Strategic Climate/Energy Policy Issues Paper

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Executive Summary

The task to make Australia 100% clean-energy is much larger than generally thought requiring approximately 250% more electricity generation than at present.

A clean-energy Australia would be an all-electric Australia fed by an abundant, secure and reliable flow of clean electricity, not reliant on fossil fuels.

As of today less than 40% of our fossil fuel supply gets burned in power stations.

If tomorrow by magic all of today's power supplies came from clean sources like sun and wind, more than 60% of fossil fuel usage and carbon dioxide emissions would remain untouched.

There's only one conclusion. Eliminating all fossil fuels and their emissions will need much more electricity than now. Analysis says about 2½ times more, at least.

Where will all that extra electricity come from?

How can everything be made to work on electricity?

Those two questions define the strategic needs of our climate/energy policy.

Renewables, hydroelectricity and nuclear energy are now the world's main sources of clean electricity.

In Australia, hydroelectricity is generally considered to be near its limits.

As for solar and wind electricity, at Australia's current record growth rates it will still take over 60 years to reach clean electricity goals. This analysis is optimistic and ignores factors like population growth and rising living standards.

It also ignores the need to turn intermittent solar and wind generation into a reliable energy supply. Storage is claimed as the answer. Batteries, pumped hydro and hydrogen are all popular candidate technologies. At the scale needed for major electricity grids these must still be regarded as speculative and not the firm basis a sound strategic outlook requires.

The difficulties in scaling this mix of technologies up so it is reliable, available and affordable are so large that it is unlikely to happen without a significant contribution from nuclear power. Given the popular prejudice against nuclear, governments need to be talking to their citizens intelligently about the problems with our current trajectory so they can understand the need.

Then there's the issue of electrification, converting every present use of fossil fuels into electricity-driven processes. Transportation, metal production, fertilisers, explosives, petrochemicals, plastics – the list is huge and the efforts have barely begun. Impressive advances in electric cars are the main exception.

Getting the energy mix right also has implications beyond energy policy itself. A failure in this area represents a security risk. In the absence of international agreements that bind competitors to limit their emissions too, a unilateral reduction, using a bad technology mix would be economically damaging, as well as futile.

This would leave Australia with the worst of both worlds – a damaged economy for no measurable decrease in carbon dioxide emissions.

Major Points

1. Climate/energy policy should aim at 100% clean energy, with low or zero carbon dioxide emissions and no fossil fuels. Australia does now have clean energy policies but focused on "percent renewables" targets. These have shortcomings. They limit the scope of energy technologies. Their reference points are prevailing levels of electricity generation. And their end goals are much too small to displace fossil fuels. New policies should be based on numerical targets comprising properly assessed clean energy quantities.
2. However sourced, clean electricity is the energy medium for achieving policy objectives. Clean economies will ideally be all-electric. Strategic plans must include clean energy goals, the means for reaching them, and the innovative technologies for replacing fossil fuels with clean electricity ("electrification"). The associated transition is huge. It will need a policy timeframe reaching to at least 2050.
3. Analysis shows that around 40% of all fossil fuel is presently consumed in electricity generation. "Percent renewables" targets in effect ignore the other 60%. Further analysis leads to an estimate of at least 2.4 times present electricity generation to enable elimination of all fossil fuel. 2019 generation was 954 PJ[1], which means a minimum target of 2250 PJ to allow for the new electricity demands of electrification.
4. Renewables-based policies rely on growth in solar and wind energy because hydroelectricity growth prospects have long been limited by environmental concerns. In 2019, solar (64.6 PJ) and wind (70.3 PJ) together yielded 134.9 PJ, 14.1% of total output and 6.0% of the proposed new target. If current record growth rates of solar and wind were maintained it would take 65 years for total generation to reach that target. It looks unreasonable to rely on solar and wind for meeting future clean energy needs.
5. In the same vein it is unreasonable for policy to rely on energy storage to provide large scale stable industrial, commercial and urban energy supplies based on intermittent renewables. Pumped hydro faces similar limitations to expansion as hydroelectric generation. Hydrogen, already a major industrial gas, is attracting much attention but must be considered as unproven in this application.
6. Nuclear energy is the one source of reliable heavy duty industrial scale clean electricity that could match present fossil fuel-based generation. Nuclear energy already provides 30.5% of the world's clean electricity. Most advanced economies are well positioned for nuclear expansion. Australia differs due to its longstanding legal and cultural anti-nuclear sentiment. Australia should initiate a strategy for encouraging its citizens to feel at least as comfortable with nuclear energy as are the populations of the 31 nations now generating nuclear electricity. In time the necessary legislative changes should follow.
7. The all-electric clean energy economy will need a suite of new electrification technologies. These present a technical challenge at least as great as supplying adequate quantities of clean electricity. A co-ordinated national electrification strategy involving major industries and their supply chains should be undertaken. Realistically, some fossil fuel uses may not be amenable to electrification and policy should provide for quotas of fossil fuels to be reserved for those uses.
8. The economics of clean energy presents a potential danger to Australia's global trade. There are regular claims that clean energy will be cheaper than fossil fuel-based energy. This seems like wishful thinking. In the absence of binding international agreement on emissions, unilateral emissions reduction by Australia could be economically damaging as well as futile in relation to global climate goals. Australia's energy policy should therefore remain responsive to the global situation. In any event it should give priority to protecting Australia's competitive position in value-adding energy-intensive resource-based industries.

[1] The energy unit favoured here is the petajoule PJ, 10^{15} joules, as used in the official compilation of Australian government energy statistics Australian Energy Update.

The policy challenges of climate and energy.

Australia needs a strategic policy for its future energy supplies. The policy should deliver an abundant, secure, reliable and economic energy supply meeting the future needs of industry, commerce and households. At the same time it must be aligned with climate goals for lower carbon dioxide emissions. These two objectives constitute a “climate/energy” policy.

The “climate objective” rests on the basic tenet of climate science (see for example American Institute of Physics “Discovery of Global Warming”[2]) that emissions of the greenhouse gas carbon dioxide (CO_2) from combustion of carbon-containing fossil fuels can influence climate. Fossil fuels contain energy. Energy systems based on their combustion and energy conversion to electricity have long formed the major part of global energy.

While a majority of Australians accepts the general principle of human-caused climate change (see e.g. this recent survey[3]), there are prominent dissenters, differences in views on mitigation strategies, and wide variations in political approaches to the issue. However most would likely agree that national CO_2 emissions should be cut, that Australia should meet any international obligations it has entered into regarding climate change, and that domestic and international audiences should be satisfied that Australia is doing its part in addressing the global problem of climate change.

