A tale of two futures
Infrastructure Partnerships Australia
2022 Annual Infrastructure Oration

Thank you, Rod, for the invitation to speak tonight.

The last function I attended where the topic was infrastructure was an Academy of Technology and Science dinner, at the Royal Brighton Yacht Club, eight years ago.[i] Rod, you will remember it well, because you were the guest speaker. At the time, you were Chair of Infrastructure Australia. I still recall the care and pride with which you explained the crucially important role of planning, based on evidence and integrity.

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Tonight, I'll be talking about the clean energy transition in Australia.

I'm focusing on energy for two reasons.

The first is the essential role energy plays in our modern civilisation. If we hadn't learned to harness energy, humanity would not have made the step from the Stone Age to the Bronze Age.

Second, the *importance* of investing in a clean energy future is highlighted by the tragedy of the Russian invasion of Ukraine, where the well-intentioned response of European neighbours is constrained by their dependence on oil and gas supplies from Russia.

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Distinguished guests, we are at a turning point in history. We are in the early stages of the most fundamental shift in the global energy supply since our ancestors tamed fire.

Tonight, I'll be asking you to imagine two futures.

My nightmare, and my dream.

They are starkly different. And the decisions we make now will decide how close we get to my preferred outcome.

But to help you see these two futures, I first have to tell you a bit about the past and the present.

In the past, each time we developed a new form of energy supply it added to what was already there. Coal added to biomass, oil added to both, and natural gas came along to top up the cocktail.

Today, more than 70% of our national greenhouse gas emissions result from burning these fossil fuels.

This time, we need to plan for an energy *revolution*, in which clean electricity, primarily from solar and wind generation, will *replace* coal, oil and natural gas, instead of topping up the cocktail.

This will be a global project, of unprecedented scope and difficulty, to dramatically reduce our emissions and bring net zero within reach.

Fortunately, Australia is a world leader in the adoption of solar and wind electricity generation. Between them, solar and wind contribute about 25% of our national electricity output, on par with California.[ii,iii]

And if you look at solar alone, we have the highest rate of installed solar capacity per person in the world.

We cannot afford to lose this momentum.

Because the key to bringing net zero within reach will be to electrify everything.

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I think about electricity in many different ways: as a tool, a friend, a challenge and an opportunity.

In my early career as a neuroscientist, I worked with electricity on an exquisitely small scale, designing equipment to measure the electrical activity of brain cells. For the technically inclined, the level of power in a single brain cell is measured in picowatts – a millionth of a millionth of a watt.

I later joined a company that specialised in charging stations for electric vehicles. There, the power was measured in kilowatts – thousands of watts.

Then, all of a sudden, South Australia was hit by a series of storms, and my world of electricity scaled up dramatically. When I was asked to chair a review of the National Electricity Market, I had to think about gigawatts – billions of watts.

Among many issues addressed by the review, including governance, power system engineering, connection requirements and weather monitoring, we looked at the electricity system infrastructure. We recognised the need for national scale thinking when planning transmission lines, and thus we recommended that AEMO should develop an integrated system plan.

Our review also recognised the importance of physically strengthening the poles and wires to withstand more intense weather events, like the floods that have tragically wreaked havoc across New South Wales and Queensland these last few months.

Most importantly, we acknowledged the need to embrace solar and wind electricity and distributed generation in a two-way network, but to do so while preserving system stability.

Now, you should have no doubt – transforming our existing electricity system to run almost entirely on solar and wind electricity is hard. Hard to build the scale, hard to preserve reliability, hard to manage the system.

Let's stop for a minute to quantify the scale. In electricity systems, the biggest unit for measuring energy is terawatt-hours. The Australian electricity system produces slightly more than 250 terawatt-hours every year, more or less the same as the annual production of electricity in California.[iv]

Tonight, I am defining a new energy unit, exclusively for the use of Infrastructure Partnerships Australia, called the ozziewatt-hour. One ozziewatt-hour equates to the entire annual production of electricity in Australia.

Expressed in this newly minted, enormous unit, our existing solar and wind generation contributes a quarter of an ozziewatt-hour. Thus, to complete the transformation of our existing electricity system we will need four times as much solar and wind generation as we have today.

The bigger challenge is that our economy uses *two* ozziewatt-hours of energy *outside* the electricity system, through the direct combustion of oil, natural gas and a little bit of coal for industrial heat, for steam and hot water, for transport and building heating.

