INTERMITTENT RENEWABLES
What are they really for?

Grid-connected intermittent renewables, such as wind and photovoltaic solar, are worse than useless. In most cases, their only function is to provide a continuing demand for fossil fuel, and to obstruct adoption of the only generating technology that can (maybe, still) save us from climate change. What you have been told about intermittent renewables is almost entirely misleading or downright untrue. Intermittents are the modern-day emperor's new clothes, but few people have yet admitted it. There is too much money to be made, and there are too many careers to be advanced by ignoring, denying or obfuscating the truth.

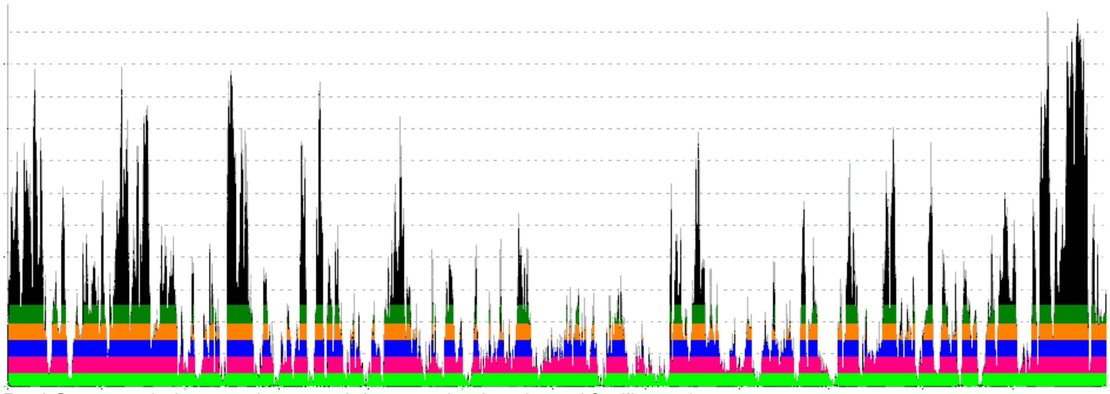
Why should you believe what I say? You shouldn't! Not unquestioningly or uncritically, at least. I don't hope to prove anything or immediately persuade anyone with this document alone. Ideally, you should do as much checking as you can using basic research techniques, simple arithmetic and open-minded enquiry. Then, you need to tell the world whatever you have concluded. Of course, you won't ever reach complete certainty, unless you dedicate the rest of your life to re-doing the calculations and grinding research of hundreds of appropriately trained people. But please try, because the future of the world depends on your getting it right and then persuading everyone else to get it right. So, no pressure…

The start of my story. In the early 1990s, I started to worry about climate change. In those days, we were told (wrongly) that a certain particular level of annual emissions of greenhouse gas from fossil fuel would be tolerable to the biosphere for ever. But, it was obvious that virtually no one in the developed world was willing to change their lifestyle to reduce their rate of emissions to that level. A Cambridge physics professor, David MacKay, wrote a popular book which explained how little electrical power to expect from intermittent renewables like wind, solar panels, and similar sources. An authoritative organisation, namely WWF, also published a report which stated that nuclear power was not a feasible solution. The amount of greenhouse gas released in making and handling nuclear fuel was, it told us, so high that nuclear power was little better than fossil fuel. Looking back, I must have been gullible to believe such assertions from the WWF. Why, after all, would civil nuclear power bother to exist if it used so much fossil energy to operate? But, at the time, I just believed what I was told. None of the existing energy generating technologies was viable, it appeared. I therefore concluded that we were doomed. Later, I learned that the atmosphere cannot indefinitely cope with significant emissions of fossil-derived greenhouse gas, and later still I understood that we must remove greenhouse gas from the atmosphere because we have put far too much there already. We were, it seemed, even more doomed.