Globally and in Australia, energy use is the main single source of emissions, accounting for two-thirds of the global total[4]. While agriculture, land-use changes and certain process industries also contribute to emissions of CO_2 and some other greenhouse gases, energy produced with low accompanying CO_2 emissions is at the heart of climate/energy policy. This is “clean energy”. A successful policy is one that delivers an abundant, secure, reliable, clean energy supply. Past policies delivered energy with three of those characteristics; “clean” is the new one. Ideally, present policy should deliver clean energy at no increase in cost.

It is well recognised that new technology is the key to these policy goals. Major changes in energy systems are required. Fossil fuel usage must be reduced. “Clean electricity” will become the main medium for energy supply. A transition will be needed in both the sources of energy and the means for using electricity to produce all, or almost all, the goods and services on which the Australian economy relies. These changes are so great that, despite the oft-expressed urgency of reducing emissions, the policy timeframe must in practice extend to at least 2050.

There are huge challenges in meeting these policy objectives. They are not uniquely Australian; they are shared with the rest of the world.

Specifying clean energy.

Clean and *abundant* are two key qualities for successful energy policy that need to be specified.

Energy is the capacity to do work. Energy is a term in everyday usage but actually refers to a somewhat abstract concept in physics. Oddly, energy in itself is not tangible but its effects are. There are many forms of energy. They are largely interconvertible. Energy quantities are measurable. There are many different units used for that purpose. They can be confusing for those not using them regularly. Online tools[5] help with conversion and comparison. The basic energy unit is the joule (J). The related basic power unit is the watt (W). One watt = one joule per second. While interconvertible, the different units tend to be associated with different forms of energy and activity, like kilowatt-hours for electricity, gigajoules for natural gas, BTU for air-conditioning. The choice of units for describing energy quantities in energy policy is important because they can help or hinder in conveying clarity.

When referring to national and global energy data, electrical or otherwise, it is desirable to employ energy units large enough to keep the numerical values small and manageable. The favoured units in this document are the petajoule PJ, 10^{15} joules, and the exajoule EJ, 10^{18} joules. The PJ is a convenient size for Australian data. It is used in the official compilation of Australian government energy statistics Australian Energy Update[6]. 1 PJ = 277.8 GWh (gigawatt-hour, GWh, is a popular unit for quantifying electrical energy). The EJ suits energy data for the world and larger economies like the USA.

[2] The Discovery of Global Warming https://history.aip.org/climate/co2.htm
[3] “Climate of the Nation 2019” https://www.tai.org.au/content/climate-nation-2019
[4] https://www.iea.org/topics/climate-change
[5] http://www.onlineconversion.com/energy.htm
[6] Australian Energy Update https://www.energy.gov.au/sites/default/files/australian_energy_statistics_2019_energy_update_report_september.pdf

Users of various global statistical compilations like IEA Key World Energy Statistics[7] and BP Statistical Review of World Energy[8] (which has just converted to EJ units) are faced with a confusing array of energy and power units. Again, online energy conversion tools can help solve the problem.

"Clean energy" associated with zero or minimal CO_2 emissions is a key objective of climate/energy policy needing clear specification.

In isolation, for its end user, electricity is always perceived as a "clean" form of energy. Regardless of how it was fuelled, electricity was once promoted[9] as the shining example of clean domestic energy, in contrast to say firewood, coal or briquettes (e.g. in Victoria), where consumers could experience unpleasant combustion products. The smoke and soot that might be emitted at distant power stations did not affect them. The situation changed in the 1980s with rising recognition that, regardless of source, invisible odourless power station CO_2 emissions were accumulating in the atmosphere globally and having an impact on climate through the greenhouse effect[10]. Certain other emissions could also have a more local impact on health.

The key "clean" specification for an electricity generation and supply system is its life-cycle emissions intensity. This is the quantity of CO_2 emissions per unit of electrical energy output, taking into account all steps in the energy production and distribution chain. For example, a solar panel emits no CO_2. However there are many processes involved in producing raw materials, manufacturing panels, transporting and installing systems, eventual end-of-life decommissioning and disposal, etc. These stages and their supply chains will involve fossil fuels, the emissions from which must be included in determining "life-cycle emissions" and attributing them to each unit of energy generated over the lifetime of the solar system.

Methodology for calculating life-cycle emissions intensities is complex but well established. The results depend on geographical variations in the kinds of energy used during the life-cycle stages. Table 1 shows some typical values for various energy sources and technologies (from Intergovernmental Panel on Climate Change).

Table 1. Some typical life-cycle emissions intensities for electricity generated by different technologies (kg CO_2/MWh)[11]

Black coal	Gas combined cycle	Solar PV utility scale	Solar PV rooftop	Geo thermal	Conc. solar	Hydro electricity	Wind offshore	Nuclear	Wind onshore
820	**490**	**48**	**41**	**38**	**27**	**24**	**12**	**12**	**11**

While quantifiable, "clean electricity" is a qualitative target; there is no set standard or limit. The lower the emissions intensity, the "cleaner" is the energy. No present energy technology has zero life-cycle emissions.

Emissions intensities will generally decline as the overall proportion of clean energy in global production systems rises. In practice, arbitrary clean targets are in use. For example a recent OECD report on system costs for decarbonisation of electricity[12] to meet the Paris 2C climate objective uses a target of 50 kg CO_2/MWh. A 95% cut in emissions from coal-fired power generation would equate to emissions intensities of 40 to 50 kg CO_2/MWh (or, in terms of joule units, 11 to 14 kg CO_2/GJ).

50 kg CO_2/MWh can be considered a reasonable clean target at present and on that basis all the non-fossil-fuel systems listed in Table 1 would qualify as "clean".

[7] Key World Energy Statistics 2019 https://webstore.iea.org/key-world-energy-statistics-2019
[8] BP Statistical Review of World Energy https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf
[9] "Winter has a dreadful habit of bringing families together" *The Australian Women's Weekly,* May 7, 1980 https://trove.nla.gov.au/newspaper/article/57125640
[10] https://history.aip.org/climate/co2.htm
[11] "IPCC Working Group III – Mitigation of Climate Change, Annex III: Technology - specific cost and performance parameters - Table A.III.2 (Emissions of selected electricity supply technologies (gCO 2eq/kWh))" https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf#page=7
[1212] "The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables" https://www.oecd-nea.org/ndd/pubs/2019/7299-system-costs.pdf

Sources of clean energy.

All the sources in Table 1 that qualify as clean produce energy in the form of electricity. Hence a clean energy world will be an all-electric world, or as Australia's Chief Scientist describes it[13], an "Electric Planet". There may be other clean usable forms of energy, like the heat from nuclear fission.

The clean energy front-runners at present are hydroelectric, solar and wind energy. There are many proposals and plans for essentially "running everything" on those three energy sources. Perhaps the best known is The Solutions Project[14], which offers a detailed global roadmap.

However many other energy technologies have received varying degrees of attention. Energy in general is fertile ground for new ideas and inventions. Some seem plausible when first announced, others can turn out to be examples of perpetual motion machines or engines that "run on water".

