“Call me emotional, but my anti-nuclear arguments are based on evidence”

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“*Call me emotional, but my anti-nuclear arguments are based on evidence*”, writes Senator Scott Ludlam in an opinion piece in the Guardian last month. I’m certainly interested in looking for and studying this evidence, but I found Ludlam’s column a little bit lacking in good evidence. So I wanted to write down my thoughts, and my responses, and some context about how the “evidence” we’re presented with here ties into the rest of the existing evidence around this subject.

On the issue of nuclear power, for Australia or more generally, Ludlam is certainly emotional. Not that that’s wrong, or that pointing that out constitutes some sort of rebuttal. Emotion in and of itself is not bad, but as Carl Sagan noted in his 1987 essay *The Burden of Skepticism*, “*when we recognise some emotional vulnerability regarding a claim, that is exactly where we have to make the firmest efforts at sceptical scrutiny. That is where we can be had.*” Emotion, therefore, must be handled with caution and scepticism, particularly when the global ecological stakes of “being had” are high. Just like a lump of plutonium, emotion shouldn’t be feared and completely shunned, but it should be handled with appropriate care. Let’s not let this issue of being “emotional” be a distraction from the question of this supposed evidence, though. Ludlam claims this is “based on evidence”, so let’s see it. Don’t change the subject to a red herring of debating whether “being emotional” is bad.

Of course everybody always insists that their positions are “based on evidence”. Every creationist and anti-vaccination activist always insists that their own position is “evidence-based”, often as a result of the Dunning-Kruger effect and an inability to comprehend what is good-quality evidence and what is not - that not all “evidence” is equal. There’s often a strong conspiracy theory element along for the ride. All the scientists, researchers, and credible sources are part of the big bad conspiracy, secretly handed their “shill cheques” from “Big Pharma”! (Or Big Agroscience, Big Windfarm, or whoever it is this week.)

Activists getting their entire education and their entire literacy concerning a particular subject only from an echo chamber of other activists, only from other people who are self-selected to share the same highly polarised belief, is a problematic factor here too. Everything is often cherry-picked from conspiracy websites and other activists, without any peer-reviewed and impartial research literature in sight. The need for “independent” media is frequently cited, but all too often this means that credible information is discarded in favour of an opinion column or conspiracy website.

In his 1974 Caltech commencement address, Richard Feynman described a crucial component of scientific practice that, as he described it, is “*a specific, extra type of integrity that is not lying, but bending over backwards to show how you are maybe wrong, that you ought to have when acting as a scientist.*” Bending over backwards to show how you’re, maybe, wrong. This, in a nutshell, is what is usually lacking from this kind of highly vocal and politically charged pseudoscience.

It’s not ok to claim to have “evidence” for your position if this “evidence” is based on myths or misconceptions that have been carefully, patiently corrected and explained in simple terms a hundred times before. As Ludlam noted in a recent tweet (30/03/2015), no one has time to spoon-feed you. I’m not suggesting this comes about through any kind of deliberate malice, incompetence or stupidity, but through what often seems to be a deliberate decision to avoid exposure to any evidence or expertise that questions the cherished ideology.

Sagan characterised this problem well in *The Demon-Haunted World*: "*Mr. Buckley - well-spoken, intelligent, curious - had heard virtually nothing of modern science. He had a natural appetite for the wonders of the universe. He wanted to know about science. It's just that all the science had gotten filtered out before it reached him. Our cultural motifs, our educational system, our communications media had failed this man. What the society permitted to trickle through was mainly pretense and confusion. It had never taught him how to distinguish real science from the cheap imitation. He knew nothing about how science works.*"

But to be honest, if people have never, ever seen credible science, and the only thing they've ever been exposed to as "research" or source material is YouTube activism and conspiracy theorist websites, can you really blame them? If the problem really does come from genuine, innocent ignorance, in those cases then a little bit of spoonfeeding is necessary. What other approach can make the world a better place? Ideally we would have every single citizen in our democracies equipped with a critical thinking toolbox, with high standards of science literacy (and education more generally). Then we wouldn't need any technocracy. (Or, would our democracy in fact be a technocracy?)

But in the real world we don't have that high level of careful education both in the "nuts and bolts" of science and technology as well as the crucial scientific method - at least not yet - and therefore we do need at least a bit of technocracy. (Every citizen, and every politician, is a technocrat at least to some extent. If you say vocal, passionate and emotional anti-vaccination activists are wrong, you're a technocrat.)

Everybody claims that their position is evidence-based, and such a claim means absolutely nothing in and of itself. Nobody proudly proclaims "My feels are based on science illiteracy and conspiracy websites!" instead of being based on evidence. Anti-vaccinationists love to scream and hysterically berate Senator Di Natale for ignoring their "evidence based" position, supposedly at the behest of Rupert Murdoch and his vast vaccine-selling conspiracy. Homoeopaths loudly proclaim that homoeopathy is based on evidence - but some people obviously have different definitions of "evidence" from others, which is the fundamental problem here.

I'd be interested to know - in what context, in what circumstances, does Senator Ludlam support the use of nuclear power? If no such circumstances exist at all, based on present knowledge, what new evidence or information would change your mind? For many anti-nuclear-power activists, I suspect this is tantamount to asking an anti-vaccination fanatic which vaccines they think are good, and in what context they think any particular vaccines are acceptable.

What would it take to change your mind?

Personally, my support for nuclear power as a highly important tool for scalable, environmentally friendly, reliable, proven, safe and economically realistic replacement of coal-fired generators is a conclusion that I've formed based on all the science and evidence that I've seen, including extensive reading of the works of anti-nuclear-power activists, up to the present time. This is not some kind of ideology or dogma - it is possible that I might change my mind tomorrow, if compelling new data or evidence came along which wasn't consistent with this position.

It's not ok to cherry-pick science that suits your prejudice or ideology while ignoring the majority of the credible science that doesn't, or to call for "more research" while ignoring existing scientific consensus if it doesn't suit your pre-decided ideology.

As Sagan once put it, science is not just a body of knowledge - *it's a way of thinking*. Similarly, pseudoscience or science denial is not just a body of supposedly factual statements which are wrong - it's often a pattern of corrupted or pathological thinking. These patterns tend to display a high degree of consistency whether you're talking to anti-vaccination activists, anti-biotechnology activists, "wind turbine syndrome" activists, creationists, anti-fluoridation activists, or anti-nuclear-power activists. This "pseudoscientific method" is remarkably consistent and independent of the actual science and technology being discussed. Because this "method" is much more significant than the actual subject-matter knowledge in different areas, this may help to explain why "crank magnetism" is so prevalent.

We always hear the same things from all of them. We need "independent" sources! We need independent media! Usually, in this quest for "independent" research, truly independent and credible sources are discarded (because they don't fit the prejudice) and the non-peer-reviewed blog of the feelpinion of some activist at best, or outright conspiracy theorist at worst, is selected as the credible source material which has the "truth" that other sources are covering up. Truth which just so happens to conform to the existing prejudice and feelpinion.

The highest-quality, peer-reviewed research and scientific data that disagrees with the pre-decided ideology is ignored, discarded or claimed to be the work of some big, bad conspiracy, with Big Vaccine, Monsanto, Big Nuclear or Big Climatology secretly handing out bags of cash to scientists and technical experts in exchange for lies (lies which always seem to escape the peer-review process undetected, supposedly - even though they are detected and exposed in the case of people like Andrew Wakefield and Gilles-Éric Séralini).

Despite the constant conspiracy theorist allegations from activists, I've never seen a retraction of any credible scientific paper on climatology, on the benefits of vaccination or fluoridation, on the safety or public health benefits of genetically modified plants such as Golden Rice, or of any of the published, peer-reviewed papers from people like James Hansen or Barry Brook (among many others) reviewing the value and the importance of nuclear power for scalable, economically realistic fossil fuel replacement and climate protection.

Any claims that support the activist's pre-decided ideology from any non-peer-reviewed opinion column, activist website or conspiracy theorist's blog are immediately and completely accepted without hesitation, at the same time that the peer-reviewed literature is ignored. Paying attention to the literature that stands up to peer-review, and recognising that not all "evidence" is equal, is the only way that we escape from a seemingly endless loop of "he said, she said" back-and-forth in the opinion columns.

"*Peak nuclear has passed.*"

People with a determination to believe in Malthusian catastrophe love to believe in the story of "peak" - peak oil, peak phosphorus, peak copper, peak food, peak uranium, or whatever. Peak anything, and peak everything. Just like a Christian dispensationalist who wishes for Armageddon, the "end times" and the destruction of mankind and can't wait to bring it on, the Malthusian fatalists seem excitedly determined to see dystopian resource-deficient futures come to pass, something like those painted in *Mad Max* or *Interstellar*. Some of us, like Norman Borlaug, choose to try and push humanity in a different direction.

What exactly does "peak nuclear" actually mean, anyway? It doesn't really mean anything.

The notion of "peak" production in natural resources was popularised by the work of the geophysicist Marion King Hubbert - a rather interesting and clever guy who was never one to shy away from a bit of maths where appropriate. His works are well worth reading to help us understand how we got to now in terms of an economy dominated by fossil fuel combustion, how we use the fossil fuels today as well as how we will transition away from their use. Stuart McMillen's "Peak Oil" is a beautiful little two-minute introduction to Hubbert's ideas.

But what of "peak nuclear"? What did Hubbert have to say about nuclear power? To answer that we can turn to, among other things, Hubbert's 1956 paper *Nuclear Energy and the Fossil Fuels*.

Concerning nuclear power, Hubbert concludes that "*In order to see more clearly what these events may imply, it will be informative to consider them on a somewhat longer time scale than that which we customarily employ. Attention is accordingly invited to Figure 30, which covers the time span from 5000 years ago - the dawn of recorded history - to 5000 years in the future. On such a time scale the discovery, exploitation, and exhaustion of the fossil fuels will be seen to be but an ephemeral event in the span of recorded history. There is promise, however, provided mankind can solve its international problems and not destroy itself with nuclear weapons, and provided the world population (which is now expanding at such a rate as to double in less than a century) can somehow be brought under control, that we may at last have found an energy supply adequate for our needs for at least the next few centuries of the foreseeable future.*"

Figure 30 from Hubbert's paper makes it particularly clear what the capability of fission power is capable of when viewed in terms of a Hubbert linearisation. When we apply the same thinking and the same models that pioneered the modern concept of "peak oil" to nuclear power, what do we find?

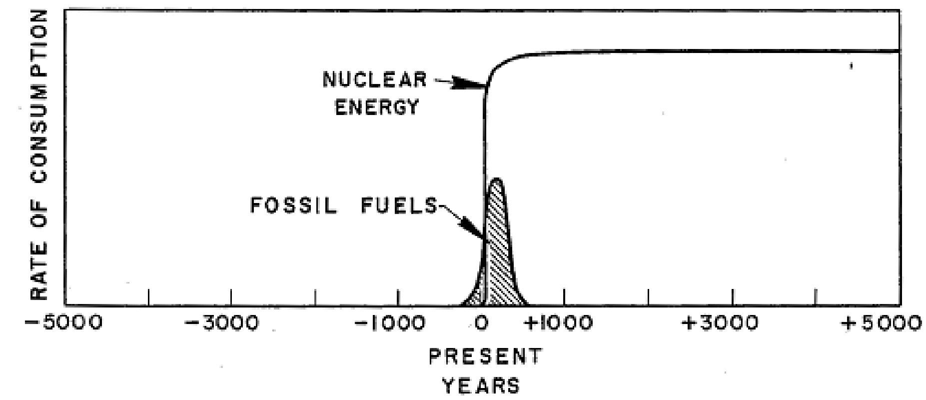

Figure 30 – Relative magnitudes of possible fossil-fuel and nuclear-energy consumption seen in time perspective of minus to plus 5000 years.

Figure 1: This is the "Hubbert peak" for nuclear energy.

60 years ago Hubbert understood the change in direction that the fossil fuel extractive industries needed for their sustainable transition, but apparently they didn't listen. If Hubbert was making these kinds of statements today, concerning the value of nuclear power as the sustainable replacement for fossil fuels, I suspect his petroleum paymasters might have been less impressed. Maybe the CFMEU would be running "*Hubbert will kill the coal industry!*" ads in the newspaper instead.

(It should be noted, however, that we're really not in any danger of running out of fossil fuels, and "peak oil" depletion doesn't really appear to be a problem. We'll hit atmospheric physics and climate limits well before actual depletion of these fossil fuel resources.)

"*There's no science to support an Australian nuclear industry, says Senator Scott Ludlam*"

That's a big claim. So, what is the science and evidence base for that? We still haven't actually gotten to that evidence.

Right now, electricity generation in Victoria (which is allowing me to write this post) is emitting about 1370 grams of carbon dioxide to the atmosphere per kilowatt-hour. In Ontario, also a developed and industrialised first-world economy with a high standard of living, electricity generation is emitting carbon dioxide to the atmosphere at 1.75% of that rate, or about 24 g/kWh. In France, coal combustion for electricity generation is comprising only 1.8% of the energy supply on the grid, and in Ontario, coal use has been rendered completely extinct for the last four years - it has been sent the way of smallpox and polio.

A backbone of reliable fission power, combined with a little bit of hydroelectricity, natural gas and wind power, has actually done this. Reliable and near-complete replacement of fossil fuels has been achieved in Ontario, with a complete exit from coal use, with huge environmental, climate protection and public health benefits. The real-world exist from coal also means a huge reduction in the amount of radioactivity released to the environment and the radiological dose to the public from power generation in Ontario. This hasn't destroyed the economy, bankrupted the province and put everybody out of a job, either. Why the hell aren't we doing this throughout the world already?

