ASPI

SPECIAL REPORT

Designing for resilient energy systems

Choices in future engineering

Edited by Paul Barnes and Neil Greet

October 2019

ASPI AUSTRALIAN STRATEGIC POLICY INSTITUTE

RISK & RESILIENCE PROGRAM

ENGINEERS AUSTRALIA

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Cover image: Turning LED light bulb on or off with finger: iStockphoto kyoshino.

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About ASPI

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FOREWORD

Dr Paul Barnes

A reality of modern times is the public expectation that not only will flows of potable water from their taps and home sewage systems simply always be there, but their lights will always turn on at the flick of a switch. An enabler that underpinning all these expectations is an effective and efficient electricity supply.

These services along with transport, and telecommunication systems are universally considered to be essential for raising the quality of life for humans. Access to these services is also a central factor in the productivity of firms and thus of entire economies, making them a key enabler of economic development.

Electricity networks are complicated technical supply systems with attributes that are more than a composition of many parts; they are a collective of many different types of parts, linked together and interacting with each other at different levels of scale.[1] They are systems nested within systems, and it is their coupling and ensuing interactions that make them dynamic and at times unpredictable.

Essentially, the networks are complex adaptive systems, even those operating under conventional linear settings of generation, transmission and consumption. This is an important issue in our current complex 'always on' world where there is a need for assurance of reliability and interoperability within and across infrastructures. Significant vulnerabilities[2] in large power systems come from the complex interactions between the physical infrastructure (generation stations, transmission lines), the governance systems connected to them, as well as fluctuation in demand, diversity of generating sources, public policy, cost incentives and – not the least – weather.

It should not be surprising that a popular and recurrent catchphrase central to essential service providers (public or private) is resilience. Resilience is a relatively new concept in applied engineering. It is different to robustness which is more familiar and central to many design approaches used in buildings and structures. It's about a capability inherent to a system to remain functioning even when affected by disruptions.

A recurrent theme in the management of such systems[3 4 5] has been the failure to detect signs of trouble in one section of a wider system that fails or triggers significant disruptive effects in other systems via the inter-connectedness of these systems. Such phenomena have been referred to as 'network events'[6] or 'normal accidents'[7] in relevant literature. The potential for the rapid spread of consequent impacts, geographically and through time, often renders a comprehensive understanding of a network crisis beyond the grasp of system operators or regulatory authorities. These events have been variously described as 'outside of the box,' 'too fast,' and 'too strange'.[8]

Beyond issues of reliability, resilience and complexity is the significant global trend of transitioning from the use of carbon-based fuels (coal and oil), as a predominant source of electricity generation, towards the use of renewable sources. One factor that complicates this transition is the high proportion of the world's population still relying on these carbon-based energy sources in their daily life, while another is the simple sunk cost investment in existing carbon-based energy infrastructure.

As noted by the Australian Chief Scientist, Dr Alan Finkel, in the 2017 report *Independent Review into the Future Security of the National Electricity Market – Blueprint for the Future*[9], our complete electricity system is also in the middle of this energy transition. Dr Finkel states that there is 'no going back from the massive industrial, technological and economic changes facing our electricity system'.

The review also suggests that ensuring reliable, affordable and secure electricity supplies will require an orderly transition, better system-wide planning and stronger governance. Together these factors will depend on a strong commitment to national coordination involving all levels of government, industry groups and the private sector.

A further factor in this transition is the increased prevalence of new types of electricity transmission networks such as smart grids.[10] These can be more complex than the conventional network infrastructure by orders of magnitude given the use of enhanced connectivity and flexibility provided by using 'internet-of-things' mediated control systems.

These innovations will result in a completely different energy ecosystem[11] that enables new means for operators and consumers to: influence the efficiency, sustainability and safety of electricity production; optimize electricity generation, transmission and consumption; manage introduction of renewable sources; deliver faster detection and restoration of services if lost; and importantly, create new business models.

This new electricity landscape has been described as a prime example of the Fourth Industrial Revolution[12] resulting from a convergence of 'game changing' technologies such as distributed storage and generation, smart meters and smart appliances. It has been estimated that adoption of new [on the] 'edge of the grid' technologies globally could bring more than $2.4 trillion of value creation for society[13] and industry over the next 10 years, by increasing the efficiency of the overall system, optimising capital allocation and providing new services for customers.

The transitional energy challenges Australian society faces currently – and into the future – will be left to future generations of engineering professionals to solve. These inherited challenges combine questions of adopting and integrating renewable energy sources, enhancing efficiencies in the distribution and supply of energy and designing new types of energy infrastructure. These issues are central to deciding on options for how humans may have to live, and prosper, under very different conditions to those of past generations.

But what do young Australian engineers who have inherited our present world think about the challenges of designing resilient energy systems within the parameters of new and emerging technologies? Commissioned by Engineers Australia in partnership with ASPI, this report presents the thoughts of four young engineers on innovative energy design projects they are currently working on, as well as their views on the challenges they foresee for the design of future energy systems. These four sections are bookended by the views of two established leaders within the engineering profession.

The first section, by Neil Greet, examines wider contexts of the challenge of moving towards industry-wide use of renewable energy sources and supporting infrastructure. A key point in this section is the need to balance inevitable competing views of proponents of the changes with the views of those more cautious about whether energy transition is such a critical national issue.

Following this Clare Paynter dives into a deep yet concise review of Australia's historical energy development. She provides the context behind the current political opportunities for successfully addressing the energy transition, including the benefits of being an early adopter of new technology, how risk can become better distributed and how we can improve knowledge transfer. The section concludes by emphasising the role of leadership in transitioning to a stable, secure and sustainable Australian energy system.

In the third section, Alan Reid, examines the market presence of innovative home energy monitoring and residential-scale electrical storage and management technologies. Alan also examines governance challenges that arise from large-scale disruptive innovations, with the advent of the 'prosumer' of electricity combined with system decentralisation through localised grids.

In the fourth section, Tara-Lee Macarthur examines energy transition in the context of three distinct yet linked themes: engagement between customers and electricity suppliers, innovation and collaboration and approaches to 'sustainable' engineering. While each is a standalone issue, Tara-Lee shows that together those themes are enabling factors in the broader context of a rapidly changing sociotechnical landscape. Central to this change is the challenge of how prosumers can and should collaborate with utilities companies to sustain the previous energy model's valuable attributes of being affordable, secure and safe, regardless of future energy models.

In the fifth section, Jack Bryant argues that the key challenge to renewal and resilience within our power systems isn't technological change alone, identifying linkages between energy policy and governance arrangements as also important. He suggests a system-wide approach, coupled with good governance, is required to provide well-balanced energy solutions. This section examines some of the most recent policy challenges within our power system, whilst also exploring some of the emergent technology opportunities which are available to address known vulnerabilities across electricity networks.

Finally, the Hon Trish White, National President and Chair of the Board of Engineers Australia, scans the challenges and opportunities the next decades of electricity network development is likely to bring. Many of these are social and economic but they will be driven in part by the ability of engineers to respond and adapt to evolving changes. A critical message from Ms White is that engineering solutions must be integrated with business, political and social systems. Australia cannot afford to manage separate domains and hope that a seamless and orderly transition will occur by itself.

A core goal of capturing the thoughts and views of these emerging professionals is that, while they have inherited our world, they are now central to the challenge of implementing systems that use the new technologies and ultimately to decommissioning the component parts of our current energy infrastructure systems. This endeavour combines questions of choosing alternative energy sources, evolved means to supply energy and the design of new energy infrastructure networks. These issues are central to deciding on options for how humans may have to live, and prosper, under very different ambient conditions to those of past generations.

A further important factor is that legacy energy systems will have to coexist for a time with the newer solutions that will then become emergent norms: a transition that will bring its own tensions. But as Gramsci has said 'the old is dying and the new cannot be born (in this interregnum a great variety of morbid symptoms appear).'[14]

The authors in this volume show that we can have some confidence that our futures are in good hands.

THE ENERGY TRANSFORMATION

Neil Greet

An energy transformation is occurring in Australia and it has only just begun. This transformation is spreading across all aspects the energy system with the ongoing use of carbon-based fuels as the dominant source of globalised energy production being challenged. The framing of the transformation narrative is well-established but has become negative and divisive.

The transformation is manifesting itself in a politically ambiguous manner with some advocating that 'more of the same' is the pathway to success; a position which is countered by an opposing view that rapid change is necessary. This mix has affected political debate from the Federal sphere to local council chambers and sustains a cacophony of disagreement across industries and communities.

When the western world embarked on the industrial revolution and moved from biomass to coal and oil as the main energy source centuries ago enormous transformations occurred across societies. The advancement of industrial capacity fuelled the hegemonic advantage of the western world. Yet it is important to understand that this old energy revolution is still in motion with approximately 1.1 billion people[15] in the world still relying on biomass energy sources and living in poverty.

The nirvana of transitions will never be possible, and a valid question is 'why change?' Surely if a better future cannot be guaranteed then don't change what has worked in the past. The end point is not clear, and it's easier to rest in the known and protect what exists. Perhaps the difference in framing such a transition can be summarised by the following (differing) viewpoints:

- Dr Alan Finkel, the Australian Chief Scientist, in the 2017 *Independent review into the future security of the National Electricity Market – blueprint for the future* described the need for 'A reliable and low emissions future: The need for an orderly transition'.[16]
- The Hon Matt Canavan, the federal Minister for Resources and Northern Australia said at the National Press Club on 28 Mar 2018: 'I don't like the term transition: it's a euphemism for destruction of jobs; let's be frank, if you want to shut down the coal industry, say that's what will happen.'[17]

As a thinking nation Australia must discuss what an energy transformation means for its future. It is not simply about types of generation of power or the faux war of 'renewables vs fossil fuels' fought on social media. The question goes to the heart of aspirations for resilient communities and aspirations for future generations. Access to energy pervades all aspects of life and we must assume that the transition is unlikely to be quick or uneventful.

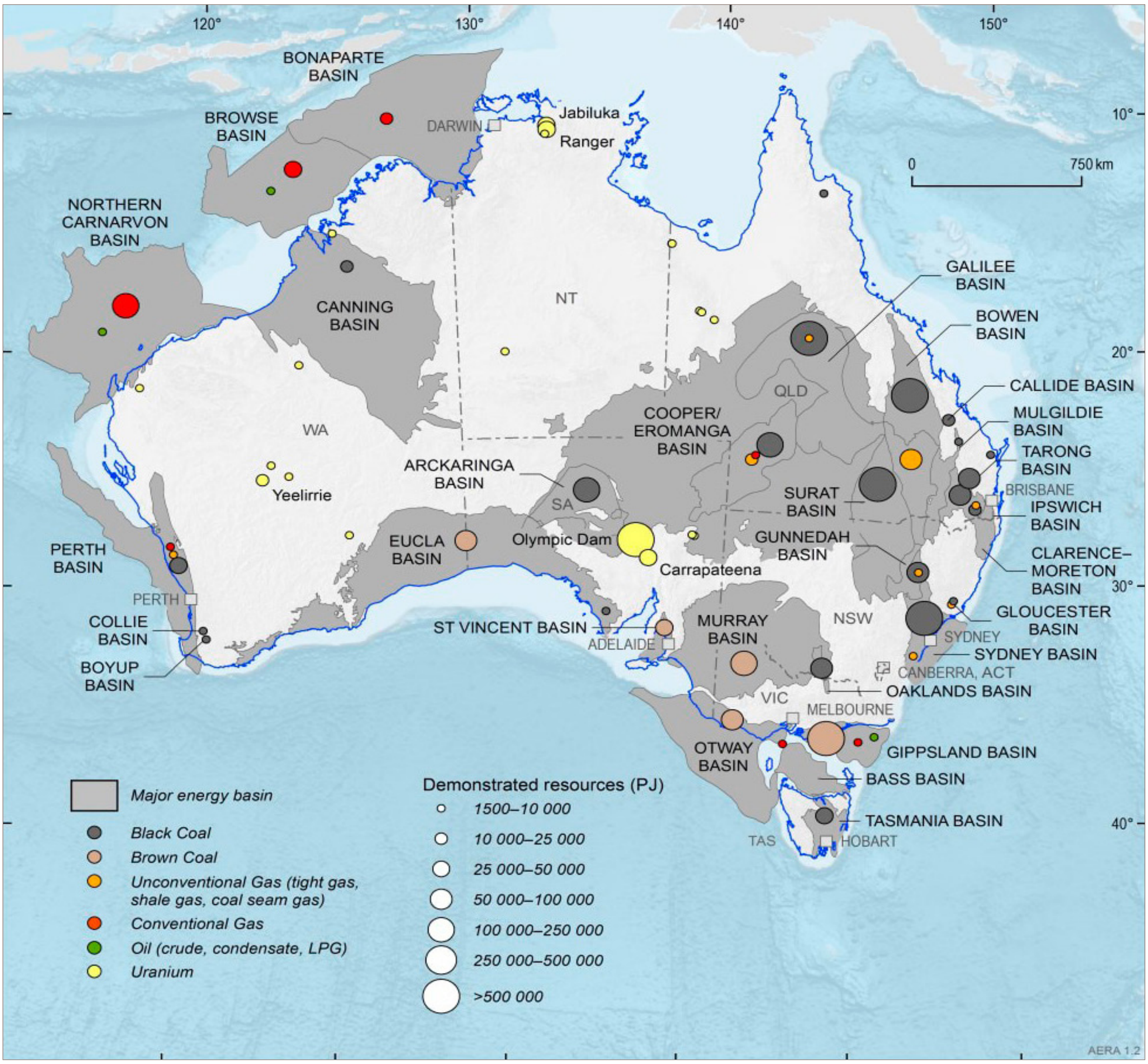
This section examines the nature of this Australian energy transformation, what it looks like, the opportunities, vulnerabilities and the nature of resilience of supply in the face of transition.

Drivers and enablers of the transition

Australia is a major net energy exporter and makes a significant contribution to global energy security. It is the world's largest exporter of coal and a major supplier of energy to world markets exporting more than three-quarters of its energy output, worth nearly A$80 billion per annum. [18]

Australia has an estimated 46% of uranium resources, 6% of coal resources, and 2% of natural gas resources in the world. A fossil fuel energy map is at Figure 1.

Figure 1: Australian fossil fuel resources

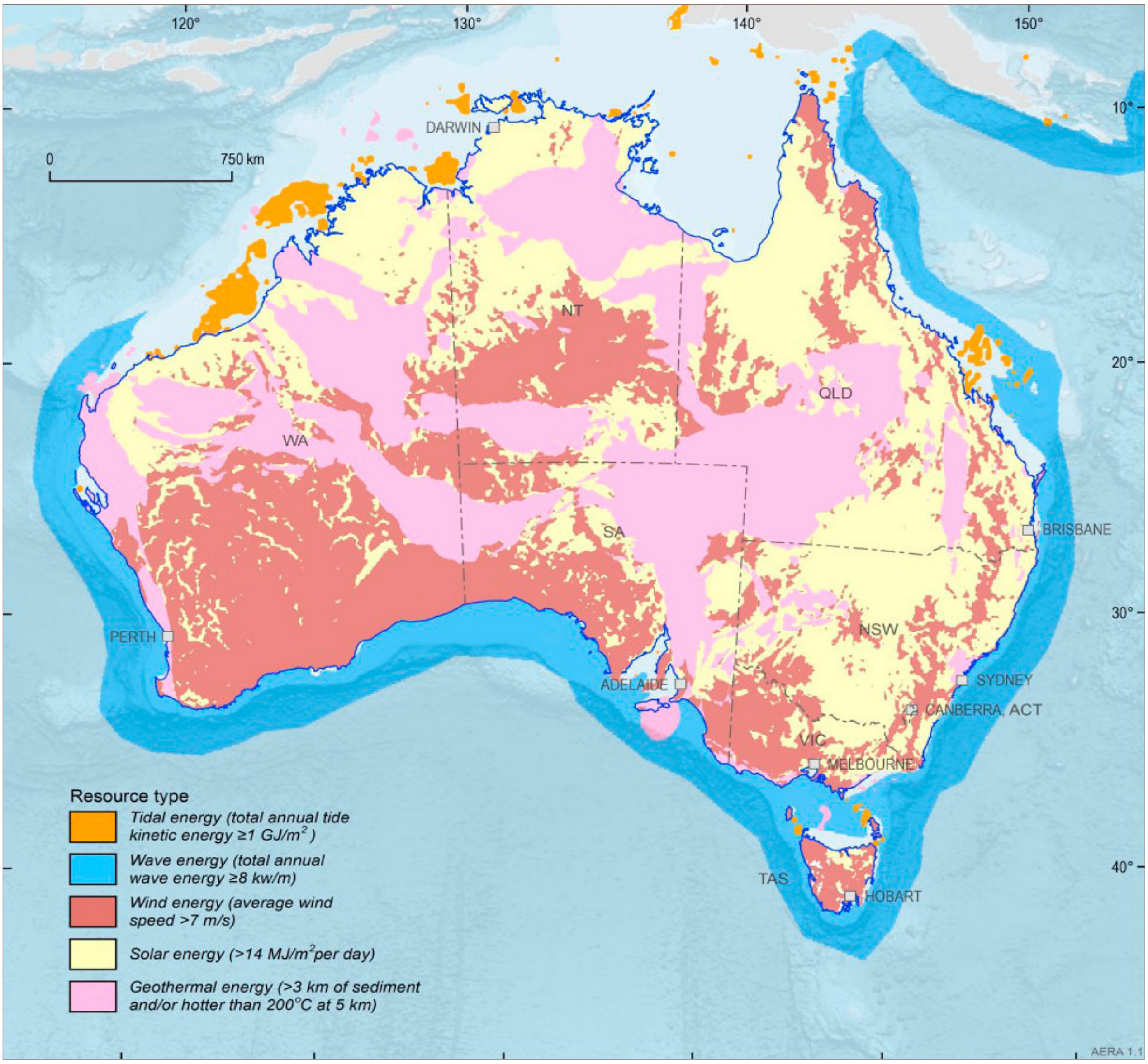


Source GeoScience Australia[19]

To complement Australia's existing status as a fossil energy superpower, there is a strong argument from renewable energy proponents that this same energy superpower standing can be created with solar, wind, geothermal and tidal sources. Australia's potential renewable energy sources are depicted in Figure 2. Many proponents of renewable energy sources advocate swapping these for its fossil fuel 'gifts'. A reality is that such a change is not a simple 'one for one' swap.