Geothermal energy provides an interesting policy case study. Enhanced Geothermal Systems (EGS) tap energy from fractured hot deep dry rock strata, as distinct from near-surface conventional geothermal fields in volcanically active regions. Fluids are injected and recirculated between the hot underground rock and heat exchangers feeding thermal power generators at ground level. Around 2010, confidence in EGS was great enough for its inclusion as a "baseload power source" in Australia's official clean energy scenarios. Government agencies were involved in mapping the best prospects[15]. Huge "reserves" of heat energy were identified, with many considered favourable because of depth and temperature. There was much investment activity. As it turned out the problems of recirculating corrosive brines, at temperatures over 200 C, high pressures, and depths of several kilometres, were great (as some had anticipated). Now, a decade later, the early optimism has faded.

Wave energy and tidal energy have also attracted degrees of interest over many decades. Now they have largely been overtaken by solar photovoltaic technology and wind. Large solar thermal installations have been built and operated for extended periods, e.g. in Spain and the USA. Solar thermal technology has the intrinsic advantage of inbuilt thermal energy storage that enables generation to continue long after solar input falls at night. However uptake in Australia and globally has been relatively low in comparison to solar PV and wind, due mostly to its higher cost.

Liquid biofuels synthesised from biomass have received much attention because, like conventional oil-based liquid fuels, they offer the high energy density essential for uses like aviation. Life-cycle emissions intensities are difficult to establish and can be controversial. Liquid biofuels are generally for direct use and not aimed at conversion to electricity.

Carbon capture and storage technologies aim to enable the continued use of fossil fuels for electricity generation by isolating and disposing of most or all of the CO_2 produced in the combustion process instead of emitting it to the atmosphere. In Australia, the Global CCS Institute[16] was initiated in 2009 with a government pledge of $100 million annual support[17] initiated at Prime Ministerial level. Eleven years later, commercial feasibility of the technology remains uncertain. The barriers to adoption at scale, such as financial and energy penalties of the processes and availability of suitable disposal sites, are large. The waste CO_2 weighs around 2.5 times the mass of fuel burned, has zero value and must be handled and processed in quantities exceeding any other industrial operation. These are severe handicaps.

Hydrogen is another "technology" (it is actually a gas) presently topical in the energy field, attracting worldwide government and investor attention. It is seen as a major economic opportunity for Australia, which has produced a National Hydrogen Strategy[18]. Hydrogen is not a source of energy but a combustible gas that can be manufactured, stored, used as a fuel and exported. Like electricity it is a medium for energy transfer. Hydrogen is "clean" or "green" if the energy used to produce it is clean. Hydrogen is already a major industrial material. Globally, about 70 million tonnes are produced annually[19], mainly from natural gas, oil and coal, for use in the petrochemical and fertiliser industries. Those processes emit CO_2 as waste. Hydrogen production with CCS is included in the national strategy. There have already been several waves of interest in a "hydrogen economy" since the 1975

[13] https://www.chiefscientist.gov.au/news-and-media/national-press-club-address-orderly-transition-electric-planet
[14] https://thesolutionsproject.org/
[15] http://www.ga.gov.au/scientific-topics/energy/resources/geothermal-energy-resources
[16] https://www.globalccsinstitute.com/
[17] https://www.nature.com/articles/news.2009.372
[18] https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf
[19] http://ieahydrogen.org/pdfs/Global-Outlook-and-Trends-for-Hydrogen_Dec2017_WEB.aspx

publication of *Energy, the Solar-Hydrogen Alternative*[20] by J O'M Bockris. Evaluation of the many proposals presently in circulation should wait for further development.

Specifying *abundant* energy: Clean electricity targets.

Setting proper targets is a vital part of a clean energy strategy. Clean energy, obviously, is an emerging category specified to meet a new need. It must grow in quantity until it comprises the total energy supply. Elimination of fossil fuels and related emissions is the ultimate aim. Targets define the growth needs, influence the strategy and provide the measure of success.

Because the growth potential of hydroelectricity, until recently the main renewable source, is generally considered low, present Australian clean energy policies rely almost entirely on growth of solar and wind energy. Hydroelectricity generation has remained constant for several decades. Australia is a dry, weathered continent with relatively few large rivers. Early large dams exploited the best sites. By around 1978 vigorous environmental objections to large new dams, e.g. the Franklin Dam protest movement[21], began to have an impact.

In every jurisdiction energy policy goals tend to be set in terms of clean electricity targets, usually in the form of renewable energy targets. For example Victoria's clean energy plan[22] is a renewable energy plan. All but one Australian states have legislated renewable portfolio goals. At the moment, Victoria's target is 40% renewables by 2025, Queensland's 50% by 2030, and ACT's 100% by 2020. Policies in the USA have similar features; over half the states have legislated renewable goals.

When a goal is set in terms of "percent renewables", the target is deemed to have been reached, and the policy to have succeeded, when the electricity supply within the target area comprises "100% renewables".

Setting targets in terms of "percent renewables" is problematic. First, growth performance is tracked in terms of prevailing outputs of electricity grids. There is no specific provision for the major expansion in electricity output that full electrification of the economy and total elimination of fossil fuels will inevitably require. Second, the "percent renewables" performance measure counts intermittent and continuous electricity output as equal, which they are not. It implicitly assumes that remedies for intermittency, such as grid-scale energy storage technologies, will have reached commercial maturity before the nation becomes fully reliant on clean renewable energy. This is far from certain.

Climate/energy strategies should set targets in terms of specific quantities of clean electricity. This raises a new problem. There is no doubt that, all else remaining equal, an all-electric economy will need more electricity than now, even without growth. How can clean electricity targets be determined for a future all-electric economy? What information is needed for that task?

The key facts about Australia's present energy supply are given in Table 2. These come from BP Statistical Review of World Energy 2019[23] and the latest (May 2020) update of Australian Energy Statistics Table O[24]. They are converted here for convenience to PJ units. Primary energy at 6042 PJ comprises fossil fuels and total renewables. By difference, total primary energy from fossil fuels is 5863 PJ.

Table 2. Australian energy statistics 2019

Energy Type	Quantity petajoules PJ
Total primary energy consumption	6410
Total electricity generation	954.4
Hydroelectricity	51.9
Wind electricity	70.2
Solar electricity	64.6
Other renewables	12.9
Total renewables	199.6
Total fossil fuel primary energy	**6210**
Electricity from fossil fuels	**754.8**

20 https://books.google.com.au/books/about/Energy.html?id=IfVEAQAAIAAJ&redir_esc=y
21 *Commonwealth v Tasmania* http://www.austlii.edu.au/au/cases/cth/HCA/1983/21.html
22 https://www.energy.vic.gov.au/renewable-energy/victorias-renewable-energy-action-plan
23 https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf
24 https://www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%2C%20Table%20O%20Electricity%20generation%20by%20fuel%20type%202018-19%20and%202019.pdf

The first six lines are the raw statistics. In the last three lines:

- *Total renewables* is the sum of the four renewables lines.
- *Total fossil fuel primary energy*, 6210 PJ, is the difference between *Total primary energy*, 6410 PJ, and the sum of four categories of renewable energy also classified as primary energy, 199.6 PJ.
- *Electricity from fossil fuels* is the difference between *Total electricity generation* and *Total renewables*.