This highly successful, reliable, almost total replacement of fossil fuels for electricity generation has never been done anywhere with a "only renewable allowed" approach. It's a fantasy. With nuclear power, on the other hand (combined with other clean energy technologies) it is well proven and reliable. The science to support the deployment of fission power for the replacement of coal-fired generation in Australia actually looks really clear. This is especially true in Victoria, where there are 1370 reasons why this should be done in a timely fashion.

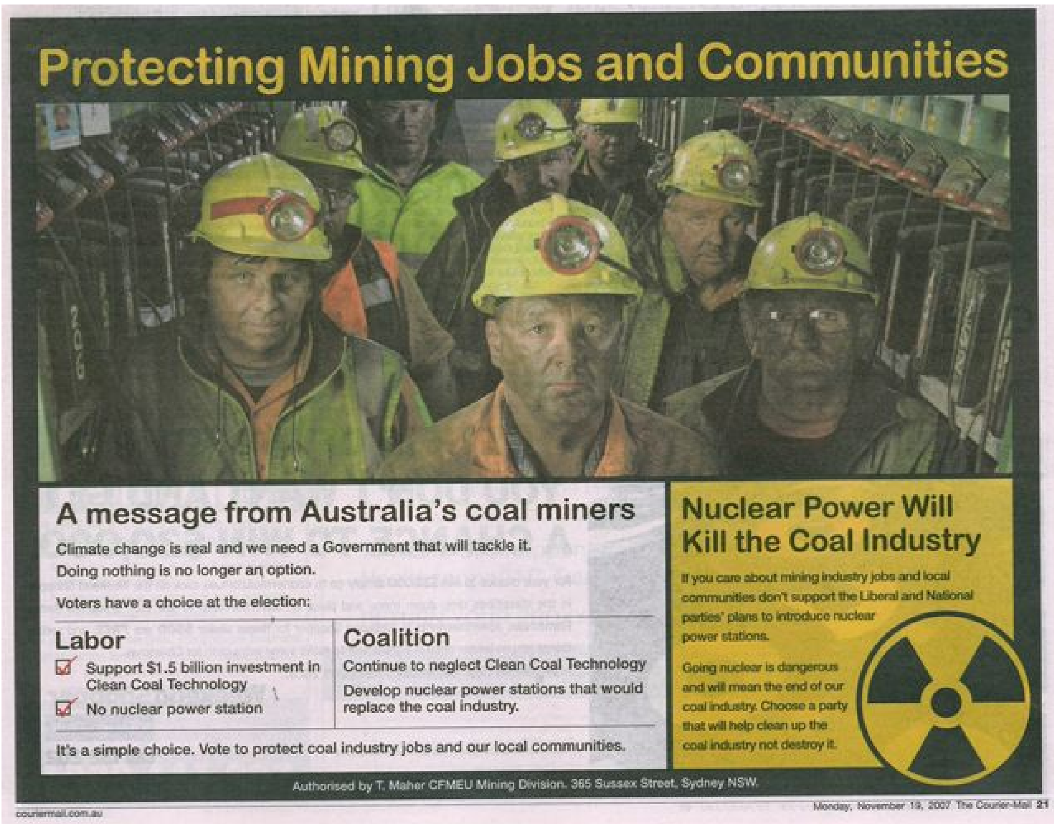

Figure 2: They don't protest that "solar power will kill the coal industry!" They know that some technologies are a real threat to the status quo and others are not so much.

"Nuclear power has hit the headlines again."

Keeping this fresh in the public consciousness and in the media is good. It means we have every opportunity to see what "science" and "evidence" can actually materialise from people like Ludlam. More and more politicians and citizens seem to get it, while these activists seem to fail to produce any new material, sticking with the same very limited, weak "evidence". The public is catching on that this anti-nuclear-power "evidence" is so lacking, too. A recent poll shows that 65 percent of people polled in South Australia support some form of nuclear power and/or other nuclear fuel cycle industries being introduced or expanded in their backyard. The longer that people like Senator Ludlam fail to show us any convincing form of evidence that stands up to peer review, the more they will continue to lose in the opinion polls.

"As climate change emerges from future predictions into present reality, a new generation is querying whether opposition to the nuclear industry might be an ideological hangover that we can no longer afford."

It's a good thing, too. It's certainly something that the Australian Greens have to take a serious look at to improve their prospects at the ballot box - not only in the context of policies around nuclear technologies but certainly in other areas such as biotechnology as well. This isn't just something that a "new generation" has problems with - in my experience these concerns that people have with Greens behaviour and policies in these areas span multiple generations and demographics.

This vague usage of the term "nuclear industry" is unhelpful. What exactly are we talking about here? Nuclear power, nuclear weapons, research using tools such as neutron optics for materials science and other basic science, or nuclear medicine? Does the "nuclear industry" bogeyman include our academics, our radiopharmacists, and public organisations like ANSTO, lumped together with private energy utilities?

"*The South Australian royal commission into the nuclear fuel cycle has rebooted the conversation around international spent fuel dumping at the same time the new chief scientist has thrown nuclear into the mix as part of the solution to climate change.*"

The storage of slightly-used nuclear fuel in Australia, and the recycling and efficient use of that fuel, is not "dumping". We'll come back to that.

"*The question of whether to "value add" our uranium exports with an enrichment and fuel fabrication industry is being considered from the prime ministers office on down.*"

Well good! Along with the storage and recycling of slightly-used nuclear fuel, these technologies allow Australia to make a greater contribution (along with our natural uranium exports) to the global effort to replace fossil fuel use with scalable, reliable clean energy. Furthermore, although climate protection is the most important goal, Australia has the opportunity to benefit economically at the same time.

If you don't like the mining of uranium, then the efficient use of the vast amounts of fertile and fissile material around the world that we've already got, without new mining, is obviously something valuable to pursue.

Going forward into the future we won't use uranium enrichment much or at all. Isotope separation is intrinsically expensive and energy intensive, and we'll move away from the need for it. Even though the energy available from low-enriched uranium in a light water reactor is far larger than the energy spent on the enrichment of its LEU fuel, it's still intrinsically wasteful and inefficient to spend this cost and energy so that we can only convert a tiny fraction of the uranium into energy. (And, to be honest, if we're going to enrich uranium I'd actually prefer we don't do it in Australia, at least in the short term - better to do it in other countries that already have a much cleaner carbon-free energy supply than Australia does, for the moment.)

It's more efficient and elegant to dispense with isotope separation and simply take natural uranium - all of it - as our nuclear fuel. We can take our existing stockpiles of slightly-used nuclear fuel, our existing stockpiles of "depleted" uranium, our existing stockpiles of thorium (including in tailings that have already been mined), and our existing stockpiles of highly concentrated, high-grade fissile HEU and weapons-grade plutonium from the ongoing disassembly of nuclear weapons stockpiles, and we can turn all of that fuel into a vast, enormous clean energy resource without actually mining any new fuel at all.

We can take that highly concentrated, potent energy resource from a decommissioned nuclear weapon and turn it into a vast amount of clean power - recovering some of the huge amount of money and energy that was spent building up those terrible weapons stockpiles of the Cold War. That weapons-grade fissile material is then permanently destroyed, and utterly incapable of any nuclear weapons use ever again. None of this is science fiction, or novel engineering which we need to figure out. We know exactly how to do it with existing technology. This will all result in a much smaller demand for natural uranium - indeed, ongoing conversion of weapons stockpiles has already been reducing natural uranium demand for many years. We've already got an enormous amount of nuclear fuel in the world, and it is just sitting around waiting to be used with no need to mine anything.

We could replace all the world's coal combustion for many centuries without actually mining any uranium, if we really needed to. It is interesting to note that some people protest against the intolerable supposed evils of uranium mining while simultaneously protesting against the recycling of existing stockpiles of slightly used nuclear fuels, against fast reactors and other such technologies for the highly efficient conversion of nuclear energy. If uranium mining is supposedly such a menace, and you're supposedly so concerned about climate change, which way do you want it?

Australia's total natural uranium production last year was about 6000 tonnes. Total global production of oil in 2014 was 4221 megatonnes, and global coal production was 3934 megatonnes of oil equivalent. Total global production of natural gas was 3461 billion cubic meters. At 41.9 PJ/Mtoe and 38.2 PJ/bcm for oil and natural gas respectively, that's a total annual world extraction of 474 EJ of primary energy in the form of fossil fuels.

If you take an actinide fuel like uranium and you convert the entirety of that uranium efficiently into thermal energy using something like an Integral Fast Reactor you generate about 80 TJ/kg of heat from that fuel. (Natural uranium, depleted uranium, thorium, used LWR fuel, weapons-grade plutonium or HEU, whatever. It doesn't really matter. Complete, efficient utilisation of any fissile or fertile fuel will give you roughly the same number.)

So how much uranium would we need to replace all that fossil fuel? Just under 6000 tonnes per year.

To replace all the extraction of all the fossil fuels on Earth.

"Nuclear power will kill the coal industry" indeed.

(Converting the heat from a fission reactor into liquid fuels for transport requires a little mucking around with CO_2 extraction from the atmosphere and Fischer-Tropsch-like synthesis starting carbon dioxide. This requires a bit of extra heat and electric power, for example for gas compression. We know how to do it, though.) Now we start to see the problem. Replacing all fossil fuel extraction on Earth might involve a little tiny bit of lost revenue and a little bit of political opposition from some industries that may be a little upset.

Even with enrichment, storage of the unused depleted uranium, and inefficient once-through conversion of a tiny part of that low-enriched uranium to energy in a light-water reactor, Australia's annual uranium production produces energy which is about equal, after Carnot inevitably takes his share, to all of Australia's present demand for electricity. In this once-through kind of fuel cycle the unused energy doesn't disappear, though. It's not wasted. We can easily go back and take that depleted uranium, take that slightly used fuel, and squeeze all its heat content out efficiently at a later time - an output of energy equal to all the production of fossil fuels on the planet.

A homework question for the reader: *What does 6000 tonnes of natural uranium cost? And what does the earth's annual total output of fossil fuel cost?*

BHP Billiton's proposed expansion of South Australia's Olympic Dam copper mine has the capacity to produce 500 kilotonnes of copper per annum. After copper sulfides are separated from the crushed ore, the tailings stream will contain about 15 kilotonnes of uranium (per year).

Suppose we convert that uranium to heat, again efficiently using the entirety of the uranium, and we have about 1.2 ZJ of thermal energy. (Welcome to the zettajoule civilisation.) Now take about 474 EJ of that energy and replace all the extraction of all the fossil fuels on Earth. What's left over?

We're left with another 700 EJ or so, on top of that, after we've replaced all the global extraction of fossil fuels - in other words, a further "spare" energy supply of roughly 1.5× the total present global supply of fossil fuel energy. So we're talking about doubling all that energy supply, with no greenhouse gas pollution, and then adding more energy on top of that.

What would we do with that energy? What would it mean for humanity? What would it mean for the betterment of humanity, for the advancement of public health and the environment, human development, increases in life expectancy and quality of life, and the global alleviation of poverty? What would this mean for the ample provision of electricity, and energy more generally, to the billions of people in the world presently in energy poverty? Not to mention economic growth and job creation.

And this doesn't involve any uranium mines or any fossil fuel extraction, anywhere. This is the use of uranium which is a byproduct, a waste, from the tailings of one copper mine in South Australia.

"*The most common accusation levelled at opponents of the nuclear fuel chain is that our arguments are emotional, or that were trying to silence rational debate through unspecified means.*"

The problem that I have with the Australian Greens' policies concerning nuclear power (and other technologies, such as research reactors) is that the evidence to back up the stated policies simply doesn't exist. No credible, fact-based evidence is given which is compelling or sensible to justify the policies that are proposed.

It's fine that people have emotions, but emotions alone don't make for a good argument as the basis of science and technology policymaking, especially when the climate stakes are high. We don't make our policies concerning vaccination based only on emotions. If we did, I'm sure we'd see much more Greens support for the anti-vaccinationists. Is the policy based on evidence, or is it based on emotion, or both? Both is perhaps an acceptable answer, but simply saying yes to emotion doesn't address the central thesis of Ludlam's article, which is that these policies are based on evidence. It's ok to have emotions, but emotions are not evidence. We're still on the hunt for this purported evidence.

What do they have to show to the community in response to these criticisms? I look forward to hearing it, as do many others. It's highly relevant to our decisions at the ballot box. Being able to convincingly respond to this point, not just in the context of nuclear power but also in the context of other science and technology issues - such as nuclear science and technology other than nuclear power, say research reactors, or biotechnology and agricultural GMOs - may make a real difference for the Greens in terms of picking up voters that at the moment they won't pick up, or at least won't preference them as highly.

I do find it interesting and noteworthy that Senator Ludlam notices that these views come particularly often from young people. I think that's a great thing. I have heard it claimed before from other anti-nuclear-power activists (not Senator Ludlam, but others) that support for nuclear power is particularly associated with older generations, not with young people, and obviously that is not the case. In my experience, these views (in support of nuclear power) are evenly distributed, without being particularly polarised into certain age or other demographics.

"*Here's the thing: we have no argument with the science of nuclear fission whatsoever. A 50-year research arc stretching from Curie and Rutherford to Einstein and Szilard was validated when Enrico Fermi's team confirmed the neutron radiation beaming invisibly from a pile of uranium on a squash court at the University of Chicago in 1942.*"

"*The first real-world application lit up the desert at the Trinity Test Site in 1945; the second, less dramatically, was packed into the hull of the USS Nautilus nuclear submarine in 1954.*"

"*The problem is not with the science; that argument is long done. The problem is with the applications of the science.*"

"*I would respectfully ask anyone who believes nuclear energy can play a constructive role in decarbonising the worlds energy systems to try some science of your own. Test your theory against the data, and see how it stacks up.*"

Look at how sciencey we are! Fermi and Szilard and... oh yes, we sound very sciencey! Of course sounding "sciencey", especially for a non-technical audience, is a crucial part of the shtick for all activists and science deniers, from anti-vaccinationists to creationists and anti-biotechnology activists.

