The projects that can power Queensland to a zero pollution future

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1 Queensland has the foundation projects in place to make the leap to zero emission electricity

No doubt you've heard the saying about renewable energy that, "when the wind doesn't blow and the sun doesn't shine, well the power doesn't flow". It's certainly true that the sun sets and clouds are a fact of life. And the wind varies widely in a single location. We have detailed weather records that tell us exactly that.

What many of those that are fond of this saying don't realise is that talented mathematicians have used these weather records to examine what patterns of power production we could expect with large amounts of solar panels and wind turbines installed across many regions of the world. This includes Australia and indeed now also Queensland. They have then examined whether the power wind turbines and solar panels would produce from these weather patterns could ensure we satisfied our electricity demand over the same time periods. Yes, these studies confirm that we can't do it all with just wind and solar photovoltaic panels. Yet they also find that it is possible with a reasonably moderate amount of energy held in storage which can then be drawn upon at the flick of a switch – that can include chemical batteries, hydro, bioenergy, hydrogen or even insulated tanks of fluids heated by the sun. Another important finding is that investment is required in new power transmission lines so that we can readily transfer power from where it is windy or sunny to wherever it is needed.

One of the first mathematicians to analyse Australia's historical weather patterns to see whether we could achieve highly reliable electricity supplies with all our energy coming from renewable sources was Dr Ben Elliston – a software engineer and a researcher at the University of NSW. Since his first study was published in 2013, researchers at Australian National University, the Australian Energy Market Operator and other organisations have built their own mathematical models of the energy system incorporating historical weather records. These confirm we can achieve highly reliable electricity supplies powered entirely or almost entirely from renewable energy.

In 2019 Dr Elliston undertook a follow-up study focussing in on Queensland[1]. This study found that the state could achieve a highly reliable supply of electricity based entirely on renewable energy sources within its own state, plus a modest amount of imports from NSW.

Such mathematical studies provide a very good guide as to what is possible because they are informed by the real-world experience from hundreds of renewable energy projects installed around the world.

Understandably though many in the community want more than a mathematical model to give them confidence that 100% renewable energy is possible. They'd like to understand what would need to happen with on the ground examples to deliver on what a mathematical model says is possible. This report is intended to help do precisely that.

Green Energy Markets maintains a database which tracks the progress of every single major renewable energy project in operation, under construction or proposed by companies for development across Australia. In addition, we also closely track how many rooftop solar systems and battery systems are installed across the country and work with government agencies to forecast how many are likely to be installed in the future.

It turns out that people and companies have already laid out the set of projects that come very close to delivering on what Dr Elliston assessed would be required for Queensland to achieve reliable electricity with net zero greenhouse gas emissions.

[1] Dr Ben Elliston (2019) Report to the Queensland Conservation Council – Preliminary questions about 100% renewable energy in Queensland

Table 1-1 details the mix of renewable energy project capacity by fuel type which Elliston's modelling indicated could deliver a reliable supply of electricity for Queensland. We have then compared this to the capacity of projects that are already in place or contracted to be built, and then also the capacity of projects that are proposed or in planning. While there are some shortfalls relative to what Elliston had modelled, in particular for solar thermal, it is likely this could be largely covered by surpluses in capacity across other fuel types. While further detailed weather-based modelling is required to thoroughly assess these existing and proposed projects' ability to match supply with demand, a range of businesses have now laid out a pathway that puts us well on the way to a pollution-free electricity system.

In terms of solar photovoltaics Queensland has a very large surplus of capacity relative to what Elliston estimated was required. Households and businesses across Queensland are continuing to turn to solar as a quick and easy way to reduce their electricity costs, with around 3,000MW already installed across the state. This exceeds Elliston's requirement by 1,100MW. In addition Green Energy Markets' forecasts prepared for the Australian Energy Market Operator (Central Scenario) envisage that by 2030 a further 3,000MW will be installed by 2030 and 5,000MW by 2040 – bringing the total installed capacity to around 8,000MW or 6,100MW more than Elliston had estimated was necessary.

In terms of solar farms installed in large ground-mounted field arrays, Elliston's model estimated 9,956MW would be required. Queensland is already a fifth of the way towards that amount with solar farms already in place or contracted. If we then consider the 24,169MW of projects developers have proposed then there is a surplus of 16,160MW.

In terms of wind power capacity there is a very slight shortfall of 185MW in terms of actual projects relative to modelled requirements. Given the steady stream of new project proposals being announced over the past 12 months, this will gap will undoubtedly soon be bridged.

The bigger gaps between Elliston's modelled supply and what companies and households are already working towards delivering, lie in his reliance on solar thermal with heat energy storage and gas turbines using biofuels to balance out wind and solar PV. However, Table 1-1 also illustrates that Elliston did not incorporate the use of batteries instead for balancing out supply. Elliston's report was prepared using cost assumptions from several years ago. Considerable advancements have since been achieved with battery energy storage that mean this is now a more attractive option. In addition, Australia's Energy Market Operator has already laid-out an expansion of the Queensland-NSW interconnector in its recent Integrated System Plan that is substantially larger than what Elliston expected. And lastly, he constrained his analysis to only use pumped hydro capacity already in operation or contracted and didn't consider other proposed projects in Queensland.