Broken down this way, the energy components suggest a method for estimating how much electrical energy might be needed to replace all fossil fuels. The first step is to understand how much fossil fuel energy presently goes towards generating the 754.8 PJ electrical energy component. That statistic is not separately kept but can be calculated using power generation efficiencies. Thermal generators operate at a range of efficiencies, depending on fuel type and generator design and age. Energy is lost as heat, according to thermodynamic principles. The main points are:

- For coal-fired power from older sub-critical generators (referring to the boiler pressure and hence temperature) common in Australia, efficiencies are low, around 30%[25].
- According to the US Energy Information Administration[26] average US conversion efficiency for all fossil fuels in 2019 was 37.4%. Coal generation had an average efficiency of 32.5% and gas generation 43.6%.
- BP Statistical Review of World Energy 2019[27] (page 60) quotes an overall average conversion efficiency of 38% for thermal power generation in the OECD.
- Compared with the USA, Australia's generation fuel mix has less gas, more coal and much more brown coal (over 20% in Australia, less than 5%[28] in the USA). Brown coal (lignite) is a less efficient fuel due to its high water content, up to 70%[29]. Generation efficiencies in Australia will therefore be lower than in the USA.

Taken together, these factors suggest that around 33% would be a reasonable working figure for average thermal generation efficiency in Australia. At that efficiency, the 2019 thermal generation output of 754.8 PJ would have consumed input fossil fuel energy of 2287 PJ (754.8/0.33). This is **36.8%** of Australia's 2019 total fossil fuel consumption of 6210 PJ.

There are other data from disparate sources consistent with the view that around 40% of fossil fuel commonly goes into power generation.

First is the explicit statement in a US Energy Facts[30] brochure that 38.3 quads out of a total of 101.3 quads (quad, quadrillion BTU, is an energy unit favoured by the US Department of Energy. 1 quad = 1.055 EJ) of US primary energy is used for electricity generation. That's **38%**.

Second, emission data show that about 40% of global CO_2 emissions arise from electricity generation[31], which is to be expected if 40% of fossil fuel is consumed in generators.

Third, again from BP Statistical Review of World Energy 2020[32], global fossil fuel consumption in 2019 was 492 EJ and total electricity generation from fossil fuels was 61.0 EJ. Assuming an average generation efficiency of 33%, fossil fuel used was 185 EJ, which is **38%** of the total.

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25 https://www.worldcoal.org/coal/uses-coal/coal-electricity
26 https://www.eia.gov/tools/faqs/faq.php?id=107&t=3
27 https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf
28 https://www.eia.gov/todayinenergy/detail.php?id=30812
29 https://environmentvictoria.org.au/our-campaigns/safe-climate/problem-brown-coal/
30 https://www.eia.gov/energyexplained/us-energy-facts/
31 https://www.planete-energies.com/en/medias/close/electricity-generation-and-related-co2-emissions
32 https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

So there are several ways of arriving at the conclusion that around **40% of fossil fuel is presently used in electricity generation**, which of course must mean that **60% is not**.[33] Policies merely providing for clean energy to replace the fossil fuels now fed into power stations cannot possibly eliminate emissions. Those targets fall far short of strategic needs and are bound to give misleading indications of clean technology progress.

The above summary provides enough information to help make a rough estimate of Australia's future clean electricity needs. The key facts are that in 2019 37% (2287 PJ) of Australia's fossil fuel supply was used in thermal generation of 754.8 PJ electricity and 63% (3923 PJ) was used for other purposes. The issue is, if electrical energy is the only form allowed, how much would be needed for those other purposes? The intuitive first approximation to an answer is, by simple proportion, 3923/2287 times 754.8 PJ, or 1295 PJ. This is in addition to the prevailing electricity consumption of 954.4 PJ.

The result of such calculations is that an all-electric Australia would need 2249 PJ electrical energy. The figure is quoted much more precisely than the methodology justifies. 2250 PJ will be used here, roughly 2.4 times 2019 electricity output. Furthermore, the calculation refers essentially to an overnight transformation of the energy system. It contains no allowances for population growth, changes in prosperity levels (such as per capita GDP) or changes in energy productivity. At this point, assumptions about such changes out to distant dates where all electricity could be generated cleanly would introduce very large new uncertainties.

Some caution is needed. The new target makes no reference at all to any of the innovative pathways needed in practice for clean electrification of the Australian (or any other) economy. It is derived using just arithmetic and an assumption of proportionate usage of energy. It is theoretical and approximate; in the absence of real replacement electrified processes it is more likely to be conservative than generous. These are uncertainties. The main conclusion is firm. Present targets are much too low.

Underestimation of future clean energy needs has been common. For example the Integrated System Plan[34] of Australia's national electricity market operator AEMO contains no explicit allowance for major new sources of electrical energy demand out to 2040. Future renewable energy targets in the USA are based on existing generation levels. None of the well-known sources of long term energy projections like the International Energy Outlook[35] (US Energy Information Administration) and World Energy Outlook[36] (International Energy Agency) explicitly reflects the greater electricity needs of a clean energy transition over coming decades.

To improve on the above approximation would require systematic analysis of every present application of fossil fuels, identification of electrified alternative technologies, and establishment of their practical electrical energy needs. This is not feasible at present. Those alternatives are largely unknown or untested. However a case study for electrified transportation demonstrates a sample of what might be required.

Data are available for the running energy requirements for a wide range of passenger electric vehicles in the USA, e.g. in the chart below[37]. The distribution of fuel economies is fairly narrow, with the majority lying between about 4.2 and 6.5 km/kWh. Another chart of a broader range of EV data[38] includes a calculated average of 18.5 kWh/100 km, which is 5.4 km/kWh. Those two sources are in good agreement.

[33] US Energy Information Administration publications give a useful breakdown of where that 60% goes. Coal: 92.6% is burnt for electric power generation, 7.3% in other industries. Natural gas: 35% is used in the electricity industry, 33% goes to other industries, 17% goes to residential use and 12% to commercial use, mostly for heating buildings and water, for cooking and drying, and for refrigeration and cooling, and 3% goes to transportation. Oil: Only 1% is used in power generation. Most is refined into petroleum products for a wide range of final uses. 69% of those products (petrol, diesel etc.) go to transportation and 25% to industrial applications such as petrochemical feedstocks, petroleum coke, asphalt and lubricants. 3% goes to residential and 2% to commercial uses.