Thus, to replace our use of fossil fuels with renewables, Australia's domestic electricity system of tomorrow will need to generate *three* ozziewatt-hours per year.

Generation that will come almost entirely from solar and wind.

This transition will be a massive task. To produce three ozziewatt-hours of electricity from today's starting position of a quarter of an ozziewatt-hour, we will need twelve times our current solar and wind generation.

This transformation raises significant issues for you, the planners and investors in our national infrastructure.

A case in point is the tension between transmission lines and batteries.

Arguably they are both infrastructure, but they are fundamentally different solutions to the problem of reliability.

At one end of the spectrum of possibilities, we end up relying heavily on interstate transmission lines.

They reduce the consequences of intermittency by bringing solar and wind electricity from different weather regions to where it is needed, for example from South Australia on a windy winter's day to Victoria where the wind happens to be still.

But in practice, interstate transmission lines are expensive and take as much as ten years to go from planning to completion.

The planning overhead involves the grid operator, the regulator, the rule maker, multiple state governments, the federal government, local communities and landowners. After all that comes construction, which is expensive and slow.

At the other end of the spectrum, we end up relying heavily on large-scale utility batteries.

They reduce the consequences of intermittency by locally storing excess electricity for when it is needed.

Importantly, they don't require new transmission lines because they are usually built on existing solar and wind farm sites, or otherwise located near an existing transmission line. For example, the Victorian Big Battery, commissioned last year, was built next to an existing high voltage transmission hub just outside of Geelong.[v]

Astonishingly, even if they are very large, utility battery installations can take as little as one year from financial close to commencement of operations.[vi]

Of course, we will end up with a mix of batteries and interstate transmission that is somewhere in between these two extremes. Finding the optimal balance will require insightful planning and investment right across the nation.

Irrespective of the role of batteries, we will need lots of *local* transmission lines to connect renewable energy zones to the major population centres and industrial loads.

Unfortunately, because of the complexities in planning and community engagement, these, too, take a long time to build.

To add extra pressure to the challenge, if we over invest, or if we under invest, prices will go up and this may undermine public support for decarbonising the electricity supply.

These cumulative factors make it critical that we optimise our transmission line planning and investment.

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The long times taken to build local transmission lines to connect renewable energy zones leads to another tension, this time between large scale solar and rooftop solar.

If you had asked me twenty years ago whether rooftop solar would ever become a significant fraction of our total solar generation, I would have said no! Obviously not!

Because rooftop solar cannot share the economies of scale enjoyed by large-scale generation.

But last year, 3.3 GW of rooftop solar was installed, which exceeded the 3 GW installation of large scale solar and wind combined.

There are many reasons for the dominance of rooftop solar, like the individual incentive to save on your household electricity bill by generating electricity at home.

However, arguably the main reason for the comparative success of rooftop solar is that it does not have to wait for new transmission and distribution lines to be built. The typical process from quotation to completed installation is just a few weeks, including the time for approvals.

Last year, 8% of the total electricity generation in the national electricity market came from rooftop solar; this was twice the amount that came from solar farms.

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Nevertheless, we'll need plenty of large scale solar and wind farms to meet our future domestic energy demand, as well as to realise our ambition of becoming a globally significant hydrogen exporter.

Hydrogen that can be used instead of diesel in heavy duty trucks and long-distance trains, instead of bunker fuel in big merchant ships, instead of natural gas for industrial heating, instead of thermal coal to generate electricity, and instead of metallurgical coal to produce steel.

I call Australia's vision to become a major hydrogen exporter 'shipping sunshine'.

Success will require electricity generation much bigger than the three-fold increase we'll need to meet our domestic demand.

To get a sense of just how much bigger, consider the quantities of LNG that we currently export. Measured by energy equivalent, to export a comparable quantity of hydrogen made by electrolysis we would need eight ozziewatt-hours of solar and wind electricity.

If you expand the exercise to export as hydrogen the energy equivalent of our coal exports, that's another 14 ozziewatt-hours.[vii]

Three plus eight plus fourteen: that's a whopping 25 ozziewatt-hours in total.

That's more annual electricity generation than in the entire United States, which sits at about 16 ozziewatt-hours.[viii]

This scale will not overwhelm our domestic electricity grid because most of the export-oriented hydrogen production facilities will be remotely located. Nevertheless, they will require planning and massive investments in infrastructure like ports, roads, rail, pipelines and liquefaction plants. They will also need enormous caverns or containers underground for large-scale hydrogen storage.