The following section examines in further detail the potential alternative options to solar thermal and gas turbines using biofuels.

Table 1-1 Fuel mix modelled as required to deliver 100% renewable energy power supply and actual projects in place and proposed

Technology	Elliston requirement[2]	Operating, underway or proposed	Shortfall/Surplus to requirement
Rooftop Solar PV	1,900MW	3,000MW operational and 8,000MW expected by 2040 based on current trends	Surplus: 6,100MW
Solar PV farms	9,956MW	1,947MW operational or contracted and 24,169MW proposed	Surplus: 16,160MW
Wind	11,782MW	2,269MW operational/ contracted and 9,328MW proposed	Shortfall: 185MW
Bioenergy	3300MW of gas turbines delivering 1,700GWh per annum	500MW of bioenergy plants in place producing 1,500GWh per annum and 98MW proposed. 3,555MW of gas turbines installed but currently equipped for fossil fuels.	Sufficient available biomass resources to meet energy requirement but existing gas turbine capacity requires modification and eventual replacement
Hydro	820MW with 7000MWh of pumped energy storage	979MW operational or contracted and 1,570MW proposed with total of 17,500 MWh of pumped energy storage	Surplus: 1,729MW and 10,500MWh of pumped storage
Solar thermal	4,700MW with 37,600MWh of energy storage	50MW project proposed for Mt Isa with 700MWh of energy storage	Shortfall: 4,700MW and 37,000MWh
Small batteries	None	56 MW with 126MWh of energy storage operational. 4,525 MW with 8,872MWh of storage projected to be installed by 2040 (under High DER scenario for AEMO)	Surplus: 4,582MW and 8,998MWh of energy storage
Utility-scale battery systems	None	103MW with 159MWh of energy storage contracted. 3,533MW with 10,712MWh worth of storage proposed.	Surplus: 3,636MW and 10,871MWh of energy storage
Interconnector import	2,000MW	550MW to 850MW of import capacity committed. AEMO ISP plans 2 stage increase of 2,372MW	Surplus: 922 - 1,222MW

[2] See Dr Ben Elliston (2019) Report to the Queensland Conservation Council – Preliminary questions about 100% renewable energy in Queensland. Accessible from: https://d3n8a8pro7vhmx.cloudfront.net/queenslandconservation/pages/5065/attachments/original/1602034931/Briefing_Paper_on_100RE_Scenarios_for_Qld_2019.pdf?1602034931

1.1 Addressing the gaps

The main gaps in actual on the ground projects relative to modelled requirements lie in solar thermal and gas turbines fuelled by bioenergy. Yet even here, means to bridge these gaps are becoming apparent.

1.1.1 Bioenergy and gas turbines

Bioenergy involves using the energy embodied within natural materials derived from plants and animals. In Queensland some of the current examples used to produce electricity include such things as the waste fibrous residues left over after extracting sugar from sugar cane, or the methane-rich gas produced from decomposing natural materials like food scraps in landfills, or even the shells left over once macadamia nuts have been extracted.

Elliston proposed the use of 3,300MW of gas turbines fuelled by liquid biofuels to provide a means of providing large amounts of power but which would only be needed over short periods of time. This capacity was envisaged to only need to deliver 1,700GWh of electrical energy over a year which equates to just 6% utilisation of the turbine capacity.

Queensland already has 3,555MW of gas turbines installed. It also already produces 1,500GWh of electricity per annum of power from bioenergy and it has enough agricultural waste materials to supply a further three times that amount of electricity through the use of materials such as cereal straw and plantation wood residues. However, these bioenergy materials are not easily converted into liquid or gaseous fuels that could be readily transported and used in the existing gas turbines. Instead it may make better sense to pursue three alternative options to fill the place of liquid biofuels employed in gas turbines.

Expanding the use of small-scale bioenergy plants instead of large gas turbines

Bioenergy has the virtue that it can be used to create electricity in much the same way as fossil fuels using the same technologies of steam and gas turbines, as well as reciprocating engines (these are like a very large car engine). These plants can then be turned up or down as required independent of short-term weather conditions to balance out wind and solar and meet gaps in demand, as well as help stabilise the electricity system through slowing or containing frequency and voltage deviations. However, sources of bioenergy are highly dispersed and it can be costly to transport them long distances. This means small power plants located nearby to where agricultural products are harvested can be a more economical option than using existing, often very large gas turbines. Also the nature of the bioenergy materials often means that they are more easily converted into electricity via:

1. reciprocating engines (once the biomass is gasified) – this is commonly used for producing power from urban biological waste in landfills or wet wastes such as sewage or animal wastes which can be converted into an energy rich gas; or
2. burning in a boiler to create electricity via steam turbines – which is what is used in the sugar cane harvesting industry.