Energy production and climate variability are inextricably linked. In order to stay below the upper 2° C temperature increase limit of the Paris Climate Agreement, global emissions would have to peak no later than 2020 and be reduced by around 7% annually thereafter. Meeting the lower 1.5° C target requires even more rapid reduction. By contrast, continuing emissions at current levels or at worst case increasing emissions will result in the type of catastrophic scenarios described in a 2014 Intergovernmental Panel on Climate Change (IPCC) report. Even so, IPCC scenarios still rely heavily on carbon removal from the atmosphere as a prerequisite for meeting the 1.5° C target.[20]

Figure 2: Australian renewable energy resources



Source: Geoscience Australia[21]

Energy is a globally traded commodity that fuels industry, communities and individual homes. Since World War II, international trade entered a long period of record expansion with world exports rising by more than 8% per annum in real terms from 1950 to 1973. From the blip that was a series of oil crises the world's output of goods and services quadrupled, and growth extended to virtually every region of the world particularly India and China.[22] Staggeringly the world population has grown by nearly 5 billion since we passed 3 billion mark in 1960. Simply put more people living with improved quality of life increases the demand for energy.

At the same time, new technologies and advancements are disrupting traditional energy business models built off the back of World War II. This is not to suggest that energy is the cause of global disruption. However, it appears that we have entered an age of disruptive politics globally, with rising dissatisfaction from social and economic inequalities, with climate impacts and the rise of China and India, all manifesting at a time when many want to pull off an energy transformation of the like not seen since the disruptive 'war of the currents'. [23] There is potential for systemic disruptions if the energy transition is not managed in concert with such fluid global factors. Global socio-economic norms that have operated throughout the post-World War II experience cannot be expected to simply continue unchanged.

Against this backdrop the nexus of energy, environment and economic issues along with the addition of new transformative technologies offers a range of potential opportunities. It is not simply new technology for electricity generation. The technological changes are spread across all sections of the energy system; from fuel type, storage, smart grids, the use of data analytics, business models and evaluation of consumer behaviours.

Conversely, technology can also offer false hope for meeting all the challenges of the transition process. Innovators and opportunists may seek market advantage through the offering of a technological 'silver bullet'. For instance, negative emissions technologies, none of which exist at scale today, create a false sense of security when marketed as easy solutions. As technologies succeed and fail the energy system will be disrupted throughout its length. Such disruptions are likely to be pervasive.

No nation, however, can afford to throw out billions of dollars of investments and decades of education and training of people that operate energy-related industries. The legacy systems do not have a magic 'switch-off' button. Sunk costs are a poor basis for continued investment though, if alternatives are better – and sufficiently cheap. The most likely and feasible path seems to be to achieve graceful degradation of old systems in concert with rising replacement systems. As an example, maximum use needs to be made of existing transmission infrastructure, which will influence the electricity grid design for years.

The nature of the transition

Change simultaneously embraces creating a competitive advantage in a world that is always offering new opportunities and fear as it causes old industries to lose market share. The transition detailed here is more than change at the margins, as it needs to continue across multi-segments of society and will take decades to be implemented. It is a mass movement supported by change across many dimensions; political, social, and technical. No one company, industry or nation can exercise all the levers of transition alone.

To think the 'transition' is just a complicated change process and assume the mantra of 'we always deal with change' is to misunderstand the complexity of the process at hand. Australia cannot afford to simply manage the energy transformation like a change management process or mobile phone upgrade, as the multi-dimensional nature and the ubiquity of the changes at hand exhibit all the characteristics of a wicked problem.[24]

The emerging changes could be described as a revolution. The language of revolution however is often used to excite people to victories against the odds probably stemming from an overly romantic view of historical revolutions like those in American and France. Each of these wrought positive political and societal effects but with significant costs. Popular narratives often concentrate more on the success of revolutions and gloss over the attendant disruptions. The renewable energy 'revolution', the big data 'revolution', and the clean coal 'revolution' are just some of the revolutions that are currently being publicised and marketed. Historically accurate views of revolutions suggest that they can be dangerous, often with unexpected impacts on individuals, regions and whole economies. More practically, this language of revolution probably mischaracterises what is going on.

The future

To successfully engage in this transition, there must be a vision of the future and clear direction of how to get there. This does not imply such an expressed vision is somehow a locked-in statement of immutable certainty. There are multiple pathways with decision points that will shape our steps to this future. The challenge for leaders during the transition is to steer a path to opportunity while carefully mitigating vulnerability.

Opportunity

As a country that understands the global energy and resources trade, a focus for Australia can shift from mass exports of fossil fuels to a revolution of jobs flowing from new energy industries. There is direct jobs growth potential in new generation (wind, solar), storage (batteries, pumped hydro), construction of new microgrids and the use of data analytics to better manage outcomes. This can further provide opportunities in advancing research and educational capabilities in an innovation ecosystem which thrives on a 'next generation' energy approach. Sizable employment capacity remains in the old energy industries, but they cannot be maintained for ever.

Perhaps the best opportunity will come from emphasising non-economic drivers and defining outcomes that enhance direct wealth generating benefits. Gauging success might vary from monetary benefit, reduced parts per million of carbon dioxide or stabilising or reducing ambient temperatures. Individuals and communities are also expected to have greater control over their energy demand and make contributions to supply.

Such localised benefits have already manifested with capital costs of storage and solar technologies reducing sharply and increased access to data analytics allowing some households to manage their individual needs through linked community virtual grids. Thinking about different outcomes and measuring different value chains allow alternative future pathways to be constructed.

The 'Next Generation' energy solution embraces integrated components within complex systems. The yet unexplored benefit is the combination of technologies to achieve an advantage that further drives the energy transformation. So, the question is, 'What would a viable model for a Next Generation integrated energy system look like?'

Many of the component technologies necessary to implement a better energy system exist today but what is lacking is an integrated design approach. In the case of an integrated system, there is a need to identify energy systems that could also be 'system integrators' in themselves.[25]

While not the panacea for Australia's energy needs, hydrogen is one example of an 'integrator'. This concept is described at Box 1.

Box 1: Hydrogen as a system integrator

Hydrogen can be used to produce a range of energy products as it can be used for power generation, for fuel cells in vehicles and trains, to produce ammonia, to supplement gas supplies and to produce gas. Therefore, hydrogen could be an important component of an integrated energy system, particularly as it could employ excess renewable energy capacity. The production and transformation of energy in regional or subregional networks using such 'energy integrators' could exploit an energy resource that is not used to maximum effect today. It is about integration, resilience, economics, energy security and scalability. It is about integrated design. The key issue is that hydrogen, in this case, is the medium to produce both a time and mode shift of renewable energy as a part of a designed, integrated energy system.[26]

Vulnerability

The National Resilience Taskforce examined the fundamental drivers of vulnerability in framing the challenge of planning to manage significant national disasters. As part of this process the taskforce defined vulnerability as:

> [It] arises from the relationships that we have with the things we value (people, places, objects, critical services, emergency services, etc.) and how these things may be disrupted as a result of an emergency or crisis. Vulnerability also arises from the tensions and trade-offs we have to make about where to allocate limited time, effort and money in disaster preparation, response or risk reduction to protect those things of value.[27]

The current energy system has technical and economic vulnerabilities which are managed daily through well-developed processes and regulation. For instance, in the National Electricity Market the regulator (Australian Energy Regulator – AER), the operator (Australian Energy Market Operator – AEMO) and the rule maker (Australian Energy Market Commission – AEMC) operate as a collective team adapting to change in various forms. Consideration of catastrophic network failure or pre-existing vulnerability is not in the remit of this regulatory trio.

In Australia, as in most modern economies, institutional trust is being eroded as communities become confused about offerings within the energy system and trajectories of future development. The United Kingdom Energy Research Partnership provides an example of what it considers needs to be done to address failures in community engagement on energy issues. The partnership made a call for a strategic narrative accessible to affected end users in its 2014 report *Engaging the public in the transformation of the energy system*. However, while the public largely supported transformation in energy policy, trust in the UK Government and energy industry was low.[28] A lack of trust in the energy system as a public entity was a fundamental vulnerability.

A little recognised societal vulnerability in Australia is a lingering sense of complacency. As a settler nation Australia has been imbued with a narrative of hard work and aspiration leading to success. This may have been reinforced by having experienced 27 years of uninterrupted annual economic growth. Australia has sustained its wealth throughout these years of economic success and so contrary opinions, or warnings against complacency, can easily be ignored by a narrative that because Australia has repeatedly 'pulled through' tight spots in the global economy where other economies have not, we simply will this time. This is not just an economic narrative; it has become a strong national narrative emphasising confidence of success.

While complacency may be ingrained to varying degrees in the stories we tell each other, the growing complexity of our electricity systems is an empirical factor that – while easier to address than beliefs – remain a significant concern.

The least understood vulnerability arises from the nature of interconnectivity of the component parts of the systems. Complex energy networks have intrinsic vulnerability due to dependency on other systems which may exhibit varying levels of stability. These threats can manifest themselves in many ways, but particularly in the cyber domain. Some examples are direct attacks on critical infrastructure involving the acquisition of remote control of decision-support software and the theft of market-sensitive information that provides advantages to competitors. Planning for a range of potential and likely disruptions is critical to the normal functioning of existing systems and the uneventful transition to newer forms. The identification of vulnerabilities and development of risk mitigation options are important activities across the networks.

Energy resilience: a systemic view

Elements of Australia's wider energy sector operate in an ad-hoc system, organised within stovepipes of energy types (electricity, liquid fuel, gas). The *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future* report emphasised the importance of a coherent approach to future energy needs and security of source and supply.

It could be argued that the review constitutes a *de facto* blueprint for a national energy security strategy. Without this, the absence of a coherent strategic road map on energy futures creates wider systematic vulnerability and uncertainty as well as reduced security.

The reliability of supplies of liquid fuel supplies in Australia exhibits characteristics of a systemic national level vulnerability. Australia is an outlier in the global community in the way we think about liquid fuel security. When we consider similar sized economies to Australia, most see fuel security as part of their strategic capability and take steps to manage fuel security with that in mind. For instance, European countries seek assured liquid fuel supply not only to meet International Energy Agency agreements but to hedge against aggressive Russian energy policies.

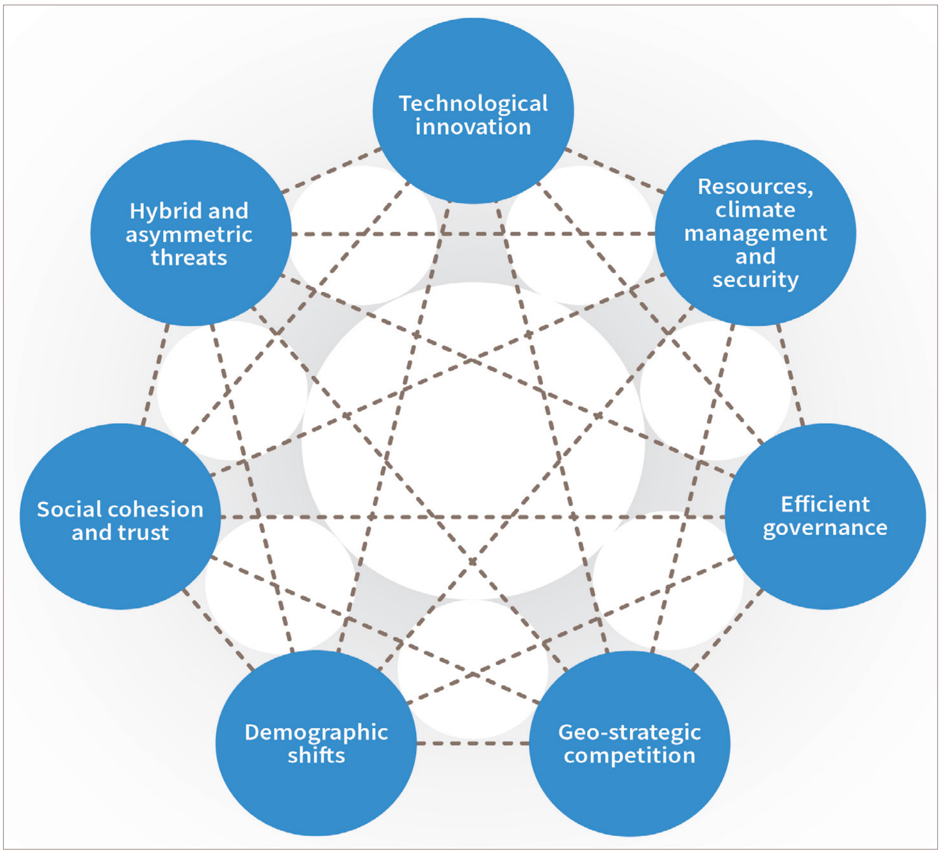
Australia, by comparison, has chosen to apply minimal regulation and government intervention in pursuit of market solutions that deliver fuel to Australians as cheaply as possible. The recent draft report into liquid fuel security in Australia details reserves at 22 and 23 days of consumption cover for diesel and jet fuel respectively.[29] A national energy strategy could also be effective in shaping longer term policy to reduce reliance on just-in-time delivery of refined fuels across extended maritime supply chains.

The notion of resilience becomes a key consideration in framing the complicated nature of the energy transition. Resilience does not simply mean rebounding after a disruption – it is not the stoic staring down of vulnerability and remaining unchanged. Resilience can be construed as an attribute of a system (electricity network) to remain functional when placed under pressure; in other words, a tendency to remain stable and functional by adapting to changing circumstance or operational conditions – avoiding crises versus needing to recover from them.

It is a systematic condition of a system that when examined in depth can support management decisions about managing vulnerabilities and multiple failure pathways that might be present. An indicative range of enablers and vulnerability factors relevant to modern energy systems are displayed in Figure 3.

Describing the vulnerability factors as an interconnected system where relationships are one to many and varied in complexity is fundamental to understanding systemic uncertainties in energy systems. Failure to address the factors in this ecosystem is to encourage unintended consequences and at worst catastrophic failure. The elements shown in Figure 3 are both vulnerabilities and enablers in that they can individually (and collectively) be sources of failure or factors conveying deep capability.

Figure 3: Vulnerability factors for interconnected energy systems



Source: A Kaspersen, I de Sola, *The global risks report 2015*, World Economic Forum. The model has been adapted to describe energy risks rather than global risks.

Enhanced resilience for energy systems is not an ephemeral concept but a pragmatic goal that requires comprehensive understanding and appreciation of the challenges of managing complex technical systems and the nature and sources of disturbances that can occur and that are likely to occur.

From a whole-of-economy perspective this would mean the alignment of policy, practices and decision-making across public and private sectors to ensure wide geographic stability of energy supply. If this stable system of supply is disturbed, there must be a planned set of processes and activities and the intent to regain and sustain optimal capacities for energy production and utilisation should significant losses occur.[30]

Conclusion

> 'If it ain't broke, don't fix it' is the slogan of the complacent, the arrogant or the scared. It's an excuse for inaction, a call to non-arms. (Colin Powell)[31]

This section seeks to contextualise elements of an energy transition playing out across Australia. No single individual or organisation is responsible for the transition: it is a collective effort. But implicit in that statement is the requirement for pragmatic leadership across social, political, economic and technical domains.

There is a risk that Australia across government, industry and the community will complacently mismanage the energy transformation and the transition from old to new will become dysfunctional. Should that occur, it would create a series of unintended and damaging consequences. Conversely, taking the opportunity for an orderly transition to settings that embrace the use of new 'energy' technology in novel ways will aid continued national prosperity.

MANAGING TRANSITION: THE CONTEST OF HISTORY AND OPPORTUNITY

Clare Paynter

Introduction

Today, Australians are experiencing a paradigm shift in the way that electricity – a fundamental part of our society – is generated, paid for and consumed. However, to effectively manage this transition, understanding the existing system is more important than ever, allowing industry to leverage the significant knowledge and infrastructure that has shaped the power system that we have today. This chapter begins by describing how Australia's energy history started and grew, before considering the reasons behind today's challenges, concluding with five key strategies to effectively manage and seize the opportunities transforming our power system provides.

A historical perspective

Not since the Edison, Westinghouse and Tesla tussle over the world's DC-or-AC pathway has there been a more exciting time to be an engineer – or so we are told. Engineering has long been a desirable and respected profession, not least due to the calibre and ambition of those who paved the way in industry. Our electricity infrastructure is one example of this engineering legacy. It supplies almost all Australians with power, largely through one of the world's longest interconnected generation and transmission systems. In order to understand what the energy industry is experiencing during this unprecedented period of change, it is instructive to examine how Australia's energy system arrived at this point.

Australia's first foray into the world of electrification came largely at the same time and in the same way, as the rest of the world: lighting. In 1863, Sydney's Observatory Hill became one of the first illuminated locations in Australia, with a single arc lamp installed to celebrate the marriage of Prince Albert Edward, the Prince of Wales, to Princess Alexandra of Denmark. This kickstarted a rapid competition between Sydney and Melbourne in the race to pioneer the next major milestones, including more extensive lighting, installation of local generators, and the first electric trams, with Melbourne taking the honour in 1889.

Following the turn of the century, work commenced to build what would become the foundations of Australia's national power system. Through the establishment of large, centralised organisations, Victoria and Tasmania led the way. These state governments demonstrated considerable foresight, with centralised control allowing for a long-term systematic approach to implementation, resulting in ambitious and rapid development. By contrast, the other states followed a more council-centric approach, and failed to keep pace.