I don't remember where I first learned that the WWF claim about nuclear power emitting lots of greenhouse gas was wrong. Dramatically wrong. Rather, nuclear power emits almost no greenhouse gas at all other than the fairly small amount released in building the power station from concrete and steel. Apparently, it suddenly seemed, we were not doomed. Not already, and not necessarily, at least. And also, apparently, nuclear was safe, and non-polluting, and almost entirely benign in all the other ways that a generating source can be or not be benign. In truth, though, all I cared about was the not being doomed bit. Being not doomed is just so brilliant that it seems petty to bother about other, more trivial stuff.

Other people did not feel the same way. They had spent decades not liking nuclear. Despite David MacKay's solidly researched book, recent years had seen almost everyone get more and more enthusiastic about wind, solar, and other intermittent renewables. The word "renewables" had started to find its way into serious institutional and government documents that committed us to their widespread adoption. The term "renewables" rather than something more relevant like "low carbon" was chosen, presumably, explicitly to exclude lower carbon but non-renewably-fuelled (as it was in those days) nuclear power.

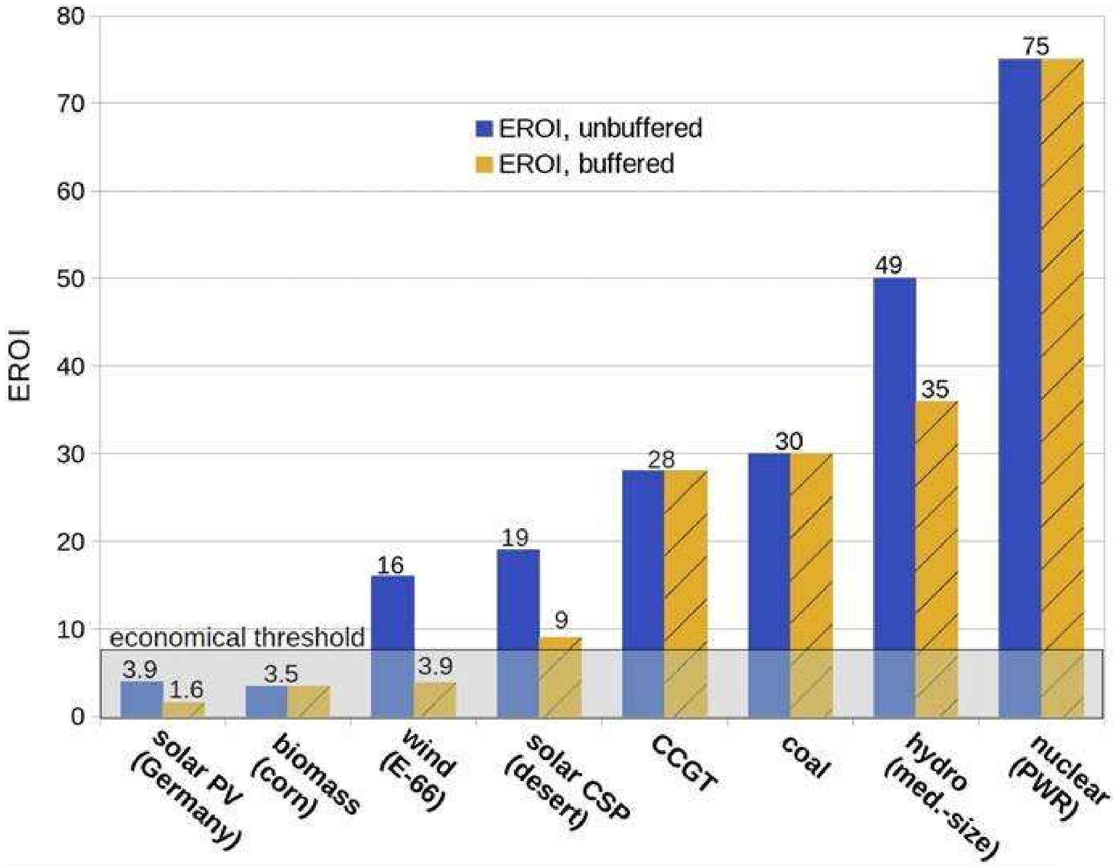
What's wrong with intermittents? Well, for one thing, what any electricity grid needs above all is energy sources that can be trusted to supply however much power the customers might demand at any particular moment. In contrast, one characteristic of intermittents is, obviously, that they are intermittent. This wasn't something David MacKay bothered to comment on much in his book - he mainly based his calculations on the mean (average) power that energy sources produced. In those days, of course, what superficially seemed to be required was some low-carbon electricity generating technology that could replace some of the fossil-fuelled generating stations already in use and thereby reduce our total emissions. Things like wind and solar could do that, at least in theory, with the remaining fossil-fuelled generators coping with the remainder of the demand. Most people did not understand that our fossil emissions had to stop almost completely, so reliable fossil-fuelled generators would have to go. After that, unless electricity could somehow be stored or unless customers could be persuaded to want only whatever happened to be available, the grid would fail. In reality, despite financial inducements, there is a limit to electricity consumers' ability to tailor their demands to continuously match the quantity of electricity being produced by such erratic sources as the wind, sun, or tides. Nor can a modern industrial society survive and compete under such conditions. Across the UK, construction of wind turbines and installation of photovoltaic solar panels was therefore justified increasingly on the grounds that grid-scale electricity storage would soon be practical, as soon as some technology had been invented to do the job. Of course, we live our lives surrounded by technologies that have been invented, developed, and made affordable and practical, so it can be tempting to assume that anything we want will eventually appear. We tend not to notice the absence of technologies, like time travel, that haven't made the grade or are simply impossible. Grid-scale electricity storage might not, strictly speaking, be physically impossible, but the chance of it occurring affordably and reliably, even in the richest countries, is essentially zero. Nor, on inspection, is the need for storage as trivial as usually suggested. Storing enough electricity for one day, even if it were practical, would not enable Europe to survive an almost windless winter fortnight, nor allow anywhere to cope with several consecutive years of energy harvests significantly above or below whatever is required. It seems likely that, if storage were feasible, enough electricity for at least a whole year of normal use would need to be stored in order to continue a fairly normal grid service, plus enough other energy for a similar period of non-grid use (like vehicle fuel). Even this would not ensure that the storage did not ever either run dry or overflow, but it would reduce the probability and frequency of such occurrences and the severity of their consequences, and it would allow some time for production or use of energy to be adjusted.