At present there are 500MW of these plants in place in Queensland and 98MW of proposed new capacity. However, with suitable storage facilities for the bioenergy it is quite straight forward for these plants to be upgraded to larger capacity power plants. These would then operate at lower average levels of utilisation than at present (bioenergy power plants tend to operate at around 30% to 50% utilisation compared to the 6% Elliston envisaged for gas turbines), and instead would be ramped-up when required to produce short bursts at a much higher level of megawatt output than occurs currently. Tripling the capacity of bioenergy capacity to 1,800MW while also adding 300MW of capacity in the Darling Downs to make use of agricultural waste in that region such as wheat and sorghum straw residues in the Darling Downs should be reasonably straightforward. This would then leave a smaller remaining gap of 1,200MW for gas turbines.

Fuel gas turbines with hydrogen produced via solar rather than bioenergy

Another option is to use solar photovoltaics to create hydrogen via electrolysis of water and then use the hydrogen to fuel gas turbines rather than liquid biofuels.

Elliston's modelling estimated that the 9,956MW of solar farm capacity installed in his model would deliver 5,400GWh of electricity per annum. Yet based on output levels from solar farms already in operation, 9,956MW of installed capacity could realistically expect to generate over 17,500GWh per annum (on DC rated panel basis after transmission losses). This suggests that under Elliston's model 12,100GWh of solar PV generation was surplus to requirements and spilled. This otherwise wasted generation alone could produce enough hydrogen to generate around 2,800GWh per annum via gas turbines[3] – which is 65% more than what Elliston's model required.

Both Japan and Europe are now mobilising considerable resources towards technological innovation and scaling up of hydrogen production via electrolysis. According to the European Commission the costs of electrolysers have plunged by 60% in the last ten years and they expect they can realise a further halving in their costs by 2030[4]. With the cost of the solar electricity driving the electrolysers being effectively free (it would otherwise be spilled) it should be possible for hydrogen costs to reach parity with the current contract prices for gas in Australia.

While conventional gas turbines have been shown to operate with fuel blends containing a very high proportion of hydrogen (GE has cited examples of its turbines operating on blends as high as 90% hydrogen[5]), to operate on 100% hydrogen for sustained periods requires gas turbines that are specially designed for this purpose. This means that while the existing 3,555MW of turbines in Queensland could play a useful role in an interim period as hydrogen production was scaled-up, new turbines would eventually need to be installed if fossil-fuel methane was to be entirely substituted with hydrogen.

This is not any kind of serious constraint. Procuring and installing 1,200MW of new gas turbines or even the Elliston's original estimate of 3,300MW of turbines should be a simple task. Last year more than 36,000MW of gas turbines were installed globally so the required capacity is a drop in the ocean of global supply[6]. In addition, constructing this capacity is not challenging either when you consider that in just the single year of 2008, over 3,000MW of gas capacity was committed to construction in the Australian National Electricity Market[7].

1.1.2 Solar thermal and potential substitutes

Elliston's model envisaged the use of 4,700MW of solar thermal capacity which would use mirrors to concentrate the sun's energy into a narrow beam that could heat a fluid to several hundred degrees centigrade that could be then stored in heavily insulated tanks. This hot fluid could then be drawn upon on command whenever needed to drive a steam turbine to generate power, even in the middle of the night. In Elliston's model these plants would be equipped to store sufficient heated fluid to be able to run the steam turbine at maximum capacity for up to 8 hours. While solar thermal plants tend to be substantially more expensive at generating electricity than solar PV or wind, their ability

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[3] This process has significant energy conversion losses within it. The conversion of water to hydrogen via electrolysis is assumed to be 65% efficient. The combustion of the hydrogen to produce electricity via a gas turbine again involves conversion losses with single cycle turbines capable of 35% efficiency, while combined cycle plants can achieve 60%.

[4] European Commission (2020) A hydrogen strategy for a climate-neutral Europe

[5] See this interview with Dr. Jeffrey Goldmeer - director of Gas Turbine Combustion & Fuels Solutions for GE Power: https://www.powermag.com/the-power-interview-ge-unleashing-a-hydrogen-gas-power-future/

[6] See: https://www.turbomachinerymag.com/worldwide-gas-turbine-forecast-2/

[7] Simhauser and Gilmore (2020) Is the NEM broken? Policy discontinuity and the 2017-2020 investment megacycle, Cambridge Working Paper in Economics

to store energy for use whenever needed means they can still play a valuable role. In addition, the fact that they employ a conventional synchronous steam turbine to generate power means they can also assist in maintaining system stability.

At present there is only a small pilot solar thermal power plant operating in Australia – the 1.1MW Vast Solar plant in Jemalong, NSW. In addition, Vast Solar has proposed a 50MW project for Queensland located near to Mt Isa. Yet while Australia's solar thermal experience is modest there are several significant solar thermal with energy storage power projects operating successfully across Spain, the United States, South Africa and China. Large areas of Queensland on the western side of the Great Dividing Range have superb conditions to operate solar thermal plants, and there is no reason why such plants could not be successfully deployed in the state. Several companies beyond Vast Solar have put forward serious proposals to build solar thermal plants in Queensland in the past, however in the face of plunging costs from wind and solar PV these proposed plants were unable to compete and have not been pursued.