The first human patient with Graves' disease was successfully treated with radioactive iodine-131 at Massachusetts General Hospital in 1941, years before Trinity. In 1946 a five-year followup of 29 patients who had been successfully and safely treated for Graves' disease using ^{131}I was published in JAMA, firmly establishing the clinical value of nuclear medicine. This is just a part of the kind of history that is completely missing from Ludlam's strange "history" where nuclear technologies flash into existence in the remote Journada del Muerto one morning in 1945 and from there, keeping with the military theme, jump straight to the launch of the USS *Nautilus* (which never burned any diesel fuel) in 1954.

If anybody in the Australian Greens does have "an argument with the science of nuclear fission" then we've got bigger problems. Really, I'd love to see this argument. It would mean that we actually have a technical argument that we can nut out as the root of this disagreement, rather than endless rhetoric and noise without any real substance.

Of course, when Ludlam says "*Without nuclear power stations there can be... no possibility of a nuclear power station being hit by a conventional bomb and setting off a nuclear explosion*" this actually is what we're looking at. This is "an argument with the science of nuclear fission". It is a denial of the science, or a nasty level of ignorance. When public statements like this on behalf of the Greens, what attempt has been made to consult professionals with relevant subject matter expertise?

The problem that I have is that you can easily go to the Greens policies webpage and find statements like these. I've quoted a few examples below.

"*The Australian Greens believe that... The use of nuclear weapons, nuclear accidents or attacks on reactors pose unacceptable risks and consequences.*" (Note in the above statement the absurd lumping together of the use of nuclear weapons alongside the use of any other nuclear science and technology, as though they're the same thing.)

"*The Australian Greens believe that... Nuclear power is not a safe, clean, timely, economic or practical solution to reducing global greenhouse gas emissions.*"

"*The Australian Greens want... Closure of the OPAL nuclear reactor at Lucas Heights*"

"*The Australian Greens want... Prohibition of food irradiation and the importation of such food.*"

So are these beliefs and policy statements science-based and evidence based? Are these policies in the best interest of public health, biodiversity protection and climate protection, and in the best interests of Australia's science, industry, research, economy and healthcare capability? That's what we need to look at - we need to find the evidence.

This is the problem. Unless credible evidence can be presented to justify what are largely scientific, technical statements, these policies should be torn up or substantially reformed. Put up relevant and credible technical evidence, the best available impartial evidence that stands up to peer review, as justification for these policies, or reform the policies.

"The World Nuclear Industry Status Report (WMISR) is an independent, painstaking statistical record of the worlds reactor fleet, its age profile, economic performance and near-term prospects, broken out country by country and updated annually."

The first of Schneider and Froggatt's "World Nuclear Industry Status Reports" was issued in 1992 as a joint publication between Greenpeace International, WISE Paris and the World Watch Institute. The second and third iterations of their report, in 2004 and 2007, were commissioned by the EFA-Green coalition in the European Parliament. Neither author appears to have any technical experience or qualification in nuclear engineering, physics, or any related discipline.

Mycle Schneider was responsible in 1983 for establishing the Paris branch of WISE, the World Information Service on Energy - an anti-nuclear-power activist organisation whose coy and mendacious name is essentially the nuclear power equivalent of the Australian Vaccination Network. The WISE website proudly self-identifies Schneider (and by extension the organisation itself) as an anti-nuclear-power activist. Antony Froggatt was Greenpeace International's Nuclear Policy Campaigner from 1989 to 1997, as well as the representative of Greenpeace International for Central and Western Europe and the former Soviet Union.

Obviously there's nothing genuinely impartial and independent here at all. The "World Nuclear Industry Status Report" is not subject to any kind of peer-review, genuinely independent fact-checking or oversight - it's really just a report published on the website of a group of anti-nuclear-power activists. It has no more peer review, and no more credibility, than the work that Storm van Leeuwen and Phillip Smith have self-published on their own website, for example.

This is a good example of the problem with seeking out only "independent" data that fits the predetermined ideology, and finding "independent" sources that have about as much intellectual integrity as people on the Internet who publish their own passionate reports and research about the dangers of smart meters and wind turbines, or the dangers of vaccination, fluoridation and chemtrails.

These activists suffer from the now-familiar problem of reducing all nuclear power plant operations, all fuel cycle activities, all state-owned nuclear power operators as well as commercial operators, and all nuclear engineering and even fundamental physics and medicine research and development both in the public and the private sector all around the world into this monolithic concept of concept of the bad bogeyman "Industry". This is the classic meme of the "Big Industry" - the monolithic big-business conspiracy we see often cited by anti-nuclear-power activists, anti-GMO activists, anti-pharmaceutical activists and all the rest.

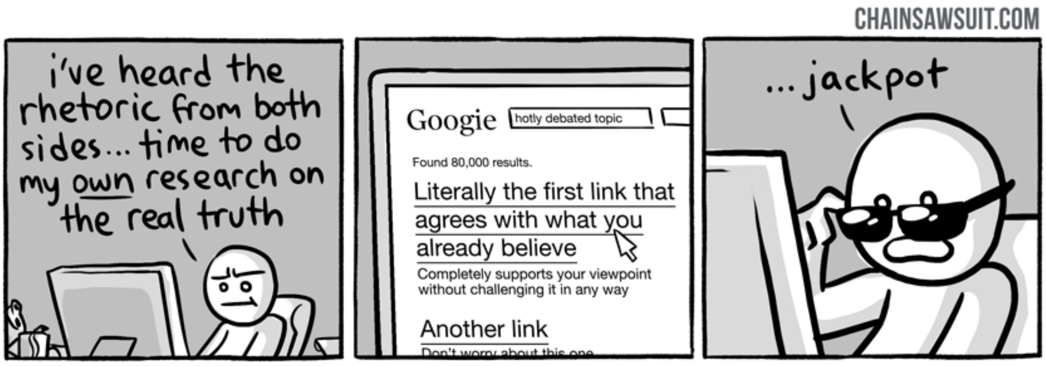

Figure 3: Big thanks to Kris Straub for that one. http://chainsawsuit.com/comic/2014/09/16/on-research/

"*Based on this available data, I have a number of theories to offer about the future of nuclear power.*"

Here we see a problem. That's the "available data". That's it? The only real "data" or evidence that Ludlam has cited is this anti-nuclear-power activist website. This is not the "available data" in any realistic sense, it's just the cherrypicked "data" which agrees with what Ludlam wants to believe. There is nothing in this set of "available data" from the professional energy policy, science or economics literature, nothing that has been subject to any kind of peer-review. This kind of definition of "data" and "research" is the problem.

There are 16 external links in Ludlam's column.

There are 9 links to various online opinion pieces and news stories from the Telegraph, the Guardian, Climate Spectator, phys.org (which is probably the most credible of the bunch), Reuters and the Independent. There's a link to the website of South Australia's nuclear fuel cycle Royal Commission, the "Beyond Zero Emissions" organisation, Schneider and Froggatt's "World Nuclear Industry Status Report" website which we mentioned above, the Greens WA website, a 2013 opinion piece by Mark Diesendorf published on the RenewEconomy website, the AEMO "100% renewable" modelling outcomes commissioned by DCCEE, and BP's "Statistical Review of World Energy". That's it.

So where is the serious evidence or research literature? There's nothing much more here than a pile of newspaper clippings, opinion columns and activist websites. There's very little actual evidence of anything. There is not one link to a peer-reviewed publication, not one credible technical or economic research paper, for example, concerning nuclear power.

This "evidence" seems rather lacking.

"*The first and second generations of light-water and CANDU reactors are entering a twilight from which they will not recover, and that nobody, not even China, is building new plants anywhere near enough to prevent a steep decline in the number and output of nuclear generators.*"

Even if that was true, which I don't think it is, is this something good?

Why is it that in every case where anti-nuclear-power activism has been successful, in Japan and in Germany for example, and in the United States and elsewhere in Europe to some extent, where perfectly good nuclear power plants have been shut down for political, not technical, reasons they have then been replaced or planned to be replaced, with fossil fuel combustion?

In Japan over the last few years enormous increases in fossil fuel combustion, with huge costs for those fossil fuel imports, have been used replace nuclear power plants that have been shut down due to successful political pressure - not because there's anything faulty with these nuclear power plants or because they've ever hurt anyone. Fortunately Japan is slowly clawing back against this oil and gas use with recent restarts of power reactors.

Following successful anti-nuclear-power activism for its closure, the Midland nuclear power plant in the United States was converted to a fossil gas combustion plant, with its waste discharged entirely into the atmosphere instead of entirely being contained and safely stored on site. The Fort St. Vrain generating station (a first-of-a-kind proof-of-concept thorium/uranium high-temperature gas-cooled reactor at commercial scale on the electricity grid) was also converted to natural gas combustion in the 1990s. The Somerset nuclear power plant was converted to coal combustion following successful activism to close it down, as was the William Zimmer nuclear power plant. This activism is climate crime. The entirety of the combustion products from these new plants just go straight out into environment and we breathe them - not into compact cask storage on the plant site or into efficient recycling.

The Vermont Planning Commission is now eyeing the electrical infrastructure that long served the Vermont Yankee nuclear power plant, and state officials have been in talks for months with fossil fuel developers who are interested in the Vernon area, building new natural gas infrastructure to replace Vermont Yankee with only a short pipeline spur needed to tie the new plant into the planned Northeast Energy Direct pipeline as it passes through Massachusetts.

Houston-based fossil fuel logistics giant Kinder Morgan is planning the new pipeline to bring large quantities of cheap gas from shale hydrofracturing in Pennsylvania into the New England market, and Kinder Morgan and the rest of the shale gas hydrofracturing industry are happy to seize the opportunity for expansion that the success of anti-nuclear-power activism in Vermont (and elsewhere) has given them. Vermont's anti-nuclear-power activism movement has certainly gotten what it wanted, so I hope they're happy.

There is no "Solartopia" replacing these perfectly good, safe, reliable and very cost-effective nuclear power plants, only *Gasland*.

Why is it that every single nuclear power plant that has ever been closed down as a result of the occasional success of anti-nuclear-power activism has been replaced with coal and fossil fuel combustion? It is never, ever being replaced with solar or wind power. That's a fairytale, and the reality is we get additional new fossil fuel combustion for absolutely no reason, when there is no need for it. We need to be building more nuclear power. It needs to be reasonably fast and affordable. We need to be replacing the existing coal-fired plants we've already got, and building new nuclear power plants instead of new coal-fired generators. Closing down good, existing nuclear power plants and replacing them with new fossil-combustion power plants is absolute madness.

Why are we repeatedly seeing, in Germany as well as Japan and many other nations, so-called "environmentalists" who give a higher priority to the anti-nuclear-power ideology than they do to fossil fuel replacement? What quantitative value do you place on this anti-nuclear-power ideology, and what are you willing to pay for it, measured in billions of tonnes of otherwise avoidable carbon dioxide emissions and degrees of temperature anomaly? They're not interested in clean energy. They're not interested in climate change mitigation - they're only interested in making it worse. By "green power" they mean the replacement of existing zero-emissions nuclear power with new fossil fuel combustion. But not natural gas - gas is too expensive, but that's ok because they can just use good old coal instead.

In Germany we continue to see the same thing: *"The main challenge of the Energiewende is to replace nuclear power, which accounted for about one-fifth of the total German electricity generation, with green power."*

"*The government had hoped to rely on gas-fired power plants to produce much of the rest of the country's electricity, enabling Berlin to meet its reduction targets, despite the decommissioning of nuclear. A drop in the price of coal prompted producers to rely on traditional coal-fired plants instead, triggering an increase in carbon emissions.*"

This idea of replacing existing, good nuclear power with "clean energy" is absolutely absurd. You've *already got* reliable clean energy, with the infrastructure already paid for, so you want to rip it out, and replace it with what? Oh, coal is the cheapest, let's use that! There is no evidence that any technology exists which is better than nuclear power in terms of public health impact, climate protection, land use footprint, biodiversity protection, scalability, reliability, economics or any other metric you choose.

Champions of Germany's "energiewende" admit this has got nothing to do with fossil fuel replacement and it has got nothing to do with climate change mitigation. Germany's *kohlewende* is only about anti-nuclear-power ideology and the replacement of nuclear power, regardless of whether new fossil fuel combustion that is used for that replacement.

This replacement of nuclear power with, say, solar power or wind power has never been done, anywhere in the world. Even if it could be done, there is absolutely no evidence that such a replacement offers any benefits in terms of economics, land use and rewilding, fossil fuel replacement and climate change mitigation, or public health and biodiversity impact. The replacement of nuclear power with fossil fuels, however, is the usual scenario that occurs when anti-nuclear-power politics succeeds. This is a proven technology in terms of supplying the same amount of reliable energy in an economically viable way, but this is a dangerous regression in terms of clean energy, in terms of safety, climate protection, public health and biodiversity protection.

For years the anti-nuclear-power activist movement has tacitly encouraged, enabled and legitimised this stupidity.

In Kyoto, the prefectural government signed an agreement with Alaska earlier this year to explore the possibility of importing their natural gas. The LNG import agreement "*represents a step forward for Kyoto to achieve a larger goal: ending prefectural dependence on nuclear power by 2040.*"

Their strategy calls for expanding LNG facilities at Maizuru and installing new LNG pipelines in the Kansai region. The prefecture envisions Maizuru supplying not only Kyoto, but other prefectures in the region with gas to try and replace the energy produced by nuclear power plants in Fukui prefecture. The replacement of safe nuclear power with dangerous fossil fuels.

Figure 4: Ichihara's Cosmo gas refinery burned uncontrollably for 10 days following Japan's 2011 earthquake. It seriously injured many people, and released enormous amounts of pollution into the environment, and you've probably never even heard of it. You'd be surprised how often some of these photos have been circulated in the media as "Fukushima" images.