Real German wind energy harvested data, randomly coloured for illustration.

Wind supplies much of the UK's intermittent energy. Wind power varies so greatly (theoretically as the cube of wind speed) that it would never be practical to store or use it all. The most nearly continuous power, shown by coloured bands nearest the bottom of the chart, would probably usually have some potential value despite being occasionally interrupted. Coloured bands progressively higher up would only be useful for applications with progressively high electricity demand and progressively low financial or resource overheads. The most infrequent electricity, illustrated by an area shown in black on the chart, would be prohibitively expensive to use because the plant to use or store it would stand idle so much of the time and would so seldom be used. The black area on the chart is intended only as an illustration and has not been calculated, but it is apparent that the amount of energy discarded for this reason is always likely to be a significant proportion of all the wind energy collected.

Ignoring, for now, the problems of storage, how about the scale of energy production from intermittent renewables? That was, surely, the issue that David MacKay's book was intended to highlight. Wind turbines and photovoltaic solar panels do make electricity, but most of the time they do it in extremely small quantities. Of course, that can be dealt with by simply building such generators in astonishing, perhaps absurd, quantities. Not all countries have the resources, like available space, or sun, or wind, or money, to do that. But, by siting wind turbines expensively in seas around the coast, the UK actually can do that. And, although it is a subject of debate, perhaps the world can mine and refine enough minerals for the world's intermittent renewables hardware. So, does that solve the quantity problem?