We expect that over the next decade as solar and wind capacity in Queensland rises to represent a substantial proportion of supply, coal plant approaches retirement, and solar thermal technology advances and costs fall we will see renewed interest in solar thermal and more project proposals will emerge. However, Queensland has other options on the drawing board that could play a substitute role.

These need to bridge both a capacity gap of 4,700MW as well as the 8 hours of energy storage totalling 37,600MWh.

AEMO has already laid out in its Integrated System Plan an expansion of the interconnector with NSW which exceeds the 2,000MW envisaged in Elliston's model by between 922MW to 1,222MW. If we take the middle ground of 1,072MW then this reduces the capacity gap to 3,628MW of capacity and would probably reduce the energy storage requirement in proportionate terms to 29,000MWh. Worth noting is that the benefits of the upgraded interconnector are not just that it allows Queensland to import power from NSW when it has a shortfall of in-state generation. The upgraded interconnector will also allow exports to the rest of the country when Queensland has a surplus of generation. Given the state's proposed solar capacity is so large, being able to export surplus power to other states will be of considerable value to Queensland.

The remaining solar thermal capacity gap of 3,628MW is then substantially exceeded by a combination of batteries and hydro projects totalling almost 8,900MW.

In terms of energy storage current proposals for batteries and pumped hydro deliver 30,370MWh, which which slightly exceeds the remaining energy storage gap. Also, it is worth noting that these calculations only include project proposals where battery capacity has been specified. There are numerous solar PV farms which include provision for a large battery system, but are yet to determine the capacity of the battery they might ultimately adopt and hence were left out of this assessment. In terms of pumped hydro the projects currently proposed fall well short of what is technically achievable. Analysis by the Australian National University has shown that Queensland has more than 1,770 sites suitable for pumped hydro facilities which are capable of storing 7 million MWh of energy[8].

While solar thermal provides its own fuel source to replenish its energy storages, pumped hydro and batteries would need an additional energy source in order to charge up their energy storages. This could be largely delivered through exploiting the large excess of solar photovoltaic capacity we have documented. Elliston's modelled mix involved solar thermal providing 15,400GWh per annum. The 6,100MW of projected rooftop solar that

[8] Australian National University (2017) ANU finds 22,000 potential pumped hydro sites in Australia, 21 September 2017. See: https://www.anu.edu.au/news/all-news/anu-finds-22000-potential-pumped-hydro-sites-in-australia

is above what Elliston included would produce around 7,000GWh per annum after accounting for battery charging and discharging losses. The remaining energy required could be delivered by installing 4,000MW of solar farms out of the 16,160MW of surplus projects.

Further explanation of these options are provided below.

Hydro

Elliston's model incorporated two pumped hydro projects – Wivenhoe and Kidston – providing 820MW of generating capacity and 7000MWh of energy storage. This actually omitted other existing Queensland hydro power plants which provide an additional 159MW. While these do not have the capacity to pump water back into storage they typically generate the same amount of electricity per annum as Elliston had incorporated from the combination of Wivenhoe and Kidston, illustrating the usefulness of this other hydro capacity to deliver power over sustained periods of time when required.

In addition to these operating and contracted projects, there are also another 1,570MW of project proposals including three pumped hydro proposals incorporating 10,500MWh of storage. One of these projects will involve a new dam on the Broken River at Urannah in Central Queensland, which will need to undergo environmental impact assessments to evaluate whether it is appropriate to proceed.

Small, consumer-embedded battery systems

Elliston's model didn't include any use of chemical battery systems to help balance out other sources of supply. However, there is already an active, albeit relatively small, household consumer market in battery energy storage systems. Around 14,000 battery systems are already in place in Queensland which provide about 56MW of capacity and 126MWh of energy storage.

Battery technology analysts such as Bloomberg New Energy Finance and the CSIRO anticipate that battery systems will achieve substantial reductions in costs, with CSIRO anticipating a halving in their cost between 2019 and 2030. Given consumers can pay anywhere from around two to four times the price to import power from the grid relative to what they are paid for power they export, there is already a significant financial benefit available to consumers from using a battery to store power from their solar system that would otherwise be exported and then using it in the evening to displace the need to import power from the grid. Given plans by regulators to shift consumers towards tariffs that will exacerbate these differences even further, the revenue offered by batteries is likely to increase over time.

Analysis undertaken by Green Energy Markets for the Australian Energy Market Operator projected that customer-embedded battery installations would begin to grow rapidly in the second half of this decade as batteries achieved significant reductions in costs. Under a scenario where Queensland implemented similar battery rebate measures as Victoria, South Australia and also being contemplated by NSW (denoted as the High DER scenario in our modelling) it was expected that by 2040 there would be almost 9,000MWh of battery storage within households and businesses in Queensland capable of delivering a maximum of 4,582MW.

Utility-scale battery systems

At present there are two small utility-scale battery systems in place and another large system under contract to AGL which is in the process of being prepared and financed for construction. Altogether these represent 103MW of capacity and hold 159 MWh of energy. In addition our database has another 13 battery systems being pursued by developers for which capacity has been defined which total 2,533MW and 6,712 MWh of energy storage (several more Queensland solar and wind farms projects have set aside land to add a battery system but have not actually detailed anything concrete about the battery capacity they might install).