Replacing fossil fuels is not the goal here - they have no interest in reducing fossil fuel use, and they are actually interested in *increasing* it. What a slap in the face for the Kyoto protocol.

In 2013, Mitsubishi Heavy Industries and the Tokyo Electric Power Company announced a partnership to construct two new power plants in Fukushima Prefecture. The partner companies aim to build a pair of new 540 MW generation units, with a total generating capacity that replaces about one single nuclear power reactor, and to have these generators online by the mid-2020s. The Japanese government may provide financial assistance.

What new technology are these new power stations using? Solar power, or geothermal? Could it be, say, wind power? Tidal?

Tepco and Mitsubishi Partnering on Fukushima Coal-Fired Plants

Tepco, Mitsubishi group to build coal-fired plants in Fukushima

Well, I hope you're happy.

It's incredibly important for climate protection, today, to use the nuclear power plants we've already got which are effective, safe, reliable and already paid for. A new nuclear power plant is not economically competitive with an existing nuclear power plant (and no other clean technology comes close), and existing nuclear power plants provide environmentally friendly, reliable, safe, cheap and economically stable clean energy. Closing down existing nuclear power plants and replacing them with fossil fuels, as we're doing in some parts of the world today, is a climate protection disaster.

To meet short term climate protection needs, the power reactors we built decades ago must be respected and valued, and operated safely and efficiently for as long as possible, for as long as the best practical nuclear engineering can allow. This is the best possible short-term climate change mitigation step we can take today - to avoid anti-nuclear activists (and a temporary cheap surplus of hydrofractured shale gas) succeeding in any more premature shutdowns of good nuclear power plants and their replacement with fossil fuels. Plants in Japan, and Vermont in the United States for example, should be restarted and encouraged to keep operating instead of expanded fossil fuel combustion. Having these plants around, with their capital costs already paid off, is a huge advantage financially.

"*This theory is supported in the WNISR 2015, which demonstrates that "peak nuclear" was as long ago as 2002, that the long decline to obsolescence is well under way, and that the average age operating reactor is now 29 years.*"

Based on this methodology that Ludlam uses, this curious definition of "obsolescence", what energy generation technology is the world's most popular as well as the world's fastest growing? What energy generation technology is the least "obsolete" technology in the world, under Ludlam's metric? The answer, of course, is coal. Just because it is doesn't mean it should be, though.

"*Here is another theory: that a new generation of 21st century light water reactors will produce the most expensive electricity ever generated, in the unlikely event that they proceed all the way to completion.*"

"*Flagship projects in Finland and France are now so catastrophically over budget that there is a real possibility they wont ever be switched on.*"

Ludlam is referring to the first-of-a-kind EPR projects at Olkiluoto Unit 3 and Flamanville Unit 3. At this stage, it actually looks like the first EPRs generating electricity on the grid will be Taishan Unit 1 and Taishan Unit 2, coming online over the next year, with these nuclear power reactors costing about half of the Olkiluoto Unit 3 project.

The EPR is not a particularly economically efficient design for a power reactor - it has a lot of extra layers of redundant bolted-on safety systems stacked on top of each other, acheiving safety in a relatively economically inefficient way, rather than starting with intrinsic safety from the inside, from the physics of the fuel out.

"*In 2008, the UK government announced that they would build 10 new reactors, with the first power being produced in 2018. Seven years on, that has been reduced to just one proposed new reactor at Hinkley Point. Construction is yet to begin, and even the previously optimistic projections suggesting the first electricity wouldnt be generated until 2023 are now out of date, with the developer now refusing to provide a new estimate. The cost, originally proposed to be less than £10bn, then £14bn, then £18bn - at which point brokers suggested that investors should sell their shares in EDF - has now been estimated to be as high as £24.5bn.*"

Yes, the proposed EPR for Hinkley Point C is very expensive. Anti-nuclear-power activism makes a significant contribution towards nuclear power plants running behind schedule, through lawsuits and activism campaigns designed to inhibit and delay the licensing and approval process. Because the cost of nuclear power is capital intensive, mostly concentrated up-front in the construction of the plant, these delays cost significant amounts of money since the capital finance costs money for every day that the plant is sitting idle and isn't generating money selling electricity into the grid. But it's true that this is not the only factor at play here.

Of course we note that Ludlam has chosen only a couple of new nuclear power plants as his examples - these new nuclear units at Olkiluoto, Flamanville and Hinkley Point are the most expensive examples that can be found anywhere in the world. No other nuclear power plants recently built or currently underway anywhere else in the world are mentioned. Isn't that interesting? I know a cherry farm looking for some good seasonal labor.

It's easy to find plenty of examples of crazy costs for projects in the "renewable" energy sector. For example, Carnegie Wave Energy's world-first wave energy farm recently connected to the electricity grid off Garden Island in Western Australia has cost about AUD$100 million, both from state and federal government handouts and private capital. It consists of three CETO 5 modules each with a nameplate power capacity of 240 kW. It is expected that transport and electricity conversion steps will derate this capacity by about 20%, with a capacity factor of 20%-40% applicable to the system in continuous operation. So, this system has a nameplate power capacity of about 580 kilowatts, and a capacity factor of about 20%-40%, or about the same as for wind energy.

For comparison, the Alinta wind farm near Geraldton is comprised of 54 wind turbines with a nameplate power rating of 1.65 MW each. So, the existing Garden Island wave energy farm, at a cost of $100 million, is equivalent to about one third of one single wind turbine. If the Alinta wind farm cost the same as the wave farm, for the same amount of nameplate capacity at about the same capacity factor, then the wind farm would have cost $15.5 billion. Obviously wind energy is far more affordable and realistic than this project.

The 580 kW Garden Island plant, with a capacity factor of about 30%, will generate about 1.5 GWh of energy per year, on average, and the Flamanville Unit 3 EPR will generate 13740 GWh of energy each year. You may argue that it's a new technology, a first-of-a-kind plant, and the technology has not yet reached the point of widespread industrial deployment and economies of scale. Perhaps that's a reasonable argument. But why is the double standard acceptable when it comes to nuclear power?

AREVA's EPR is currently the only modern power reactor design approved by the UK's Office of Nuclear Regulation. If the UK wants to buy a new power reactor right now, this is the only one that can be licensed - there is no choice. If there was competition, how much could the proposed pricing be driven down?

The four 1000 MW PWRs in phase 1 of the Ningde Nuclear Power Plant have cost USD$7.6 billion *total for all four reactors*. The first three units are on the grid now, with the forth expected to be online soon. Let's keep doing *that*! If we replicate that widely, coal can be replaced easily and rapidly, and we can solve this. So why is it that a 1000 MW PWR can be built at Ningde, efficiently and safely, with years of operational experience, at *6.5 percent* of the cost of the proposed Hinkley Point C EPR?

Why is there not more competition in the market for new UK nuclear build? Since the EPR is the only design with a current Generic Design Approval, it's worth asking why the current GDA process seems to be so prohibitive for other nuclear power vendors.

The approval process for nuclear power plants in the UK has been framed in a way that discourages vendors from applying for approval for new nuclear power designs, and the government has spent no effort encouraging vendors to get new designs approved.

The UK model is basically copied from the model of the US Nuclear Regulatory Commission, which arguably works better in the US because it's a big country - US electricity demand is 12 times that of the UK. After a new reactor design is approved by the US NRC, the vendor has reasonable confidence that many reactors can be sold, which allows nuclear power vendors in the US market to justify the enormous up-front costs of NRC licensing. This is not the case as strongly in the UK, where the potential market for new nuclear power plants is significantly smaller. However, the US regulatory approval process for new nuclear power reactors does seem to suffer from some of the same problems we see with new nuclear power in the UK.

The UK regulatory system requires a large fee, of about £40 million, charged up front for the approval of a new nuclear power reactor design. This is large enough to discourage nuclear power vendors from putting their designs on the table for validation and potential deployment, and the 5 year approval period certainly doesn't help either. The current round of approval processes for new UK nuclear builds began in 2007 with four different designs on the table - AREVA's EPR, the Toshiba/Westinghouse AP1000, GE Hitachi's ESBWR, and AECL's ACR1000. The ESBWR and ACR1000 were withdrawn, leaving only the AP1000 and the EPR.

The AP1000 application was later suspended because the submission did not use SI units. As much as I like SI units, I'm sure for £40 million in fees the ONR's nuclear engineers can take care of the conversions where appropriate. That's how the EPR remained as the only candidate design on the table for approval. This expensive process led to GE Hitachi pulling the ESBWR out of the approval process despite having already spent £20 million on UK approval, and it led to AECL not really trying with their ACR1000 submission.

Do these approval costs really need to be so high? What if these costs were mostly paid for by a tiny tax on nuclear power, with say 10 percent paid by nuclear power plant vendors? This would make design licensing for new nuclear power plant designs more accessible, and it may well have encouraged the Korea Electric Power Company to have applied for a GDA for their modern and proven designs on a purely speculative basis. Increasing competition between vendors for new nuclear power plants is likely to save the UK taxpayer more money in the long term, even if nuclear power vendors aren't being charged up-front for the entirety of their design approvals on a simple cost-recovery basis.

Why does every nation need to have have a completely separate, independent process for reviewing and approving each new power reactor design from scratch, at great expense? With increasing standardisation of "off-the-shelf" power reactor designs into global markets, once a particular design has been carefully scrutinised by the US NRC for example, why can't the findings of this analysis be transferred to say the UK regulatory authorities, perhaps peer-reviewed, and reused? If a careful, relatively patient and expensive engineering and safety analysis for a given nuclear power reactor design has already been done, in France or the US or any other nation, why can't this be transferable into different countries seeking to license and build new power reactors?

It seems like there might be a valuable role for the IAEA to play in such an international cooperative process. This would save a lot of time, and a whole lot of money. High standards of engineering and quality assurance would still be maintained, with needless redundancy removed, meaning a big win for taxpayers as well as a big win for climate protection.

Under the "contracts for difference" for clean energy announced by the UK government in 2013, energy from landfill gas combustion will receive an assured "strike price" of £55/MWh, sewage gas combustion will receive £75/MWh, and waste combustion with heat and power cogeneration will receive £80/MWh.

The CFD mechanism basically means that the government will pay energy utilities a "top up" for the difference if the market price they're receiving for electricity is below these agreed prices.

(These prices do not factor in environmental impact, scalability, or the fitness-for-purpose of any particular generation technology to actually do the job of replacing existing gas and coal-fired power generation in a scalable, reliable and environmentally-sound way.)

The strike price agreed for the Hinkley Point C power reactor is £92.50/MWh. The strike price for onshore wind power is £95/MWh and £100/MWh for hydroelectricity, rising to £120/MWh for large-scale solar photovoltaics and £145/MWh for geothermal energy. For offshore wind power it's £155/MWh, rising to a staggering £305/MWh for wave and tidal power.

Now, we were saying something about "the most expensive electricity ever generated"?

In their 2011 peer-reviewed paper *How carbon pricing changes the relative competitiveness of low-carbon baseload generating technologies*, published in the journal *Energy*, Martin Nicholson, Tom Biegler and Barry Brook find that *"Nuclear energy is the cheapest option and best able to meet the IPCC timetable for greenhouse gas abatement."* This is a paper that stands up to peer review in a professional research journal. It's important to remember that this is not the same thing as some self-published activist website - not all "evidence" is equal.

The authors find that "*an objective analysis of these data shows nuclear power to be the standout solution for low-emissions baseload electricity, in terms of cost and ability to meet the timetable for greenhouse gas abatement. Further, nuclear power's relative competitiveness increases as the carbon price rises.*"

The authors go on to further conclusions - "*Of the other candidate technologies, solar thermal is, by comparison, the least competitive, and there is no clear evidence that its costs will compete with nuclear, even in the long term. Further, depending on CCS (CO_2 capture and storage) technologies delivering the desired emissions outcome by 2050 is a risky strategy at this stage of their development. Renewable energy technologies are unlikely to be able to supply the majority of electricity for most regions at reasonable cost, particularly in the urgent timeframe required for climate change mitigation.*"

"*Solar thermal is currently the most expensive of any of the low carbon baseload technologies at any carbon price, and would remain more expensive than established nuclear even if its costs could be halved. STE (solar thermal) is still more expensive than PF (pulverised fuel) coal without carbon dioxide capture and storage below a carbon price of $140 [per tonne CO_{2e}]. Minimising the use of gas in STE plants through larger solar fields and more thermal storage will reduce the impact of carbon price on STE generating costs but increase the capital and maintenance costs. In sum, STE seems unlikely to become cost competitive with nuclear.*"

"*Established nuclear technology stays as the lowest cost at any carbon price, and its relative competitiveness vis-a-vis other fit-for-service technologies improves as the carbon price rises. All three carbon dioxide capture and storage technologies are the next most competitive, but their relative competitiveness varies as the carbon price rises, with IGCC becoming the least-cost CCS technology once the carbon price has risen above* $\sim$ \$140 *per tonne CO_2 equivalent.*"

Solar power is not cheaper than coal, nuclear is not cheaper than coal, wind power or anything else is not cheaper than coal (in the absence of a carbon dioxide "price" or similar market mechanism). If any reliable, scalable technology (clean or not) was actually, genuinely cheaper than coal, the relatively free market would be out there using it extensively right now, without complaining about market uncertainty, subsidies or renewable energy targets, and it would already be supplying the nation's electricity instead of coal. But no such "coal beating" technology exists at that price point.

Why are anti-nuclear-power activists so scared of nuclear power in a relatively free market that they demand legislation to be put in place banning any private industry from constructing or operating it with private investment? If it's supposedly so much more expensive and uneconomical compared to the supposed alternatives then why is legislation to ban it needed? If nuclear power is supposedly so much more expensive than other clean energy technologies (with some kind of anti-greenhouse-gas market mechanism in place) are we to believe that the market can't figure that out on its own?