In 1916, the Tasmanian Power Authority commenced operation, seizing on its plentiful water resources by commissioning the first large-scale generation, the 6.8-megawatt Waddamana Hydroelectric Power Station. This was ably supported by 100 kilometres of 88 kilovolt transmission line, allowing the hydro resource to support a rapidly developing Hobart. Right on its tail, Victoria established the State Electricity Commission of Victoria (SECV) in 1921, bringing the 50-megawatt Yallourn brown-coal-fired power station online to electrify Melbourne, supported by 160 kilometres of 132-kilovolt transmission line. As recognised pioneers in the field of power generation, Tasmania and Victoria continued to dominate the pre-World-War-II development of Australia's power systems, advancing into higher voltage transmission, connecting greater distances, and building increasingly larger generators. During these exciting years, Victoria and Tasmania become the global experts in brown coal and hydro generators respectively.

Despite electricity advancement coming to a grinding halt during wartime, the conclusion of World War II saw several factors combine to drive a new surge forward, including growing electricity demand, droughts in Tasmania and coal shortages on the mainland.

In this context, the Snowy Mountains Hydro-Electric Scheme cemented itself as the nation-building project that the country, the power system, and the farmers desperately required. Considered since the 1880s, the Snowy scheme was debated at length for the irrigation boost that it could provide to NSW farmers by diverting the Snowy River. However, the end of the wartime halt of new generation projects finally provided the catalyst needed to commence a 'nation building' project of this scale. Between 1949 and 1974, the Snowy scheme built seven power stations (totalling almost 4,000 megawatts), 16 dams, 145 kilometres of tunnels and 80 kilometres of aqueducts. Over 100,000 workers from 30 different countries played a role in construction – many then settling in the area and making Australia their home. More than just an electricity project, the scheme provided a sense of national achievement and contributed to the fabric of society.

New opportunities

As a country blessed with natural resources, Australia had long exported alumina. However, with the advent of lower coal prices, new smelting industries became a real possibility, with Tasmania's Bell Bay smelter leading the way into this energy-intensive industry in 1955.[32] In 1963, 100 years after the first light at Observatory Hill, Alcoa opened the larger Point Henry smelter and adjoining coal-fired power station near Geelong in Victoria, boosting Australia's manufacturing capabilities, creating thousands of jobs and supporting an entire community. This served as a precedent for several other smelters that would eventually be dotted along Australia's east coast, establishing new jobs and industries at each site and influencing power system development throughout the late 20th century. In 2014, Alcoa made the decision to finally close the Point Henry smelter due to high electricity costs, bringing the challenges of running heavy industry loads into the current energy debate.

Throughout the 1970s and 1980s, the power industry made significant advances, connecting the more remote parts of the country, connecting Broken Hill and associated mining sites to the New South Wales grid via a 260-kilometre 220-kilovolt line, as well as Western Australia's eastern goldfields to Perth via a 655-kilometre 220-kilovolt line in 1984.

In 1987, the Northern Territory contributed Australia's first combined cycle gas plant; a change triggered by remoteness and newly discovered gas fields. While Darwin's Channel Island Power Station was initially intended to be fuelled by coal, it switched part way through construction as gas was discovered in Central Australia, with a 1,600-kilometre pipeline built to supply the power station.

In 1992, Queensland pushed the bounds of large power system management, extending the network 400 kilometres north of Townsville, supplying far north Queensland with coal-fired power generated over 1,000 kilometres away.

Turning points

Thus far, Australia's energy history was largely one of opportunities and advancements built upon steady technological advancement and steady population growth. However, in the early 1990s, there was substantial disruption to this, once again driven by Victoria. Proponents for smaller governments, buoyed by Ronald Reagan and Margaret Thatcher's economic successes overseas and citing economic failure in Victoria during the late 1980s, looked to outsource large government owned enterprises, thus unlocking investment from private enterprise with promised efficiency dividends. In 1993, Jeff Kennett and Alan Stockdale, Victoria's Premier and Treasurer respectively, enacted their plan to return the budget to surplus, selling off the lucrative SECV amongst other assets with staggering speed and efficiency.

Memories of the SECV are still met with fondness. With unparalleled training opportunities, a deeply ingrained mentoring culture, world-leading expertise, and conditions ahead of its time, the SECV was a job for life. However, engineering managers over 55 years of age were now encouraged to take lucrative retirement packages, designed to reduce the liabilities for the new private owners. Engineers moved to take the place of the recently retired managers, leaving a void of expertise in their own technical roles, and importantly, gaps in mentors for the next generation.

The SECV's regular engineering and apprentice intake ceased, with university power engineering places following suit with reduced tertiary training options. Not limited to just Victoria, engineering roles across the country were now in short supply. These systemic changes to Australia's power industry resulted in reduced job intakes and knowledge transfer, the aftermath of which is still felt today.

Amidst the upheaval, development forged on: In 1998, the National Electricity Market (NEM) commenced operation under the management of the National Electricity Market Management Company, later the AEMO. In 2005, Tasmania joined the NEM, and in 2006, the Basslink interconnector finally connected Tasmania's hydro-rich resources to the heart of Victoria's coal-fired generators.

The achievements of those who contributed to shaping Australia's electricity network are undeniably impressive. As a modern society, the comforts we all take for granted are largely the rewards of their visionary and boundary pushing work, with increasingly bigger transmission, interconnection, market design, and power stations so large that the scale cannot be conveyed on paper. However, while the development was innovative and world leading, it was not the paradigm shift of both technology and economics that we see today. Rather, Australia's historical energy development trajectory was consistent and well planned. This context helps to understand the drivers behind the challenges felt today.

A very different beast

Despite the backdrop of regulatory and management changes and privatisation, Australian communities began to explore new technologies, driven by plentiful renewable resources and high energy costs. In 1987, Esperance in Western Australia became home to Australia's first commercial wind farm, Salmon Beach Wind Farm. With the farm demonstrating that sizeable fuel savings could be obtained, Western Australia continued to lead the way with increasingly larger and more commercially viable wind farms. With its smaller scale, solar presented a slightly different trajectory, able to play small roles in lower-profile installations.

Box 2: The Northern Territory – a solar luminary

With high diesel fuel costs and plentiful solar resources, the Northern Territory was a forerunner in deploying a range of different technologies, which was key to ultimately picking the 'winner' – flat plate photovoltaic (PV). This included the *Solar Systems* concentrating dishes deployed to remote aboriginal communities in the early 2000s, the *Bushlight* program that deployed PV to remote communities coupled with user-friendly interface to promote demand management, and Uterne, a 1-megawatt installation of single-axis PV in Alice Springs, the largest installation in the southern hemisphere when installed in 2011.

Despite the slow start, renewables in Australia have now taken off at breakneck pace – so much so that the system is barely equipped to keep pace, with interest from prospective generators vastly outstripping network capacity. However, part of the challenges of integrating renewables stems from the fact that solar and wind technology is diametrically opposed to traditional generation, and as such, simply connecting into a long-standing grid causes challenges. There are several ways this materialises.

Bigger is not always better. Unlike the development of increasingly larger coal-fired power stations throughout the 1970s, 1980s and 1990s, increasingly larger solar and wind farms are less common. Large-scale projects require significant grid infrastructure. For example, western Victoria has become a hotspot for renewable generation, but lacks the infrastructure to connect it all. The *Energy Security Board Post 2025 Market Design* report highlights the dependence of natural resources at their location (e.g. high wind or plentiful wind) to efficiently connect that generation with upgraded transmission.[33] Therefore, smaller renewable generation with geographical diversity provides enormous benefits to balancing out the solar and wind conditions of otherwise inconsistent fuel sources combined with a transmission system which allows generators to access the market.

It is not always cheaper to build solar and wind farms today. The demonstrated cost reduction of PV and the project cost reduction for batteries now provide a significant incentive for developers to deter investment until the situation becomes a little clearer, unlike the steel and concrete required to build more traditional assets. From a network planning point of view, this adds an additional factor that simply didn't exist before.

Whilst thermal generators have significant ongoing fuel costs, wind and solar (with fewer moving parts and a free resource) have almost none. Consequently, different market players are entering the market, often taking on assets for a few short years. At the extreme end, some developers remain acutely focused on short-term profits over the long-term power system.

Finally, whilst the latter half of the 20th century focused on continually expanding the network and accommodating greater demand, this is no longer the case. Today, demand, fault current (the electrical current that flows after fault conditions, typically higher in thermal generators than inverters) and inertia (the rapid and automatic injection of energy to suppress frequency deviation) are in short supply, with power system rules struggling to keep up.

Social license and communications

The 2019 Australian federal election could have been a turning point for the energy industry. It still may be, as the outcome seems to say that, whilst climate change is important, so are jobs and livelihoods in regional areas. Large-scale solar and wind farms, built almost exclusively in regional Australia, sometimes represent a disconnect between the towns that host these farms, and the inner-city developers that build them. The conversation has started around social licence, but has a long way to go – communication, context, and the genuine need to appreciate the perspective of those around you are key.

The election showed that whilst Australians do not have a consensus on climate change, they are interested. This relates to the professional sector too – network development and advocacy is no longer the domain of expert engineers, but rather legions of economists, lawyers, financiers, honourable and more enterprising renewable energy developers. Some consumers demand active participation, others wish not to be inconvenienced for bowing out. All of this means that increasingly complex notions – inertia, fault current, system strength, marginal loss factors (the cost that generators bear for losses in the electricity network) – must be articulated in a way such that everyone understands, allowing for a richer and more appropriate debate. This is no easy feat considering the complexity of these notions, coupled with overarching pressures such as developers racing to connect to the network before the physical local network reaches capacity.

Market versus regulatory tension

An additional challenge is the inability of regulatory changes to keep pace with the market. With the market originally designed for one or two thermal generation connections a year (due to the lengthy process of building large coal and gas power stations), the process is significantly strained from the torrent of renewable connections coming through today. Whilst independent reviews and clear guidelines remain important, the ability to keep pace with a more agile market is proving challenging. Large-scale batteries are a potent example here, with several high-profile examples, most notably the Hornsdale Tesla battery, soaring to national attention. With a number of these large-scale batteries now operating and many more likely to provide vital frequency stabilisation, the connection and registration requirements remain challenging. Whilst a precedent now exceeds, a relatively bespoke pathway forward awaits enterprising developers.

Battle of new technologies

Amidst this confusion, the sector remains divided on potential solutions, particularly the role of gas and nuclear. Gas, first heralded by the International Energy Agency (IEA) in 2011 as an ideal transition fuel, presents as an incredibly divisive issue today. Firstly, liquefied natural gas is largely exported, while domestic supply is constrained, meaning domestic prices have risen sharply. The 2019 AEMO report on eastern Australia gas price projections predicts that 'prices are expected to trend upward by almost AUD3/GJ between 2018 and 2032'.[34] With the states and territories taking passionate and polarised stances for or against fracking for gas.[35] However, gas now faces a conundrum: if consumers do not care for emissions, gas is more expensive than coal; for consumers motivated by emissions, solar or wind plus batteries will soon become a lower cost alternative.

Seizing on the increased media interest, nuclear is yet again being pushed forward as the panacea by a small yet vocal sector of the engineering community, many of whom have worked in the power sector over long careers. Whilst attractive for its more traditional generator performance and low emissions, nuclear represents yet another turning point in the industry, requiring enormous capital investments best suited to government ownership, and either heavy subsidies or a carbon tax required to become financially viable. If we get solar, wind and demand management right, perhaps we don't even need it.

So, how do we manage this ongoing transition?

It is challenging to envisage what the next 10, 20 and 30 years of the power system may look like, nevertheless, there are five key aspects to best prepare for a safe and sustainable transition.

1. Leadership

With so many moving parts, there is an audible cry for clear and cohesive leadership that will provide guidance in an environment of broad, sweeping developments.

Energy leadership historically came through centralised authorities, with a clear and definitive mandate to consider the entire system. Whilst largely disaggregated today, the benefits of vertically integrated utilities like Horizon Power in Western Australia highlight the power of this combination, able to swiftly implement holistic and forward-thinking solutions, such as the Onslow microgrid in northern Western Australia.

Today, with a sharp reduction in the number of organisations able to view the network holistically, increased responsibility has shifted to organisations such as AEMO, the Australian Renewable Energy Agency (ARENA) and the Energy Security Board to provide this leadership. This environment provides an opportunity for organisations such as Engineers Australia, coordinating the rationale voice of thousands of members, to provide clear, reasoned and timely contributions to the debate.

2. Proactive design

Future changes, including electric vehicles, more renewables and storage will be so complex that all parties need to play an active role in managing the transition. For new and existing generators, this includes proactively designing systems to provide grid support, such as new ways of providing grid services and maximising overall value instead of simply financial yield.

3. Innovation

The industry knows that the future power system will be different, but what it looks like is less certain. As a country, we must get better at innovation – which means developing an increased risk threshold (potentially taking on more responsibility for things going wrong), investing in new ideas, and being prepared to fail.

Australia's remote micro-grids were always renewable innovators. This opportunity is now greater than ever, with off-grid systems providing the opportunity to test new ways of operating the power system in a smaller, cost-optimised manner, with the challenges immediately boiling to the surface and so able to be solved.

4. Sharing responsibilities

A fundamental challenge to today's power system is that system operators (such as AEMO) remain almost solely responsible for keeping the lights on, despite lacking visibility of new distributed energy resources coming online. The system operators seek to compensate for their reduced visibility and control by suggesting increasingly onerous generator performance requirements for all operators, including new generators. Therefore, a tension results – often at considerable costs to new generators. To resolve this stalemate, the industry must become better at proactively recognising and addressing the needs of system operators, and potentially enacting measures to share some of the liability when it comes to shared failures in operating the power system.

5. Promoting transparency and knowledge sharing

In order to motivate the multiple facets of the industry, more sophisticated conversations are needed to allow broader understanding. To start, industry must become more transparent, removing the secretive nature of proposed developments and simplifying the connection process. Complementing this, industry knowledge sharing requires a new push, closing the gap created by privatisation in the late 1990s. Organisations like Engineers Australia can play a critical role in facilitating effective mentoring relationships and making progress here.

Conclusion

Whilst historical events have shaped today's energy system, we now need to learn and adapt to successfully transition to a more distributed energy system – equipped with context and curiosity, today's energy professionals can make a profound impact on the future energy grid. With limited interconnection potential and renewable energy installation rates of four to five times faster per capita than the European Union, Japan, China and the USA[36], Australia is already a global leader in this field. However, in order to best move forward, the whole energy industry needs to work towards an improved understanding of the power system and the financial drivers, so that collective outcomes can be sought that are best for the grid, the market, and most importantly, the communities they wish to power.

INNOVATION AND GOVERNANCE: MAKING A DIFFERENCE IN THE COMMUNITY

Alan Reid

The virtual power plant revolution

The industrial revolution fundamentally changed the way people interacted with energy and had a profound impact upon both the way we lived, and our quality of life. The introduction of new technology that provided automation of manual tasks and the production of usable energy ushered in the next stage in the evolution of human civilisation.

Until recently, however, not much had changed. For a century, electricity operated on a centralised generation and distribution model. Very large spinning machines, born of the industrial revolution, burned a combustible fuel to produce electricity, which was pushed down long conductors to reach houses, where it was consumed. Technology, however, has changed. Generators have evolved to be fired on alternative fuels, machines have been developed that burn no fuel whatsoever, but generate electricity from the movement of the wind, or the radiation of the sun. Devices have been introduced that can store that energy for use later.

This wave of new technology has potentially delivered us to the precipice of another energy transformation. Since the industrial revolution, other than incremental efficiency gains, not much had changed in the relationship between energy and the consumer. However, the proliferation of residential scale generation and storage assets is slowly starting to erode this model and introduce a new one: decentralised generation and distribution. The introduction of this new model paves the way for a new type of generation 'asset' – one on which a new energy evolution may be born from the virtual power plant (VPP).

A VPP is an interconnected ecosystem of disparate consumer-owned generators acting in unison to balance the grid and reduce vulnerabilities. On face value this may not seem all that profound, however, Energy Networks Australia (ENA)[37] predict that by 2050 between 30% and 45% of Australia's entire electricity needs will come from customer-owned generators.[38] While somewhat subtler than the industrial revolution it does, as the last one did, fundamentally and permanently alter the relationship between energy and the consumer. Households may no longer passively consume energy without thought or knowledge of the goings on in the market or the grid. The VPP will be the driving force behind the transition away from our current model, that centralised model which has been in existence for more than a century.

Based on growth projections, VPPs will soon exist at a capacity similar in size to that of traditional spinning generators. Functionally, a VPP can also match the output of those large-scale generators; delivering energy on demand, responding to market triggers for the delivery of energy services and providing load balancing functions to the wider electricity grid. The main difference between a VPP and the large-scale spinning generator however is that a VPP exists in consumers' houses. This fundamentally changes the way energy is produced and consumed in some key ways:

1. The generation asset is owned or leased by consumers, not a generation company. This means the profits from that generation and delivery of services to market go directly to households. Estimates for the ENA state that network companies will pay distributed energy resource customers $2.5 billion per annum for network support services by 2050.[39]
2. A VPP consists of multiple systems connected at multiple points right across the grid rather than at one connection point such as a traditional large-scale generator. Problems that occur in isolated parts of the grid can therefore be solved by those consumer assets which are directly connected to that part of the grid, meaning that energy will not need to be transported across large distances. This helps improve grid asset utilisation, lowers losses in the system, and increases local grid stability, in turn helping drive down electricity prices; By 2050 it is estimated that $16 billion per annum in network infrastructure investment can be avoided due to the use of VPPs, and the total cumulative reduction in expenditure on the grid will be $101 billion. [40]
3. The fuel that powers this generator comes from the sun, a clean and almost infinitely abundant source resulting in lower greenhouse gas emissions and a decreased dependence on finite fossil fuels. This helps mitigate the effects of anthropogenic climate change, accelerates our transition away from a finite fuel source, and stimulates the growth of an industry and the creation of jobs.
4. The VPP consists of a community of consumers' generation and storage assets acting together autonomously in orchestrated harmony. This controlled, unified action increases the resilience of the grid against blackouts caused by poor power quality as a result of uncontrolled generation.