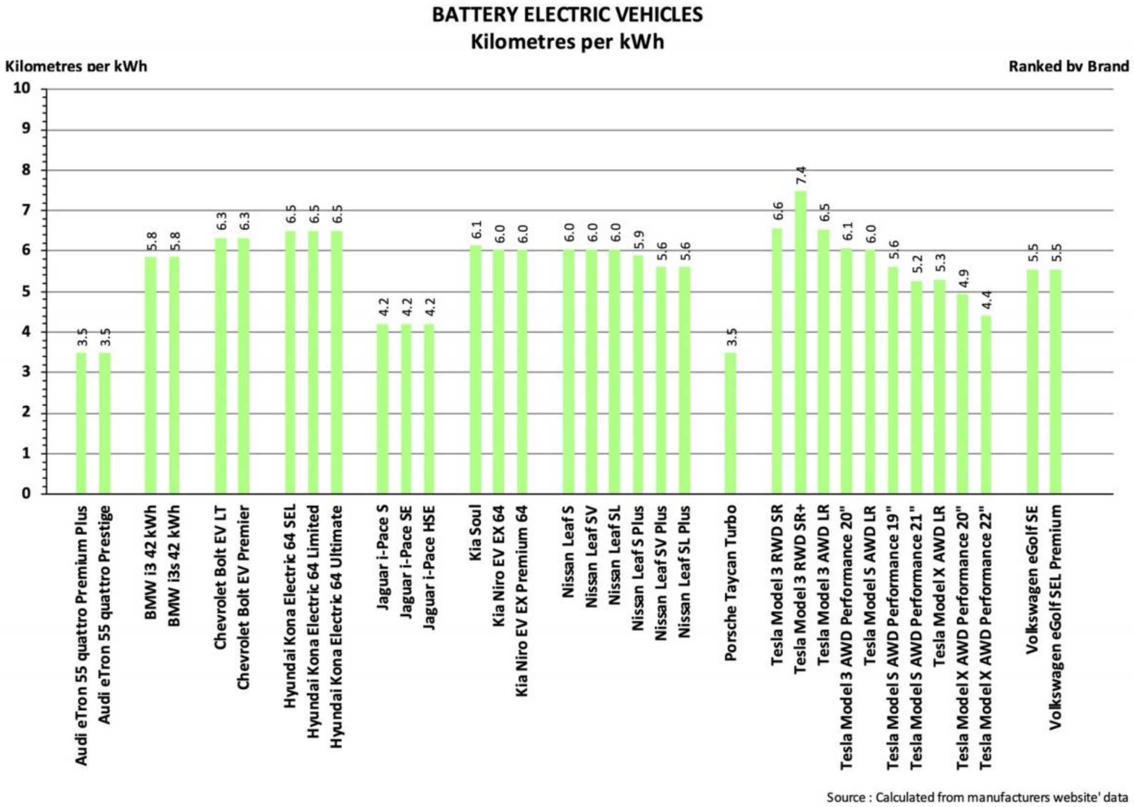
[34] https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2019/Draft-2020-Integrated-System-Plan.pdf

[35] https://www.eia.gov/outlooks/ieo/pdf/ieo2019.pdf

[36] https://www.iea.org/reports/world-energy-outlook-2019

[37] https://twitter.com/jpr007/status/1213860974144278529/photo/1

[38] https://ev-database.org/cheatsheet/energy-consumption-electric-car



At say 5 km/kWh and an Australian average usage of 12,600 km per annum, the annual consumption per average vehicle would be 2520 kWh. With a total passenger vehicle fleet of about 15 million, the total electrical energy consumed would be 37.8 TWh or 136 PJ.

With enough information this example could be extended to commercial road transport now using diesel fuel. US figures for relative consumption of gasoline and diesel[39] help with making a rough estimate. They suggest that an additional 43% of the passenger energy requirements or 58 PJ electrical would be needed to fuel the commercial truck and bus fleet. So total electrification of Australia's private and commercial road transport might add 194 PJ to electrical energy demand or about 20% of present consumption.

This rough estimate refers only to the operating energy needs of vehicles. A complete analysis must include energy associated with manufacture of vehicles, drive-trains, batteries, etc. Such embodied energy levels[40] are said to be higher for commercially available electric vehicles than for comparable combustion engine models. However at this time they are not directly relevant to Australia's energy supplies as it has no domestic automotive manufacturing industry.

This transportation case shows the general approach for estimating total future electrical energy needs. However compiling the complete "bottom up" inventory of additional electrical energy demand for every use of fossil fuel presents a major challenge. In most cases the path to working electrified technologies has barely begun. When electricity simply replaces the chemical energy in liquid fuels, as in powering a motor car, the electricity requirements might be relatively easy to determine. Eliminating fossil fuels in metal smelting, fertiliser manufacturing, petrochemicals, plastics, other non-metallic materials, explosives, etc. will require quite new technologies. Australian policy should support such efforts. In the USA, government is involved in a program of electrification in all economic sectors[41] through its National Renewable Energy Laboratory. There are enthusiastic claims[42] that

[39] https://www.eia.gov/energyexplained/use-of-energy/transportation.php
[40] https://www.sciencedirect.com/topics/engineering/embodied-energy
[41] https://www.nrel.gov/analysis/electrification-futures.html
[42] https://www.theaustralian.com.au/business/the-deal-magazine/the-young-entrepreneur-kicking-goals-for-carbon-capture/news-story/1f5fc32bf5943d7e21e3a1a47c7f8aed

substitute technologies are already available or at advanced stages of development[43] but they should be treated cautiously until proven at full commercial scale, especially for heavy industries like cement making and steel making.

Some important applications of fossil fuels depend not so much on their energy content as on their rich organic chemical constitution. Fossil fuels contain several thousand chemical compounds, mainly hydrocarbons, and there are literally thousands of petroleum-based materials and other products[44]. The BP Energy Outlook[45] explicitly shows a non-combusted end-use sector for fossil fuel in its statistics base. This sector comprises some 6% of the total, mainly for plastics production. Alternative electrified processes in that sector could be the most difficult of all. Should it emerge that there are no feasible alternative paths, some present uses may need special exemptions and rely on a set of “reserved applications” of fossil fuels.