Wind power or solar power proponents constantly lobby for subsidies, handouts and government support mechanisms such as the RET that are specifically ideologically biased in favour of those technologies, and yet it is demanded that nuclear power must be expected to financially compete with dirty fossil fuels in a free market with no support, with no market signal or price applied to carbon dioxide emissions. This is a hypocritical double standard, trying to have it both ways to suit an ideological bias at the expense of the cheapest, most effective climate protection.

At a certain price on carbon dioxide emissions, nuclear power will become cheaper than coal. Other clean energy technologies will also become more attractive relative to conventional fossil fuel combustion, as will advanced fossil fuel based technologies such as carbon dioxide geosequestration - however, that's not to say that there aren't likely to be significant limitations in terms of scalability and technological maturity, both in terms of technologies such as solar power and technologies like carbon dioxide geosequestration.

As per the example I cited above, the credible research literature seems to tell us that nuclear power is amongst the cheapest, if not the cheapest, of any scalable, reliable clean energy technology for coal replacement. Therefore, it becomes an attractive competitor with traditional coal combustion, in a financial sense, once a greenhouse gas price is introduced at a certain level - and since other technologies such as solar thermal are significantly higher in cost, they will remain uncompetitive at that level of greenhouse gas price, and further distortions of the market through extra-inflated greenhouse gas prices, specific subsidies, "renewable energy targets" or other ideologically-biased technology-specific subsidies would be needed for the higher-cost technologies to compete. But there is no rational reason why you would do this, in terms of ecological protection or public health protection - it simply seems like a waste of money.

Perhaps introduce some sort of "clean energy target" or incentive mechanism for capital-intensive new construction (like the US loan guarantee program, for example) that applies consistently and fairly for all generation of clean energy to replace coal plants, without ideological discrimination for or against any particular technology, if the greenhouse gas price signal itself is not a strong enough signal. Remove any "compensation" for coal-fired power stations, and prevent them from simply continuing to burn coal and pass the cost along to consumer bills. Then, with those basic constraints, the market will be relatively free to deploy whichever technologies are the cheapest way to deliver real clean-energy replacement of coal. But the anti-nuclearists won't support this, because then the market will go and use nuclear power! So they insist that nuclear power must be ideologically banned.

We don't need to have this argument or debate about whether nuclear power is too expensive, or solar is too expensive or whatever. Let the market decide, since they're very very good at working out the cheapest, most efficient solution. Simply put a price on greenhouse gas emissions, and remove ideological legislation banning nuclear power. Remove any handouts or subsidies that are specific to any particular technology, such as coal or fossil fuels, or solar or wind, or nuclear for that matter. I agree that nuclear power shouldn't intrinsically expect subsidies from the government - with the possible exception of technology-neutral clean energy incentives that apply equally to one highly reliable, dispatchable kilowatt-hour from solar, wind or geothermal sources equally as with nuclear power. Solar or wind energy shouldn't expect technology-specific ideologically biased, winner-picking incentives or subsidies either.

Support the actual goal we're trying to achieve through whatever solution is technologically and economically superior - but "renewables" is not that goal. This is a classic example of what is referred to (commonly by information technologists and engineers) as the XY problem. The person wants to do X, and the person doesn't know how to do X, but thinks they can fumble their way to a solution if they can just manage to do Y. They don't know how to do Y either, so they ask for help with Y. Other people try to help them with Y, but are confused because Y seems like a strange problem to want to solve. After much interaction and wasted time, it finally becomes clear that the user really wants help with X, and in many cases that Y wasn't even a suitable solution for X.

The problem occurs when people get stuck on what they believe is the solution and are unable step back and explain the original problem in context. The problem is asking about your attempted solution rather than your actual problem. This leads to enormous amounts of wasted time and energy, both on the part of people asking for help, and on the part of those who are willing to help.

The fundamental problem we need to solve is scalable, afforable clean energy for coal replacement. The fundamental problem is *not* "lack of renewables".

"*How about this theory: that a new generation of small-scale fission plants burning thorium or mixed oxide plutonium fuel, or advanced fusion technologies cooking hydrogen into helium will be so costly, unmanageable or simply unbuildable that they will play no meaningful role in the transition to a zero carbon world.*"

Mixed-oxide uranium-plutonium fuel is not a novel fuel requiring a special reactor design - it's a type of recycled fuel that can be used, and is routinely used, in widespread commercial light-water power reactors. The use of mixed-oxide fuel does deliver a bit more energy than the once-through use of low-enriched uranium in a light-water reactor, but it still has a long way to go in terms of unused energy content - it's far from perfect. MOX isn't really what we're talking about when it comes to efficiently harnessing the entirety of the energy content in these nuclear fuels.

Some anti-nuclear-energy activists might try to tell you that, today, no advanced fission reactors of these types of designs exist. So here's a list of metal-cooled fast-spectrum reactors, molten-salt reactors, thorium-fuelled reactors and high-temperature gas-cooled prismatic and pebble-bed reactors, the so-called Generation IV reactors (depending on exactly how you define that term), that we're told supposedly don't exist today. Many of these reactors are not in operation today, having been decommissioned after serving a healthy lifespan or serving their intended research and development objectives, although quite a few remain in operation today.

Not all these reactors were electricity-generating power stations on the grid - many are prototypes, developmental systems or research reactors designed for a range of applications, from research and materials development to naval propulsion and exotic applications such as spacecraft power. Many of them do however supply, or did supply, electricity into the grid as competitive, operational nuclear power plants.

- The Fort St. Vrain nuclear generating station in the United States - a high-temperature helium-cooled reactor that employed uranium-thorium TRISO fuel in a prismatic graphite core.

- The Peach Bottom 1 nuclear generating station, a high-temperature helium-cooled reactor that employed uranium-thorium carbide fuel kernels in a prismatic graphite core.

- The Oak Ridge National Laboratory's Molten-Salt Reactor Experiment - the working prototype for modern Liquid-Fluoride Thorium Reactors.

- Germany's AVR helium-cooled high-temperature pebble-bed reactor, employing uranium-thorium BISO/TRISO "pebble" fuel.

- Japan's High-Temperature Test Reactor, a helium-cooled high temperature reactor employing uranium dioxide TRISO pebble fuel.

- Germany's THTR-300 high-temperature, helium-cooled reactor employing uranium-thorium TRISO pebble fuel.

- China's HTR-10 high-temperature helium-cooled pebble bed reactor, employing uranium TRISO pebble fuel.

- Britain's *Dragon* high-temperature helium-cooled reactor, employing TRISO pebble fuel.

- Experimental Breeder Reactor I in the United States, the world's first electricity-generating nuclear power plant, and a fast-spectrum breeder reactor.

- Experimental Breeder Reactor II, which served as the proven walk-away-safe prototype for the Integral Fast Reactor.

- Kazakhstan's BN-350 metal-cooled fast breeder reactor, notable for its integrated desalination plant which generates 120 megalitres of fresh water per day with no greenhouse gas emissions.

- The US Fast Flux Test Facility, a fast-spectrum test reactor for research, fuel testing and radioisotope production.

- Germany's SNR-300 metal-cooled fast reactor, which was a completed power-generating reactor but was never connected to the grid.

- The Fermi Nuclear Generating Station unit 1, a prototype metal-cooled fast breeder reactor as well as a commercial grid-connected nuclear power plant.

- The Atomics International Sodium Reactor Experiment in the United States, the first nuclear reactor in the United States to produce electrical power for a commercial power grid.

- The S2G metal-cooled fast-spectrum submarine powerplant that powered USS *Seawolf* for part of her life, as well as the S1G shore-based fast-reactor prototype for *Seawolf*'s metal-cooled fast reactor.

- France's *Rapsodie* metal-cooled fast reactor.

- France's *Phénix* metal-cooled fast reactor.

- France's *Superphénix* metal-cooled fast reactor.

- Germany's KNK-II metal-cooled fast reactor.

- Russia's BN-800 metal-cooled fast breeder reactor.

- Russia's BN-600 metal-cooled fast breeder reactor.

- The Dounreay Fast Reactor, a fast-breeder research reactor as well as a grid-connected nuclear power plant.

- The Dounreay Prototype Fast Reactor, a fast-breeder research reactor as well as a grid-connected nuclear power plant.

- The dozen-or-so advanced fast-spectrum reactors with a liquid lead alloy coolant that powered the Soviet Union's Alfa-class submarine fleet.

- Japan's *Monju* metal-cooled fast breeder reactor.

- Japan's *Jōyō* fast-spectrum, metal-cooled research and test reactor.

- The China Experimental Fast Reactor (CEFR).

- India's Fast Breeder Test Reactor.

- The fleet of small BES-5 metal-cooled fast reactors powering the Soviet Union's RORSAT satellites.

- The SNAP-10A metal-cooled uranium-zirconium-hydride spacecraft reactor.

- Russia's BR-1, BR-2 and BR-5 fast reactors.

- The SEFOR experimental fast-breeder reactor in the United States.

- The unique mercury-cooled Clementine research reactor built in the United States in 1946; the world's first fast-spectrum reactor.

- The thorium/^{233}U core installed in the Shippingport nuclear power station in the United States, able to "breed" energy from thorium in a light-water (thermal) reactor.

- The Ultra-High Temperature Reactor Experiment (UHTREX); a very high temperature experimental gas-cooled reactor.

- The US Aircraft Reactor Experiment - a beryllium-moderated, high-temperature reactor using molten salt as its fuel and liquid metal as the secondary coolant.

- The Heat-Transfer Reactor Experiments, HTRE-1, HTRE-2 and HTRE-3, developed as part of the US Aircraft Reactor Experiment program.

- NASA's SAFE-30 and SAFE-100 nitride-fuel heatpipe-cooled reactors, designed for spacecraft power systems and incorporating Brayton-cycle gas turbine power conversion.

- Russia's TOPAZ metal-cooled hydride-moderated reactors designed for spacecraft power.

- The Soviet Union's RD-0410 carbide-fuelled nuclear thermal rocket engine.

- The family of Kiwi / Phoebus / NERVA XE / NERVA NRX nuclear thermal rocket engines tested in the United States.

"*The Thermonuclear Experimental Reactor in the south of France - a prototype fusion plant - was expected to cost $5bn. Following chronic delays and management turmoil that estimate has blown out by billions. The prototype will most likely not be operational by 2020. Even the proponents have stopped making confident estimates of when actual power stations might be able to begin making a contribution to decarbonising the worlds energy systems.*"

The International Thermonuclear Experimental Reactor is a very large, complex and expensive enterprise of basic science and engineering research, and it never claimed that it was going to be a power station. Along with other projects like the International Space Station and the Large Hadron Collider, ITER really epitomises the remarkable success of today's "Big Science" projects, involving a cooperative enterprise of 35 countries which has come together with remarkable success for something with that many politicians involved. It's coming together really well, involving physicists and engineers and industry from around the world already acheiving remarkable technical milestones such as the development of some of the largest and most advanced superconducting magnets ever built, and it looks like it will see first plasma experiments in the tokamak by the end of the decade.

As well as the direct contributions to ITER from 35 countries, many nations around the world are also working on their own, smaller research projects in plasma physics and engineering, involving research infrastructure such as Germany's Wendelstein 7-X superconducting stellarator and Australia's H-1 national stellarator facility. This research infrastructure enables fundamental studies of plasmas and magnetic plasma confinement, materials engineering for plasma-facing surfaces in fusion reactors, and technologies in areas such as instrumentation, plasma diagnostics and plasma heating that contribute towards basic science and engineering research as well as to the international development of fusion power reactors and their deployment in the future.

These projects don't really go overbudget because they simply have no way of doing so - national science and research budgets are already constrained enough as it is. As far as energy infrastructure is concerned, what is really important right now is the rapid replacement of coal-fired generators. Basic research is a completely separate thing, but it's really important too. Fundamental science and engineering research is really important - and the Australian Greens have usually been good about recognising that importance for our country, for the most part.

It's certainly true that we're not building nuclear fusion power plants to replace coal-fired plants today. But personally I remain confident that the new generation of nuclear fission power plants that we build today possibly won't be replaced with another generation of fission power plants when they reach the end of their lifetimes 50 or 60 years from now, but replaced with fusion power instead - *probably* deuterium-tritium fusion under magnetic confinement in a tokamak-like arrangement, but that's just my best guess. We'll see how it goes.

"*Nuclear plants using low-grade uranium take almost half their operational life "paying back" the energy it took to build them.*"

This claim is taken from anti-nuclear-energy activist Mark Diesendorf, in an opinion piece published on the notoriously shonky RenewEconomy website. Conveniently, the cited piece on RenewEconomy "is an edited extract from Mark Diesendorf's new book" and "the references are given in the book".

So you're expected to go and buy his book to actually get any references. It's all the fun of a scientific journal with an expensive subscription - except without any peer review. A book for the popular market does not have the same level of credibility as an academic paper. So, what if anything do we have on this subject in the credible peer-reviewed literature?

So, what's out there in the credible literature concerning EROEI (and "energy payback time", which can be derived from the EROEI) for nuclear energy as it compares to other clean energy technologies? As it turns out from my quick search, not much actually. (Perhaps you know where to find a good literature review on the subject? Let me know.) There is a strong consensus in the credible literature concerning the whole-of-lifecycle greenhouse gas emissions intensity of nuclear power and other clean energy technologies, though. Wind power, nuclear power and hydroelectricity all tend to be about the same, all very small, with solar photovoltaics being a little bit higher than that - photovoltaics are pretty consistently the "worst" clean energy technology in terms of lifecycle greenhouse gas emissions, although they are significantly better than any fossil fuel combustion.