Box 3: The Smart Gateway – virtual power plant innovation

The 'Smart Gateway' is the device which makes the VPP possible. It is responsible for monitoring and control of consumer-owned generation and storage assets and aggregation of this community of devices to deliver a coordinated service to the grid. Australia is uniquely positioned globally with regard to Smart Gateway innovation and has been the pioneer in the introduction of the VPP. Renowned companies in this space such as Reposit, SwitchDin, Mondo and Evergen have all been founded and are based in Australia.

Reposit has been the global leader of technological innovation with the Reposit Smart Gateway being the only VPP control device in Australia when viable home battery options first entered the market in 2015. Reposit was also a global launch partner of Tesla's Powerwall 1 when released for commercial use.

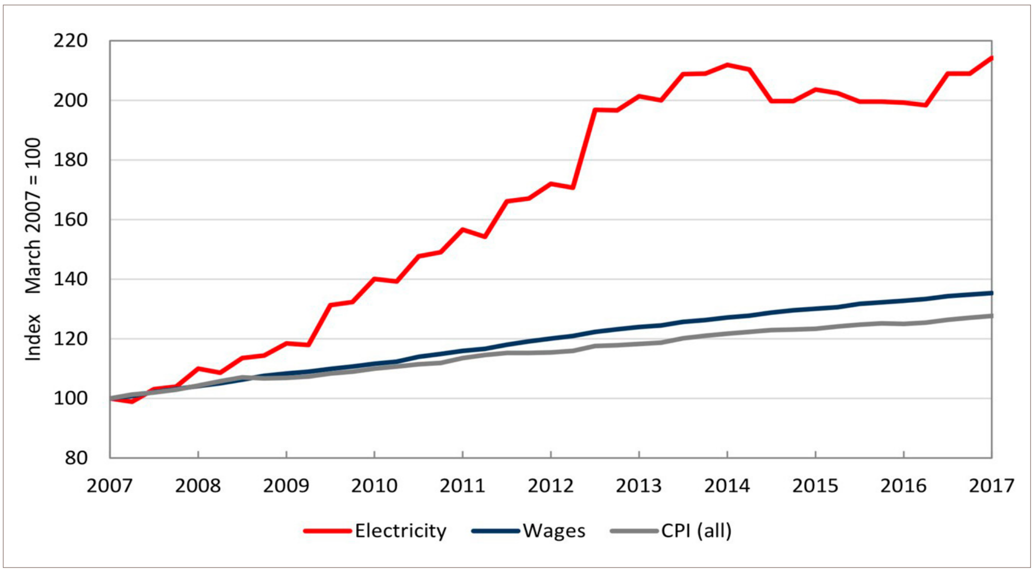
Since first using a VPP to trade on the electricity market in mid-2015, Reposit now operates 12 unique VPPs throughout Australia, including the largest operational VPPs across many states, and the largest nationally with the Canberra VPP consisting of nearly 1,000 homes. Reposit has evolved as indeed the market has, and today it is the most intelligent VPP-ready Smart Gateway on the market (In 2018, Reposit was awarded Engineers Australia's prodigious Sir William Hudson Award for Engineering Excellence for its Canberra VPP – the highest recognition for any engineering project in Australia.)

Critically however, not all storage and generation assets are created equal, and currently the majority of batteries installed in Australia do not have a Smart Gateway attached. The result is an increase in uncontrolled generation on the grid which can exacerbate issues around grid stability and resiliency, and ultimately drive up electricity costs. If policy around incentivising uptake of Smart Gateways for battery and PV owners in Australia is not set correctly, we are at risk of watching this global market advantage slip through our fingers.

What's behind the change?

The last decade has been a tumultuous period for the electricity sector. During this period electricity bills for the average Australian household have nearly doubled, increasing by 80% to 90% in real terms.[41] During that same period, the electricity consumed per Australian household, however, has remained relatively constant with an average annual growth of 0.7%.[42] In fact, the growth in the cost of electricity over this period has far outstripped the growth of almost all other consumer goods and services, and critically also far outstripped growth in average wages, as illustrated in Figure 4.

Figure 4: CPI for electricity compared with other sectors and wage growth



Source: Australian Competition and Consumer Commission, 2017

Placing the microscope on residential power bills reveals a mixed bag for the consumer. In September 2017, the Australian Competition and Consumer Commission released the report *Retail Electricity Pricing Inquiry: Preliminary Report*.[43] The ACCC found, among other things, that 'The market is exceptionally complex, and consumers have no ability to exit the market'. Or in other words, 'it's complicated'. Notwithstanding, there are some clear conclusions that can be drawn on the impact for the electricity consumer:

- Electricity is not an intuitive product to understand. There are multiple entities in the value chain, some heavily regulated and some not. There are complex laws and rules that govern the industry, which operates via a delicate balancing of technical and market forces. The energy offers presented to consumers are also opaque and hard to navigate. The overall result being many consumers do not exactly understand what they are buying from whom.
- The largest cost drivers in residential electricity bills are fees from the grid owner/operator. They pass on the costs of building and maintaining the poles and wires that transport the electricity from where it is generated to households. Trends in residential electricity consumption, the proliferation of 'dumb' uncontrolled generation assets combined with a 'building-block' regulatory framework have resulted in large-scale investment in building additional capacity into the grid. The current average cost to build one megawatt of additional capacity in Australia's grid is around $225,000.[44] In contrast, the avoidance or delivery of a megawatt of demand via a VPP can be less than 10% of this cost.
- Despite the rise of small-scale contributors, the wholesale market for electricity is becoming more 'centralised', meaning an increasingly small number of large generators supply the market. This reduces competition and vests a great deal of power in those companies over the market, which can result in upward pressure in the wholesale price of electricity.

- Deregulation of the retail market has precipitated the race to the bottom by electricity retailers. Many retail electricity plans are convoluted and complex, bundling many tariffs together, some of which use inflated base pricing to compete on an aggressive and disparate discounting basis.

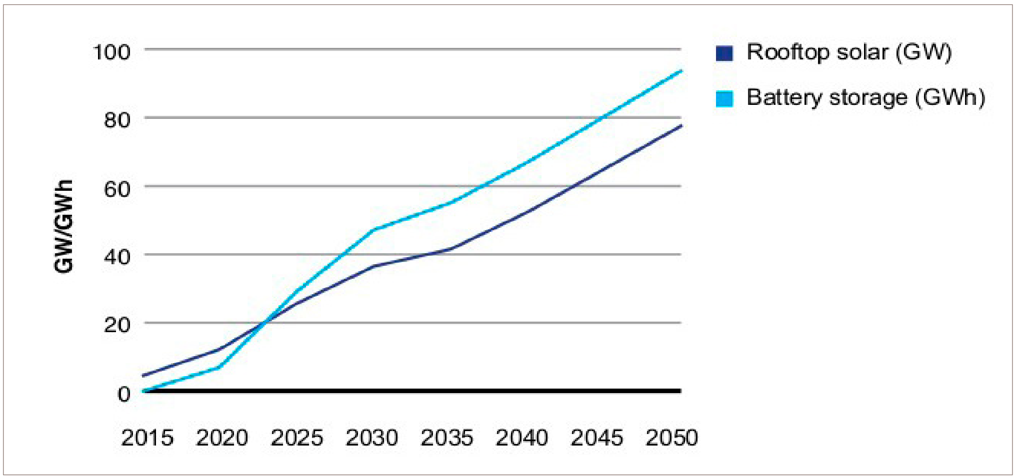
All this has placed an immense burden on electricity consumers, and despite ready access to the service has driven many into 'energy poverty'. The ACCC notes 'many households cannot absorb these increases … some consumers have been forced to minimise their spending on other essential services, including food and health services, to afford electricity bills.'[45] Unfortunately, those consumers who are in positions of vulnerability are the ones who are hit the hardest by issues in electricity affordability. Increases in social inequity and the numbers of consumers pushed into financial hardship are an unfortunate but important consequence of electricity price pressure.

The social and economic impacts of rising electricity costs outlined above have driven many consumers to shine a light on the electricity sector. Increasingly, consumers are scrutinising increases, asking questions of utilities and regulators, and seeking to redress the imbalance of power in their relationship with electricity. Ultimately, these forces have resulted in the electricity sector becoming the single most distrusted in Australia behind banking and insurance.[46]

The rising price of electricity combined with a lack of confidence in industry has resulted in consumers taking matters into their own hands. They are becoming more knowledgeable, engaged, and are taking action to lessen the burden of their bills. To this end, and where they can, consumers are investing in the VPP, with Energy Consumers Australia finding in a recent survey: 'Over 5% of people have already purchased a home energy management system and a further 20% looking to do so, and battery storage interest is high with around 30% considering procuring the technology.' (Energy Consumers Australia, 2018).[47]

Figure 5 shows the projected cumulative capacity of installed rooftop solar and battery storage across Australia over the coming decades. To put this into context, the national maximum summer demand across the entire of the National Electricity Market was 32.9 gigawatts in 2016–17.[48] According to this graph the cumulative installed capacity of rooftop solar is set to surpass demand of the entire NEM sometime around 2027, a mere eight years from now.

Figure 5: Projected rooftop solar and battery storage installed capacity nationally

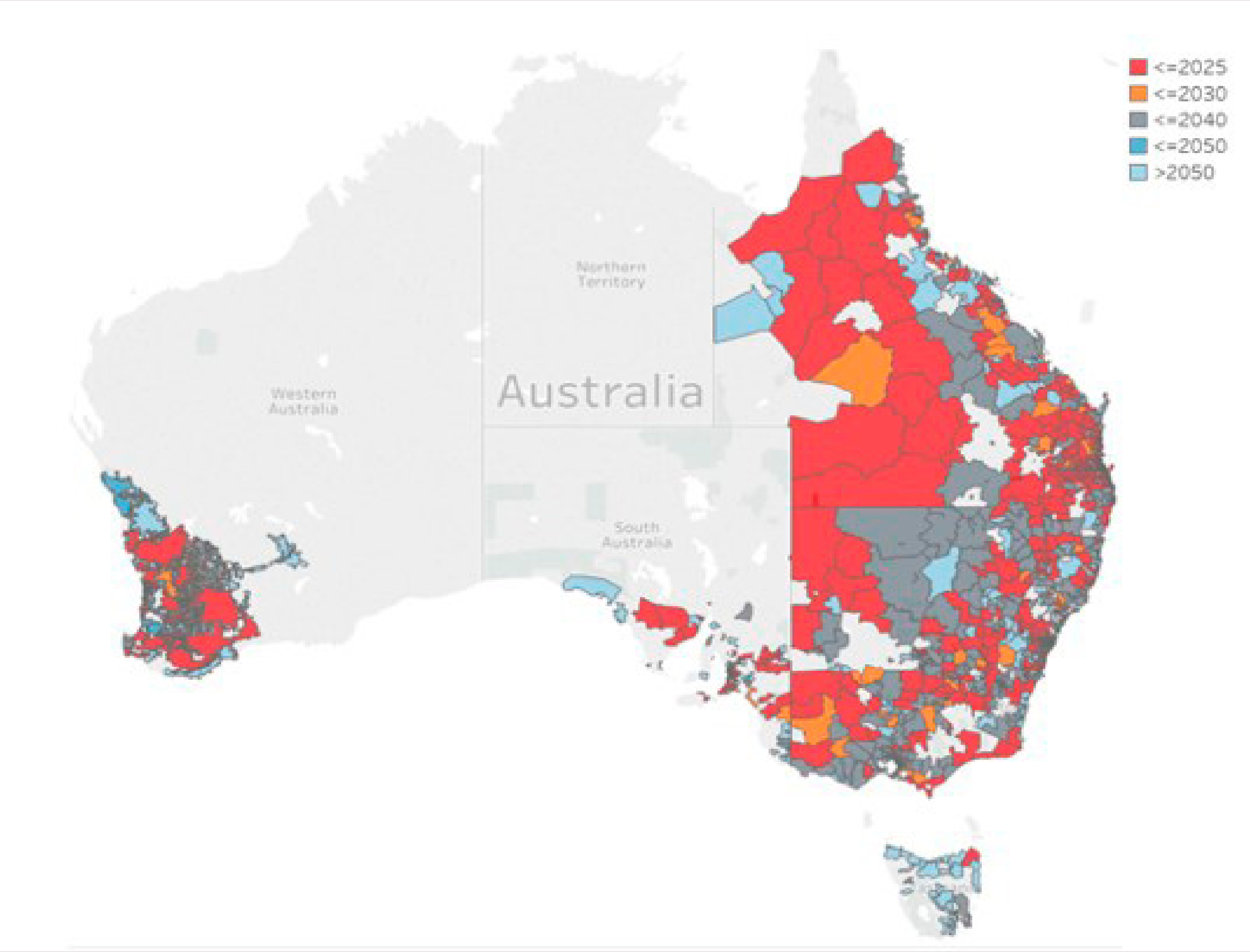


Source: Energy Networks Australia, 2017

The implications for the grid

As the centralised generation and distribution model implies, the national electricity grid was designed and built for power to flow in one direction: from the generator toward the load. With VPPs growing at an astonishing rate, the new decentralised model will mean that power across the grid will flow in both directions. This places the grid under even greater pressure, as 'reverse power flows' (electricity flowing from households back toward the large-scale generators) create voltage imbalances and stability issues. Figure 6 illustrates the impact of this showing, by postcode, the projected decade in which reverse power flows from uncontrolled generation cause significant grid stability problems unless addressed through system management changes. From this we can see that much of the grid will feel the impact of reverse power flows in or before 2025, with regional areas being some of the earliest to experience this.

Figure 6: Projected decade in which penetration of rooftop solar results in reverse power flows



Source: Energy Networks Australia, 2017

Challenges in regulation and electricity system governance

It is safe to say that the electricity sector will continue to face a turbulent future. Consumers are unhappy and distrustful, technological innovation is driving change at an unprecedented rate, and the framework that governs it all is complex, with many interdependencies. In June 2017, the expert panel convened by COAG and chaired by Dr Alan Finkel published their report on the future security of the NEM, *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future*.[49]

The report identified three pillars as necessary for delivering desirable system outcomes:

1. Orderly transition

2. Better system planning

3. Stronger governance.

The three pillars lay the foundation for articulating and addressing regulatory and governance challenges introduced by the evolution of the electricity market over the coming years. They also set the scene for further investigation into the challenges faced by the electricity sector as it transitions while maintaining resiliency, safety and affordability.

Challenge 1 – Installers: managing the transition in the community (Pillar 1)

The electricity sector is one of the most complex markets the everyday consumer will encounter. For all consumers, their interface into this market when purchasing solar or batteries is their installer. The installer is a crucial piece in the overall VPP value chain for two key reasons:

1. The installer is the subject matter expert and the trusted advisor for the customer. The Installer assists the consumer to choose the best technology for their needs and provides ongoing post-installation support and service. The installer educates the consumer on their system, helps them understand how the VPP works, and how they use the technology to participate in the market and secure returns from their investment.

2. The installers need to be capable of ensuring that these systems are installed in a skilled, compliant and safe manner. These systems by their very nature are complicated, with many different electrical components and interconnections. A quality installation is key to ensuring operational uptime of these systems and overall availability of capacity of the VPP.

Battery installation is a unique skill distinct from the installation of other residential electrical assets and requires time and experience for the installer to become proficient in execution. It also takes time and effort on the part of the installers to become the subject matter experts in the operation and benefits of the VPP for the consumer. Misinformation or gaps in information can have a significant impact on the consumer experience and result in poor outcomes for consumers and industry.

Ensuring installers have the skills, knowledge and expertise necessary to safely install batteries and educate consumers about their smart energy systems will be a key challenge to building consumer trust and proliferating the VPP. A lesson from the apartment construction sector is that regulation and certification capacity is also needed to ensure that installers are operating to required standards, with self-regulation not demonstrating good outcomes in that sector.

Challenge 2 – Big data and system interfacing (Pillar 2)

The VPP operates on the premise of real-time orchestration; many individual units all acting in unison to deliver an aggregated service to the market or grid. Enacting this sort of distributed control schema requires the transfer of large amounts of data across many system interfaces. Ensuring that the optimal outcome is achieved for all participants in the value stack is dependent upon making sure the correct data is available to the correct parties in a timely manner. This is also the key to improving system planning.

The interface between VPPs and various markets and systems is integral to the continued resilient operation of the electricity grid. The ability of the VPP to send granular and near instantaneous data of current and forecasted future behaviour introduces a new level of system wide planning. Whereas previously grid operators used assumptions and historical trends to forecast for planning purposes, the VPP provides remarkable insight into system wide load and generation right down to the individual household level. This introduces ability for more robust planning, which reduces uncertainty around load and also can help to avoid over-investing in grid capacity, thereby driving down costs.

However, overlaying complex system wide data and control on top of existing grid management architectures is no simple exercise, and there are many risks in doing so, not least of which is cyber security. The continuous exchange of data, including the ability for global control across and through the VPP can introduce vulnerabilities to cyber-attack. This will require vigilance, constant monitoring and best practice security measures. We must be careful not to trade off cyber security for the benefits of big data and a narrow conception of cost minimisation. The costs of recovering from a disabling cyber incident, and the loss of consumer trust were that to occur, need to weigh in business decisions.

Challenge 3 – Improving regulation (Pillar 3)

The current Electricity Regulatory Framework was enacted via the creation of the Australian Energy Market Agreement. This agreement was last amended on 9 December 2013[50] and provides for two institutions to oversee the Australian regulatory ecosphere:

1. The AER is the economic regulator and the body responsible for enforcing national energy legislation
2. The AEMC undertakes rule making and energy market development.