1.1.3 Maintaining electricity system voltage and frequency

Electricity systems need to maintain voltage and frequency within very stable levels with minimal variance in order to ensure electricity supply is safe and functional for electrical appliances and equipment. Conventional power plants, which rely on heavy rotating machines, tend to behave in a manner which acts to automatically and very quickly resist the effect of events (like another power station and power line breaking down and tripping-off the grid) that might lead to fluctuations of voltage and frequency and therefore help to maintain them at stable levels over very short time periods. Wind, solar PV and batteries on the other hand utilise computer-based control systems known as inverters to regulate their output to the grid rather than the rotational speed of turbine. These inverters, as they are currently usually designed, don't automatically act to resist the effect of events that alter voltage or frequency.

Elliston's modelling includes a simplifying assumption that to ensure a stable system no more than 75% of supply could come from inverter-based sources of power. This then creates a need to supplement wind, solar and batteries with the solar thermal and gas turbines that employ rotational generating machines. However, higher levels of inverter-based energy sources are possible through either of the following:

- Supplementing wind and solar power plants with synchronous condensers – a rotational machine that behaves like conventional turbines to resist changes in voltage and frequency. These are already being rolled out in South Australia and north-west Victoria where large amounts of solar and wind are connecting to the grid.
- The use of what are known as grid-forming inverters in combination with batteries. Grid-forming inverters are programmed differently from conventional inverters and automatically moderate the output of a battery to resist changes in power system frequency. Such a style of inverter is currently being employed in Dalrymple located on the fringe of South Australian grid on the Yorke Peninsula[9].

As noted by Elliston, it is likely that significant financial savings could be achieved if we can reduce the amount of conventional rotational generation (or synchronous condensers) in order to maintain stable power voltage and frequency. Consequently this is an area of active power engineering research that should provide improved technology and greater confidence in operating power systems with very high levels of inverter-based power sources.

1.1.4 Many options exist and more will emerge over time to achieve zero pollution electricity

It is important to recognise that the fuel mix put forward by Elliston as capable of delivering highly reliable electricity supply with 100% renewable energy sources is not the only viable nor probably the most optimal mix of technologies that Queensland should ultimately pursue. Likewise just because the projects we've collated in this report are concrete and tangible initiatives being pursued by companies and consumers today, doesn't mean they represent the best mix of options for supplying Queensland's electricity needs ten to twenty years into the future. They also need to be further evaluated through a weather and energy market model to assess whether they may need augmentation to realise similar levels of reliability as Elliston's modelled mix.

But what these two studies help to illustrate is that it is well within the capabilities and available resources of Queensland to phase out polluting sources of electricity.

[9] Further, more detailed explanation of how a grid-forming inverter can act to stabilise system frequency is published here: http://www.wattclarity.com.au/articles/2020/04/do-you-know-the-difference-between-virtual-inertia-and-fast-frequency-response/?utm_source=rss&utm_medium=rss&utm_campaign=do-you-know-the-difference-between-virtual-inertia-and-fast-frequency-response

Queensland actually has a multitude of options for how it might achieve 100% renewable and reliable and affordable electricity supply. While only one solar thermal project is currently proposed for Queensland, there's no reason why they couldn't be employed in Queensland in the future because this state has far more attractive sites to employ solar thermal than places like Spain or the US where it has been deployed to date. At the same time given the ongoing substantial growth in the use of rooftop photovoltaic solar and the industry's success in reducing costs, it seems that an energy mix with little rooftop solar and no use of small scale batteries is unlikely to be the energy mix we should to be planning for. Also, the entire global auto industry as well as governments throughout Europe and parts of North America are pivoting towards a future where vehicles will be predominantly powered by electricity from batteries and these would be produced at a vast scale. The auto industry has already achieved dramatic reductions in cost and expect these to continue over the next ten years. Several nations are announcing intentions to completely ban petroleum fuelled vehicles in their cities. Given this development, in conjunction with the proliferation of low cost solar photovoltaics, it seems unlikely that batteries won't represent an economically attractive alternative to gas turbines or solar thermal in ten years time. Yet if it turns out that gas and steam turbines remain as attractive options after ten years then Queensland could also scale up their use beyond the 3,300MW outlined by Elliston via hydrogen produced from solar PV and bioenergy.

We don't have to reach a landing right now on what is the precise mix of technologies that need to be in place in ten to twenty years' time. In many cases we can wait and see and let businesses battle it out amongst themselves as to which are the most competitive options.

But there are some decisions that need to be made sooner rather than later. The most important is that Governments needs to back their grand talk and promises of addressing climate change with laws that turn these words into action. Building new power plants are an expensive business involving assets that last decades. Banks don't lend money to build such assets based on a politician's good intentions and verbal promises to do something in ten to twenty years' time. So governments need to convert their emission reduction promises into binding legal targets and plans to manage the retirement and replacement of aging and polluting fossil fuel power plants.

