Writing...
FACTS, OPINIONS & IDEAS

The future of energy – an Australian way

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> Energy idea: harness the heat of the tomato in the toastie.
> Senator Briggs@Briggs (Tweet, 2021, April 12)

Context

The first place in Australia to install a permanent electricity grid was the small country town of Tamworth, on Kamilaroi country in New South Wales, in 1888, when street lights were connected to two 18 kW coal-fired generators supplied by the neighbouring Gunnedah black coal basin. The coal was of such excellent quality that it could be literally dug up and shovelled straight into the nearby generator. The ready availability of coal in the Liverpool Plains and across the country was quickly noticed: today, Australia is the world's second largest exporter of coal. We are the world's largest exporter of liquefied natural gas. Despite what we might hear from our politicians, Australia isn't in the process of stopping climate change – we're selling it.

We continue to burn fossil fuels locally too. Today, more than 90% of our energy consumption still comes from burning coal, oil and gas. But times are changing; the world is a different place from 200 years ago and we know things now that we didn't know then.

This essay discusses the current energy transition in Australia in four parts and presents the extraordinary position we find ourselves in of leading the world in one of the key planks of the transition –

the deployment of renewable electricity. It outlines where we are now (Part 1), how things are changing (Part 2), a reimagined electricity system with resilience at all scales (Part 3), and the real reforms that will help us get there (Part 4) – a real Australian way to a renewable energy future.

Australia has transitioned from having the third most carbon-intensive electricity generation in the world in 2010 to now regularly receiving more than a third of its electricity from renewables. One in five households in the country have solar photovoltaics (PV) systems on their rooftops – the highest rate of PV uptake in the world. At times, over 100% maximum instantaneous solar and wind penetration is achieved in some regions. We are moving quickly from one of the dirtiest power systems in the world to one of the cleanest, and we have (surprisingly) found ourselves as one of the places the world is looking at to figure out how to go renewable, even as we sell record amounts of coal and gas overseas.

We have a long way to go – we still use fossil fuels (coal and gas) to make more than three quarters of all electricity in Australia. We use a bunch of gas to do other things too: heat our homes, cook our food, make our stuff, or drive us places. Actually, only a quarter of our country's energy use goes into making electricity. Transport, manufacturing and mining together comprise the real lion's share of total energy use (that is – the processes of digging, making and transporting stuff), but transitioning to renewable electricity, alongside electrifying everything, is perhaps the first step that we can quickly take to then be able to decarbonise the even harder challenges ahead.

We are all on this journey together, from when we flick on a switch at the wall, to when we fill up our cars with petrol, to when we pay our power bills, to how we vote for fossil-fuel controlled politicians. And there's not a moment to lose. To avoid catastrophic climate change of 2-plus degrees warming we need to solve this problem in the next decade. We might not even have that long.

In this process of rapid decarbonisation, as we kick out the small number of fossil fuel oligarchs who have corroded our political systems for the past century, hopefully this will amplify our ability to address the other real and perhaps even more pressing challenges of building new political power structures that truly value humanity and community and our natural environment.

Let's start.

Part 1 – Where we are now?

The story begins with an intense moment of nuclear fusion at an appropriately safe distance from Earth (150 million kilometres away) in the sun's core. Under immense pressure, two atoms of hydrogen fused together to become a helium atom, releasing a searing blast of light that made its way through the sun and across the dark cold reaches of space to hit our planet at just the right time to be absorbed by a young green leaf. This leaf, full of juicy chlorophyll molecules, used this photon of sunlight to break the bond between a CO_2 molecule that happened to be floating by, releasing the oxygen and absorbing the carbon, and grew to be a slightly bigger green leaf.

While other leaves got munched or burned, this one made its way to the bottom of a riverbed next to a bunch of other leaves, where it was deposited with a layer of silt and subsequently compressed over a geological age to form a shiny black coal seam bed layered between sediment.

Two hundred million years later, after being rudely thrust up into the Gunnedah basin by a shrug of tectonic movement and fed into a furnace on a conveyor belt, this ancient leaf's carbon was re-attached to oxygen to form a reincarnated CO_2 molecule, and in the process released that stored ancient blast of sunlight to heat some steam that spun a turbine that turned a generator that's likely powering the device that you're now reading these words on.