Here we get into murky questions, with even more illusive answers. Energy Returned on Energy Invested (ERoEI or EROI) is a theoretical measure of how many times as much energy comes out of an energy generating technology as goes into building, maintaining, and eventually disposing of it. An ERoEI of one is obviously pointless. An ERoEI of some small number like 2 would probably be sufficient for a hand-to-mouth subsistence society with no sophisticated manufacturing and no institutional structures for healthcare, culture, government, or other basic services. A society like ours clearly needs a much higher ERoEI, arguably of about 7. But, in truth, calculating such requirements with any confidence is too difficult. Nevertheless, we should wonder, what ERoEI is achievable with rather diffuse and inconvenient energy sources like wind or solar? Disregarding the problems caused by intermittent generation, the ERoEI for wind turbines is argued by one source to be about 16 and that of solar photovoltaic is said to be less than 4.

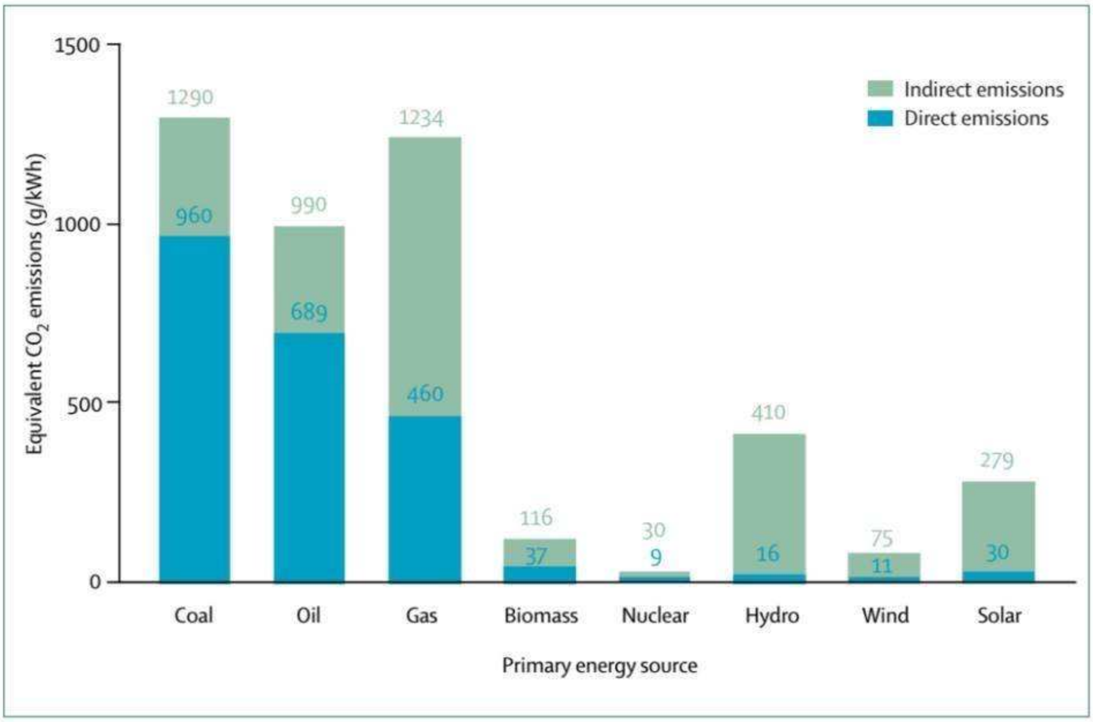


Energy Returned on Invested, from Weißbach et al.,1 with and without energy storage (buffering). CCGT is closed-cycle gas turbine. PWR is a Pressurized Water (conventional nuclear) Reactor. Energy sources must exceed the "economic threshold", of about 7, to yield the surplus energy required to support an OECD level society.