Also, while we don't know precisely what mix of technologies will power a future zero emission system, we can be almost certain it will involve a lot more wind and solar energy. This simple reality suggests that new transmission infrastructure will be required to link up major electricity demand centres with areas of high quality wind and solar resources, because these aren't necessarily in the same places as we've located coal and gas power plants. New transmission is also useful in a high wind and solar system because it should allow for projects to be spread out over a wider geographic area which are then subject to a greater diversity of weather patterns that will help to smooth out the effect of localised weather changes on the output of individual solar and wind farms.

Building new transmission is under the control of government-regulated monopoly businesses and it typically takes five and as long as ten years to plan out and undertake the construction of new transmission lines. Because of the long lead times involved, commitments to new transmission can't wait around for perfect information and certainty and some need to begin now.

2 How a 100% renewable electricity system would unfold across Queensland based around current proposals and trends

Given weather patterns can vary quite significantly across the state of Queensland, the places that renewable energy projects are placed can have important ramifications for realising a reliable supply of electricity while keeping the use of more expensive energy storage, bioenergy and hydrogen down to a minimum. Elliston's analysis needed to not only balance the different attributes of different fuel types and technologies but also how patterns of weather play out over different locations over time.

In seeking to determine how the projects already in place and proposed in Queensland might be able to meet Elliston's modelled requirements it was important to align solar PV and wind as closely as possible to the locations Elliston envisaged or otherwise achieve broader geographic dispersion.

The map in Figure 2-1 details the allocation of project capacity by region based on existing and proposed projects within these regions (with the one exception that we have allocated 300MW of bioenergy capacity in the Darling Downs and Condamine region to exploit large agricultural residues in the area). Omitted from the map is the 8,000MW customer-embedded rooftop solar and 4,582MW of customer-embedded battery capacity expected to be installed by 2040. This is likely to be reasonably equally distributed with population across the regions. Gas turbine capacity has also been omitted because the current locations of gas turbines are not necessarily ideal where they shift to operation on either biofuels or hydrogen.

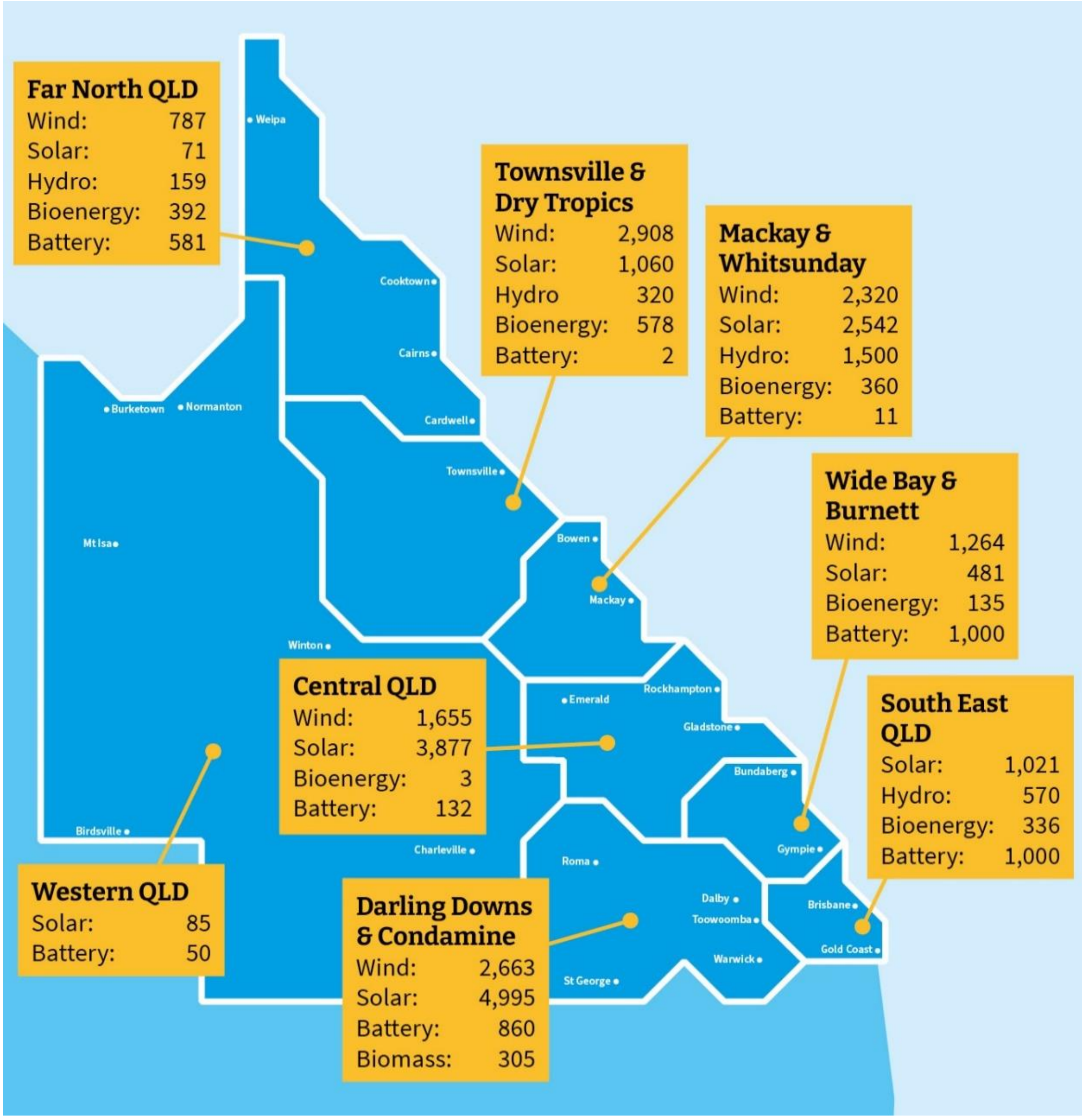
The employment that is estimated to be supported by the shift to this 100% renewable energy system is detailed in Table 2 1 below. Most of the capacity is not yet in place and would need to be constructed, which would represent a very large program of construction and installation activity and employment providing more than 140,000 job years of employment. If this transition was undertaken over a 15 year period then this equates to nearly 9,400 full-time jobs throughout this entire period. The ongoing full-time equivalent jobs in operating and maintaining the renewable energy facilities and batteries is estimated to be just under 11,000.