Fossil energy is truly incredible. An average fit and motivated labourer can, in a year, do around 150 kilowatt-hours (kWh[1]) of manual work for a salary of perhaps $50,000. A wheelbarrow of coal in a power plant can generate more than double this in less than three seconds for less than $50, with an ability to produce light, sound, heat, motion, computation or any of the other remarkable capabilities of electricity. By the turn of the 20th century, the burning of fossilised plants and animals from hundreds of millions of years ago provided energy for nearly every aspect of life: light and heat and cooking and refrigeration in our homes, power for manufacturing and transport and farming, and the raw energy for the great engines of industry across the country, all connected by a spreading interconnected network of poles and wires and pipelines.

Soon after the physical infrastructure was established (though always a little behind) came the formation of energy markets and regulatory structures. Electricity assets were originally state owned but are now largely privatised across the country. Customers in Australia now pay around $1 a day to be connected to the grid, and a usage charge of around 25 cents per kilowatt-hour – working out to around $5 a day for an average family house (using around 20 kilowatt-hours per day). Of the typical bill, 45% of it pays for the poles and wires in the ground (generally majority owned by overseas companies), 40% goes to generators for making the electricity, 10% goes to your retailer for buying and selling the electricity on your behalf, and about 5% goes to paying for supporting renewables through the Renewable Energy Certificate scheme introduced by the Howard government in 2000.

In all, the traditional system has been remarkably successful – vast sums of money are now transferred to those involved in providing energy, both nationally and globally. It is no coincidence that six of the top twenty largest companies on the planet by revenue are involved in the buying and selling of fossil fuels (e.g. Sinopec, China National Petroleum, Shell, China State Grid, Saudi Aramco, and BP; Fortune, 2021). These companies and their industry as a whole, as a result of their astonishing profitability have enormous influence over the legislation that governs their activities. In Australia, the companies involved in the selling of fossil fuels overseas include BHP Billiton, Woodside Petroleum, Santos, Origin Energy, Whitehaven Coal, Rio Tinto, Whitehaven Coal, Anglo Coal Australia, and Peabody Energy, and they have been vastly profitable over the past century – it's likely your bank or superfund has directly invested a large portion of your money in them and made significant returns on your behalf. Through the actions of their industry advocacy organisations, the Australian Petroleum Production and Exploration Association and the Minerals Council of Australia, they wield significant influence on public policy.

I write more about this later in this article (I reckon it's actually the biggest piece of the puzzle), but first, let's talk tech: Energy no longer flows one way from centralised fossil fuel generators to our houses as it did in 1888; the impact of atmospheric CO_2 is becoming catastrophically visible at planetary scales; and the political power of the fossil fuel industry is crumbling as their social licence to operate rapidly dissolves. The legacy that they have left us is becoming increasingly harder to ignore.

If we knew in 1888 what we know now, we might have created our power system differently. Knowing what we do now – what future do we want to create? Here are the five things that have changed dramatically in the past century, propelling us to a radically different energy future.

Part 2 – Five things that are different now than in 1888

1. Solar panels are cheaper than marine-grade plywood

The first solar cell was made in 1839 by 19-year-old Edmond Becquerel, who noticed a piece of silver chloride generated electricity when sunlight hit it. This cell was less than 1% efficient but we have come a long way since then. The first 20% silicon solar cell was made in Australia 30 years ago by my honours research supervisor Andrew Blakers and his supervisor Martin Green at the University of New South Wales in 1986 at a time when solar energy was largely a fringe technology for hippies and space agencies. By tweaking the chemical composition of the silicon lattice at the contact of the solar cell at the rear of the device they were able to crack the magical 20% efficiency barrier in a solar cell that could be mass-manufactured with an earth-abundant material (silicon is the second most abundant element in the earth's crust after oxygen – which it pairs with to form silicon dioxide). Today, PERC (passivated-rear-emitter contact) solar cells comprise more than 90% of all solar panels sold in the world today. Soon this Australian invention will be generating more than half of the world's solar electricity, reducing 5% of the planet's carbon emissions since 1990.

The invention of the PERC cell, alongside hundreds of other clever incremental engineering improvements and the vast growth in manufacturing scale have brought the price of solar panels massively (and exponentially) down in price. From more than \$10,000 per m^2 in the 1970s, to less than the cost of marine-grade plywood – now \$40 per m^2 and falling rapidly. Solar electricity is now the cheapest form of producing electricity at time of use, and it has quickly been noticed. More Australians have solar panels per capita than any other country in the world and showing no signs of slowing.