If we have life-cycle analysis of greenhouse gas emissions for a particular energy technology, which is something where we do have plenty of credible research literature with strong consensus, and we have some data on the overall greenhouse gas intensity of energy generation in the economy where that technology is built and used, then we can use this data to straightforwardly estimate the EROEI (for an energy technology with no direct greenhouse gas emissions from combustion). The life-cycle greenhouse gas footprint for a given technology is basically the greenhouse gas intensity of the overall energy inputs from the economy divided by the EROEI for that technology - so a given clean technology can be made "cleaner" in terms of lifecycle greenhouse gas emissions in one of two ways; either by improving the EROEI or by bringing down the overall greenhouse gas intensity of energy in the economy where that technology is constructed.

For example, in Australia, we might assume that the overall greenhouse gas intensity of our energy inputs is about 1000 gCO2/kWh. (This may vary a bit, since it depends where you are and what kind of energy you're using - for example vehicle fuels, natural gas for process heat, or electricity.) In any given economy with a given average for the greenhouse gas intensity of the various lifecycle energy inputs, the lifecycle greenhouse gas emissions intensity, basically is inversely proportionate to the EROEI. If the LCA greenhouse gas emissions data for a particular energy technology in a particular energy economy tells us that, for example, the LCA greenhouse gas intensity of nuclear power is about 25 gCO2/kWh, then we can assume the EROEI to be 1000/25, or 40, since the lifecycle greenhouse gas intensity effectively serves as a measurement of the energy input required from the economy per unit of energy returned.

We can repeat the same process for other technologies, but obviously the conclusions we find are basically the same conclusions we draw about lifecycle greenhouse gas emissions for various clean energy technologies. Hydroelectricity, nuclear power and wind power are all about the same, with essentially negligible greenhouse gas emissions and pretty good EROEI, and solar photovoltaics are a bit worse.

(It is noteworthy that in the short term at least, the development of nuclear power in Australia will involve components and materials that are manufactured overseas, in nations with an established clean energy base, with greenhouse gas emissions that are lower than Australia's. Therefore, even though nuclear power has a very strong EROEI anyway, the lifecycle greenhouse gas footprint of this manufacturing of components and nuclear fuels is likely to be very low indeed, even better than it would be with the same manufacturing being done in Australia. Moving the entire economic value chain into Australia is likely to be a longer-term prospect that is valuable for Australia but is less relevant to the urgent goal of greenhouse gas mitigation.)

"*Thorium technology is frequently pitched as the front-runner to replace uranium fission plants, but there are sound reasons why nobody has ever been able to get an industry on its feet, despite a global abundance of the raw material.*"

Thorium-fueled nuclear power is not "frequently pitched as the front-runner to replace uranium fission plants" by the majority of nuclear engineers - there's nothing wrong with thorium, but there is simply no need and no reason to "replace uranium fission plants". There's nothing wrong with them, and they're a well proven technology.

Thorium is not essential is not essential to make nuclear power safe, reliable, environmentally beneficial and economically attractive - even though we can continue to make it better, nuclear power already hits all of those attributes quite well with existing nuclear power plants.

That's not to say that thorium cannot also be used as a nuclear fuel along with the other nuclear fuels - it can be used, in a number of different types of fuels and types of reactors. A number of power reactors on the electricity grid, as well as prototypes without grid connection, have already operated successfully for many years around the world using thorium, including the Fort St. Vrain and Peach Bottom HTGRs, the AVR and THTR-300 pebble-bed reactors in Germany, the ORNL Molten-Salt Reactor Experiment, and the light-water-moderated thorium breeder reactor core at Shippingport nuclear generating station.

"*Almost anything is possible if you hurl enough money at it, but because the thorium fuel chain is not as intrinsically tied to nuclear weapons production as uranium technology, the technology has never benefited from the impossibly deep pockets of the weapons developers.*"

Interestingly, it looks like Ludlam has been carefully reading the "we missed out because of nuclear weapons" works of the thorium evangelists. Essentially nothing has "benefited from the impossibly deep pockets of the weapons developers" except the engineering and operation of "production reactors" that are optimised for the efficient production of weapons-grade plutonium or other synthetic radionuclides of interest in weapons engineering. The objective of such a a design is not compatible with the objective of efficient, reliable, safe and cheap energy generation - which is why these kinds of reactors often look significantly ifferent to nuclear power reactors. As I mentioned above however, one thing that does "benefit from the impossibly deep pockets of the weapons developers" is the large stockpiles of highly-enriched uranium and weapons-grade plutonium in the nuclear weapons states from the dismantlement of nuclear weapons. This is an enormous resource of clean energy which we can efficiently extract without mining anything, and without novel nuclear reactor designs. We can recover some of the vast expense that went into those stockpiles of nuclear weapons, and generate a huge amount of clean energy for fossil fuel replacement at the same time.

"*Not so the plutonium sector: the dreamers of infinite energy took the reprocessing technology used to build the Nagasaki bomb and envisioned a "closed loop" nuclear economy which would recycle fissionable uranium and alchemic traces of plutonium into mixed oxide fuel for feeding back into reactors.*"

"*It is hard to gauge how much has been spent on this vision of a nuclear perpetual motion machine, but were fortunate in that it's been a total failure, because the environmental, public health and security consequences of a globally distributed plutonium economy at scale are almost too hideous to contemplate.*"

The conversion of abundant natural uranium-238 into nuclear power (through the in-situ conversion of that uranium into fissile plutonium-239 which then fissions) is not a "perpetual motion machine" - it's the consumption of that ^{238}U which is then turned into energy. This uranium represents an incredibly dense, incredibly abundant and long-lasting energy resource for humanity, but certainly nobody ever claimed it to be a "perpetual motion machine". This is polemic nonsense, and it is scientifically illiterate. Nobody claims that finite energy from proton fusion in the sun is a "perpetual motion machine", either.

In his 1983 paper in the (peer-reviewed) American Journal of Physics, Bernard Cohen concluded that "all the world's energy requirements for the remaining 5 billion years of existence of life on Earth could be provided by breeder reactors without the cost of electricity rising by as much as 1% due to fuel costs. This is consistent with the definition of a "renewable" energy source in the sense in which that term is generally used."

However, Cohen's model only considers the available supply of fission energy from natural uranium-238 - it does not include the (even more so than uranium) practically infinite energy resources tied up in thorium, lithium and deuterium on Earth. So the timescale in question is far, far longer than the 5-billion-year timescale that Cohen proposes. Maybe 10 billion years - the lifetime of the Sun.

(Life on Earth won't be around 5 billion years from now, anyway. As it evolves towards the end of the main sequence, a bit of an increase in the sun's luminosity will kill everything on Earth in maybe 2 billion years from now, well before the sun has actually moved into its red giant phase).

However, several billion years is a really long time, and it might be quite plausible that biological evolution can keep up with the lifecycle of the sun, and adapt to the star's increasing power output over this immense timescale. Life on Earth then is likely to be as different from us as we are from the most primitive single-celled organisms. Of course that's only if our descendants, with many other plants and animals, haven't long since left Earth for younger stars and younger worlds.

As for the Nagasaki bomb, building a plutonium implosion weapon like that requires that you start, basically, with a uranium-238 target that is loaded into a nuclear reactor, and this target is allowed to "cook" in a neutron flux for a controlled amount of time. In the case of producing a nuclear weapon, the goal is to have good control over this irradiation process in order to control the ratio of the different plutonium nuclides formed. Ideally for a weapon, this should be almost entirely plutonium-239 with the smallest possible amounts of plutonium-238, plutonium-240 and plutonium-241, since these represent big impediments to the practical engineering and construction of a nuclear weapon. This is particularly true for the alpha heating contributed by the ^{238}Pu content.

After the uranium target has been irradiated with neutrons in the reactor for a certain controlled period of time, it needs to be removed from the reactor, and at this point the isotopic composition of its plutonium content is fixed and can no longer be changed, say by any kind of chemical processing. It is then remotely moved into a hot cell for chemical processing, where it is dissolved and plutonium is chemically separated with something like a solvent extraction which is chosen to be specifically selective for plutonium, such as PUREX - the Plutonium URanium EXtraction. The plutonium complex in solution is separated from the leftover, unchanged uranium (which is almost the entirety of the material present), the highly radioactive fission products, and the other transuranic elements formed alongside the plutonium, and the plutonium is separated as a salt and reduced to a lump of plutonium metal - this is going to require the irradiation and remote handling and chemical processing of perhaps something close to a tonne of uranium.

The plutonium metal is then alloyed, cast and machined appropriately - however, at this point, with this "pit" of plutonium alloy fuel, our hypothetical "N$^{\text{th}}$ country", would-be terrorist organisation or proliferation-breakthrough nation still has to actually know how to successfully design and build a nuclear weapon.

Nuclear power doesn't give you any of those things. Nuclear power, including highly efficient extraction of all the energy stored in natural uranium, doesn't require any of those things. Nuclear power reactors aren't designed to have target material inserted into the core, given a certain amount of time in a neutron flux, and removed and remotely moved for radiochemical processing. If a nuclear power plant is shut down and defueled on a very short cycle then this is absolutely nonsensical for the efficient generation of nuclear power - and it is a clearly suspicious and easily monitored activity.

If nuclear fuel is recycled with a plutonium-selective PUREX extraction chemistry then that gives you one of those steps - but only one, and this does nothing in terms of enabling the other steps that are needed to manufacture practical fuel for a fission bomb. This is the way that some nuclear fuel recycling has been done in the past, and continues to be done, but it is not required for the efficient use of nuclear power.

Efficient conversion of uranium-238 into abundant energy using something like an Integral Fast Reactor doesn't require the separation of plutonium from the minor actinides or other components of the fuel - it all stays mixed together, in a state that requires remote handling and is very resistant to any kind of would-be weapons diversion. During each cycle of the IFR fuel through the integrated fuel processor included in the power plant, nothing really needs to be separated from the nuclear fuel. The fuel rods are essentially "mixed up" at each processing pass, keeping the distribution of fissile material homogeneous through the fuel assembly, which is important since burnup and the transmutation of ^{238}U into fissile plutonium is not homogeneous through the fuel assembly.

Some of the neutron poison fission products such as samarium-149 are removed from the fuel at each recycling pass - even though the neutron cross section for these sorts of fission products is much less significant in a fast neutron spectrum than it would be in a thermal-spectrum reactor, it doesn't hurt to remove them. Not all the fission products are separated, so the fuel does stay very radioactive, and the minor actinides contribute to some of this radioactivity, too. This makes any kind of diversion or transport of this fuel extremely challenging and easy to detect.

The stainless steel fuel clad is also replaced, and the fuel is recycled back into the reactor for another pass without any separation of any of the uranium, plutonium or minor actinides.

"*Whether or not a commercial fusion/thorium/plutonium power industry emerges in the next 20 or 30 years would be irrelevant to the climate debate if not for the huge commitment of resources, expertise and time that are going into these new reactor types, and that is cash thats not being spent on scalable, decentralised clean energy networks.*"

As the peer-reviewed literature shows us, nuclear power is the cheapest, most fit-for-service, most scalable and reliable clean energy option. It is the best, and the limited resources that are available to meet the immense challenge of rapid and scalable fossil fuel replacement should be directed towards the best technologies first.

It *is* money that is being spent on scalable clean energy - a technology that is more scalable than other clean energy technologies. As far as "decentralised" energy generation is concerned, there is absolutely nothing to indicate that "decentralised" generation is more useful to acheive the goal of scalable coal plant replacement. (If you want small-scale, community-owned and highly distributed power generation, there's no reason why you can't have that using systems such as the 10-megawatt Toshiba 4S "nuclear battery", supplying 10 megawatts of power around the clock, constantly and with no maintenance or intervention, for 30 years. Presumably this kind of decentralised, community-owned, small-scale microgeneration would be subject to the same kinds of subsidies and feed-in tariffs that the champions of decentralised power from solar photovoltaics expect for their kilowatt-hours, too.)

"*Clean energy is already more efficient than nuclear*"

So what exactly does "efficient" mean here? As the literature I've mentioned above shows, there is absolutely no evidence that this is the case - for any plausible value of "efficient".

I'd like to see opponents of nuclear energy show us the most convincing, compelling argument against the use of nuclear power they possibly can, using credible evidence from reputable primary sources such as research published in professional journals of science, engineering or economics which stands up to a decent standard of peer-review in both the pre-publication and post-publication sense.

As another example of a peer-reviewed scientific paper which assesses the environmental and public health consequences of nuclear energy, in a 2013 paper in the journal *Environmental Science and Technology*, Pushker Kharecha and James Hansen from NASA's Goddard Institute made the following findings concerning nuclear power, taken from their paper abstract:

"*Because nuclear power is an abundant, low-carbon source of baseload power, it could make a large contribution to mitigation of global climate change and air pollution.*"

"*Using historical production data, we calculate that global nuclear power has prevented an average of 1.84 million air pollution-related deaths and 64 billion tonnes of CO_2-equivalent greenhouse gas emissions that would have resulted from fossil fuel burning. On the basis of global projection data that take into account the effects of the Fukushima accident, we find that nuclear power could additionally prevent an average of 420,000-7.04 million deaths and 80-240 billion tonnes CO_2-eq emissions due to fossil fuels by midcentury, depending on which it replaces. By contrast, we assess that large-scale expansion of unconstrained natural gas use would not mitigate the climate problem and would cause far more deaths than expansion of nuclear power.*"

Nuclear energy is recognised by most of the world's expert climatologists, scientists and engineers as an incredibly valuable, important tool for climate protection. Leading climatologists and atmospheric scientists James Hansen, Kerry Emanuel, Ken Caldeira and Tom Wigley made a firm statement of the facts and their views on nuclear power at the recent UNFCCC COP21 conference:

"*Nuclear power, particularly next-generation nuclear power with a closed fuel cycle (where spent fuel is reprocessed), is uniquely scalable, and environmentally advantageous. Over the past 50 years, nuclear power stations by offsetting fossil fuel combustion have avoided the emission of an estimated 60 billion tonnes of carbon dioxide. Nuclear energy can power whole civilisations, and produce waste streams that are trivial compared to the waste produced by fossil fuel combustion.*"

"*There are technical means to dispose of this small amount of waste safely. However, nuclear does pose unique safety and proliferation concerns that must be addressed with strong and binding international standards and safeguards. Most importantly for climate, nuclear produces no CO_2 during power generation.*"

About 71 percent of climate science experts surveyed in a recent poll (a poll that specifically looked at climatologists) agreed that nuclear power will play a crucial role in any plan to stabilise the effects of anthropogenic carbon dioxide emissions. At the same time, 67 percent agreed that "renewable" energy sources such as wind, solar and biomass would not scale up fast enough to meet the world's expected energy requirements within a safe greenhouse gas budget.