Taking intermittency into account by including the efficiency reductions resulting from discarded energy and hypothetical storage of some kind, the ERoEI figure, regardless of source, inevitably gets much lower. For this, a resultant effective ERoEI below 4 is said to be likely for wind and 1.6 for solar photovoltaic. To my mind, even if these figures are correct, they alone are not sufficient to conclusively prove anything. However, they do certainly imply that these electricity sources cannot power our society.

100% INTERMITTENT RENEWABLES ALONE

ERoEI seems a useful concept, but its implications are imprecise. So, it is better if we use carbon intensity, which obviously really matters, as our measure. According to one assessment, intermittents add about 75 (for wind) to 279 (for solar) grammes of CO_2 equivalent to the atmosphere for every kWh of electricity they produce. This is not an especially bad figure but, if compared with nuclear, not a good one either.



Full energy chain CO2 equivalent emissions by primary energy source.

Markandya, A., & Wilkinson, P. (2007). Electricity generation and health. *Lancet*, 370(9591), 979-990. doi:10.1016/S0140-6736(07)61253-7

Also, this figure is only applicable if none of the energy produced is wasted or unused. This is not the case when a intermittent generating source is used alone to supply a grid that can tolerate no intermittency. Storage, if it were possible, would multiply the effective carbon intensity several times. Despite this, the most enthusiastic proponents of intermittents advocate a 100% intermittent renewables grid. Most of them agree that this requires huge energy storage. In the USA, they claim that existing water bodies such as irrigation reservoirs can provide much of this. However, it is difficult to see how the same reservoir can provide both irrigation whenever needed and energy storage whenever needed, and it is not clear where the water is to be stored for re-use at the lower end of its journey. The UK is unusual in having huge underground salt caverns which could be used to store artificial hydrocarbon gas made from surplus electricity, thus providing enough energy storage for several weeks of consumption. However, converting electricity to gas and back again is inefficient, with only a fraction of the original energy surviving the round trip and all the rest being lost on the way. This multiplies the carbon intensity of the stored energy by the inverse of the relevant efficiency, resulting in unacceptably high carbon emissions to the atmosphere. Of course, not all the energy generated needs to be stored, because some can be used immediately to supply the grid, but calculating how much of that could really be done is not easy. (Immediate use without inefficient conversion or storage is much less of an option for such non-grid uses as vehicle fuel, of course.) Furthermore, no physical storage system can be of infinite size. So, even if the storage never runs dry, it is eventually likely to overflow instead, further reducing efficiency and increasing carbon intensity. Probably the greatest concern should be that a 100% intermittent renewables grid will certainly not work if the gargantuan financial and resource demands of such a scheme are not fully and continuously met. In real life, it is predictable that lack of unconditional willingness to supply perpetual and unlimited resources will lead to either a spasmodically functioning grid or undesirably high fossil emissions, or both.

INTERMITTENT RENEWABLES AND HYDRO IN COMBINATION

Hydro generation or pump storage serving the grid together with intermittent renewables (or, indeed, nuclear) is, at first sight, a match born in heaven. This combination is low carbon (in the right, normally temperate, environment) and can always be quickly adjusted to provide however much power the grid requires. Unfortunately, few countries have enough suitable sites to provide for their own grids in this way, let alone any surplus which might profitably help to balance neighbouring countries' grids. The UK is lucky in having geography suitable for an increase in hydro resources, but nowhere near enough to balance the capacity of intermittent generation plant already built.