Overall it is clear that setting long term clean electricity targets for planning purposes is too urgent to wait for this detailed process-by-process analysis and will have to be based initially on relatively crude estimation methods like the “top-down” approach derived above. There are a few published estimates available against which to compare this estimate, which is 2.4 times present Australian electricity usage:

- Prof MZ Jacobson (Stanford University) leads The Solutions Project[46], which provides roadmaps for infrastructures of 139 countries to be powered almost entirely by renewable electricity from wind, water, and sunlight. For its global total, Jacobson’s electrical energy inputs for 2050[47] is 373 EJ (annual output from a total world load 11.8 TW). In the terms used above this equates to a multiplier of about 3.8 (2019 global generation was 97.2 EJ).
- Jacobson’s work also contains all-electric energy requirements for individual economies. For Australia the figure is 3750 PJ, 3.9 times 2019 output of 954 PJ.
- In his well-known book Sustainable Energy – without the hot air[48], the late Prof DJC MacKay (Cambridge University) gave an estimate of partial 2050 energy needs of an electrified UK. He considered electrification of just transportation and heating. His result was “nearly triple the present UK electricity supply”, i.e. a multiplier of “nearly three”.
- Prof BW Brook (University of Tasmania) in a peer-reviewed 2012 publication[49] arrived at a multiplier of 3.6 for the increase by 2060 in global electrical energy needs with a high level of electrification.
- Prof A Blakers et al (ANU), in the 2019 paper Pathway to 100% Renewable Electricity[50], indicated that the 100% renewables target, applicable to but not limited to Australia, would require an approximate trebling of electricity production.
- An apparent outlier comes from the 2010 Zero Carbon Australia Stationary Energy Plan[51]. This 10-year roadmap for 100% renewable energy in Australia projected a total 2020 energy demand of 1660 PJ, all in the form of clean renewable electrical energy, which is about 1.9 times Australian electricity output of 870 PJ for 2010, when the plan was prepared. It represents the lowest of the estimates surveyed here.

Some of these estimates explicitly allow for global growth in population and living standards, which means higher energy consumption, and improvement in energy productivity (the economic indicator connecting GDP with energy usage), which has the counter effect of lowering energy consumption. These confounding influences need to be considered further.

More work is needed to establish a sound clean electricity target. For the moment a multiplier around 2.4 must suffice. Published estimates confirm that this is likely to be a conservative estimate. An Australian energy policy should provide for a program to establish a more reliable target or multiplier.

[43] https://www.mineralcarbonation.com/
[44] https://www.ranken-energy.com/index.php/products-made-from-petroleum/
[45] https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf
[46] https://thesolutionsproject.org/
[47] https://www.sciencedirect.com/science/article/pii/S2542435117300120
[48] https://www.withouthotair.com/
[49] https://www.sciencedirect.com/science/article/abs/pii/S0301421511009189
[50] https://ieeexplore.ieee.org/abstract/document/8836526
[51] http://media.bze.org.au/ZCA2020_Stationary_Energy_Report_v1.pdf

Plans, performance, perceptions – the numbers.

Climate/energy policies worldwide tend to be a mix of targets and broad rhetoric related to climate change mitigation. Rhetoric expresses determination, resolve, commitment and a decisive will but often lacks a clear plan and clear targets. The Green New Deal[52] proposed for Unites States legislation is a good example. Where nations have set goals quantitatively they often contain emissions reduction targets aligned with the Paris Accord[53] and clean energy targets of the "percent renewables" variety discussed above. Nations set their own "Paris targets". For example Australia pledged to reduce emissions[54] to 26–28 per cent on 2005 levels by 2030.

There is political debate on Australia's progress[55]. Dissatisfaction with energy and climate policies and its reliance on renewables is common. The latest review of Australia's climate change policies[56] concluded that stakeholders saw a lack of long term climate change strategy. The Australian Government's May 2020 Technology Investment Roadmap discussion paper[57] aimed at a policy framework for accelerating development of low emissions technologies immediately elicited critical commentaries like Energy policy disaster continues[58] and Emissions debate goes from inane to ridiculous. Australia's performance in reducing emissions has been labelled explicitly as a failure in policy.

The one undisputed fact is that global emissions continue to rise[59] and "carbon emissions grew by 2.0% in 2018[60], faster than at any time since 2010-11". Australia's emissions related to energy usage (electricity, transport, and stationary energy excluding electricity) in the National Greenhouse Gas Inventory[61] are barely changing. For example in recent successive two years they were 537.5 Mt (2018) and 532.5 Mt (2019). These inventories are complex compilations of many sources and do not exclusively refer to CO_2 or to energy.

So the evidence is that present policies are having only a minor impact on the central objective, to reduce emissions by eliminating fossil fuel use, and policy deficiencies are topical in critical public commentary.

In contrast, public response to clean energy performance seems enthusiastic. Here is a sample of media pieces that followed the release of Australia's 2019 renewable energy statistics in April 2020:

- *By any measure, 2019 was a remarkable year[62] for the Australian renewable energy industry* (from the Clean Energy Council, the peak body for the clean energy industry).
- *Australian renewables growing at record rates[63]* (from ARENA, the federal government funding agency for renewables projects).
- *Australia could get 90% of electricity from renewables[64] by 2040 with no price increase* (from *The Guardian*, Australian edition of British daily newspaper).

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52 "H.Res.109 – 116th Congress (2019–2020): Recognizing the duty of the Federal Government to create a Green New Deal" https://ocasio-cortez.house.gov/sites/ocasio-cortez.house.gov/files/Resolution%20on%20a%20Green%20New%20Deal.pdf
53 https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en
54 https://publications.industry.gov.au/publications/climate-change/system/files/resources/c42/factsheet-australias-2030-climate-change-target.pdf
55 https://www.climatecouncil.org.au/joint-statement-australia-not-on-track-2030-target/
56 https://www.environment.gov.au/system/files/resources/18690271-59ac-43c8-aee1-92d930141f54/files/2017-review-of-climate-change-policies.pdf
57 https://consult.industry.gov.au/climate-change/technology-investment-roadmap/supporting_documents/technologyinvestmentroadmapdiscussionpaper.pdf
58 http://catallaxyfiles.com/2020/05/21/energy-policy-disaster-continues-more-intervention-less-market/
59 https://www.c2es.org/content/international-emissions/
60 https://www.hydrocarbonengineering.com/the-environment/12062019/bp-releases-its-statistical-review-of-world-energy-2019/
61 https://www.industry.gov.au/sites/default/files/2020-05/nggi-quarterly-update-dec-2019.pdf
62 https://www.cleanenergycouncil.org.au/resources/resources-hub/clean-energy-australia-report#:~:text=Australia's%20large%2Dscale%20renewable%20energy,thirds%20of%20this%20new%20capacity.&text=This%20extra%20capacity%20increased%20renewable,generation%20to%2024%20per%20cent.
63 https://arena.gov.au/blog/australian-renewables-growing-at-record-rates/
64 https://www.theguardian.com/australia-news/2020/apr/29/australia-could-get-90-of-electricity-from-renewables-by-2040-with-no-price-increase

- *Australia is the runaway global leader[65] in building new renewable energy* (article by ANU academics from *The Conversation*, an online source of news and views from the academic and research community).
- *Another remarkable year: 2019 saw renewables records tumble[66]* (from PV magazine, a trade publication).
- *At its current rate, Australia is on track for 50% renewable electricity in 2025[67]* (from ANU College of Science online news).