The rapid influx of solar electricity has had technical impacts on the grid that aren't completely trivial to solve (including challenges of minimum demand and distribution network voltage management), which I will write about more later, but the fundamentals are immovable. Solar panels are cheap, and getting cheaper, and will likely be the world's dominant provider of energy within our lifetimes, covering nearly every available rooftop.

2. Wind turbines can generate electricity and can also be located offshore

Humans have been harnessing the power of the wind ever since we first set sail on the oceans. In the 9th century, in what is now modern-day Iran, wind turbines began pumping water and powering grain-mills. In 1887, one year before the first Australian electricity grid as installed in Tamworth, James Blythe in Scotland developed the first electrical wind turbine with a 10 metre-high tower and cloth-sailed fans to generate less than 10kW of electricity.

Wind power increases with the cube of the wind speed and as the square of the blade length. That is, to generate more power, put wind towers in windier spots and build them with bigger blades, and this is exactly what the world has done. Wind turbines being installed now generate more than 3 MW per tower with blades more than 50 m long. Offshore turbines can be three times bigger. The wind provides around 5% of the electricity of the planet (solar is around 3%), and together their growth is outstripping everything else combined – more than 80% of all new electricity capacity in 2020 was solar and wind.

If I am being completely honest, I am not sure how much I like looking at wind farms compared to a clear ocean horizon or a mountain range. I was lucky enough to travel to the top of a turbine on TV for an episode of ABC Catalyst in 2021 – it was a spectacular view and a brilliant piece of engineering, but without my evangelical renewables hat on, I probably would have preferred a view of the beautiful Kaurna country without the industrial scale electricity generation plant. And I think this view is often shared by those who live near wind farms. Much angst against the wind industry might have been saved by a redesigned business model that instead of paying landowners $10,000 per year per turbine on their property and their neighbours $0, wind farms redistributed rents more equitably based on visual obstruction and proximity. $5000 to the owner and $1000 each to neighbours would likely do it, or reduced electricity prices for anyone that can see a turbine within 5 km (or high-voltage transmission line for that matter). But even still, you would be hard pressed to find someone who had an ocean or mountain view who did not feel a little uneasy replacing it with a view of spinning turbines. Call me biased.

But luckily, in addition to solar panels that you can stick on your rooftops, wind turbines can also be built far enough out at sea to be out of sight. Either way, wind is incredibly abundant, very cheap, very clean, and also highly complementary to solar. When the sun isn't shining, the wind is often blowing. The greater the geographic coverage, the smoother the variations in net output from renewables – meaning we can count on them more.

3. Energy storage will be ubiquitous and also on wheels

I am currently writing this sentence on a computer that is powered by a 50-watt-hour lithium battery. The simple reversible chemical reaction of moving atoms of lithium between two porous contacts (lithium cobalt oxide and graphite) has provided incredible energy density at rapidly reducing price. Now below $150/kWh and falling rapidly, lithium batteries have now found usefulness in a very wide range of applications and scales, from solar-powered garden lamps, to mobile phones, to household batteries, neighbourhood batteries, and really big grid-scale batteries, the latest of which is 450 MWh in Victoria.

Perhaps the most transformative application of lithium-ion batteries will be their widespread deployment in electric vehicles. There are about 6000 electric cars on the road in Australia at the time of writing. CSIRO predicts conservatively that there will be more than 4 million on our roads in 10 years. It is likely that everyone reading this will own (or share) an electric car sometime in our lifetimes.

More than a way to decarbonise our transport, the electrical energy storied inside cars will likely soon be able to be harnessed to power our homes, provide vital grid support services (and be paid for it), and help us store our solar-generated electricity long enough for us to be able to use it at night-time when the sun goes down. It's perhaps hard to overstate the impact that electric vehicles will have on the grid.

But there's another chemical that's even better for storing energy – dihydrogen monoxide – we know it as water.

More than 95% of all currently stored electricity in the world today is stored in water up a hill. The concept is relatively simple, water is pumped up a hill when energy is abundant (e.g. during the day when the sun is shining), and then allowed to flow back through a turbine when its needed later. The amount of energy that can be stored is proportional to the water pumped, which allows for much, much larger amounts of energy to be stored than chemical batteries. In contrast to historical hydroelectricity, no new rivers need to be obstructed – simple off-river pumped hydro 'turkey-nest' dams can provide more than enough storage across Australia and the world to provide sufficient daily storage and reserves.