Table 2-1 Employment supported from establishing 100% renewable energy system by region

Region	Construction (job-years)	Ongoing operations (FTE)
Central Queensland	13,783	952
Darling Downs - Condamine	17,733	2,473
Far North Queensland	5,038	1,293
Mackay-Whitsunday	21,465	1,373
South East Queensland	7,652	1,728
Townsville - Dry Tropics	11,021	1,381
Western Queensland	349	69
Wide-Bay Burnett	9,358	1,666
All regions (small solar and batteries)	54,340	0
TOTAL	**140,739**	**10,935**

In subsequent sections we will narrow-in on three areas of Queensland from the far north to the south to examine how projects in these regions could substitute for coal power plants in the surrounding area.

Figure 2-1 Locations of generating capacity under 100% renewables system



2.1 Townsville, Dry Tropics and the Far North

Based on projects already in place or proposed the Townsville Dry Tropics region would be expected to host 4,868 MW of capacity, while the Far North region is estimated to host 1,990MW. This area has been a hot bed of both wind and solar development and construction activity in the last few years and in just the past 4 years has added over 500MW of solar farm capacity and 340MW of wind farm capacity. In addition, there are 6,687MW of project proposals. Table 2-2 details the number of projects in place and proposed within the region and the capacity that would be utilised in a 100% renewables system.

Table 2-2 Power project mix for Townsville and Far North compared to coal alternative

Fuel	Number of projects	Capacity operating/ committed/ contracted (MW)	Proposed (MW)	Required (MW)	Annual energy (GWh)
Biomass	17	275	48	969	849
Hydro	4	159	50	209	128
Pumped Hydro	2	250	20	270	-
Solar	24	534	2,634	1,131	2,576
Wind	13	340	3,355	3,695	11,329
Batteries	5	3	580	583	-
TOTAL	**65**	**1,562**	**6,687**	**6,858**	**14,883**
Collinsville 2 (Shine Energy)	1		1,000		7,008

By comparison there are no coal power plants in operation in either of these regions but there has been considerable political interest in establishing a new coal power station nearby to Townsville for several years. This political push for a new coal power station has struggled to materialise into much more than political hot air because no company with any genuine commercial or technical expertise in power generation had any serious interest in building such a power station in the area.

However, after the Federal Government announced it would fund a feasibility study into a coal power plant in the region, a company with little background in the power sector, Shine Energy, emerged to express an interest in building a new coal power plant in Collinsville – half way between Townsville and Mackay. Interestingly a small 190MW coal power station used to operate in Collinsville but after many years of marginal operation where it ran at a fraction of its rated capacity due to a lack of competitiveness, the owner of the plant – RATCH – elected to mothball it and then decommission it in 2018. RATCH subsequently built one of the several solar farms that now surround the old coal power station site.

At present there is very little detail available about the design of the coal power station Shine Energy is interested in pursuing. However much of the political discussion has centred on a type of coal plant involving very high pressure operation, sometimes referred to as ultra-supercritical and misleadingly referred to as “high efficiency, low emission” or HELE. While such a plant has slightly higher energy conversion efficiencies than other coal plants operating in Australia, minimum economic scale tends to quite large and such plants would typically be 1000MW in size. Based on the historical performance of the last coal plant constructed in Queensland (Kogan Creek) such a plant could be expected to produce around 7000GWh of electricity per annum which is about half the amount of energy that the 100% renewables mix of projects would be capable of producing.

It is important to note that major upgrades of the transmission network would be necessary to support new generation in the area whether it be renewables or coal. Renewable energy projects established in the region are already capable of generating more power than local demand. A range of constraints already apply to the existing power plants and in order for these two regions to exploit their full potential of projects, investment will be required in new transmission and also voltage support (likely to require synchronous condensers). Although voltage support could also be provided by the addition of biomass or hydro plant and possibly also batteries. Another potential solution would be establishing hydrogen production or metal smelting facilities in the area that would add extra electricity demand. If some of that hydrogen were also coupled with gas turbines for supplemental power generation this would also assist in supporting voltage.