This inconsistency is an important issue for Australian climate/energy policy. Plans, performance and perception ought to be better aligned. Public perceptions and expectations are politically important. The present misalignment needs to be examined.

Table 3 gives a snapshot of movements in energy technologies and fuels in Australia's electricity supply over the past decade. Data for the last two calendar years are both included since the figures for 2019 are in preliminary form and will eventually be amended slightly. For consistency, all data are taken from one source, the latest (May 2020) update of Australian Energy Statistics Table O[68]. Originally in units of GWh, they are converted here to PJ.

The trends are all clear and reflect trends in the full energy dataset[69] going back to 1989-90. Fossil fuels have declined and renewables increased, with the greatest increase in solar energy. Growth in renewables is in line with incentives in the earliest scheme of 2001[70] and in successive policies at state and federal levels.

Table 3. A decade of change in Australian electrical energy Petajoules, by source

ENERGY SOURCE	YEAR		
	2010-11	**2018**	**2019 (prelim)**
Black coal	421.0	434.1	418.9
Brown coal	199.1	129.5	119.3
Gas	176.4	184.9	195.7
Oil	11.1	19.5	20.8
Total fossil fuel	807.6	768.0	754.7
Bioenergy	7.6	12.8	12.9
Hydroelectricity	60.5	63.0	51.9
Wind	21.9	59.1	70.3
Solar PV small scale	5.5	35.8	44.8
Solar PV large scale	0	8.4	19.8
Solar PV total	5.5	44.2	64.6
Total renewables	95.5	179.1	199.7
Total electricity	912.9	947.1	954.4

In 2019 fossil fuels accounted for 79% of total electricity generated and renewables 21%. Over the decade the fossil fuel contribution declined by 6.6%. Total renewables generation increased by a factor of 2.1. Hydroelectricity, the largest renewables source up till 2019 when it was overtaken by both wind and solar, has fluctuated over the past 30 years around an average of 57 PJ with no consistent trend.

The most striking change in the decade was the growth in the renewables wind and solar, which increased by factors of 3.2 and 11.7. By 2019, solar (64.6 PJ) and wind (70.3 PJ) had together reached 134.9 PJ, which is 14.1% of total output. Public announcements and associated public perception clearly reflect that growth rate rather their absolute contributions.

As the above headlines broadcast, 2019 was indeed the best year for solar and wind output. In numerical terms, their total output increased by 31.6 PJ. The clean electricity target calculated above is 2250 PJ. If that record rate of increase was merely

[65] https://theconversation.com/australia-is-the-runaway-global-leader-in-building-new-renewable-energy-123694
[66] https://www.pv-magazine-australia.com/2020/04/09/another-remarkable-year-2019-saw-renewables-records-tumble/
[67] https://science.anu.edu.au/news-events/news/its-current-rate-australia-track-50-renewable-electricity-2025
[68] https://www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%2C%20Table%20O%20Electricity%20generation%20by%20fuel%20type%202018-19%20and%202019.pdf
[69] https://www.industry.gov.au/sites/default/files/2020-05/nggi-quarterly-update-dec-2019.pdf
[70] http://www.cleanenergyregulator.gov.au/RET/About-the-Renewable-Energy-Target/History-of-the-scheme

maintained (many commentators believe it will grow) it would take another 65 years for renewables to reach the target. This is the more modest measure of progress by which the prospects of renewable energy should be judged rather than the hyperbolic media headlines quoted earlier.

Favourable publicity for solar and wind energy also plays down their intermittency. At present, while weather-dependent renewables comprise a minor part of total supply, intermittency can easily be managed, for example, by drawing on other stable output or by rapid start-up open-cycle gas-fired generators. As intermittent input rises, energy storage would be required. Pumped hydroelectricity is a proven storage technology at the required scale; other technologies are still speculative. Solutions such as electrochemical batteries and chemical storage like hydrogen or ammonia get regular favourable mentions in the popular media[71]. Public opinion seems to be that breakthroughs will soon make them practical for time-shifting intermittent generation at the required huge scale. At the very least this view is debatable. Many of the technologies are mature. The industry is hardly in an emergent stage. The U.S. Energy Storage Association[72] with more than 160 members is a 30-year old national trade association. Battery storage has been used for decades to allow time-shifting of energy, with many such installations worldwide[73]. For large power grids, scale as always is the issue. Once again, public and political enthusiasm on technical matters ought not qualify for leading policy formulation.

Finally, a comment on popular claims that economic benefits of renewables[74] will drive their growth. “Accelerating the deployment of renewable energy will fuel economic growth, create new employment opportunities, enhance human welfare, and contribute to a climate-safe future”. If this were true then any economy that pursued clean energy more vigorously than, say, its competitors would face no economic risk. Its energy supply would not become costlier. The earliest policy papers on climate change and its mitigation, like the UK Stern Review[75] (2006) and Australia’s Garnaut Climate Change Review[76] (2008) dealt largely with economic aspects, especially quantifying the damage costs imposed by climate change. Garnaut examined the likely effect of human induced climate change on Australia’s economy, environment and water resources and recommended policy frameworks to improve the prospects of sustainable prosperity. Both reports contributed to a considerable global effort on determining the economic costs of climate change and its mitigation. Nowhere have economists concluded that mitigation measures will have the kinds of benefits listed by IRENA. “Economic costs” and “opportunities for economic growth” are essentially incompatible. Fossil fuels have developed as the cheapest and most used energy sources. Unfortunately they also give rise to the greatest emissions. Garnaut wrote in 2008 “Climate change is a diabolical policy problem. It is harder than any other issue of high importance that has come before our polity in living memory.” He did not mention opportunities for economic growth. As producers of Australia’s energy intensive exports have frequently noted, unilateral pursuit of climate objectives would impact Australian industry adversely. Climate/energy policy must therefore be aligned with global movements.

To complete the successful transition to clean energy, nuclear power will be needed.

Renewable energy does contribute usefully to meeting the challenges of an economy based on clean energy but the numbers on progress to date towards realistic targets do not inspire confidence in present policies that rely almost totally on future growth in solar and wind energy. This is the main reason why Australian climate/energy policy should now include nuclear energy, which has one of the lowest life-cycle emissions (see Table 1).

Nuclear power[77] is generated in a thermal power station for which the heat source is a nuclear reactor and the fundamental heat generation process is controlled nuclear fission. Heat generates steam that drives a steam turbine connected to a generator, just as in fossil-fuelled power stations. Generating units are of similar size, typically around 1 gigawatt, producing around 30 PJ clean electricity per annum. Electricity is produced continuously, as in other thermal generation.