While electric cars will likely smooth out the intra-day variations in solar and help with daily cycling, modification of existing hydroelectricity projects (such as the Snowy Mountains 2.0 Scheme and Lake Cethana in Tasmania) and a handful of new projects should provide more than enough weekly and seasonal storage and reserves to allow 95% of our electricity grid demand to be provided by renewable sources.

4. Computers exist

Humanity went to the moon with the computing power of two Nintendo 64s. The phones in our pockets are thousands of times more powerful again. Phones transmitted 8 kilobytes per second in 1888; optic fibre can transmit more than 100 terabytes per second today. In the 1800s money was gold backed, but it is very different today. All of this means that real-time coordination, optimisation and settlement of the electricity system, including all of the technical grid services required to keep it running, and even from the millions of distributed energy resources across the grid, is very possible.

5. CO_2 from burning fossil fuels warms the planet

The final, and perhaps the most significant change in our energy landscape from 1888, is our understanding of the impact of carbon dioxide on our planet. First outlined by physicists in the early 1900s and by the 1950s understood in detail for its dangerous impact on our planet, the science now is crystal clear: burning fossil hydrocarbons (coal, oil and gas) releases carbon dioxide into our atmosphere, which traps heat in our planet. While there is a natural carbon cycle (plants: breathe in carbon dioxide, store carbon, breathe out oxygen; animals: breathe in oxygen, eat carbon, breathe out carbon dioxide), the addition of vast amounts of fossil carbon into the atmosphere is occurring at rates far greater than the natural carbon cycle can absorb. Hence CO_2 levels are increasing exponentially, as are global temperatures and the frequency and intensity of extreme weather and climate events.

There has been ample communication of this science to policy makers since the 1960s. A 1965 White House paper from the US President's Science Advisory Committee titled 'Restoring the quality of our environment' had a section 'Carbon dioxide from fossil fuels – the invisible pollutant', which highlighted:

> Man is unwittingly conducting a vast geophysical experiment. Within a few generations he is burning the fossil fuels that slowly accumulated in the earth over the past 500 million years. The CO_2 produced by this combustion is being injected into the atmosphere… By the year 2000 the increase in atmospheric CO_2 will be close to 25%. This may be sufficient to produce measurable and perhaps marked changes in climate, and will almost certainly cause significant changes in the temperature and other properties of the stratosphere

The latest Intergovernmental Panel on Climate Change (IPCC) Sixth Report, nearly 60 years later:

> It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.
>
> The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.
>
> Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened.

The heating of the oceans has already locked in hotter temperatures for the next century due to the excellent ability of water to store heat energy (the same reason why a tomato in a toastie gets incredibly hot).

How much policy has changed in half a century? How much meaningful regulation has been enacted to reduce fossil fuel burning? For those countries with fossil resources to burn and sell – and Australia is right at the top here – the answer is 'a pitiful amount'. There is an intriguing (and somewhat depressing) story as to why this is the case. It is perhaps the single biggest impediment to an energy future the majority of us would like (discussed further in the next section), but nevertheless, the climate impact of burning fossil fuels is a key piece of information not available in 1888.

Part 3 – Energy reimagined

If we were to design our energy system from scratch today, how would we do it? My view is outlined below.

If you are not into the detail, you can skip this section and go straight to Part 4 with the conclusion that it is both doable and cost-effective without requiring any technological breakthroughs; the only question is how it fits within our national priorities. But if you are interested on what it might look like – in addition to being truly sustainable, carbon neutral and agile – our energy system, if I were to design it today, would be *resilient* at all length scales. That is, able to provide safe, sustainable, secure, reliable electricity at *all* scales – from homes to neighbourhoods to countries to the entire planet (A–D below) – with robustness for any disruptions or outages at any scale. That is, a fault at any level would not disrupt the ability to generate or receive electricity. In practice, and with a little bit of technical detail too, this is how it might work.

A. Households

In addition to appropriate solar-passive design, orientation and energy efficiency (the initial steps of the excellent Retrosuburbia blueprint of David Holmgren), any house with sunlight-receiving roof space would have solar panels on them, with inverters that support at least a power-point and a usb outlet in the face of a network outage.