INTERMITTENT RENEWABLES AND FOSSIL FUEL IN COMBINATION

Grid-connected intermittents started to be seriously considered at a time when the objective was assumed to be a reduction in fossil fuel use, not an almost complete cessation of it. That meant fossil fuel generation could fill in the gaps left by intermittents, meaning no energy storage would be required. It was taken for granted that simply replacing some fossil fuel generation with intermittents would reduce total fossil emissions. After all, how could it not? In fact, though, as the proportion of intermittents feeding the grid increased over the years, it became apparent that rapidly varying the output power of fossil-fuelled generating plant and keeping it running in case it was suddenly needed was significantly reducing fuel efficiency. Worse, the requirement to have enough fossil-powered plant to instantly cover every weather eventuality while running most of it lightly and seldom led to fuel-inefficient, cheap, highly responsive Open Cycle Gas Turbines (OCGT) being installed instead of fuel-efficient, expensive, slow-reacting Combined Cycle Gas Turbines (CCGT). It is difficult to calculate whether the result of adding substantial amounts of intermittent renewables to the grid reduces fossil fuel use below that which would occur using gas generation alone, but it is clear that any reduction is small, if it exists at all. Certainly, since intermittents themselves have significant lifetime carbon emissions, the combination of intermittents and fossil fuel generation cannot achieve anywhere near the required virtually-zero outcome which we now know to be required.

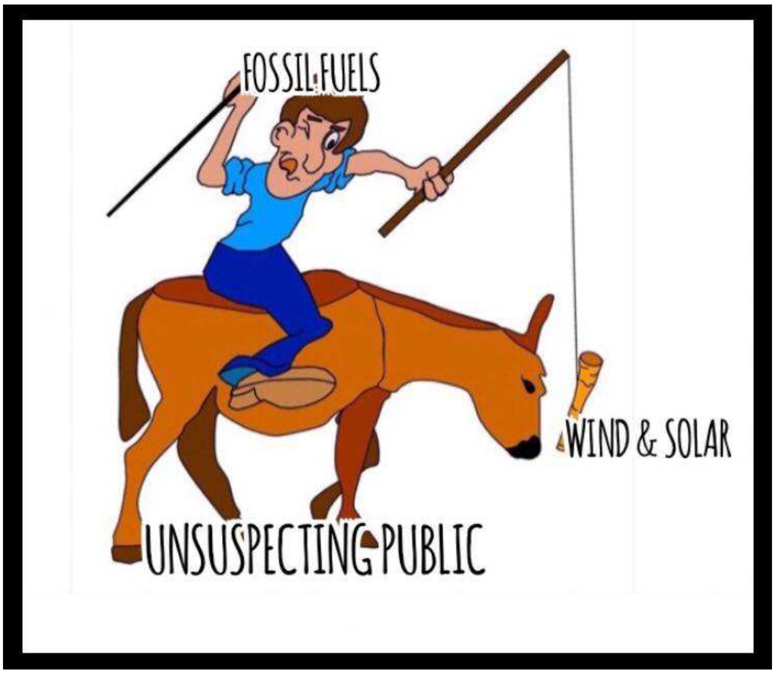
INTERMITTENT RENEWABLES AND NUCLEAR IN COMBINATION

Although intermittent renewables and gas supplying the grid together don't produce much less climate change than fossil fuel doing it alone, this combination does work financially, at least for the gas-powered generating industry (and for gas suppliers as well, of course). This is because gas is expensive stuff, whereas it is cheap (and easy and quick) to buy generating plant that runs on gas (especially OCGT). So, the gas-powered generating industry is fairly happy for its plant to stand idle whenever the wind blows and sun shines, because it avoids spending money on fuel, and not much money has been invested in plant. Nuclear is financially very different from this. A nuclear-powered generating plant may last for up to a hundred years, but building it costs a vast amount of money, which all has to be found very near the start of the project. Whoever commits to building a nuclear plant takes the risk of running out of money if anything delays the start-up date. This risk increases the rate of interest on the borrowed money, and makes the loan more difficult to arrange. Even if governments stick to their word, and anti-nuclear campaigners fail to delay the project and regulators immediately allow each stage of commissioning to proceed, the many early years of nuclear plant operation are a race to pay off the loan while continuing interest demands are added to the remaining debt. For technical reasons, existing designs of nuclear reactor cannot change their output power quickly enough to allow them to save fuel whenever sun is shining or wind blowing. Typically, the best they can do is to waste some of their power output at windy or sunny times so that spasmodic electricity from intermittents can be used (pointlessly) by the grid instead. Newer nuclear designs may be able to adjust much more quickly, but this does not help them much financially because any fuel they might save has little cost (and low environmental impact) anyway. What does cost so much money is for a nuclear plant to be there and available at all, almost regardless of how much electricity is demanded of it. Logically therefore, any nuclear plant might as well generate as much electricity as possible. Certainly, it should not keep stepping aside in order to make room for other forms of generation which have no functional reason to even exist.