The first installations of residential battery storage systems in Australia, however, were undertaken in 2015 (Clean Energy Council, 2018). Therefore, the rules that govern the way the market is regulated were written and last amended prior to the emergence of residential storage technology and VPPs. While the regulations are written to be technology agnostic, this has resulted in some key challenges in applying the rules to distributed assets that are seeking to participate in electricity markets in an aggregated manner. In particular:

1. Regulatory 'grey' areas can stifle innovation – These areas create room for interpretative error and uncertainty, potentially hindering the ability of participants to innovate. Consistency in the interpretation and enforcement of regulation can be *ad hoc* in nature and situationally differ where these grey areas exist.
2. Slow regulation can miss the opportunity – The consumer revolution is underway and VPPs are growing. If holistic regulatory adaptation takes too long to bed down, there may a splintering that occurs in which individual organisations (especially grid operators) are forced to create and enforce their own solutions leading to unnecessary regulatory complexity and reactionary policy.
3. VPPs are treated as a novelty solution – The Regulatory Framework lacks in providing long-term stable funding options for VPPs. Many grid operators can only utilise auxiliary allowances such as the 'Demand Management Innovation Allowance' to fund VPP operations. This places a limitation on the scale of the VPP and presents a barrier to them becoming a more permanent fixture in long-term grid planning and operation.

4. Innovative companies need a reliable source of guidance – With increasing complexity, uncertainty in the regulatory environment, and rapid increases in technological innovation, it is often difficult to obtain consistent and accurate advice on how to integrate new technologies into existing regulatory frameworks. Existing channels aren't necessarily suitable for providing the assistance required for innovative companies to navigate these issues in a timely and consistent manner and can tend to push back on innovation to maintain the status quo. The federal government acted in 2015 with its National Innovation and Science Agenda.[51] Unfortunately, because innovation was perceived as a 'Turnbull' failure to connect with Australians at the 2016 election, the federal government has stepped back from taking a leading position. This must change and the government needs to return to providing active guidance.

Implications for policy-makers

The 2017 *Independent Review into the Future Security of the National Electricity Market*[52]laid out the desired outcomes for the electricity system of security, increased reliability, increased customer reward and decreased emissions. At the policy level, the structure of the regulatory environment into the future should be shaped by a set of core principles that support and deliver upon these desired system outcomes, such as:

1. Find ways to deliver positive outcomes for consumers and market participants under existing regulatory frameworks.
2. Remove barriers to consumers being able to make money from their systems and better understand energy offers.
3. Incentivise larger scale adoption of VPP grid services by addressing and removing risk for traditionally risk-averse businesses.
4. Be holistic and seek to undertake 'least regret' actions to future proof rather than isolate to solving singular issues.
5. Incentivise investment in the skills and knowledge of the battery installation workforce across Australia. The ACT Government has provided a model of this with Reverse Auction procurement requiring enhanced skills investment in the Territory.

Consumer sentiment is clear: they are no longer willing to shoulder the burden of rising electricity costs are and seeking to regain power in their relationship with energy. Discontent combined with technological innovation are driving a seismic structural shift in the electricity industry. The time is now for industry to respond in a proactive way to support the needs of the consumer both now and into the future.

Any reform agenda for electricity needs to start with refocusing regulation. The way the market is governed should be grounded within a set of core principles that seek to drive mutually beneficial outcomes for all those in the electricity value stack. This will help reengage consumers, rebuild trust in industry and ultimately embrace the consumer revolution rather than resist it.

DELIVERING SUSTAINABLE ENERGY SOLUTIONS: A COLLABORATIVE CHALLENGE

Tara-Lee Macarthur

The shift to renewable energy sources is picking up speed across the world. Germany and the Scandinavian countries have ambitious targets and while Australia lags in some area, Australians have exceptional take-up rates of rooftop solar. The more the nation can embrace and prepare for a staged progression the easier change and transition will be. A key issue in the progressive changes towards new energy network options will be the ability to design sustainable energy solutions. While there are many enablers of sustainable energy networks, this section will explore three main themes: customer expectations, collaboration and sustainable engineering.

The first theme will explore the relationship between the consumer and the electricity grid, examining customers' expectations and changes in energy usage behaviour. The second theme examines where collaboration is already happening and identifies opportunities to expand and encourage new kinds of innovation and collaboration. The final theme discusses how sustainable engineering solutions will be crucial for the safety and reliability of the future network and a thriving energy transformation.

Meeting customers' expectations: sustaining trust

In 2018, it was estimated that the total electricity generation in Australia was around 261,405 gigawatt hours.[53] Consumed across the seven main energy sectors: agricultural, mining, manufacturing, construction, transport, commercial and residential. In recent years, residential energy consumption has been relatively flat or in decline in response to higher electricity prices, energy efficient appliances and going off the grid but remains approximately 10% of total consumption.[54]

Traditionally customers connected into a utility's service area and sourced their energy needs from a single retailer. Today, customers are beginning to take advantage of new technology, managing and generating their energy. Due to this, grid operators and utilities must adapt as customers begin to source their own energy and many do not require the utility's grid, which may lead to a vast reduction of the utilisation of the grid.

Some utilities and retailers have acknowledged this fact and have already begun adapting by focusing on a customer-centric model and supporting the following initiatives:

- connecting and incentivising residential rooftop solar, electric vehicles (providing charging stations and electric highways) and battery storage. Consumer interest in these products is accelerating
- allowing customers to 'buy' and 'invest' in renewable energy through their residential power bills
- providing digital metering and smart metering
- providing different tariff and pricing models.

In addition to the above, the Energy Charter, another significant step towards the transformation of the Australian energy industry, came into effect on 1 January 2019.[55] The Energy Charter is an industry-led collaboration established to deliver solutions that are in line with community expectations. This charter remains on ongoing initiative which sets principles and guidelines for the energy companies across the complete value chain.

This change in the traditional energy model is a challenge for utilities as new ways must be found to augment the network allowing for distributed generation, while continuing to provide uninterrupted service to all customers. Regardless of how the energy network of the future looks, customers are expecting the affordability, security and safety of the old network to remain. This is the underlying goal that utilities will be assessed and judged against by customers, so the technical prowess of the engineering solutions that are produced are simply enablers of this goal.

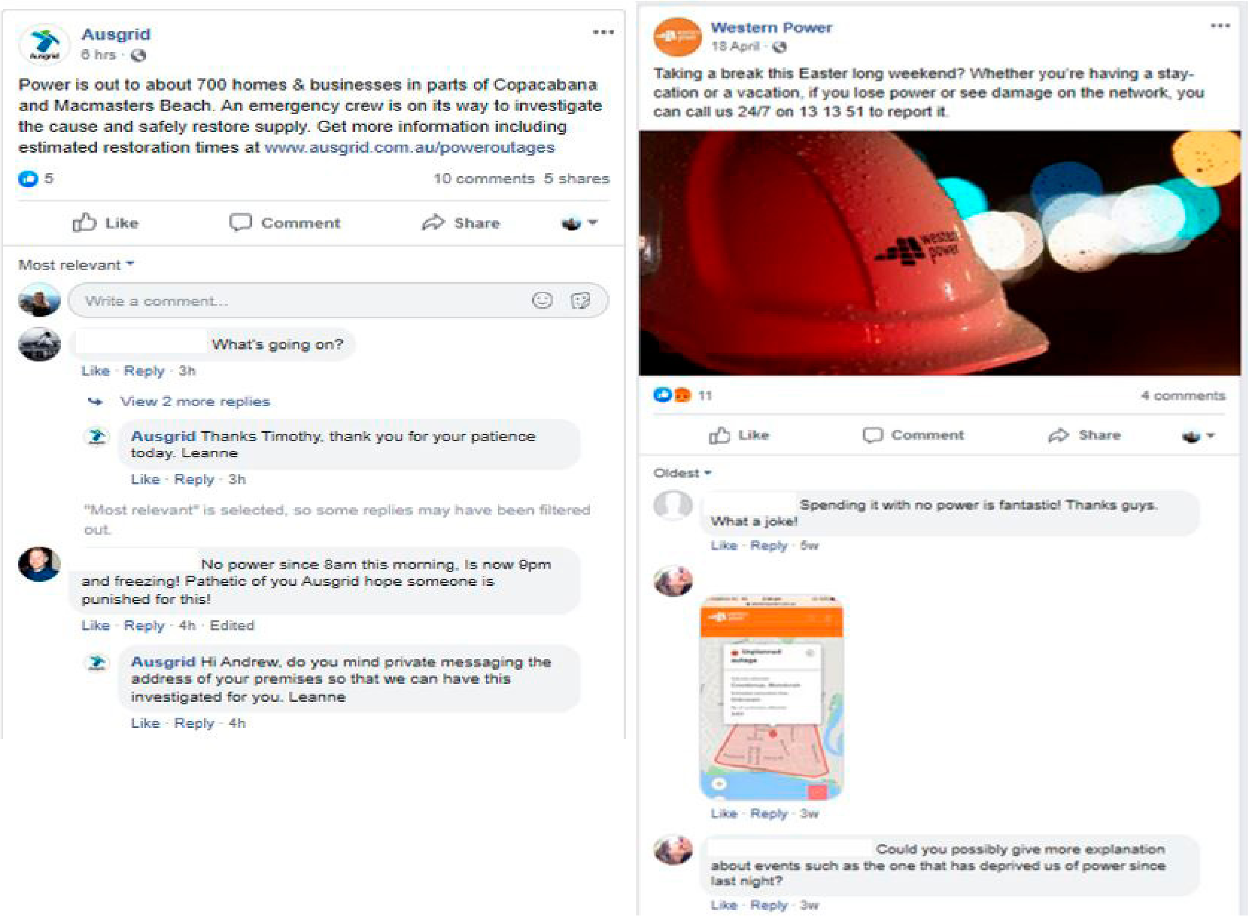
A social challenge for utilities and grid operators is that customers think about energy service companies more when the power is off than when it is on. For customers, losing electricity is the loss of a necessity, as essential as running water, food and shelter. To the customer wanting to cook dinner or watch TV, the duration of the outage can feel longer than it is and, if outages occur more than once a year, they are outraged. But to other customers the loss of electricity can be life threatening.

The reasons for outages can vary and may last a few seconds or a few hours, or days depending upon the cause. Some of the most common causes in Australia are high peak demand (also due to natural causes; for example, high temperatures), failure of equipment, traffic accidents, planned maintenance activity or natural causes. In other parts of the world, some outages are also caused by, for example, theft (of power infrastructure, i.e. copper), negligence of equipment maintenance and safety of the public (goes along with theft), or weak (or no) maintenance practices. There is a lot to protect the network against, yet some failure contexts are uncontrollable.

Customers and their needs are changing. Customers have a greater need for reliability and real-time information. Some want real-time information and want to access it without talking to anyone, and some like the confidence of talking to a service representative. When there is an outage of a service, whether it be power, telecommunications or otherwise, customers check online or post on social media to find out what is happening or to vent their frustration. The frustration is less often about why the outage has occurred and more about the unavailability of services and lack of information (See Figure 7).

As depicted in Figure 7, while social media is excellent for customer reach and engagement with the provider, it is also an avenue for negative feedback. However, unlike other industries such as banking, telecommunications, transport and hospitality, utilities seem cautious about embracing social media platforms. Utilities shouldn’t shy away from social media and should take their cue from companies who’ve successfully used social media to reach their customers, creating understanding, changing mindsets and informing.

Figure 7: Typical social media reactions after blackouts



Source: Screenshots from Facebook, June 2019.

Requirements for a collaborative approach

Given that the form and components of electricity networks are changing quickly, it is critical for industry to innovate and seek enhanced means to collaborate with suppliers and end-users of their services. The industry cannot rely on engrained ways and traditional methods to keep up with consumer and technological changes and must look to use technology and diversity to help drive collaboration.

Today collaboration is assisted by cloud, digital technologies and sharing platforms. This helps communicate beyond a single organisation, allowing companies to collaborate and interact with diverse stakeholders such as suppliers, partners and customers to come up with new, innovative approaches to services and systems. It is also important to note that stakeholders will collaborate differently and will not all participate in similar ways. While cyber security remains an ongoing and increasing threat to open systems design, technology helps provide a new platform, making wider collaboration possible.

Young engineering professionals and entrepreneurs have a history of bringing fresh approaches to technical problems. Equally they tend to be early adopters of new technology and are up to date with what is influencing other industries. Young professionals push for new technology to save time and create shortcuts which can result in getting products to market faster. Enabled by the Internet of Things and Industry 4.0[56] initiatives, industry can see results and data from their trials that is near or real-time, helping them innovate further.

Over the decades to 2019, Australian manufacturers had survived the some of the most challenging periods in our economic history. Instances such as the rise of global competition; the global financial crisis; the cessation of local automotive manufacturing; and the rapid integration of digital technologies throughout social media offerings and commercial settings. Historically, there has been strong collaboration and innovation that's been driven by manufacturers and utilities, and this will continue to be necessary, but only if a business case can be proven to support the necessary investment by both parties.

Local manufacturers' requirements must be factored into development planning where practical and feasible to do so or it may become a problem where local manufacturers and energy systems designers and operators do not understand each other. Compliance with design and manufacturing standards for electrical goods are critical for safe usage. These standards do vary across state and territories as do electrical equipment regulations.

By coming together and collaborating, the energy industry, operators and regulators can better understand problems. Difficult negotiations are necessary in a collaboration to identify what solutions are already available, what has been tried and is successful and in deciding the best solution for all parties. Numerous energy-focused or renewables projects will benefit from the engagement of government, industry, universities and customers, especially in getting a new product or service to market faster. Coordination of industry groups is enabled by informed and timely government policy and regulation. At this point, different jurisdictions and different political ideologies support some of Australia's industry sectors and not others. The energy transformation will fail if government policy does not integrate with industry efforts.

A notable example of government, industry and universities working together and collaborating to develop effective solutions to future technical challenges in and across the electricity distribution network is the A$5 million funding in 2017 of the Brisbane-based energy tech company NOJA Power by ARENA.[57] NOJA Power were tasked to develop breakthrough technology to solve the challenges of ensuring that the electricity grid is stable as renewable energy is integrated.

A core aspect of the innovation was smart switchgear that was designed to monitor energy flows, including voltage, current and phase angles on electricity distribution networks. The switchgear included monitoring capability units that can read real-time data up to a hundred times faster than existing supervisory control and data acquisition monitoring systems.

Key anticipated outcomes of the project include:

- Reduction in the cost of connection and increasing the value delivered by renewable energy in Australia
- Developing new protection, control and monitoring firmware to address renewable energy challenges
- Reducing or removing barriers to renewable energy uptake
- Increasing Australian skills in renewable energy
- Improving power system security, reliability and stability in Australia.[58]

The opportunity to innovate by research groups, industry participants and market operators and regulators lays the foundation for the continual advancement of the ability to monitor and control the changing national electricity grid. A collaborative partnership of participants, ranging from a highly specialised manufacturing facility, to ARENA, AEMO and several universities and utilities, has been formed.

This solution was developed collaboratively and benefited from an analysis in real-world situations. This successful collaboration proves that when groups work together they combine their skills and knowledge and solve complex technical challenges more efficiently. The former Chief Executive Officer of ARENA, Ivor Frischknecht,[59] has suggested that this smart generation of switchgear can enable better integration of renewable energy supplies into conventional networks and improve grid stability.

The benefits of collaboration

If the industry wants to improve the way that Australians use energy at home and work, it needs to enable the community to participate in dialogue about technical innovations and to be part of the solutions. The new collaborative energy services model requires utilities to engage with and empower their customers, improving relationships between the utility and customers and the community and improving solutions.

First, there needs to be communication platform that can provide customers with 'why energy service providers do what they do'. The message needs to have a balanced and objective view on new technology, programs or services and justification for choosing them. This will actively encourage participation and demonstrate that 'services linked to smart meters can lower their electricity costs'.[60] Secondly, there needs to be good governance and policies in place.

Policymakers need to be proactive and not reactive. Professor Heather Lovell from the University of Tasmania says that, to avoid future policy failures, governments needs to review processes, avoid ignoring successes and stop the rebound on policies.[61] Unfortunately, energy policy is dysfunctional across various Australian governments and jurisdictions and Professor Lovell's advice may not be heeded. Mitigation of policy failures is difficult to design for but advancements can be made.

One example of collaboration is the use of smart meters. These devices will provide benefits to customers such as real-time information about their energy usage, and visibility and degrees of control over their usage. Information generated by the devices can also assist utilities in future demand planning, outage detection and supply restoration after loss.

Utilities can analyse smart meter data to gain a better understanding of consumers, enhance customer experience, and improve the design of new products and services. The data can also be used across all levels of the business: by executives for strategic forecasting; engineers for systems planning and optimising the management of aging assets; and field staff for improving response and operations.

One challenge is how to make customers aware of how valuable the energy consumption data is. As the data that the meters collect contains sensitive consumer information, privacy is a key concern and is a significant challenge of real-time data collection. How can we help consumers understand the opportunities that will exist with this information and to be more accepting of the release of their data to a third party? The answer is likely to include effective data security so that consumers can trust third parties with their data.

Without customers willing to participate, it does not matter how enabling the new products and services are; consumers won't buy in. The industry needs to continue to:

- explain to consumers why they need to collect data and what the benefits are
- consider community, customer and participant interviews and participation on steering committees or boards for new programs or services
- host community sessions, surveys and feedback questionnaires to engage with customers
- update consumers and provide face-face sessions during different stages of projects
- help educate and notify customers in advance and get the buy-in needed.

Some of the current energy challenges we face here, such as the smart-meter rollout are also common around the world. What we do not realise is that solutions might already exist, but that the success has not been shared around the industry. By sharing knowledge, it can help fill knowledge gaps, increase innovation, improve efficiency and more. We could help solve someone else's problem by sharing our own best practices and challenges at conferences, participating in industry groups and publishing technical content on LinkedIn. With all the research that is happening around the county and the world, the energy industry should collaborate with other companies, learning from and levering their experiences.

There are many ways to support collaboration, not just through financial funding but by providing expertise, data and the opportunity to test ideas in simulated or real-life scenarios. In industry, however, many companies and utilities are often cautious and guarded with their information because they believe their market advantage will be at risk if their data and information is given out.