There are more than 3 million solar PV systems on Australian rooftops today, but nearly all of those systems are completely useless in a blackout. That is, if the power goes down in your street or state, the solar PV system on your roof that you likely paid $5000+ for won't even be able to charge your mobile phone. It's ridiculous.

For an extra couple of hundred bucks you can now get an inverter that at least has a power socket that outputs electricity when the sun is shining (the Fronius GEN24 plus is an example). In the short term, all PV customers should be informed about this option. In the medium term, this functionality should be required of all inverters and baked into the Australian Standard for grid-connected inverters (AS 4777.2).

Household PV systems and eventually household batteries and electric cars should also support the larger grid to operate securely – they are already doing this through increased voltage and frequency support, and in the future should have additional grid-forming capabilities added to support system strength when efficient to do so. All of these functionalities should respect customers' rights: the ability to consume self-generated power, the right to data privacy, and the ability to be remunerated for providing a public service. Beyond electricity, the need for household gas supplies will eventually be made redundant as we electrify (almost) everything through electric heat pumps for water and space heating/cooling, induction stovetops, and perhaps also efficient wood-stoves (Retrosuburbia again), or some combination of each to provide a truly resilient, sustainable household energy ecosystem.

B. Neighbourhoods

Just as households have embraced solar, small businesses are starting to do the same. Soon, most residential suburbs around Australia will be generating enough electricity to meet most household and light-industrial electricity consumption needs; the challenge will be in storing the electricity for when it is needed.

Household batteries will store some of this energy, and electric vehicles will store even more – and also be able to transfer it back to the grid with 'vehicle-to-grid' technology. 'Vehicle-to-load' technology – having a usable power socket in an electric car – should be the default before long, too.

But there is a natural length scale for battery storage that supports broader network performance and electricity supply for all members of the community, whether they own panels, batteries, electric cars or not, and that is at the *neighbourhood* level. The distribution network comprises the poles and wires that carry electricity from the high-voltage transmission lines to the lower voltage lines that we see at the end of our streets. The distribution companies have to make sure voltages stay within correct, safe limits, and it is becoming increasingly tricky to do this in a system that was designed for one-way flow of electricity from big coal generators to people's houses.

Neighbourhood-scale batteries can help with this, allowing distributors to control network voltages, but also letting households within the community store their excess solar power during the middle of the day to later use at night-time. Batteries of about 100 kWh–5 MWhr storages hit a sweet spot in terms of economies of scale, community resilience, and appropriate sizing to store a majority of residential electricity needs after the sun goes down.

Such neighbourhood batteries could also serve as a community hub in the event of wider outages or disaster events, or additionally serve as electric vehicle charging stations. The Kalgoorlie-Boulder Community High School is one such example, and cities across Australia are funding trials and pilots for many more.

The challenge for neighbourhood-scale batteries is in the regulation and market structures that support fair use by both the distribution system operators, retailers and customers, but there are no insurmountable reasons to neighbourhood batteries supporting the storing and sharing of locally generated electricity, and broader resilience and network grid support for the wider community.

C. Countries

Building on the energy resilience of households and communities, countries would have resilient sustainable reliable and secure electricity supplies at the national scale. The Australian Energy Market Operator (where I work for my day job – though this essay is written solely with my university hat on) has recently committed to being able to operate the entire east coast Australian grid at 100% renewables at any time of any day by 2025. This ambition will likely also apply individually to each of the east coast states separately.

It is a bold challenge, but doable. It will likely require a combination of solutions:

1. A diverse and distributed portfolio of solar and wind farms – the bigger the geographic spread, the less susceptible to local weather changes;
2. Storage provided by pumped hydro, grid-scale batteries, electric vehicles, and household batteries;
3. Better interconnection between states and between areas of renewable generation (known as Renewable Energy Zones) – with real and much-updated consultation and benefit sharing agreements with anyone potentially impacted by new transmission lines;
4. New synchronous condensers – spinning machines that don't generate or consume (much) electricity, but provide system 'inertia' to keep the grid stable (four have just been installed in South Australia to help with this);
5. Widespread deployment of 'grid-forming' inverters that help solar and wind generators (including household solar panels, batteries and eVs) provide similar grid-stability to the old coal and gas turbines (this technology is starting to be deployed now in big batteries);
6. Refreshed electricity market structures that (a) allow distributed and neighbourhood resources to participate, (b) support flexibility of demand in meeting variable supply, and (c) adequately remunerate the ancillary services for electricity that are required to keep the system secure, reliable, resilient, and re-startable (this is what I work on for my day job).