"*So here's another theory: that clean energy technologies, principally solar, wind, energy efficiency and distributed storage are rapidly out-competing nuclear energy on cost, speed of installation and community acceptance.*"

As far as cost and speed of installation are concerned, the peer-reviewed literature I've mentioned elsewhere basically establishes that this is simply not the case. The idea that other (less scalable and more expensive) clean energy technologies are "out-competing nuclear power on community acceptance" is an interesting and novel argument against the use of nuclear power, though.

The results of random independent polling of over 1200 South Australians published by SACOME in 2014 showed that far more South Australians support uranium mining (55%) and the development of nuclear power (48%) than oppose these industries (26% and 33% respectively). "Strong support" for nuclear power, at 29%, outweighs "strong opposition" to nuclear power at 20%. In both cases just under 20% of the cohort sampled were neutral on these issues. 63 percent of people considered nuclear power as either an important contribution to climate change mitigation or as an alternative at least worthy of consideration, and 45% of respondents considered nuclear power to be a sustainable and environmentally sound energy technology. Only 23% of people said they saw no role for nuclear power in climate change mitigation, and 35% of people disagreed with considering nuclear power a sustainable and environmentally sound energy technology. A poll taken by Adelaide's *Sunday Mail* last month showed a considerable majority of support for "moves to create a nuclear industry in South Australia", with 65% positive responses. It seems like public opinion surrounding nuclear power is more positive than some people think - or more positive than some people want to believe.

Even if there is some opposition though, what does that mean, how should we respond to that, and how should that influence the decisions that we make?

For a successful technology reality must take precedence over public relations, for nature cannot be fooled.

If homoeopathy is out-competing vaccination "on community acceptance" does that mean we should ban vaccination and put government subsidies into homoeopathy? If "wind turbine syndrome" pseudoscience gains a foothold in a community and community acceptance of wind turbines falls, should wind turbines be banned? If a crowd of vocal, emotional people from *Melbourne Against Chemtrails* marches down the street in protest against an insidious global conspiracy being sprayed in our skies, does that mean that civil aviation does not have social license to operate?

If there are dozens of passionate, emotional, anti-vaccination activists marching down the street demanding government action against the evil conspiracy of vaccines, there has to be some point, even in a democracy, where we say no, you're wrong, there is no credible science and evidence to back this up and we are not going to enact policy to do things the way you want. You've got to draw the line somewhere. How do you draw the line on "community acceptance" of science denial?

The Australian Greens clearly do not consider this a stumbling block when it comes to vaccination policy, for example. So why do the Greens address this differently when it comes to nuclear power, as opposed to say vaccination? I'm concerned that there is an inconsistency here, and it comes from an ideology that is skewing the way we draw these lines for different technologies. Why aren't different technologies, for example vaccination and nuclear power, being examined in the same consistent way?

Personally, I think it will be beneficial for the Greens to take a hard look at themselves with regards to their stated positions and policies (like I mentioned previously) on nuclear technologies (and in policy matters concerning certain other fields of science and technology, such as biotechnology, too).

Yes, you're likely to lose one or two votes from the extreme activists if you take a more evidence-based approach in these areas, just like they will lose a couple of votes from the extreme anti-vaccination activists. This doesn't have to mean becoming outspoken pro-nuclear-power communicators overnight; it could just mean a willingness to question old ideologies, to look at the best available credible research, and to listen to these concerns from the scientific community. The activists will certainly be extremely vocal and emotional in response to this "betrayal" - they will kick and scream that they will destroy the primary vote of the Greens at the next election.

Although that's what the activists might think they will acheive, realistically they are nowhere near as influential as they like to think that they are. Just like the Greens position on vaccination policy, you're going to gain a whole lot more overall positive support from sensible people, and the tiny amount of support that is lost will be insignificant relative to the support that is gained.

"*The June 2015 BP Statistical Review of World Energy showed that nuclear now contributes just 4.4% of the global energy mix.*"

"*BP concludes that consumption increased for all fuels, reaching record levels for every fuel type except nuclear power.*"

The report from BP cited by Ludlam finds that global primary energy production grew by 0.9% between 2013 and 2014, from 12807.1 Mtoe to 12928.4 Mtoe. Nuclear power was found to have contributed 316.9 Mtoe of that 12928.4 Mtoe in 2014, or 4.23 percent. The BP data finds that global nuclear energy generation grew by 1.8% from 2013 to 2014, with increases in nuclear energy generation in South Korea, France and China outpacing declines in Japan, Belgium and the UK over the same time period. These calculations are based on Japan moving to zero nuclear power generation in 2014, but this data is obviously already obsolete as restarts of power reactors continue in Japan along with the new builds continuing to come online throughout Asia and the rest of the world.

I find it interesting that Ludlam immediately accepts BP as an authority, without any scepticism or hesitation. There is no snide anti-corporate rhetoric here, no criticism of BP's social responsibility, no conspiracy ideation, no bogeyman of "The Industry". Big Fossil is suddenly Ludlam's best mate where it is convenient to suit the anti-nuclear-power narrative.

"*Renewable energy, without the military-industrial head start, now contributes 6% with an annual growth rate of 12%.*"

According to the BP data, non-hydro renewable energy sources (defined in this data as wind energy, solar, geothermal, and biomass or waste combustion) contributed a global 316.9 Mtoe of primary energy in 2014. This is indeed a 12% increase on the 283 Mtoe generated from these sources in 2013, but it is only *2.45 percent* of the 2014 global primary energy production of 12928.4 Mtoe. (A large portion of this non-hydro renewable energy comes from industrial-scale waste and biomass combustion, which are hardly clean, ecologically friendly and public-health-friendly energy systems.)

Renewable energy used for electricity generation has also grown by 12 percent between 2013 and 2014. This increase was below the 10-year average growth rate for renewable energy in electricity generation, but it meant that renewable energy accounted for a record 6.0% of global electrical energy generation. (This is electrical energy, measured after the conversion of primary energy from a heat source such as a biomass combustion furnace or a solar-thermal heat source into electricity, with the inevitable thermodynamic efficiency that this entails. The two data sets, of primary energy and electrical energy, are two different things and they are not directly comparable.)

"*As part of the Greens' negotiations with Labor in 2010, Christine Milne requested that the Australian Energy Market Operator conduct detailed modelling on a 100% renewable energy plan for Australia. The various scenarios demonstrated it was entirely possible to have this in place by 2030.*"

The AEMO study that Ludlam refers to found that a "100% renewable" electricity system for Australia is likely to require much higher capacity reserves than a conventional electricity grid, and in fact it was estimated that in such a scenario the generation nameplate capacity could need to be over twice the maximum customer demand. If the fundamental objective of this model commissioned by the Greens was truly to reduce greenhouse gas emissions from the electricity sector, it's important to note that the replacement of coal-fired plants with nuclear power will acheive this much more effectively - it will reduce greenhouse gas emissions from electricity generation from 196 million tonnes CO_2-equivalent in 2010 to about 30 million tonnes by 2050; an impressive 85% reduction.

Importantly, using the same BREE costing data employed in the AEMO modelling, deploying nuclear power for the replacement of all of Australia's coal-fired generators would cost $91 billion, which is less than half of the $219 billion cost of the lowest-cost "100% renewable" scenario (going as high as $332 billion in other scenarios). This reduction in cost comes largely from removing the need for additional capacity reserves to back up the wide deployment of low-capacity-factor, intermittent generators.

As well as reducing capital costs, a NEM mix that includes nuclear power offers other benefits compared to a "100% renewable" scenario. Significantly less land use is required as well as less need for upgrades to the transmission infrastructure. Land use for US nuclear power plants averages 3.6 square kilometres per gigawatt of nameplate capacity - meaning that for clean energy in Australia we could expect to use less than 100 square kilometres, rather than 2400 to 5000 square kilometres under the renewable scenario.

A key component of the AEMO "100% renewable" scenario is the annual transport of 50 million tonnes of vegetable biomass from plantations, farms and native forests - log, slash, truck and burn. Even in plantation forestry, how much of this "waste" is home to wildlife and home to biodiversity? Furthermore, transporting this plant biomass to power stations diverts nitrogen, phosphorus, potassium and other key minerals that would otherwise be returned to the fertile soil from the decay of plant matter - essentially a massive soil mineral mining operation. Some of AEMO's models also rely heavily on geothermal energy - a technology which has promised much so far in Australia but delivered nothing, to the point where some of Australia's leaders in geothermal technology have decided it was easier to pack up and move into the more viable petroleum hydrofracturing industry.

Including nuclear power in the technology mix would avoid some of the uncosted risks and the extra "challenges" contained in the AEMO report, it would avoid the need to over-build the transmission network, and it would avoid the acquisition of half a million hectares of land. It would avoid the need for a massive new forestry industry transporting biomass on a scale significantly larger than Australia's entire output of cereal agriculture (about 35 megatonnes). It would also avoid the need for "demand-side participation" - a wonderful little piece of jargon crucial to the AEMO scenarios where we simply toss aside the simple expectation that electricity is reliably available to users on demand when they need it.

This is further evidence that this "renewable" buzzword is absolutely meaningless, and the way that it gets thrown around has absolutely nothing to do with choosing the most favorable technologies based on land use impacts, biodiversity impacts, cost, public health impacts, climate protection, scalability, reliability or any other metric that actually makes sense.

Wood smoke from cooking fires causes about 3.5 million premature deaths a year, including half a million children, mostly in the developing world. Wood combustion may technically be carbon neutral, but it is far from being clean or safe. It is not an environmentally friendly fuel, it is not an efficient fuel (even compared to lignite), and the logistics of logging and transporting biomass on a 50-megatonne scale is clearly far from carbon-neutral on a whole-of-lifecycle basis. These points are expanded further in an analysis of AEMO's proposed scenarios by Geoff Russell.

A further detailed critique of the AEMO 100% renewable modelling is given by Dr Ted Trainer here. As Trainer points out, the issue is not whether or not a "100% renewable" electricity grid with nuclear power banned is technically possible; such a thing is probably not technically impossible, but it's completely unaffordable, and this dogma of nuclear exclusion makes absolutely no sense in terms of economics, in terms of technological maturity, risk and the confidence that the scenario can actually be deployed, in terms of water use, land use, build times, energy costs, public health impact or the reliability of energy supply. Pursuing this ideological scenario is not impossible, but it makes absolutely no sense by any rational and evidence-based metric.

"*This is consistent with the Beyond Zero Emissions Stationary Energy Plan dating back to 2010, and it's consistent with independent modelling commissioned by the Western Australian Greens for the more localised Energy 2029 project which showed that going to 100% renewable energy would be cheaper than building the next generation of fossil plants and upgrades out to the year 2029.*"

The "Beyond Zero Emissions" Stationary Energy Plan has been analysed and critically examined at great length by Martin Nicholson and Peter Lang, as well as independently by Ted Trainer, among others. Their analyses are both valuable and well worth reading. In short, Nicholson and Lang conclude the following key points:

"The ZCA2020 Stationary Energy Plan has significantly underestimated the cost and timescale required to implement such a plan."

"*Our revised cost estimate is nearly five times higher than the estimate in the Plan: $1709 billion compared to $370 billion. The cost estimates are highly uncertain with a range of $855 billion to $4191 billion for our estimate. The wholesale electricity costs would increase nearly 10 times above current costs to $500/MWh, not the $120/MWh claimed in the Plan.*"

"*The Plan's implementation timeline is unrealistic. We doubt any solar thermal plants, of the size and availability proposed in the plan, will be on line before 2020. We expect only demonstration plants will be built until there is confidence that they can be economically viable.*"

The *Zero Carbon Options* report produced by Brown & Pang and ThinkClimate Consulting in 2012 also compares a "100% renewable" reference scenario alongside a "nuclear power allowed in the mix" scenario for electricity generation in South Australia. They conclude that the "nuclear allowed" scenario is far cheaper, generates significantly more clean energy, reduces greenhouse gas emissions significantly more, uses no fresh water and uses significantly less land than the "renewable-only" (from "Repower Port Augusta") that it is compared against.

"*If this new nuclear push is really about climate, it should engage with the real question: what is the fastest, cheapest, safest way to decarbonise the global stationary energy sector?*"

This is certainly a good question to ask! But what has all the evidence that I've mentioned above actually shown us?

"*The evidence shows that nuclear is neither fast, cheap, nor safe.*"

The evidence has shown us that this is a fairytale! The continued proliferation of this fairytale is irresponsible in the context of growing biodiversity protection, water use, public health, climate change and environmental protection concerns.

"The final theory, harder to test against the evidence, is that this new nuclear push in Australia isnt about climate change at all, but that in fact were being softened up for a sustained campaign to build one or more spent nuclear fuel dumps in outback Australia."

Yes, it's "harder to test against the evidence".