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Speaking about storage, let's return to storage in the electricity sector.

Last year was a breakthrough year for big batteries in Australia. There were 30 large-scale batteries under construction at the end of 2021, with a combined capacity of 920 megawatts rated to operate for an average of 1.3 hours. These batteries are all short duration storage, up to 4 hours, ideal for providing frequency control services and overcoming short term power fluctuations.

As big as current and planned batteries are, they are only a small percentage of what we will ultimately require. AEMO is forecasting a long-term need for one hundred times this amount of short duration storage in homes and at utility scale combined.[ix]

We will also need medium duration storage, from 4 to 12 hours, as the percentage of solar and wind increases.

At very high levels of solar and wind generation, we will need long-duration storage of up to several days or weeks for those rare, protracted periods of cloudy skies and windless days. This could be supplied by pumped hydro facilities that have very large reservoirs, or hydrogen storage in giant underground caverns.

Long-duration storage will be used infrequently, so it will be difficult for investors to build a business case for its construction.

As a partial alternative, the need for long-duration storage could be minimised by preserving rapid response gas generation. The contribution to emissions would be small because the gas generators would only be used a small number of hours per year.

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Outside the energy sector, we'll need new infrastructure to support carbon capture and storage, called CCS, to soak up any residual emissions from electricity generation, as well as irreducible emissions from some industrial processes.

There are many people who believe that CCS is a strategy of the fossil fuel industry to indefinitely extend the operations of coal-fired and gas-fired generators.

In all honesty, it might have started out with that intention, but it is not economically feasible.

Instead, CCS has ended up with a very different purpose.

Let me talk about concrete, to demonstrate where we need CCS today.

For this audience, concrete is like bread and butter.

By volume, it is the most consumed product in the world.

And it's made from cement.

When cement is manufactured, carbon dioxide is released as a by-product of the *chemical* reaction that converts limestone into lime.

Despite the best global efforts of researchers in academia and industry, we have not discovered a viable alternative for lime in the cement mix.

It is unlikely that we will stop using concrete, so we will need CCS to capture the emissions from cement production.

To be cost effective it will need to be at scale. We will need to use dedicated pipelines to transport carbon dioxide from where it is captured to nearby geological formations, to bury it deep underground.

These carbon dioxide pipelines, wells and monitoring systems will represent a new form of infrastructure, which in many cases will be shared.

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I hope I have demonstrated that in our clean energy future, it is not a question of whether we'll need more infrastructure.

It is a question of *what type* of infrastructure we'll build.

We don't have all the answers yet, or all the technology.

But we will have one proven resource to help us overcome the challenges that lie ahead.

One resource that will never run out.

One resource that will always deliver.

That resource is innovation, and it will help to guide the way.

We will need innovation to implement end of life recycling for batteries, in order to avoid a major waste problem being foisted on future generations.

We will need innovation to incentivise the installation of the required storage in the electricity market.

This is especially the case for long-duration storage that will be called upon infrequently, making the economics for investment unattractive. Many industry participants are calling for a capacity market that will pay for the installed storage *capacity* and not just the energy delivered.

We will need innovations in market design, to pay for services from flexible loads, and to minimise the impact of network charges on grid-connected hydrogen production facilities.

When it comes to maintaining grid stability as we incorporate ever higher levels of solar and wind generation in the Australian electricity mix, innovation will help by delivering powerful digital control systems for the systems operator to manage connections, operations and digital twinning.

We will need to innovate uniquely Australian solutions.

This is the landscape of the clean energy future that awaits us. It's up to us to build the infrastructure to support it.

It's up to us to decide whether I wake up from a dream or a nightmare in our clean energy future.

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First, let me tell you about the nightmare.

In the nightmare, our electricity transmission lines have not been built quickly enough to connect solar and wind farms, and we have underestimated the role that batteries will play.

As a result, the rate of reduction of the emissions intensity in the electricity system is slow and prices are high.

Even though consumers have bought electric vehicles in record numbers because they love the performance, the continued use of fossil fuels for electricity generation means that the shift to electric vehicles has not delivered the emissions reduction that we anticipated.

Local blackouts have become the norm as ageing thermal generators suffer breakdowns. These blackouts have a disproportionate impact on those commercial and household consumers who do not have solar panels and batteries.

Our concrete is still high carbon because an economical chemical equivalent to cement has not been developed and public opinion has prevented CCS from being used to sequester the emissions from the conventional process. Because of inadequate building regulations, the quantities of concrete used per project have only marginally diminished.