The detail of many of the above reforms required are spelt out in meticulous detail in existing publications: the AEMO Integrated System Plan, the Energy Security Board's Post-2025 Market Design Recommendations, the AEMO Engineering Framework, and considerations of the Australian Energy Market Commission.

What are the total costs to customers? It's a little unclear, but what follows is what physicists call a 'back-of-the-envelope' calculation for the first-pass approximation of the reforms that would get us 80% of the way there.

Much of the investment will happen privately, with companies deciding to build a wind or solar farm, or invest in batteries or pumped hydro, and homes and businesses deciding to put solar panels on their rooftops, make their buildings more energy efficient, electrify their heating and cooling and purchasing electric vehicles. The number that is perhaps more helpful is the total amount of additional government investment required.

The below summary is crude and almost certainly incorrect (and perhaps the topic that this essay would receive the most flack for) but is perhaps within an order of magnitude of what might be required to turbocharge the transition.

- Installing synchronous condensers where needed to support system strength and inertia – $600 million. (Installing four syncons in SA cost approximately $190 million, so perhaps doing the same for each of Queensland, New South Wales and Victoria might be three times this.)
- Building all of the transmission network projects that are outlined in AEMO's Integrated System Plan including the new Marinus Link to Tasmania, and all future ISP projects – $16 billion. (This is the amount estimated in the 2020 AEMO Integrated System Plan.)
- Enacting all of the market reforms outlined by the Energy Security Board – somewhere around $500 million – which would include establishing new regulatory functions for distributed energy and kickstarting the widespread adoption of grid-forming inverters, and enacting reforms that would allow expedited market and regulatory nimbleness throughout the transition (an estimate of implementation costs of a significant portion of the

recommendations of the Energy Security Board's Post-2025 Market Design Program.)

- Supporting innovation in distribution network technology to better coordinate DER – $1 billion. Ausnet services, which operates the distribution network in Victoria for 700,000 customers, proposed $11 million for 'innovation expenditure' in its regulated expenditure proposal for 2021–25 to support the ability to coordinate DER to manage and enhance local network performance. Scaling this up for the NEM's 9 million customers suggests $140 million, which we can maybe round up to $200 million to account for differences in location across the network, multiplying by 5 for the 25 years to 2050. This is a really rough calculation, and there are probably better estimates. To note, there will also need to be increases in regulated expenditure too; this amount represents a crude estimate of additional investment required to support innovation beyond this.

Together, less than 20-ish billion dollars (plus or minus 10 billion dollars) of public funding would get us a substantial part of the way towards supporting provision of >90% renewable electricity in each state at any time of any day.

This is a lot of money. Figuring in the costs of building the required grid infrastructure for new Renewable Energy Zones perhaps increases this by a factor of three. Last year, $13.2 billion was traded in the National Electricity Market.

Who should pay for this? And how? It's not clear. But, for perspective, the once-in-a-generation investment in NBN high-speed internet across Australia is estimated to cost $51 billion. COVID JobKeeper during the 2020–21 pandemic was $90 billion (of which $13 billion went to firms with rising revenue). Twelve submarines, to be delivered in 2040, will likely cost more than $100 billion. Australia's defence budget is $44 billion, with an additional $270 billion (Department of Defence, 2020) committed over the coming decade. Australia's annual national tax revenue is $552 billion.

A tenth of our annual defence budget for the next decade, or a 2% increase in tax for two years, would finance a large part of Australia's entire transition to a >90% renewable electricity future. If regressive taxes are more your thing (they're not mine, but are an option) then increasing the GST to 11% for three years would do the job.

I am not an economist. These numbers are wrong. The annual-levy, defence-reappropriation and GST approaches to financing the energy transition are all ridiculously bone-headed. Health, education, Indigenous Australia and public housing need this money more than most. But this quantitative conversation should be had in the public sphere.

Funding in the order of 20 billion dollars would support the rapid transition to a country with a resilient grid at regional, community and national length scales able to support >90% penetration of renewables, and at the same time supporting individual household generation and storage to connect up with grid-scale generation and storage, with sufficient redundancy and back-up across all length scales to provide the same, if not better, security, reliability and affordability of today's electricity network.