According to the 2015 Harper Competition Policy Review, competition policy should, among other things, work in the long-term interests of consumers, foster diversity and choice and encourage innovation and entrepreneurship.[62]

All too often, the typical 'understanding' is that intellectual property (IP) is only used 'to stop others from copying us'. [63] Such a narrow outlook adversely limits the potential to maximise the commercial value of innovations, and ultimately, it potentially reduces the return on R&D expenditure writes Greg Whitehead in the February 2019 *Australian Manufacturing Technology* magazine. As David Turvey observed, 'The Productivity Commission's *Inquiry on intellectual property arrangements* suggests that Australia's current IP system may require adjustment so it avoids stifling competition.'[64] The absence of an overarching objective, policy framework and reform champion has contributed to Australia losing its way on IP policy. Better governance arrangements are needed for a more coherent and balanced approach to IP policy development and implementation. Government has a role in supporting both competition and collaboration based on economic welfare and market failures. Many hurdles in collaboration are legal, and the challenge is finding the right research partners and managing the project and commercial outcome.

However, when there is a successful partnership, great opportunity can arise as in the case with Hornsdale Power Reserve (HPR). In response to events in 2016 and 2017 which resulted in a state-wide blackout and a load-shedding incident, the South Australian Government created an energy plan which accelerated their state's energy transition. In less than six months and with the backing of key partnerships with Tesla and Neoen, HPR's site became operational on 1 December 2017.

During the early stages, HPR faced challenges with the current market rules and regulations as they were not well suited to the integration of new technology but, a year on, HPR was a very successful project on many fronts. AEMO was pivotal in assisting with regulatory issues as a part of this innovative change.[65]

Communication about outages by grid operators and utilities have been used to assist managing demand via social media posts: convincing customers to use less energy during these periods. On a larger scale, some demand response programs include contracts in which businesses get paid for agreeing to reduce their use when required to do so. An example of design collaboration and innovation between industry and utility, coming up with a new idea in response to increased demand fluctuations, is shown in Box 4 below.

Box 4: Collaboration and innovation, providing solutions

Green Mountain Power (GMP), the distribution utility in the US state of Vermont invested heavily in storage as part of its plan to reduce system peaks, increase distributed energy and system resilience. They are working at both the utility scale and customer ends of the spectrum. One solution consists of the combinations of a solar farm and 4-megawat hour battery installation and Tesla powerwalls for customers. For individual customers within their service territory, they are offering Tesla powerwalls.

For a small fee a month over a ten-year period, or a one-time payment, the powerwall battery will be installed in the customer's home, providing backup power during grid outages. In exchange, participating customers agree to allow the distribution utility to share access to the powerwall to reduce peak energy costs.

'GMP partnered with Tesla to offer residential battery storage at $15/month, which the utility in July of last year said ended up saving customers $500,000 (across 400 customers) by reducing peak demand during a mid-summer heat wave. At the time, only 500 of the slated 2,000 batteries had been deployed and the utility is continuing to roll out the program.'[66]

Sustainability-oriented engineering in policy and practice

The third theme in this section focuses on industry solutions that promote betterment for consumers from the perspective of sustainable design. Institutional efforts to include coverage of factors such as climate change and conservation of natural resources within sustainable engineering solutions have increasingly become central to technical design practice.

These tenets have become standard practice advocated by Engineers Australia for some time, regaining trust in the provision of services as well as encouraging collaboration in the use of new techniques. A sea change in professional engineering policy and practice is also evident and timely.

In 2017, Engineers Australia released *Implementing sustainability: principles and practice*.[67] Key sections from this detailed policy document provide engineers with guidance and detailed information on sustainability, and suggestions as to how sustainability can be implemented in engineering project stages; initially from planning, to design, project delivery, management and overall stewardship.

The challenge of incorporating sustainability in design and manufacturing is that most of the environmental impact is locked in early as part of the design of a product and through technical specifications and related constraints. By the time the product gets to the market there is little influence on the overall design of the product, particularly in respect to consumers or users of a product.

Unlike traditional engineering efforts, sustainable engineering focuses on products that are designed for energy and resource efficiency; producing minimal pollution and limiting environmental impacts. A critical issue central to the report is how customer expectations, enhanced collaboration and sustainable and innovative engineering are critical for the future of energy in Australia.

Today, engineers are exploring more sustainable engineering practices and integrating sustainability, which requires the simultaneous achievement of these factors. Finding a balance between environment and ecosystems continuity; societal wellbeing and viable economies is indeed a challenging goal. These 'standards' have promoted three distinct lines of policy effort: a focus on sustainability and environmental issues and economic and social betterment across a scaled level of complexity.[68] Table 1 presents examples of the three types of sustainability-oriented innovation: sustainability-relevant, sustainability-informed and sustainability-driven.[69]

Table 1: Examples of sustainability-oriented innovation[70]

Type of sustainability-oriented innovation (SOI)	Detail and example
Sustainability-relevant	Sustainability-relevant Innovation (SRI), is the most broadly applicable but the least discussed. SRI is about discovering and leveraging hidden sustainability benefits after innovation. SRI can also lead to sustainability-informed innovation (SII) and sustainability-driven innovation (SDI) projects. Car sharing is a prime example.[71] Convenience, potential to reduce traffic congestion and cost savings were recognised value drivers of the innovation[72] but other business model components such as the use of electric vehicles in a car-sharing[73] approach had potential for a range sustainability benefits.
Sustainability-informed	SII is the most common form. SII aims to meet a clear customer need using a design informed by sustainability considerations. The sustainability constraints help drive a more extensive search for new materials, new processes, and new designs that can yield higher performance products. For example, Breakthrough Energy Ventures and Hydrogen Coalition represent high-profile partnerships that serve to advance innovation and the scaling-up of sustainable energy technologies.[74]
Sustainability-driven	SDI is another kind of SOI that innovates with the specific goal of solving a public problem. SDIs will tend to push the limits and be very specific in focus. An example of technology-based innovation would be renewable energy companies like SunPower[75], which are developing high-efficiency solar photovoltaic panels to mitigate the air and climate pollution associated with fossil fuels.

Procurement practices may reinforce the purchase of solutions that do not enhance integrated sustainability. Therefore, if the additional costs associated with the development of a more sustainable solution during the tender phase are not rewarded, suppliers with sustainable solutions may miss out on the tender.

This behaviour is typically SRI and only when there is a reward for sustainable solutions (built into sustainable procurement practices) will more manufacturers put funding into their R&D stages. The ACT government in seeking its 100% renewables 2020 target has emphasised sustainability requirements throughout the reverse auction process, and a major objective has been to encourage sustainability R&D investment in the ACT. If the purchaser includes sustainability requirements at the procurement phase, then companies will head towards sustainability-driven innovation. Once identified where sustainability is addressed, then the sustainable engineering principles can be applied.

Conclusion

Energy supply and use in Australia will continue to change. In the transition to a sustainable, affordable, secure and safe energy future there should be a focus on the following three goals:

1. Gain and maintain consumer confidence
   (a) The community's trust cannot be gained if utilities are being driven purely by for-profit motivation. To be successful, utilities must provide solutions which have a purpose, with a positive impact on all stakeholders.
   (b) Communication with consumers, using all media types, needs to be transparent on pricing, the sources of outages, restoration time and upcoming projects.
2. Encourage collaboration (consumers, technology innovators and service providers)
   (a) Encourage the formation of strategic partnerships and collaboration with a variety of companies to encourage the development of new innovative and sustainable solutions.
   (b) Openly reflect and share past successes and failures to reinforce trust and effective solutions.
3. Support sustainable service design and service provision
   (a) Reinforce and support the application of sustainability-oriented innovation in the electricity supply chain across the full engineering lifecycle.
   (b) Ensure that professional and continuing education on sustainability and how sustainability can be implemented in engineering activities is a mainstay of national professional standards.

The more we can embrace and prepare for the 'next steps' the easier change and transition will be. It is an exciting time to be in the power industry.

TECHNOLOGY OPPORTUNITIES AND ENERGY SYSTEM VULNERABILITIES

Jack Bryant

As we transition to a cleaner energy future, the integration of renewable energy sources into our power system will continue to increase. From a technical perspective, renewable energy generation is typically criticised owing to its different behaviour when compared to traditional fossil-fuelled generation. However, there are always inherent challenges associated with technological innovation. One of the biggest challenges to resilience within our power system isn't technological change, but rather energy policy and governance. A system-wide approach coupled with good governance is required to provide well-balanced solutions. This section examines some of the most recent policy challenges within our power system, whilst also exploring some of the exciting technology opportunities which can be used to overcome system vulnerabilities.

Adapting to climate change

Power systems across the world, including Australia's, have experienced a rapid change in recent times owing to environmental concerns and technological advancements. The Paris Agreement, signed in 2016 with the aim of limiting global temperature rise to below 2 degrees Celsius above pre-industrial levels, has been a catalyst for change.

More severe and frequent extreme weather events are forecast to be one such implication of climate change in the future.[76] From an energy perspective, Australia will require a more resilient and robust power system which has the capability of maintaining operation and recovering sufficiently from such disruptive events – or better yet, withstanding them without interruption to operation. As the issue of climate change has become increasingly pressing over the past few decades, the generation of energy has naturally evolved as moves to decarbonise energy systems have progressed.

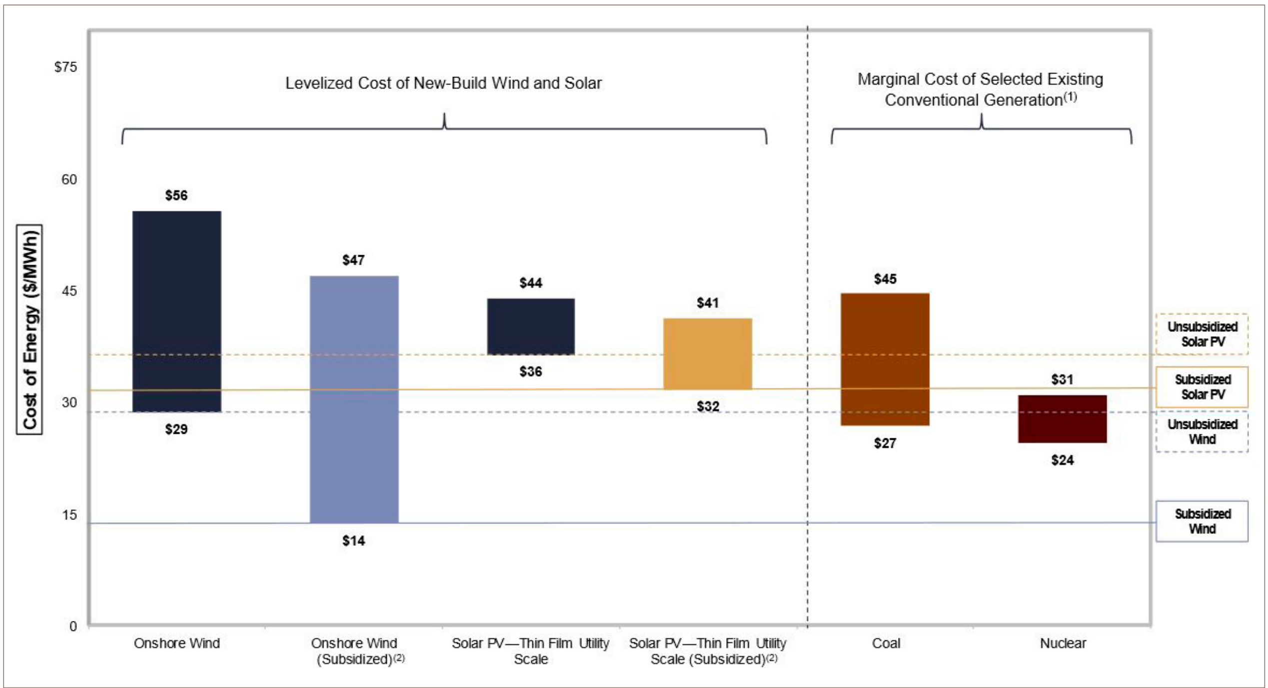
A recent assessment found CO_2 emissions from coal combustion responsible for over 0.3 °C of the 1 °C increase in global annual surface temperatures above pre-industrial levels, making coal combustion the single largest source of global temperature increase. Furthermore, with global electricity demand growing by 4% in 2018 to more than 23,000 terawatt hours, it is imperative that *cleaner* energy sources are integrated into power systems.[77]

In Australia, 2018 saw record-breaking investment in large-scale renewable energy projects, increasing from $10 billion to $20 billion, with 14.5 gigawatts of new generation under construction or financially committed by the end of the year[78] – a testament to the changing energy landscape we currently find ourselves in (see Figure 8).

A major driving force within the energy sphere is technological advancement. New wind turbines are increasingly physically larger resulting in greater capacity when compared to their older counterparts. Moreover, solar PV efficiencies continue to increase, with readily available panels now yielding close to 20% efficiency and those in the laboratory over 40%. The newest high efficiency low emissions coal plants can produce 33% efficiency. Energy storage devices, such as batteries, are also becoming increasingly used on the utility and consumer scales which is augmenting the dynamics of our power system. As these new technologies have matured, the economy of these *cleaner* sources has, quite naturally, improved.

Figure 8 shows this cost reduction in terms of 'levelised' electricity costs, defined as the price of the produced electrical energy, considering the economic life of the plant and the costs incurred in the construction, operation and maintenance, and the fuel costs.

Figure 8: Lazard's levelised cost of energy comparison.[79]



However, whilst renewable energy generation provides a range of benefits, technical challenges will be presented in the future relating to power system stability, operation, reliability and resilience. These issues will require careful management through the adoption of new, innovative technologies as well as sensible energy investment and policy.

Increasing penetration of renewable energy generation

As renewable energy generation containing different characteristics, dynamics and technology is integrated into the power system displacing fossil-fuel generation, maintaining and improving energy security and resilience must be a priority to ensure that the Australian power system is as robust and diverse as possible in the future.

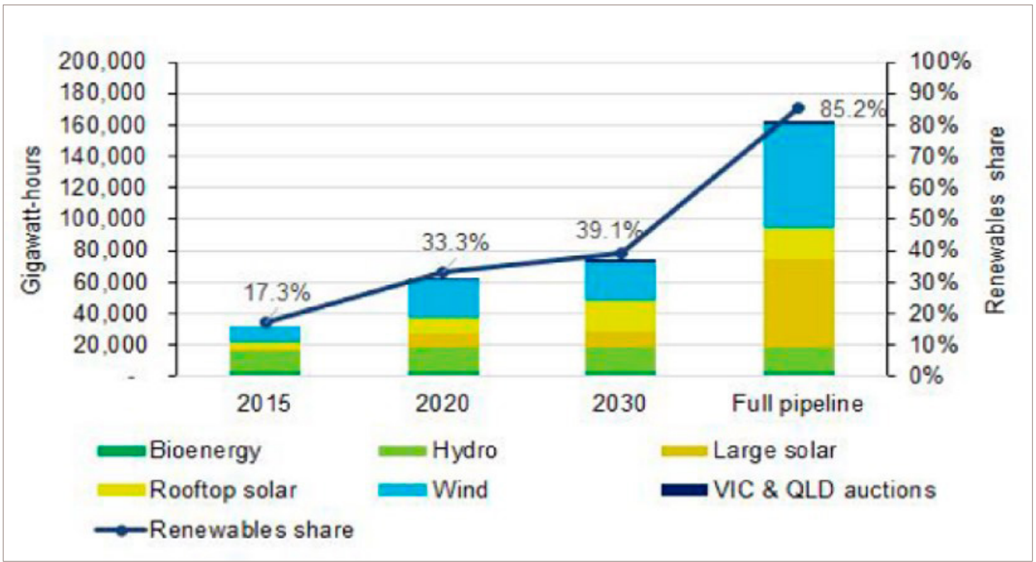
There are some key differences between traditional generation, such as coal and gas, and that of renewable energy generation (wind and solar photovoltaic). For example, traditional sources have a predictable power generation profile provided fuel is readily available. In contrast, renewable energy generation without storage is inherently variable in nature as it is governed by the natural environment. Therefore, importance will be placed on the forecasting of weather conditions in the future to reduce potential vulnerabilities.

Moreover, the machines found in fossil-fuel power stations contain large amounts of rotating mass (and thus, inertia) which provides continuity of current and stabilisation to the energy system. The property of inertia is championed by sections of industry as a factor providing significant advantage of traditional electricity generation systems over the intermittency of supply, which is often a feature of renewable sources. Renewable energy generation contains little to no inertia, which can add instability to a power system when generated in large quantities. In the future, this is one key issue which will need to be managed as the system will be more sensitive to changes in operating conditions.

The provision of supporting services that control technical characteristics of the power system such as frequency and voltage are referred to as ancillary services. These services, which (very importantly) provide necessary system control, are currently delivered predominantly by traditional fossil-fuel generation. Issues will likely arise in the future regarding how to provide and manage these services in renewable-rich power systems. New types and configurations of these services may also be required to cope with technological change to ensure energy security and resilience.

Interestingly, the National Energy Market has suggested 33% of Australia's electricity could be provided via renewable sources by 2020, growing to near 40% by 2030 (see Figure 9). Such projections emphasise the need for supportive policy and governance arrangements as they will play a key role in shaping Australia's energy future by influencing investment, driving innovation and managing power system operation. It is crucial that a balanced approach is applied whilst considering the system as a whole.

Figure 9: Renewable energy generation historic and forward estimates for the NEM.[80]



Dealing with different generation profiles

As wind and solar power are governed by the natural environment, the power generation profiles of these sources are inherently variable in nature which can lead to large power variations being injected into the system – challenging the continuity of energy supply. In the future, large-scale integration of these sources into existing supply coupled with more frequent and extreme variations in weather has the potential to magnify this vulnerability even though battery storage is a key infrastructure component. Consequently, accurate forecasting will be vitally important to aid in the power system planning and dispatch process.