There has been insufficient effort to reduce methane emissions from cattle and sheep. Australian consumers have been turning to imported meat alternatives and our meat exports are declining.

Resource companies have been forced by activist shareholders to divest or close their coal and natural gas assets. That was a mistake, because they lost the revenue stream that could have been invested in new clean technologies.

Inadequate support for affected landowners has also slowed down the development of gas pipelines. Our hydrogen export industry is developing slowly, and the market opportunity has been seized by other determined countries, such as Chile and Saudi Arabia.

I hate that future! It’s a nightmare that keeps me up at night.

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Let me tell you, instead, about my dream.

In my dream, early and equitable engagement with Indigenous communities, farmers and other landowners has allowed strong investment in electricity transmission and distribution lines, which are built on time and at reasonable cost.

New renewable energy zones are connected rapidly to the grid and investment in large scale solar and wind is booming. Large scale utility batteries and other storage mechanisms smooth supply across the full range of durations.

As a result, the rate of reduction of the emissions intensity in the electricity system accelerates and we achieve a zero-emissions electricity supply earlier than we’d anticipated.

There has been substantial investment in high-speed public charging for battery electric vehicles and smart charging in homes and depots. A well-planned network of hydrogen refuelling stations for trucks and trains lines our major highways.

These projects have supported consumers in their shift to electric cars, as well as fleet operators in their shift to battery and hydrogen powered trucks and trains. Sales of land vehicles are 100% electric, and emissions from the ground transport sector are nearly zero.

Not only is all of our electricity produced with zero emissions, but it is also low priced. Energy is not a significant cost for homeowners – whether they have solar panels or not – and Australia’s thriving manufacturing industry is competitive on the global stage.

AEMO has visibility on the millions of rooftop generators and AEMO’s digital control room software ensures efficient simulations and operations. No one can remember the last time there was a large-scale blackout, and overseas systems operators visit AEMO routinely to learn from the Australian success story.

We still use Portland cement to make concrete, but because of new regulations and voluntary industry commitments we use less per project than we used to. The emissions from cement manufacturing are captured and stored, with the cost covered by carbon trading.

The agriculture industry has cut its emissions by more than half. Our exports are strong because international buyers are aware that emissions from Australian meat and produce are lower than almost anywhere else in the world. Residual emissions are covered by offsets, the cost of which is built into the premium prices.

Our natural gas and coal companies have been using some of their fossil fuel profits to invest in CCS infrastructure, and to build a thriving direct air carbon capture and storage industry that has helped Australia become a significant exporter of carbon offsets in a robust international market.

Although world demand for our existing natural gas and coal exports has declined, Australian companies have expanded their hydrogen exports. We've switched from shipping emissions to shipping sunshine.

Investment by governments and industry in our domestic hydrogen sector helped them to build workforce skills and technological efficiencies that ensured our cost competitiveness despite high salaries, and we are the largest hydrogen exporter in the world. When our hydrogen export industry looks up, it sees other countries in the rear-view mirror.

This is the clean energy future that gives me hope!

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Coal brought us the Industrial Age.

Insightful planning, investment and innovation in our clean energy future will bring us the Electric Age.

My belief that we can achieve the Electric Age drives my passion.

It motivates me to continue working hard in pursuit of a better, brighter future for all Australians.

But this dream cannot be achieved without infrastructure.

It cannot be achieved without *your* commitment to make early, informed decisions that will enable Australia to reach net zero emissions.

May the Force be with you.

Thank you.

[i] In 2014 Rod was the guest speaker at an ATSE Victoria dinner at the Royal Brighton Yacht Club. Title of his talk was "Infrastructure: Challenges Aplenty".

[ii] https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2020-total-system-electric-generation

[iii] https://opennem.org.au/energy/nem/?range=all&interval=1y

[iv] Electricity generation in Australian in 2019 was about 265 TWh, https://www.energy.gov.au/publications/australian-energy-statistics-table-o-electricity-generation-fuel-type-2020-21-and-2021

[v] https://www.energy.vic.gov.au/renewable-energy/the-victorian-big-battery

[vi] https://infrastructurepipeline.org/project/victorian-big-battery

[vii] Metallurgical coal: 180 million tonnes (8 times). Thermal coal: 220 million tonnes (6 times). LNG: 80 million tonnes (8 times Australian electricity generation).

[viii] https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

[ix] Estimate based on AEMO plans.