This figure does not even start to take into account the significant savings for customers arising from cheaper wholesale electricity from those renewables and more widespread competitive provision of system services. The market-body references above include detailed considerations and cost-benefit analyses of what is in the long-term interests of consumers – they are legislated to consider this through Australia's National Electricity Objective, and they pursue this objective with razor-sharp focus.

It is all eminently achievable. It is all eminently cost-effective. It does not require any new technological breakthroughs. It is only a question of how it fits within our national priorities.

D. The planet

If a reliable, renewable and resilient electricity system can be achieved on local, regional and national length scales, then perhaps it could also be achieved globally too. With a grid where Australia connects electricity wires to Indonesia and China, and China connects with Europe, it would not matter if it was day or night or summer or winter or raining or sunny in any one location because the sun would be shining and the wind blowing somewhere all the time – with extraordinary resilience and redundancy.

This is maybe a little far-fetched, but is actually starting to happen. High-voltage direct-current (HVDC) cables are already transporting electricity across China and connecting countries across Europe. These cables have loss factors of around 3% per 1000 km, meaning you could transmit power literally halfway across the world, and only lose half the power. The longest HVDC cable in the world, completed in 2019, transports 12 GW of power 3300 km across China, and larger projects are slated – Australia's own SunCable project intends to connect Darwin with Singapore across 5000 km to become the leader in intercontinental transport of electricity.

Our world is already intricately connected with undersea optic fibre cables, and it's not too much of a stretch to imagine the same but with HVDC cables also – some serious thinkers in the energy sector are currently designing it.

Part 4 – The future

A 100% renewable electricity grid is incredibly doable. The technology is perhaps the easiest part. Solar panels will get cheaper, batteries too. Electric cars will be everywhere, and the smarts to connect it all and provide the essential grid services to keep the grid safe and stable are being developed right now. Market and regulatory reform is achievable too – nothing a coordinated group of economists, engineers, lawyers, industry representatives and community advocates could not figure out in a couple of years, given reasonable resources to do so. The transmission lines to connect the vast majority of the new generation required have been meticulously designed and costed, and are ready to be built with off-the-shelf components.

These are the easy things. The harder thing is to do this in a truly sustainable way.

Making the silicon that goes into solar panels without destroying old-growth forests for charcoal in Australia, or using forced Uyghur labour in re-education camps in China. Mining the copper for wires and transmission lines without devastating waterways in Papua New Guinea. Mining the lithium and cobalt for batteries and electric vehicles without toxifying the groundwater in Tibet or the Congo. Building new things without disrespecting the global rights of workers to a fair wage and fair working conditions.

These are structural problems and are perhaps the most important to solve. They exist largely due to unregulated capitalism and the state capture of politicians who would win elections at any cost and who perhaps have an eye to the revolving door of lucrative post-politician life. The industries that dominate this state-capture landscape are those of military industrialisation and fossil fuels. The destruction they have wrought on our planet is becoming ever more present.

In Australia, with fossil fuels, this influence is glimpsed in the register of donations to political parties – fossil fuel companies are some of the largest donors (close to $2 million per year). Ads placed by the coal lobby spruiking the benefits of coal and mining are often the biggest political expenditure by third-party groups in Australia. Australia is among the world's largest exporters of both coal and gas. The vast donations these companies pour into political parties help continue representation and advocacy, and fund vital advertising in a growing marketing arms race of election campaigning. This tap of cash is hard to wean from; Australia's exceptionally lax political lobbying, donation and advertising regulations have led both sides of politics to a culture of accepting whatever revenue might be available, regardless of the ethical implications. Outlined brilliantly in the Big Deal documentary by Craig Reucassel, this is a critical issue that requires structural reform.

But alongside the large cash donations for 'pay to play', it is possibly the flow of people that has bigger influence. The web of executive and advisor connections between ministerial offices and fossil fuel companies is astonishingly tangled, and while the relationship are just now starting to be mapped, they often occur unseen and out of the news. Not always though: a recent example being the hand-picked 2020 National COVID-19 Coordination Commission led by Nev Power, director of oil and gas company Strike Power, Andrew Liveris, director of Saudi Aramco, Catherine Tannam, managing director of Energy Australia and former executive with Shell, and Greg Combet former advisor for Santos. How these members could provide a broad understanding of the impact of the biggest economic shock in a generation is curious to say the least, but speaks to the extraordinary access and preference given to these industries. For the record, this commission's strongest recommendation wasn't to recommend a vaccination pathway, nor an economic reskilling for a post-pandemic landscape, but a *gas-fired* recovery (!?).

