/01/12/fresh-delay-french-nuclear-reactor-shares-design-hinkley/
23 OPR-1000, https://en.wikipedia.org/wiki/OPR-1000
24 2021-04 Advanced Nuclear Power Reactors, https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/advanced-nuclear-power-reactors.aspx
25 2010-09, The costs of the French nuclear scale-up: A case of negative learning by doing, A. Grubler, https://www.sciencedirect.com/science/article/abs/pii/S0301421510003526 Fig. 13.
26 2022-05-19 New one year delay at UK Hinkley Point nuclear plant: EDF, https://www.france24.com/en/live-news/20220519-new-one-year-delay-at-uk-hinkley-point-nuclear-plant-edf
27 2021-12-14 Make Megaprojects More Modular, Bent Flyvbjerg, https://www.researchgate.net/publication/355444633_Make_Megaprojects_More_Modular
28 2023-02-07 How Big Things Get Done: The Surprising Factors Behind Every Successful Project, from Home Renovations to Space Exploration, Bent Flyvbjerg and Dan Gardner, https://www.amazon.co.uk/How-Big-Things-Get-Done/dp/0593239512 This has 284 pages, including a Bibliography and Index. Page 158.
29 2023-02-17 Britain's flagship nuclear plant scrambles to avoid cash crunch, https://www.telegraph.co.uk/business/2023/02/17/race-prevent-cash-crunch-flagship-nuclear-power-plant/
30 2022-11-29 Sizewell C nuclear plant go-ahead confirmed with £700m public stake, https://www.belfasttelegraph.co.uk/news/uk/sizewell-c-nuclear-plant-go-ahead-confirmed-with-700m-public-stake/42181461.html
31 2021-10-26 Future funding for nuclear plants, https://www.gov.uk/government/news/future-funding-for-nuclearplants
32 Dinorwig Power Station, https://www.nsenergybusiness.com/projects/dinorwig-power-station/
33 2023-03-30 Powering Up Britain, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1147340/powering-up-britain-joint-overview.pdf Page 7.
34 2023-01-18 The Nuclear Fallacy: Why Small Modular Reactors Can't Compete With Renewable Energy, Michael Barnard, https://cleantechnica.com/2023/01/18/the-nuclear-fallacy-why-small-modular-reactors-cant-compete-with-

renewable-energy/
35 2023-03-28 Shovelling Money Into Small Modular Reactors Won't Make Their Electricity Cheap, Michael Barnard, https://cleantechnica.com/2023/03/28/shoveling-money-into-small-modular-nuclear-reactors-wont-make-their-electricity-cheap/
36 2022-03-17 Nuclear waste from small modular reactors, Krall et al, https://www.pnas.org/doi/pdf/10.1073/pnas.2111833119
37 2023-02-07 How Big Things Get Done: The Surprising Factors Behind Every Successful Project, from Home Renovations to Space Exploration, Bent Flyvbjerg and Dan Gardner, https://www.amazon.co.uk/How-Big-Things-Get-Done/dp/0593239512 This has 284 pages, including a Bibliography and Index. Page 155
38 2023-02-06 Renewables in China Trend Upwards While Nuclear Trends Flat, by Michael Barnard, https://cleantechnica.com/2023/02/06/renewables-in-china-trend-upward-while-nuclear-trends-flat/
39 2022-06-08 Cost of wind curtailment hits record high of £507m in 2021, https://www.current-news.co.uk/cost-of-wind-curtailment-hits-record-high-of-507m-in-2021/
40 2023-02-07 How Big Things Get Done: The Surprising Factors Behind Every Successful Project, from Home Renovations to Space Exploration, Bent Flyvbjerg and Dan Gardner, https://www.amazon.co.uk/How-Big-Things-Get-Done/dp/0593239512 This has 284 pages, including a Bibliography and Index. Page 173
41 2023-03-16 Jeremy Hunt wants nuclear power classed as 'sustainable': is it?, https://www.theguardian.com/environment/2023/mar/16/jeremy-hunt-wants-nuclear-power-classed-as-sustainable-is-it
42 2017-10-23 Climate change and nuclear power: An analysis of nuclear greenhouse gas emissions, Storm van Leeuwen, https://wiseinternational.org/sites/default/files/u93/climatenuclear.pdf Fig. 10
43 Powering Up Britain: Net Zero Growth Plan and Carbon Budget Delivery Plan - analysis methodology (Technical annex), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1147366/powering-up-britain-technical-annex.pdf Page 22
44 1972, 'The Limits to Growth', Meadows et al. http://www.donellameadows.org/wp-content/userfiles/Limits-to-Growth-digital-scan-version.pdf Page 125
45 Hinkley Point C nuclear power station, https://en.wikipedia.org/wiki/Hinkley_Point_C_nuclear_power_station Cost to consumers
46 Powering Up Britain: Net Zero Growth Plan and Carbon Budget Delivery Plan - analysis methodology (Technical annex), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1147366/powering-up-britain-technical-annex.pdf Page 26
47 2023-04-04 Powering Up Britain, https://www.gov.uk/government/publications/powering-up-britain/powering-up-britain
48 Department for Business, Innovation and Skills resource accounts 2009-10: including the consolidated resource accounts for the year ended 31 March 2010 (HC 211, Session 2010-11), Presented to Parliament 26 July 20, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/31923/10-p102-bis-resourceaccounts-2009-10.pdf Page 171
49 2022-09-23 UK's nuclear waste cleanup operation could cost £260bn, https://www.theguardian.com/environment/2022/sep/23/uk-nuclear-waste-cleanup-decommissioning-power-stations
50 2011-04-01 Calculating a risk-appropriate insurance premium to cover third-party liability risks that result from operation of nuclear power plants, Versicherungsforen Leipzig GmbH, https://www.versicherungsforen.at/portal/media/forschung/studienundumfragen/versicherungsprmiefrkkw/20111006_NPP_Insurance_Study_Versicherungsforen.pdf
51 2011-05-30 Germany's energy transition – A collective project for the future, Ethics Commission for a Safe Energy Supply, https://www.bmuv.de/en/download/germanys-energy-transition-a-collective-project-for-the-future
52 2023-04-16 Germany ends nuclear era as last reactors power down, https://www.euractiv.com/section/energy/news/germany-ends-nuclear-era-as-last-reactors-power-down