Globally, there are 441 nuclear power stations currently operable[78], in 31 countries. France is a prominent user, deriving about 75% of its electricity from nuclear energy[79]. France’s major step in converting to nuclear power in 1973 was actually intended to

71 https://reneweconomy.com.au/genex-remains-upbeat-on-pumped-storage-in-result-dented-by-solar-plant-outage-99479/
72 https://energystorage.org/
73 https://batteryinnovation.org/interactive-map/
74 https://www.irena.org/documentdownloads/publications/irena_measuring-the-economics_2016.pdf
75 http://www.lse.ac.uk/GranthamInstitute/publication/the-economics-of-climate-change-the-stern-review/
76 https://www.researchgate.net/publication/227389894_The_Garnaut_Climate_Change_Review
77 https://www.energy.gov/sites/prod/files/2019/01/f58/Ultimate%20Fast%20Facts%20Guide-PRINT.pdf
78 https://www.world-nuclear.org/information-library/facts-and-figures/reactor-database.aspx
79 https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx

displace fossil fuels, but not for reducing carbon dioxide emissions; its nuclear fleet was built from a desire for energy independence[80] prompted by the "first oil shock", an oil embargo proclaimed by the Organisation of Arab Petroleum Exporting Countries. Around 55 new nuclear power stations are under construction[81] globally. The majority are in China, India, Russia and the United Arab Emirates. There has also been a steady flow of nuclear plant retirements.

In 2019 nuclear energy provided 10.4% of the world's total electricity generation and 30.5% of the world's clean electricity from the major sources nuclear, hydro, solar and wind (all data from BP Statistical Review of World Energy 2020[82]).

Views on the global future of nuclear energy are closely bound with perceptions of how successful the presently dominant renewables policies are, and will be, in curbing greenhouse emissions. The so-called global energy transition to renewables has been underway for about 15 years. Germany[83] has been taking a leading role while curtailing its nuclear output.

As for results, world solar generation in 2019 was 2.61 EJ, and wind 5.15 EJ, out of total world electrical energy output of 97.2 EJ. In that year growth of solar and wind energy output was 1.08 EJ. As discussed above, for total elimination of fossil fuels an electrified world will need clean electricity in much greater quantities than it uses now, conservatively 2.4 times more or 233 EJ. So by any objective measure the transition is proceeding slowly and analysis indicates that growth challenges for solar and wind energy may be insurmountable, especially when intermittency is considered. At present growth rates of solar and wind energy it would take about 200 years for total renewable energy to reach the above target. Renewables proponents, however, remain confident.

The obvious question for Australia, where nuclear energy has been prohibited by law since 1998[84], is whether the limitations of intermittent renewables in eliminating fossil fuels will lead to global expansion of nuclear energy as a contributor to, or the main driver of, energy decarbonisation. As yet there is little sign of such a global shift. On present numbers, the renewables transition is just starting. It may well take another 10 to 20 years before the evidence on growth rates and the role of nuclear is seen as sufficiently persuasive, one way or the other. Australia will not be an early mover. It will clearly be influenced by changes elsewhere.

A common response to suggestions that nuclear energy should expand to meet clean energy growth is that it is too expensive and too slow to build. It is true that the nuclear construction industry has been in decline. In the decade to 1990 there were 227 new connections of nuclear reactors to grids. In the next two decades there were only 56 and 33 respectively. The Chernobyl accident in 1986 was a major factor in the decline. Industry competition was lowered and construction costs increased. Small Modular Reactors[85], which are factory built and shipped to site, may change the nature and cost structure of the nuclear industry but are not yet in commercial production.

Recent analyses suggest that rising nuclear cost trends over recent years might be reversible. Lovering et al (Historical construction costs of global nuclear power reactors[86]) concluded that "there is no inherent cost escalation trend associated with nuclear technology." Lang (Nuclear Power Learning and Deployment Rates; Disruption and Global Benefits Forgone[87]) found that during the 1970s there had been a sudden disruption in "learning rates" (the rates at which costs reduce due to experience gained) and claimed that past progress could be achieved again, given appropriate policies.

There are good reasons why Australia should develop a nuclear policy now. Australia has no nuclear energy. It will find itself poorly positioned to adopt nuclear energy because of its longstanding prohibition policy and deep-seated anti-nuclear sentiment. The lead time for Australian action could therefore be much longer than for most of the world's advanced economies. And Australia will be at risk of being seen politically stranded as a major supplier of raw uranium nuclear fuel feedstock while not participating to the nuclear contribution to global decarbonisation.

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[80] http://www.fundinguniverse.com/company-histories/Electriciteacute;-de-France-Company-History.html
[81] https://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx
[82] https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf
[83] https://reneweconomy.com.au/graphs-of-the-day-the-success-of-germanys-energy-transition-15022/
[84] https://minerals.org.au/sites/default/files/180605%20Removing%20the%20prohibition%20on%20nuclear%20power.pdf
[85] http://www.smrnuclear.com.au/wp-content/uploads/2020/04/SMR-GLOBAL-STATUS-REPORT-APRIL-2020_v4KP.pdf
[86] https://www.sciencedirect.com/science/article/pii/S0301421516300106
[87] https://www.mdpi.com/1996-1073/10/12/2169

Australia's energy policy should prepare for the possibility that within 10 to 20 years nuclear energy will be seen as truly essential to global decarbonisation efforts and become a major growth source of clean energy to meet climate policy goals. That change may well provide the incentive to lower costs and regulatory and material barriers to rapid growth.

To avoid being stranded Australia should start taking strategic steps now, including:

1. Legitimising nuclear power.
2. Developing the public case for its necessity, which should include the development of more reliable clean energy targets and more realistic monitoring of progress of renewables towards such targets.
3. Combatting deep-seated anti-nuclear sentiment, including common concerns about safety, radiation, waste disposal and proliferation.
4. Ongoing consultation on public attitudes to nuclear with a view to ensuring that Australians can accept the necessity of a nuclear future at least as readily as do other nations.
5. Provide balanced information on the "too slow, too expensive" objections to nuclear energy that have assumed growing importance in public discourse.

About the author

Dr Tom Biegler, an electrochemist with a PhD in Agricultural Science from Sydney University, spent most of his career in CSIRO, with some shorter periods at the Universities of Illinois, Kentucky and Bristol.

His international scientific reputation was gained through publication of over 60 research papers on electrode kinetics, electrocatalysis in fuel cells, electrochemical reactions of sulphide minerals, and electrowinning and refining of metals.

At CSIRO he led the Surface Chemistry and Hydrometallurgy sections before becoming Chief of the Division of Mineral Chemistry (later Mineral Products) in 1985 and then head of CSIRO's Corporate Business Department.

After retiring from CSIRO in 1996, he consulted on fuel cell commercialisation. In more recent years he has written and spoken with the aim of improving public understanding of energy issues such as fuel cells and the hydrogen economy.

He is a Fellow of the Australian Academy of Technology and Engineering and the Royal Australian Chemical Institute, and a former Fellow of the Australasian Institute of Mining and Metallurgy.