The revolving door goes both ways. After leaving parliament, former National Party Leader John Anderson became Chairman of Eastern Star Gas, former National Party Leader Mark Vaile became the chairman of Whitehaven Coal, Labor Federal Resources Minister Martin Ferguson was appointed Chair of the Advisor Board of the Australian Petroleum Production and Exploration Association, former Nationals Federal Energy and Resources Minister Ian McFarlane was appointed CEO of the Queensland Resources Council, and former Liberal Foreign Minister Alexander Downer was appointed board member of Lakes Oil.

These appointments are not illegal, and it is natural to remain engaged in subject matter of expertise. But there should be appropriate boundaries and revolving-door prohibitions that maintain the integrity of decision-making processes. These connections at our democracy's highest levels, between members of our National Cabinet and vastly wealthy fossil fuel companies, provide deep interaction and access to policy intent, information and formulation in both major political parties. The donations these companies then pour back into political parties help continue representation and advocacy. The lucrative open door that fossil fuel companies provide to ex-decision makers provides dangerous motivation for the corruption of decision making – the danger would be similar if renewable energy companies engaged in similar behaviour. Revolving-door restrictions would and should prevent both. But together, the influence of donations and transferral of lobbying personnel perhaps form the most pernicious challenges to transparent democracy of our time; for energy, coal and gas links have fuelled the biggest impediments to national action on climate change over the past five decades since the science became apparent.

What can we do to tackle this problem? The answers aren't clear. Scott Ludlam writes about a few of them in his excellent book, *Full Circle*, but it perhaps starts with whatever action, no matter how small, you think you can take.

At a local level, perhaps the most direct action we can do is to dry up fossil fuel capital. Whether it is switching to a bank that does not support fossil fuels (I am with Bank Australia), moving your super to a fund that does not fund them (e.g. Australian Ethical

Super), paying for a renewable energy premium with your electricity retailer (around 5% additional for your bill), or putting solar panels on your roof (if you have one). Following this, we can try to reduce the amount of stuff that we fill our lives with that take significant fossil fuels to make, transport and decommission – perhaps by giving ourselves the permission to pay a little extra for items that we will truly cherish (see Richard Denniss's *Curing Affluenza*), supporting businesses that value triple-bottom line accounting (such as Certified B Corporations), or somehow freeing ourselves of the consumerist culture that is so easy to be sucked into in the first place (I know I'm sucked in …).

In the end it will likely require non-violent direct action in the form led by the Extinction Rebellion movement – the most successful method of structural action of the past two centuries. In the meantime, we can join the anti-lobby lobby and vote for political parties that don't accept fossil fuel donations and that argue for real-time transparency of our political donations and strict revolving-door restrictions on retiring ministers.

And once we kick out the fossil fuel oligarchs and their coterie of hanger-ons that profit from them – once we shine the spotlight of national attention on their profit-seeking-at-all-costs behaviour and the corruption of our federal politicians accepting donations from destructive industries or in trying to get a high-paying job once they leave parliament – once we show ourselves that we can achieve outcomes that value human development alongside our natural ecosystems through a process of decarbonisation, first through electrification, and then for the entire energy, manufacturing and transport sectors …

Once we do all these things, then hopefully this will amplify our ability and our agility to address the other real and perhaps even more pressing challenges of our time – rebuilding new political power structures that truly value humanity and our global ecosystem; rebuilding connection with our planet's rivers, landscapes, oceans and living creatures; respecting and valuing First Nations people; pursuing the aims of providing universal access to healthcare, housing and education; and reducing inequality and supporting the just, open distribution of our collective capacity and endeavours for the benefit of all.

An Australian way to a renewable future? There's not a moment to lose – we just need to find the energy.

Endnote

1 A kilowatt-hour is a unit of energy – lifting a 100 gm apple one metre in a second requires a watt-second (1 Ws) of energy, lifting 1000 apples one metre a second, every second for an hour is a kilowatt-hour of energy (1 kWh). Leaving a 15 W light bulb on for an hour uses 0.015 kWh. Running a 1 kW aircon unit an hour uses 1 kWh. An average family home uses around 20 kWh of electricity every day.