AEMO has defined three renewable energy zones across these two regions and notes that all are heavily constrained from achieving further development due to inadequate transmission capacity, high transmission losses and issues over voltage. While AEMO acknowledges that Townsville and the Far North regions possess both high quality wind and solar resources, it has assigned a low priority to investments that would alleviate the inadequate transmission capacity holding back the further development of new renewable energy projects.

2.2 Central Queensland and the Mackay-Whitsunday Regions

Based on projects already in place or proposed the Central Queensland region would be expected to host 5,667 MW of capacity, while the Mackay-Whitsunday region to the north is estimated to host 6,733MW. To date most of the renewable energy project activity has been in the Mackay-Whitsunday area which hosts almost all the operational and contracted renewable energy capacity. But each of these regions have thousands of megawatts of wind and solar projects proposed for development. Table 2-2 details the number of projects in place and proposed within the two regions and the capacity that would be utilised in a 100% renewables system. Just like the regions to the north, there is a large surplus of solar PV project capacity, meanwhile all the proposed wind, hydro and battery projects would need to be proceed to construction. In addition, the existing bioenergy power plants would need to be expanded so they could play more of a peaking/balancing role rather than operate in their current fashion of steady baseload operation during harvesting/processing periods.

Table 2-3 Power project mix for Central QLD and Mackay-Whitsunday regions compared to coal alternatives

Fuel	Number of projects	Capacity operating/ committed/ contracted (MW)	Proposed (MW)	Required (MW)	Annual energy (GWh)
Bioenergy	7	121	0	363	318
Pumped Hydro	1	0	1,500	1,500	-
Solar	47	700	11,208	6,756	15,388
Wind	11	450	3,525	3,975	12,187
Batteries	3	0	143	143	-
TOTAL	**69**	**1,271**	**16,376**	**12,400**	**27,124**
Stanwell		1,460			9,000
Gladstone		1,680			8,000
Callide		1,600			10,000

There are three coal power stations operating in Central Queensland with a combined generating capacity of 4,740MW and average annual generation of around 27,000GWh. However, the oldest of the three plants – Gladstone – has been operating well below its rated capacity in recent times and is already being steadily displaced by the expanding use of renewable energy.

If the envisaged renewable energy projects for the region proceeded, they would be capable of producing almost the same amount of electricity per annum that currently comes from the coal power stations in this region.

The Australian Energy Market Operator has defined two renewable energy zones within these regions which it entitles Isaac (which aligns with the Mackay-Whitsunday region) and Fitzroy (aligned with Central Queensland). This area is not as constrained by transmission capacity and available demand as the Townsville and Far North areas of the state. However, as renewable energy capacity grows a transmission choke point between Central Queensland and Southern Queensland will become increasingly problematic and new transmission investment will be required between Calvale and Wandoan South. This is especially important given this constraint will also prevent effective exploitation of the 6,858MW of capacity allocated to the Townsville and Far North regions as well.

2.3 Darling Downs-Condamine

Based on projects already in place or proposed, the Darling Downs-Condamine region would be expected to host 8,823 MW of capacity. This region has already been the recipient of significant investment with 526MW of solar projects constructed in the region since 2016 and also hosts Australia's largest wind farm- Coopers Gap - which is now largely complete. In addition, another wind farm project is likely to commence construction soon – Macintyre - which will be more than twice the capacity of Coopers Gap. Table 2-2 details the number of projects in place and proposed within the region and the capacity that would be utilised in a 100% renewables system. To make use of the significant existing agricultural residues from farming and forestry activity in the region we've also incorporated 305MW of bioenergy capacity.

Table 2-4 Power project mix for Darling Downs-Condamine compared to coal alternatives

Fuel	Number of projects	Capacity operating/ committed/ contracted (MW)	Proposed (MW)	Required (MW)	Annual energy (GWh)
Biomass	2	2	-	305	267
Solar	32	526	5,557	4,995	11,378
Wind	8	1,479	1,184	2,663	8,164
Batteries	5	100	760	860	-
TOTAL	**47**	**2,107**	**7,501**	**8,823**	**19,808**
Tarong & Tarong Nth		1,850			12,000
Millmerran		850			6,500
Kogan Creek		750			5,000

There are three coal power stations operating in the Darling Downs-Condamine with a combined generating capacity of 3,450MW and average annual generation of around 23,500GWh.

If the envisaged renewable energy projects identified for this region proceeded, they would be capable of producing around 84% of the electricity that currently comes from the coal power stations in this region. The remaining power to replace the electricity from these coal generators would then come from other regions in Queensland.

According to the Australian Energy Market Operator's Integrated System Plan the transmission serving the Darling Downs Renewable Energy Zone is some of the most robust and capable of supporting new renewable energy capacity. However, upgrades that would be tied to increased interconnector capacity with NSW would certainly be necessary to support the scale of capacity outlined in Table 2-2 unless it was coupled with co-located battery capacity to smooth-out power flows.