To repeat this in simple terms, since a full 100% nuclear generation capacity has to exist in order to allow the grid to survive when there is no wind or sun, and since there is no real environmental or engineering or financial advantage in reducing the output power of a nuclear plant below the maximum it can continuously provide, there is consequently no point in having wind turbines, solar panels, or other intermittent forms of generation. A 100% nuclear-powered grid clearly makes much more sense (and seems to be, in fact, the only option available to us). The only significant caveat to this is that the usually very limited amount of hydro or pump storage capacity available in some countries can be used to reduce the nuclear generation capacity which must be built to slightly below 100% of maximum required grid power.

Despite such simple and inescapable logic, in many countries the officially-stated plan is for nuclear and intermittents to serve the grid together, with intermittents being allowed to sell into the wholesale electricity market whenever they have power, thus denying revenue to nuclear for the power it has to continue generating anyway. For new nuclear plants, this is a particularly obvious problem. If the nuclear plant does not get paid for the full amount of electricity which it can generate, the loan that built it is likely to be not paid off as quickly as it should be, with the total interest it must pay consequently increasing and continuing for longer. There is even a danger that the loan will never be paid off. This makes investors reluctant to lend money to build nuclear plants in the first place, and renders it difficult for potential plant builders and operators to contemplate nuclear projects. The gas supply industry knows this. We can be confident that one reason intermittents are promoted by fossil fuel interests and their financial beneficiaries (like environmental NGOs) is in order to obstruct finance for the nuclear industry (which is, of course, the fossil fuel industry's only effective competitor for grid generation). Far from being a potential climate salvation, intermittents threaten our future. As grid-connected intermittents are built or planned, finance for nuclear is consequently discouraged. The main exception to this is where governments finance their own nuclear plants or, as apparently planned in the UK, commit to paying for as much electricity as a nuclear plant can produce (although any government doing this should know better than to willingly subsidise pointless intermittents which will also compete in the electricity market). Furthermore, the threat from intermittents is long lasting. Once intermittents have been built, the market for gas to provide backup is sealed in, and nuclear is effectively sealed out. As future governments will surely see it, any change from a grid supplied by intermittents and gas to one supplied by nuclear means discarding one full gas-fuelled national generating capability, together with half an intermittents-powered generating capability, plus all the modifications made to the grid to allow this crazy partnership to function at all, and immediately taking on the full financial up-front commitment to another full nuclear-powered generating capability as well, without any useful extra electrical or financial provision or benefit resulting, except to the climate. Will they do such a thing? It seems unlikely. They will more probably carry on burning fossil fuel instead. That is why the fossil fuel industry, in particular the gas industry, loves and promotes intermittents. And it is the reason why we should not.

Tim Rickman, February 2020.
www.350.me.uk



FURTHER READING:

Unintended Consequences: The lie that killed millions and accelerated climate change
by George Erickson
Free at http://www.tundracub.com/pdfs/UC.pdf

After Fukushima: What We Now Know. A History of Nuclear Power and Radiation
by Andrew Stuart Jonson Daniels

Limitations of 'Renewable' Energy
by Leo Smith
Free at http://www.templar.co.uk/downloads/Renewable%20Energy%20Limitations.pdf

Renewable vs. Nuclear DEBATE facebook group
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