"*As has been the case time and again around the world, Aboriginal people will be asked to sacrifice country to a cargo that will still be carcinogenic in tens of thousands of years.*"

"*I've stood with Aboriginal people defying new waves of uranium dispossession in the Goldfields and Top End.*"

So, where is the evidence that "Aboriginal people will be asked to sacrifice country to a a cargo that will still be carcinogenic in tens of thousands of years"? What radionuclides, with what lifetimes, are we talking about here that will "still be carcinogenic in tens of thousands of years"?

When we do use nuclear power in Australia, if this is done using familiar and widespread light-water reactors, then we will obviously need to store slightly-used LWR fuel in Australia. This will probably just be stored at the plant sites right where it is generated, as is familiar practice in the United States for example.

Even before we use nuclear power in this country, storing slightly used nuclear fuel from other nations in Australia is a possibility too.

Obviously we won't be storing this slightly-used fuel forever - that would be a senselessly inefficient waste of a large resource of perfectly good fuel. This fuel will be efficiently recycled and entirely consumed for clean energy, but it is easy to store the fuel for a little while before this happens. Storing a cask of slightly-used nuclear fuel is very safe - such fuel has never harmed any person in history, anywhere in the world. (If you think I'm mistaken on that point, please show us.) The effective use of fission power in Australia for scalable coal replacement does not in any way require an importation of slightly-used nuclear fuel from other nations into Australia, but this does potentially represent a huge economic opportunity for Australia.

Because nuclear fuels have an extremely high energy density, this fuel takes up a tiny amount of space for the energy output that it generates. This temporary "sacrifice" of a tiny amount of land, until the nuclear fuel is efficiently recycled, is a trivially minor use of our land when viewed in the context of the completely unchecked, unregulated emission of billions of tonnes of carbon dioxide into the atmosphere and the climate system that we all collectively share. Kharecha and Hansen, in their 2013 paper, find that nuclear power has already displaced 64 billion tonnes of carbon dioxide emissions to the atmosphere and has the potential to displace a further 80-240 billion tonnes by mid-century.

So what particular relevance, if any, does temporary storage of a tiny amount of slightly-used nuclear fuel before it is recycled have to indigenous Australians? What reason, what relevance, is there to single out indigenous Australians or any other demographic or ethnicity for particular attention here?

What exactly is "uranium dispossession" in the Goldfields and Top End? Even if we had an explanation of what this is, why it's a problem, and evidence that it actually exists, I'd still like to know if "uranium dispossession" is a thing that is in any way different from, say, "coal dispossession", "gas dispossession", "diamond dispossession", "neodymium dispossession" or "silicon dispossession"? What is magically different about uranium that is different from any other natural resource?

I think these references to indigenous peoples are interesting little examples of what we see all too often, where anti-nuclear activists actually take advantage of indigenous people in support of their agenda, essentially using them as a political tool to suit their own ends. It is, as some people like to creatively put it, radioactive racism. Like anti-biotechnology activists and anti-vaccine activists, most anti-nuclear-power activists are relatively wealthy white people in the developed world who have never had a problem with having access to as much energy, food or medicine on demand, as much as they want, when they need it. This rubbish is preached and coached constantly to the indigenous community by the anti-nuclear-energy activists, taking advantage of the fact that, unfortunately, the average level of access to education in remote areas and in the indigenous community is lower.

"*It is reasonably easy to run emotionless arguments about the merits of nuclear power when you live a long way from the impact area of the industry.*"

Radiative forcing driven by greenhouse gases in the atmosphere does not discriminate in terms of where or who it affects.

These crucial global challenges that we face, in terms of biodiversity protection, protection of the climate system and sustainable land use and use of freshwater resources, are challenges that we all have to face together, with particular efforts being contributed by the developed nations on behalf of all humanity. Everybody lives close to the impact area of the public health impacts of fossil fuel combustion as well as indoor air pollution from biomass combustion, the latter being particularly significant in the developing world.

"*There is a reason the nuclear industry seeks stable, high isolation sites with deep groundwater and low seismic activity: because they know, and occasionally they even admit, that there is no form of engineered containment that this material wont burn its way out of.*"

The idea that used nuclear fuel can "burn its way out" of engineered containment in a storage cask is an absurd fairytale. Where is there the slightest bit of technical justification or evidence for this? Dry cask storage of used nuclear fuel has been used in the United States for 30 years, presently at more than 70 sites in 34 states, and in that time there has been no failure or breach of any cask.

"*They want remote sites because the dumps are guaranteed to eventually come apart at the seams.*"

"*To many, this is an argument for keeping the fuel in hardened, dry, above-ground or near-surface storage under continual monitoring while the research community set about developing waste isolation technologies that arent guaranteed to fail within a few decades.*"

Analysis of used nuclear fuel and cask components after decades of dry-cask storage have confirmed that these systems are providing secure and safe storage. The US Nuclear Regulatory Commission has determined that slightly-used nuclear fuel from power reactors can be stored safely in dry cask storage without any significant environmental impacts, with only a tiny bit of land use, for a period of at least 60 years beyond the operational lifetime of a nuclear power plant. This 60-year timeframe applies without any active inspection or maintenance activity - nothing needs to be done at all. It's quite routine to store this nuclear fuel at nuclear power plant sites - meaning that the fuel will be stored relatively close to electricity demand centres with lots of population. But it doesn't hurt anybody - and it's certainly not true that it has to be moved out to the most remote desert - as long as local suburban activists don't protest against it "in my backyard".

After 60 years of storage in a dry cask, the thermal power output from the stored nuclear fuel has decayed to less than 1 percent of what it was when the fuel stopped being used for energy generation, and 75 percent of the moderately-lived fission products strontium-90 and cesium-137 (with a half-life of about 30 years) have decayed away. US nuclear power operators are confident that existing dry cask storage technology, coupled with aging management programs already in place, is sufficient for dry cask storage of nuclear fuel to be sustained safely for at least 100 years.

For timescales beyond 60 years, it is a good idea to have aging management programs in place - as they already are in the US nuclear power industry, even for fuel in casks that are not that old - and to have inspection and maintenance in place to keep an eye on things. This is no different to any other form of engineering - of course you monitor it and keep an eye on it to see what is going on, just like you would keep an eye on a 70-year-old building made of reinforced concrete. (For comparison, the Ingalls Building in Cincinnati is 112 years old, and some Roman concrete structures such as the Pantheon and the Baths of Caracalla have stood up impressively well for the better part of 2000 years. Of course in a nuclear fuel storage cask the concrete outer structure certainly isn't the only layer of containment between the nuclear fuel and the outside.)

Eventually, that used nuclear fuel will be recycled and efficiently converted into abundant clean energy. The fission products which don't have sufficient demand for valuable technological applications, such as ^{90}Sr and ^{137}Cs, will be vitrified into molten glass and sealed into welded casks of solid stainless steel which can then sent permanently and safely to a deep geological repository (although they too can safely be stored on the surface for a very long time). So, how long do we need to temporarily store this slightly-used nuclear fuel for before this efficient recycling is done? 20 years? 40 years? Suffice to say that when we're talking about safe storage for 60 years, or 100 years, or more, that's plenty of time.

"*I've met with Jharkhand villagers inside the plant footprint of the Indian uranium mining complex at Jadugoda who are nursing two generations of deformed children.*"

Is uranium mining in India relevant to the discussion of nuclear power (or uranium mining) in Australia? Is there anything published in the scientific literature that demonstrates that adverse public health impacts exist which are being caused by uranium mining? Be careful with activists using pictures of sick children to try and get you to switch off evidence-based policymaking and disarm your sceptical faculties - this is exactly the same sort of behaviour the anti-vaccinationists love, for example. Is the replacement of coal combustion and biomass combustion, both indoors and outdoors, with nuclear electricity positive gain for public health of the Indian population?

Could we mitigate any possible environmental or public health impacts of uranium mining in India by cooperating with India to share world's best practices, technologies and experience in mining and in health physics, by encouraging the use of technologies (including but not limited to fast-spectrum reactors) which convert mined uranium and thorium into energy in an extremely efficient way, extracting all the potential energy content and minimising the need for mining, or by mining uranium in Australia with very strong standards of safety and environmental protection and exporting it to India? Or would the anti-nuclear-power activists protest against any such measures?

How about we completely mitigate the enormous public health impacts of fossil fuel and biomass combustion by replacing it all with clean energy?

"*I have heard first-hand from Japanese elders what it is like to be under a nuclear weapons strike.*"

If you want to hear about the horror of total war I'm sure you could just as easily ask the elders of Dresden, Rotterdam, London, Darwin or Nanjing about that. You could ask the elders of Changde and Ningbo about their experiences of bombardment with weaponised plague, anthrax and cholera. I wonder if they protest against biotechnology and vaccines in order to ensure such technology is never available to be used in that way ever again? But I digress. Of course this is not actually relevant to what we're actually discussing.

"*I've been fortunate enough to spend time with a small number of the 130,000 radiation refugees permanently displaced by the triple meltdowns at Fukushima.*"

The UNSCEAR 2013 Report to the General Assembly (Scientific Annex A in particular) provides a detailed and authoritative reference, composed of the best available science, on the health physics impacts of the reactor damage and radioactive releases at Fukushima Daiichi nuclear power plant in 2011. UNSCEAR's conclusion, to put it briefly, is that in terms of the amount of radioactivity released and the effects of that radioactivity, no adverse health effects are expected in any residents around the Fukushima region or their descendants.

UNSCEAR concludes that "*The most important health effects observed so far among the general public and among workers were considered to be on mental health and social wellbeing, relating to the enormous impact of the earthquake and tsunami, causing loss of family and friends and loss of livelihood and necessitating evacuation; and the impacts of the nuclear accident, including not only further evacuation and loss of livelihood, but also fear and stigma related to real and perceived health risks associated with ionising radiation.*" Effects such as depression and post-traumatic stress symptoms have already been reported extensively, but these are not exclusively related to the nuclear accident.

Estimation of the occurrence and severity of these health effects is outside of UNSCEAR's remit, which leaves us in a frustrating situation. UNSCEAR spends a huge amount of effort collating and carefully checking the best available science to give us the best possible picture of the radiobiology and health physics effects - but we know that the public health effects of this kind are essentially negligible.

We know that that essentially all of the real, serious public health effects are mental health effects, yet studying the epidemiology and the best possible management of these health effects is outside UNSCEAR's health physics remit. We know where the actual health effects are, but who is actually dedicating appropriate expertise and resources in this area where they are most needed? Perhaps this is something that the World Health Organisation is best equipped to handle.

In the short term immediately following the core damage and release of some fission products at Fukushima, the evacuations around the site did substantially reduce the radiological doses received by the people living in some of those areas. However, the evacuations themselves also had health repercussions for the people involved, including a number of evacuation-related deaths and ongoing impacts on mental and social wellbeing, for example because evacuees were separated from their homes and familiar surroundings and many lost their livelihoods.

Table C19 in Appendix C of Scientific Annex A to the UNSCEAR report shows the effective doses that would be received from external exposure of adults who were evacuated from various municipalities in Fukushima prefecture if they were to return to their homes. The highest dose rates occur in the towns of Futuba and Namie Machie, with effective doses from external exposure of 4.0 and 4.5 mSv respectively, for the year ending 11 March 2015. For other municipalities in Fukushima prefecture these doses are all lower, as low as 0.15 mSv/a and 0.08 mSv/a in Kawauchi village and Tamura city respectively. This data is already old, and these dose rates will continue to fall with each passing day due to radioactive decay and weathering.

Even in those locations with the very highest doses, such as Futuba, these dose rates are already far below the 20 mSv/a Japanese criteria for evacuation. The timescale where such evacuations were a sensible precaution and valuable in the Fukushima region was not very long, and this timescale has long since passed. There is absolutely no reason, in terms of radioactivity, why these people can't go home (to the task of rebuilding their tsunami-devastated connunities) at this time to these communities that are below the 20 mSv/a mark. It could have, and should have, already happened. Why should the Japanese government be spending a huge amount of money, and subjecting people to great stress and psychological harm just to avoid an extra millisievert or two per year, maybe - when there is no evidence that background radiation at these dose rates (which are not uncommon throughout the world) causes anybody any harm at all? This is hurting people, and it is a waste of resources and a distraction from the rebuilding of tsunami-devastated families and communities.

They are not "permanently displaced". Why would anybody be "permanently displaced", and what can governments (and everybody else) do to help these people get back to their tsunami-devastated communities and try to rebuild normal lives as quickly as possible? If people are being discouraged from returning to their homes in areas below the 20 mSv/a threshold (which is essentially everywhere in Fukushima prefecture outside the nuclear power plant) by science-denier activists, or being blocked from returning to their homes by science-denier policymakers, then these people are part of the problem, in terms of causing the health damage that occurs. These people are contributing to that psychological harm, just like the rest of the pseudoscience and fearmongering spready by the anti-nuclear-power activist community as well as by the tabloid media contributes to this health damage.

"*I strongly believe the theories that the anti-nuclear movement bring to these questions are sound, evidence-based and tested through three generations of bitter experience*"

Well, it looks like your feelpinions are wrong.

"*I've come to realise that attempting to eliminate emotional responses or basic compassion from arguments about industrial energy systems is a major part of the problem.*"

"*If these experiences hadnt provoked emotional responses, Id be deeply worried about my humanity.*"

As I mentioned above, it's OK that you're emotional. But you claimed your position is evidence-based, and we're going to look at that evidence. Having emotions doesn't give you a free ride when it comes to having evidence, and looking at whether that evidence you provide stands up to scrutiny. You're the one that proudly proclaimed that these positions and policies are supposedly evidence-based. When we're emotional it's important to remember that extra scepticism is needed, and we need to be extra careful to avoid being had.

"*Either way, if we're to have this argument yet again, bring it on. All we ask is that both sides of the argument work from a common understanding of what the evidence actually says.*"

Well, to sum up everything I've mentioned above, obviously your definition of evidence, your standards for determining what constitutes good-quality evidence, and what that evidence actually says are very different from mine.