In Australia, recent trials have begun to improve short-term forecasting and aid in ensuring power system stability and lower energy costs.[81] This technology will support the integration of a broad range of energy sources providing technical, social, and environmental benefits whilst bolstering system resilience.

Power system governance

The retirement of Australia's fleet of coal-fired generating units in the future will undoubtedly challenge the provision of ancillary services in the NEM. The first challenge will relate to technology – *how can renewable energy generation provide these important services to the power system?* Following this, the next issue will relate to management and coordination – *how can the services be optimally managed and coordinated?*

Use of advanced control methodologies within renewable energy generation will play an important role in ensuring grid stability in the future by allowing niche technology suppliers e to provide of ancillary services. Furthermore, *demand response* may be increasingly used where consumers are remunerated for adjusting their energy consumption to assist in stabilising the system. This is extremely beneficial on very hot days when the power system is stressed and may be even more necessary in the future as the frequency of extreme weather increases. In terms of resilience, demand response assists in avoiding load shedding, which can cause indiscriminate vulnerability.

Innovation will be key to finding new ways to provide ancillary services with the changing energy mix. A standalone technical approach will not suffice – being forward-thinking and not averse to embracing change will be crucial if Australia is to have a diverse and robust energy system. The Hornsdale Power Reserve in South Australia is a good example of the innovation required[82], which must continue unabated in all forms. However, such innovation requires risk-taking leadership – particularly when a clear energy policy doesn't exist.

The project, which (currently) contains the largest lithium-ion battery in the world, demonstrated that new technologies can be used to improve system resilience and energy security. Fast response times and flexibility in ancillary service provision are just some of the evidenced benefits from the development.

Within the technical community, renewable energy generation is sometimes met with scepticism when considering energy resilience and power system stability owing to its dynamics and limited ability to contribute to system inertia and ancillary service provision. However, this generation has the potential to provide some of the same services as traditional generation in an accurate and *faster* manner.

One of the biggest challenges facing the Australian power system at present isn't addressing the technical challenges presented when integrating these sources, but the policy, rules and frameworks which govern and influence power system operation.

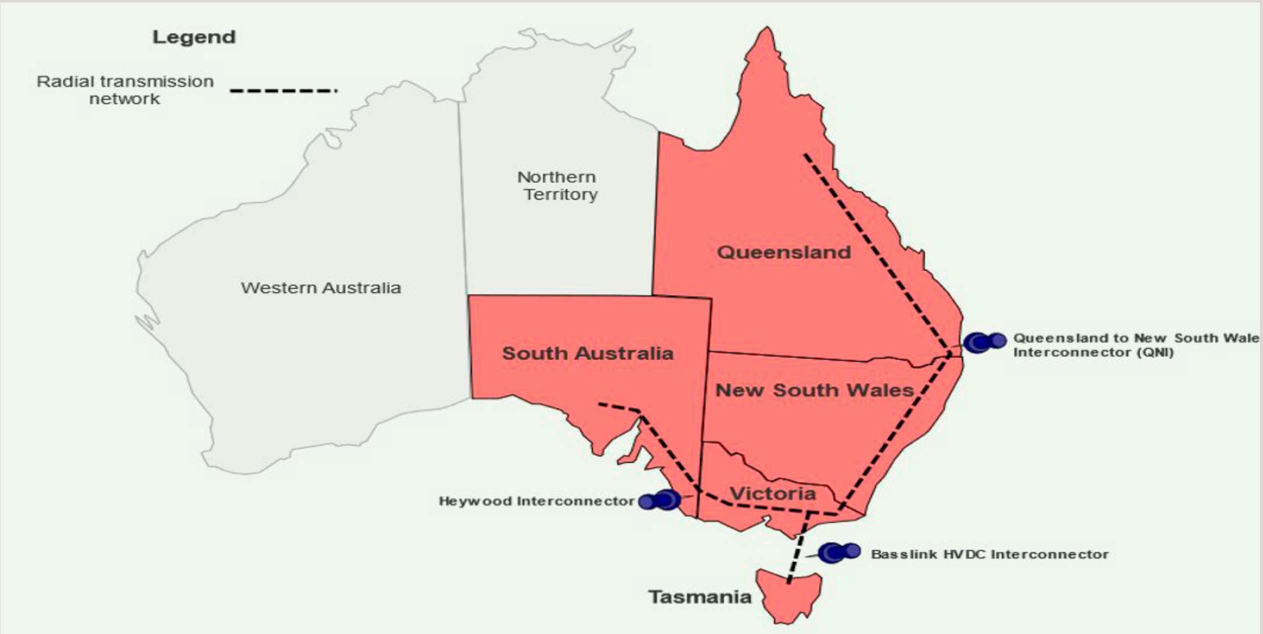
In the Australian context, the Frequency Control Frameworks Review[83], carried out by the AEMC, highlighted the power system security challenges being presented by the changing energy mix, as did its System Security Market Frameworks Review[84] and the Finkel panel[85] in its review. The reviews illustrated the importance of sound governance and policy in relation to the energy system. Box 5 describes the 2018 system separation event which demonstrated weaknesses in governance frameworks leading to instability and system vulnerabilities.

The technical challenges presented by large-scale integration of renewable integration can be overcome – having such challenges is inherent with any technological change. Vulnerabilities clearly exist at present which could potentially worsen as rapid technological change occurs within the energy sector.

In the future, there may be a need for new analyses of consumer needs that match widespread changes in technology that utilise fast frequency response and rapid response times (for example, battery energy storage systems). A lack of forethought and consideration of the technical needs of the power system will result in severe vulnerabilities in the future. It is important to ensure that the technical requirements of the power system are prioritised.

Box 5: Australian power system separation event in 2018

On 25 August 2018, a serious power system event occurred when lightning struck a transmission tower supporting multiple lines of the Queensland-New South Wales interconnector. The reaction of the power system following the lightning strike resulted in the electrical separation of the Queensland and New South Wales power systems. A short time later, the South Australian power system separated itself from Victoria owing to rapid changes in conditions on its interconnector. System separation is a major event that requires rapid response as it can cause uncontrolled events leading to widespread blackouts.



The Australian Energy Market Operator (AEMO) report, *Final report – Queensland and South Australia system separation on 25 August 2018* highlighted that these events provided strong evidence of a reduction in power system resilience.[86] The report drew comparisons with the previous Queensland separation event in the NEM which occurred on 28 February 2008. A smaller loss of Queensland – New South Wales power transfer (870 megawatts versus 1,091 megawatts) resulted in more severe power system changes when compared to the 2008 separation event – load shedding occurred, and additional regions separated (South Australia) during the 2018 event which didn't occur in the previous event.

The 2018 system separation event was significant as it highlighted that insufficient control of system frequency currently exists. A lack of primary frequency response from many generators and the distribution of frequency control ancillary services reserves across the National Electricity Market (NEM) at the time of the event were two key factors identified by AEMO for the reliance on load-shedding to rebalance the system.[87] Significant questions remain regarding the adequacy of the current market-based system given these two factors.

The primary recommendation of the investigation was to improve primary frequency control. How best to achieve improvement remains to be seen. A recent rule change request[88] submitted to the Australian Energy Market Commission proposes one such method by mandating the provision of primary frequency control in the NEM – opening discussion regarding primary frequency control to catalyse change within this space. Going forward, rule change requests will be imperative in driving necessary reform whilst ensuring transparency and considering all stakeholders' points of view.

Overall, the power system separation event highlighted the importance of ancillary services within the NEM and the need for sound governance which prioritises the technical needs of the power system to ensure necessary energy resilience is achieved. This need will be increasingly important in the future due to the changing energy mix.

Data: the oil of the 21st century

Data is becoming increasingly important in the world in which we live, predominantly due to technological advancement and the progressive digitisation of industries, including the energy system. *Big Data* is a term used to describe large amounts of structured and unstructured data. Within power systems this resource is becoming more common and can be attributed to the digitisation of control and communications devices used in the energy systems. For example, smart meters are increasingly used to take digital measurements of consumers' energy consumption. Moreover, meteorological data is used in the forecasting of renewable energy generation. As we navigate the fourth industrial revolution, termed Industry 4.0[89], the application of transformative technologies will increase, as will the amount of functional data generated or becoming accessible.

Data Analytics involves the storage, management and processing of this data into a usable and meaningful form for analysis to provide insights and influence decision-making. It allows for improved forecasting, optimisation of power systems, enhanced control and resilience of energy supply as well as systems optimisation and reducing costs. The application of machine learning and artificial intelligence techniques to find correlations and patterns within data will be increasingly utilised in the future, influencing asset management and investment options. In turn, this will affect resilience across and within systems as vulnerabilities can be highlighted more easily and then dealt with.

An increase in digitisation using large amounts of networked devices creates emergent risk exposures in the exacerbated by cyber-security vulnerabilities. Additionally, the increased amounts of data collected enhance the importance of governing access to the data from a privacy and security perspective.

The Electricity Network Transformation Roadmap[90] developed in partnership between Energy Networks Australia and the CSIRO in 2017, acknowledges the current, and future, rapid changes projected within the Australian power system over the next decade and highlights the need for 'close focus on physical and cyber security' in the development of new systems to support a diverse range of generation. Cyber security is imperative to overall system resilience and continuity. Systems that do not protect assets or inherently provide privacy lack resilience and are vulnerable to cyber-attacks. Such security capabilities must be built into the system during its design.

Microgrids – redefining power system architectures

A microgrid is, generically, a small-scale power grid that operates independently or collaboratively with other small power grids and can operate connected to and synchronous with the traditional wide area electricity networks. Conceptually they seek to decentralise power generation and alter traditional power system architectures. They are conventionally linked to with the ability to operate autonomously (islanded) as required.[91]

A range of benefits can be realised from such architectures, including increased reliability, lower costs and increased capability of supporting higher penetrations of renewable energy sources. The implementation of microgrids is one way to redefine power system architectures.

The advent of peer-to-peer trading and blockchain technology

The microgrid concept has the potential to catalyse change within energy trading. Peer-to-peer trading allows excess energy from local distributed energy resources to be traded with nearby customers/consumers. This has the benefit of potentially eliminating the need for a middleman, increasing flexibility, reducing costs and improving transparency. The use of blockchain technology can be used to keep records of energy transactions in an encrypted manner on a decentralised digital ledger. New York based start-up company TransActive Grid used secure Ethereum Blockchain software within its innovative new peer-to-peer transaction platform that allows private consumers to purchase excess electricity from each other.[92]

Applications within developing countries

Approximately 13% of the global population still lacks access to electricity. The United Nations' 7th Sustainable Development Goal seeks to 'ensure access to affordable, reliable, sustainable and modern energy'.[93] Microgrids provide many possibilities to improve people's quality of life by providing better access to electricity, and reducing reliance on the use of coal, wood and charcoal for cooking and heating. Practical implementation has occurred within challenging terrains, including high-altitude communities in Nepal, areas of East Africa, India and the Russian Artic[94], highlighting their robustness and flexibility. Box 6 provides an example of how microgrids can alleviate energy poverty.

Box 6: Alleviating energy poverty

Almost two-thirds of the population in Sub-Saharan Africa lack access to electricity.[95] Microgrids have been shown to be a feasible way in which to provide access to electricity in an economical way. In Zambia, the rural electrification rate is approximately 3.3%, with grid extension projects seeking to help meet the government's target of 51% electrification by 2030.[96] However, extension of grids in such countries can be expensive and potentially suffer from unreliability – microgrids provide one such way to overcome these issues.

For example, in a Nigerian off-grid community relying on diesel or petrol-driven machinery, the cost of running two grain-milling machines can be up to $0.63 per kilowatt-hour (kWh). However, a microgrid powering another nearby community can deliver power at about $0.40 per kilowatt-hour.[97] The second community benefits from increased energy security and resilience – improving the quality of life for its inhabitants. The concept of microgrids has the potential to provide major positive impacts for millions of people worldwide.

Closer to home, microgrids would be useful in areas such as Papua New Guinea, the South Pacific and Indonesia. Such opportunities again tie back into good policy setting – Australia's Pacific engagement[98] already active in expanding electricity networks could be strengthened through such means as it supports a more resilient region.

An unelectrified rural village in the Southern Highlands, Papua New Guinea.

An Australian perspective

Australia's NEM runs on one of the world's longest interconnected power systems. As the country's population is heavily concentrated near to the eastern and southern coast, the power distribution system is a radial design which, while standardised and well suited to the length of the system, presents vulnerabilities owing to its lack of interconnection or meshing. Microgrids are one method to improve resilience within our power system as there is inherently less reliance on transmission infrastructure. For example, the decentralised nature of microgrids is favourable for reducing risk associated with inclement weather events which have the potential to threaten energy resilience.

Numerous microgrid trials and pilot plants are becoming more prevalent across the country. One such example is AusNet Service's Mooroolbark Mini Grid Project[99] which seeks to use more active control of solar power, batteries and the grid to create efficient power storage and consumption and operates independently of the main power grid. Further trials in the future will be important to allow the technology to mature.

From challenges to opportunities

The change we are currently undergoing presents a range of opportunities, and with it stimulating technical work which provides a range of environmental and social benefits. New jobs exist in technical installation and customer servicing now which didn't exist previously.[100] As the rapid pace of change continues, the education sector will also have to keep up to ensure the youth of tomorrow are well equipped to tackle tomorrow's problems and challenges.

Australia will face a future where the energy transition continues along with a range of challenges inherent with the implementation of any new technology. Solutions to these problems requires active and progressive innovation. Aversion to these challenges will produce sub-optimal results when considering energy resilience, as well as the environment, economy and society as a whole.

A system-wide approach is not just about technology but is enabled by good governance as a necessary requirement to support both balanced solutions and out-of-the-box thinking; a critical ingredient to the innovation required. Coupled with these factors, a progressive approach to energy investment and policy will allow for increased energy resilience whilst embracing the integration of a wide range of new technologies within all levels of our energy system.

Arguably the growing need for these changes coexist with what many perceive as slow or ineffective policy direction from mainstream elected government. This may not actually be the case. Under the direction of the COAG Energy Council the Energy Security Board (ESB) established an initial Integrated System Plan (ISP) in December 2018 with several detailed recommendations for supporting transition to a lower emission and more distributed generating setting.[101]

The ESB is currently progressing consultation on a study paper that proposes a high-level structure for a regulatory framework to give effect to the reforms referenced in the action plan. The objectives, principles and high-level process would be set out in the National Electricity Law and Rules, with the detail to be set out in guidelines to be made by the Australian Energy Regulator.

The AEMO published its first (developmental) ISP in July 2018 covering a 20-year outlook for the transmission needs of the NEM.[102] The ISP and variations that will follow address a key recommendation from the Finkel report *Independent review into the future security of the National Electricity Market*.[103]

The ISP identifies and prioritises steps to optimising a least-cost portfolio of integrated system investments intended to sustain technical reliability as well as affordability within the energy system as it transitions. This is an important part of the orderly transition needed in the NEM.

While these signs show that change is occurring, Australia may need to do better and move faster to support the integrated system-wide changes that are needed. In the near term with another hot summer on the way, the Australian Energy Market Operator will continue to apply crisis management where needed and hopefully mitigate the potential for extreme outcomes from major disturbances to our electricity supply.

A NEW NARRATIVE AND OPPORTUNITY – NEXT STEPS

Trish White

Personal reflections

It helps to understand the past when you are navigating the future. As Engineers Australia celebrates its centenary and the engineering accomplishments[104] that have shaped our nation over the past 100 years, it is instructive to contemplate the Australian outlook back in 1919.

At that time, emergent from the battlegrounds of World War I, a group of forward-looking engineers decided to establish the Institution of Engineers Australia. It was in the wake of enormous global social and technological disruption. The engineers of that time knew that if Australia were to grasp the opportunities opening around new technological advances and a more connected world, it would take a well-educated and trained engineering profession to drive the innovation and turn those good ideas into practical benefit for the country. That motivation remains today with Engineers Australia's purpose, enshrined in the organisation's Royal Charter[105]: 'to advance the science and practice of engineering for the benefit of the community'. Engineers are involved in the research, design, production, operation and maintenance of many things that we take for granted in our everyday lives. While many think engineering is all about the technology, the value an engineer brings is rooted in his or her impact on people's quality of life.

Over the past 100 years, Australian engineering has underpinned productivity increases and provided new solutions and infrastructure to afford Australia much economic success. Engineering advances in the provision of electricity fuelled mass production in factory assembly lines, with growth that rapidly increased Australians' standard of living. Today, electricity is seen as an essential service, powering so many aspects of our lives and underpinning our economy – from our buildings, water networks and transport systems, to our computers, smartphones and telecommunications, energy supply is at the heart of our industries and our homes.

In 1919 there were no interconnected electricity grids, local electricity demand being supplied independently by small generating stations over lower voltage distribution systems and located close to their load centres. The development of the Eastern Australian Interconnected Electricity Grid brought an interconnected approach that allowed central management to allocate power to all reaches of the network, to meet dynamic load requirements and share reserve generating capacity.

Box 7: Eastern Australian Interconnected Electricity Grid

The synchronous Eastern Australian Interconnected Electricity Grid is one of the longest electricity grids in the world and runs from Port Douglas in northern Queensland to Port Lincoln in South Australia, covering an end-to-end distance of more than 5,000 kilometres, and 43,000 kilometres of high voltage transmissions line.

Although that grid has served the country well, recent failures resulting in widescale power outages have brought into sharp focus the need for different strategies moving forward. Transition to a modern mix of generation sources and the adoption of emerging technologies and processes pose challenges for the design of future energy systems with embedded resilience.

With their feet firmly planted in both the theoretical and the practical, engineers continue to shape the world in which we live as they use their creativity to reach for the possibilities and deliver that which has never been. The authors in the preceding chapters of this report look beyond the conventional wisdom of 100 years of fine engineering progress in the supply of energy to Australians, to consider a new narrative and opportunity that so far has not emerged in the confusion and ideology of the current energy debate.

Five major themes arise from this: transition, innovation, community, governance and leadership, and I will add a sixth which hasn't been discussed – the need for science, technology, engineering and mathematics (STEM) education.

Themes

Transition/transformation

Energy transformation is a societal consideration. No-one owns it, but all are affected. Like in any transition there will be winners and losers, new interests and established players.

The current political debate attempts to convince us that the solution is to pick a side – fossil fuel industry or renewables 'new energy', tackle climate change or reduce power prices. To the global call for greater action on climate change through energy policy change, how can Australia turn a blind eye to the impacts on future generations? Yet how can we afford to dismantle billions of dollars of investment in traditional power generation overnight and turn a blind eye to the consequent loss of jobs in dependent communities? Given that sunk costs are a poor basis for future investment, though, and renewable energy systems will also bring jobs, how can we know when the right time to shift is? It is a tricky balancing act.

Then there are the disruptors. It's an attractive business strategy, often requiring much less capital investment than was required for the incumbent players. Are the barriers to market entry diminishing as adoption of new technology gathers pace in this era of the fourth industrial revolution? Also impacting is reduction in the cost to analyse the big data that is gathered from diverse and distributed energy sources interlinked in the physical or the digital world. We can expect changed social and business structures to result.

In such an environment, governance and regulation will lag technological innovation. This is acceptable until disruption reaches a point that puts communities at risk. Energy is critical infrastructure that will always require regulation. Earlier Alan Reid gave the example of the impact of the virtual power plant 'revolution' that turns local communities into self-determining managers of their own power supply and demand. With lagging regulation of this new phenomena, issues like network frequency management are not addressed. As digitalisation of distributed energy systems is used to automate more operations, and the complexity of these highly networked 'systems of systems' increases, resilience needs to be designed into the way the systems integrate with each other and into the roles and responsibilities of the humans that interact with them.

Resilience engineering is a frame for design but also affords a mechanism to tie a global objective to distributed assets, in a way that allows rapid response to fast changing conditions. It maps functionality across to society in a methodical way that is not captured in engineering standards. Not just in the way digitalisation might automate manual tasks; resilience involves much more than reliability. It provides for maintenance of desired levels of service and recovery without irrecoverable consequences in the face of attack or disturbance – requiring an understanding not only of the performance of the systems but also of the way humans and machines interact and their actions and responses are prioritised. To be able to maintain the systems' state of awareness in these complex modern environments a semi-autonomous framework is required that tailors information to customer need in order that their responses can be relied upon to assist, rather than hinder, resilience of the system.

Building trust is also key. In the confusion of transition without adequate planning, vested interests and possibly advocates of new technologies may spin pseudo-truths using data that has been cherrypicked in favour of one solution or ideology. We live in an age of populism, where many are ready to believe fake news if it accords with their predetermined views. As the trusted voice of the engineering profession, Engineers Australia speaks, and encourages its members to speak, from an evidentiary base. It is an important element of community trust in the profession.

Framing the narrative for this new era of energy supply involves taking an attitude that is realistic and optimistic, but not naïve. Workforce displacements set alongside large numbers of changed and new jobs lend to community confusion about whether the impact of new technology adoption is a net benefit or loss. To successfully navigate our preferred future, we need to ensure we address the following important aspects in a coherent roadmap and transition plan.

Innovation

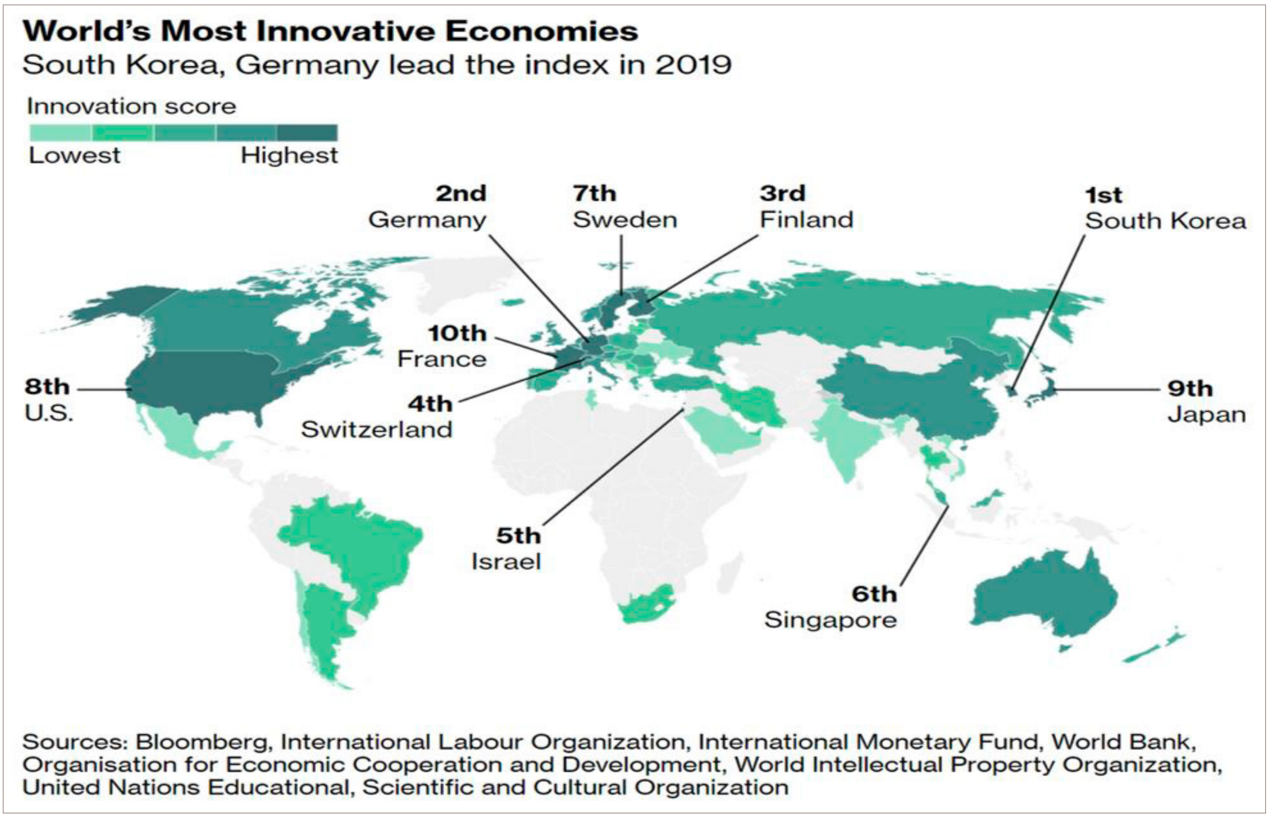
In a world that continues to become more interconnected and complex, innovation is becoming more and more critical to national economic performance, job creation and standards of living. As fundamental drivers of our long-term productivity growth wane, we need to enhance our capacity to generate value from our ideas and other sources of inventiveness. Rather than being fearful of the disruption and change that technology will inevitably bring to all countries, Australians need encouragement to see in these transformations the seeds of renewed growth that can sustain our enviable prosperity and quality of life. There is likely to be a strong advocacy role for Engineers Australia nationally on this point. The innovations appearing in many endeavours across disciplines, such as medical, biotech, robotics, advanced manufacturing, are leading to exciting technology applications and new business models along with both dramatic improvements to quality of life and some inevitable loss of jobs or pressure for workforce relocation. Advances in sensors and data analytics, advanced materials, automated and assistive technologies, virtual and augmented reality are gathering pace – all of which are likely to enhance the creation of new technical roles.

In his 2015 launch speech of the Australian Government's Innovation Agenda[106], then Prime Minister Turnbull's appeal to Australians was to look optimistically to the strength of our ideas: 'Our innovation agenda is going to help create the modern, dynamic 21st Century economy Australia needs … Unlike a mining boom, it is a boom that can continue forever, it is limited only by our imagination, and I know that Australians believe in themselves, I know that we are a creative and imaginative nation.' After the 2016 election, it was considered that this message failed to capture the Australian imagination. It is perhaps not surprising then that the 2019 Bloomberg Global Innovation Index identifies that Australia has slipped to 19th position[107] out of the top 60. There is some distance between the promised rhetoric in 2015 and where we find ourselves today.

Fundamentally, Australia has a reasonably strong research system but we do less well when it comes to commercialising our ideas. ASPI recently demonstrated that our national research and development spend as a share of GDP is low and still falling.[108] We don't have enough companies producing innovative new-to-market products and services to generate the sort of growth seen in countries like Korea and Germany (see Figure 10). Sadly, the term 'innovation' has drifted to the background, falling from political favour. Until there is better diagnosis of the problem, innovation policy will not be able to adequately address Australia's need to improve on this front.

Energy innovation is about more than renewables and storage. Innovative thinking applied across the entire ecosystem is required.

Figure 10: Global Innovation Index



Governance

In this new era of distributed energy systems, it is important to achieve a balance between the legal rights of existing players under the current regulatory environment and those of the disruptors whose additions or displacements might act to challenge the resilience of the infrastructure. Managed well, the result is a reliable and resilient energy future. If we do not get it right, we will lag other nations with our industrial, economic and environmental future suffering from our uncertainty.

Arising out of recommendations of the 2017 Finkel report[109] into the future security of the nation's electricity market, the Energy Security Board[110], was established to support the Australian Energy Regulator[111], Australian Energy Market Commission[112] in the National Electricity Market. However, in the gas, liquid and hybrid fuels and hydrogen sectors there is more work to do in order to provide for Australian businesses the standards and environment that will allow them to optimise their supply chains, eliminate inefficiencies, improve productivity and reduce risks. It is not enough to wait for a shock like the 2016 South Australian 'Black System Event' that led to the Finkel review. Proactive leadership within COAG is the starting point.

For this we need a cohesive and shared strategy, along with provision of the infrastructure that will allow everyone to do their best work. The lack of clear emissions policy for energy puts a brake on energy investment. Clearly this has been a problematic and divisive across all governments in the last decade. The longer this continues Australia's competitiveness across all sectors of industry will suffer and there will be less confidence in an orderly transition.

While there seems to be a lack of certainty on emissions policy nationally there are signs that support for distributed energy resources is central to the thinking of many consumers and industry participants. In this sense consumer expectations and industry willingness to service their customers are highly likely to build momentum to embed significant transformation into the future.

In their 2017 Electricity Network Transformation Roadmap[113], CSIRO and Energy Networks Australia suggest that five thematic lines of development will be central to Australia's future energy system:

- Customer oriented electricity – Customers are placed at the centre of Australia's future electricity system and empowered with greater choice, control and autonomy while enjoying the security and benefits of a grid connection
- Carbon abatement – Incentive-based policy options capable of enabling least cost carbon abatement
- Incentives and network regulation – A fairer system through active implementation of network tariff and retail pricing reform and modernised regulation and competition frameworks
- Power system security – Electricity networks and the power system are enabled to support an expanding diversity of energy sources, at both the customer and transmission levels of the system
- Intelligent networks and markets – An expanding range of new energy technologies and services are supported while continuing to efficiently provide a range of traditional electricity services.

Given the cross-border nature of energy networks and the global nature of our industries' value chains, the role for Commonwealth government in driving this agenda is key. However, our governance system involves state and local governments as well as the COAG and ministerial council mechanisms; it involves government departments and elected local government representatives all having a role and opportunity to inject vested interests into the planning and delivery of projects and the underpinning infrastructure. Our governance system needs the resilience to limit and deal with disturbances of that nature as well. It also needs to avoid falling too far behind the pace of industry change.

Community and customers

For most of its life, we have thought about our energy grid system with respect to one-way flows of power from generator to user. What does two-way traffic offer for enhanced industrial and domestic operations? Also, with the merging of transport, energy and telecommunications applications, what possibilities are open to us to extract better value and functionality from those systems?

Technologies like artificial intelligence, robotics and virtual reality combined with innovative business models offer businesses the opportunity to enhance their value proposition to customers and offer customers the opportunity to tailor their interactions with businesses to their own needs. Clever analytics of data collected from networked machines and people are the tools to make these tailored solutions happen, but businesses need to understand, firstly, what information is of best use and secondly, how to guarantee the security and privacy aspects associated with it.

There is a certain level of mistrust by Australians concerning major utilities, especially when access to social media allows the social consequences of energy poverty, for example, to be immediately visible. This makes the utilities companies vulnerable to disruption by new smaller players offering a more personalised service. The Energy Charter launched earlier this year by the Energy Council of Australia is a beginning of an industry-wide change in support of greater transparency and support for genuine customer outcomes and industry accountability to achieve them.[114]

The smartest companies and businesses value collaboration and partnering with other organisations, sometimes outside their sector, in order to deliver their customers what they really want. They recognise the advantages of being part of an innovation ecosystem and use those collaborations as a way to get closer to their customers, with the strength of the customer relationship inoculating them somewhat from the disruptive disturbances thrown their way.

Leadership

Transition is not a time for tweaking the rules and escaping to past methodologies. Leadership underpins orderly transition. It will take a cadre of leaders focused on a comprehensive plan of action, including politicians but also importantly, it will require strong community and industry voices with the courage to take on responsibility for seeing a realisation of the benefits of the transition.

I am reminded of the incisive leadership shown by that great engineering leader, General John Monash, as referenced earlier by Clare Paynter. In setting up the state Electricity Commission of Victoria, Monash sought a solution to make electricity more than a domain of the rich. It used brown coal, with a technology from then-enemy, Germany. He gained enormous loyalty from the workers, and the critical investment he made in people to follow through and build the system after he left, stood out.

Education and STEM

The environment in which engineers will operate in the future will have changed remarkably from that of our current time. For example, in its 2018 *The Future of Jobs Report 2018*[115], the World Economic Forum's survey of global companies employing 15 million staff pointed to half of all human work tasks being automated by 2022. Further, the 2019 United Kingdom Royal Academy of Engineering's report[116] *Engineering skills for the future* stated that:

> The quickening pace of technological advancement and its effect on our society, heighten the need to ensure that all young people develop the broad range of technical, communication and problem-solving skills that will serve them and our society over the coming decades, both as wealth creators and as citizens. This includes nurturing practical skills and creativity, alongside the development of enabling skills such as complex problem solving and critical thinking and professional behaviours such as ethical consideration and environmental awareness, increasingly identified as critical by employers.

In Australia, employment is increasingly being concentrated in service-based tasks that will require a combination of technical and 'soft skills'. The Australian Institute of Company Directors notes that specialists will be working increasingly in cross-functional teams, with higher order soft skills such as empathy, professional ethics and emotional judgment likely to be valued. Pure technical ability will no longer be sufficient; creative and interpersonal skills will be required even in domains which were once predominantly technical. Domain expertise will still be valued, although demands for specific skills are likely to fluctuate and changing skills requirements will lead to greater diversity in the workplace. The rapid pace of change means that some skills will go out of date quickly.

Universities are responding by integrating those skills across their curricula but the gap between skills demand by employers and the pace at which universities can adapt their courses is cause for frustration. Many universities are investigating the introduction of micro-credentials, to hasten, or supplement, their response to employer skills gaps. These are of short duration, are 'stackable' toward earning another advanced credential, and deliver authentic recognition of knowledge and experience in a specific field of endeavour. Several new pathways are emerging, like the recent Industry 4.0 Higher Apprenticeships model[117] offered in a collaboration of industry, federal government and university to rapidly upskill in priority areas of growing employer demand.

Engineers Australia is the body that determines professional accreditation of all university engineering courses in Australia, based on benchmarking to international standards. It is currently collaborating with the Australian Council of Engineering Deans on projects looking at the future of engineering and engineering education in Australia. Such efforts in proactive accreditation might also assist in reducing lag in supply of specialist technical skills required to capitalise on the use new technology in innovative ways.

A consideration in that work is how to encourage more students, particularly female students, to study the STEM subjects that feed entry into the engineering profession. Attraction of females to engineering and their retention is a major issue for employers, with recognition that a more diverse workforce enhances creative problem solving to deliver to customer expectations. Employer demand for female engineers was evidenced last year when, for the first time, female engineering graduate salaries outperformed those of their male counterparts. Currently women make up approximately 12% of the Australian engineering work force.[118] There's a long way to go however, with only around 6% of high school children studying the advanced maths required for university engineering entry.[119]

The challenge of the narrative

Transition has never been easy and will not be easy again. There will be winners and losers. Key to understanding the new narrative is that transition demands difficult decisions that won't please all constituents and all businesses – 'spin' from vested interests must not be mistaken for the voice of the community; we must not be distracted from the nation's best interest. The narrative needs to be backed up by strategic planning that promotes success for the nation, understands our place in a changing geopolitical world, and in this age of corporations owning increasing share of the wealth generated through held information, we also need a strong focus on the public good.

The way ahead

Importantly, we need a strategy for the transition, a roadmap for the energy industry that can progress the work required on technological adoption and changed business models, on standards, on network security and on the future of work in the industry. We also need to put in place governance mechanisms that allow for productive collaboration instead of ideological bargaining. Action needs to be taken on matters not discussed here; for example, the relationship of our energy supply to future transport and communications options and dealing with climate change. And a new narrative that focuses on resilience and essential service of our energy supply is required to shift the debate from the narrower aspect of pricing and business profit.

Up until now our power supply and our system of liquid fuel supply have been treated as operating independently. In the era of the Internet of Things, this will not be sufficient to describe the inter-relationships between these sources of energy and serve our needs into the future. We need to reconceptualise both of these from a 'systems of systems' viewpoint to release the possibilities unlocked by new technologies and business models, and overlay them upon a digital platform that incorporates both the machine-to-machine and machine-to-human connectiveness that is now possible with the Internet of Things and use of advanced data analytics. We also need to lift the narrative from the level of ideological debate about fossil-fuel vs renewable sources of power, to the level of practical security of supply.

The Australian E-NET

I introduce the idea of an Australian E-Net – just as the idea of the 'internet' connected digital machines in a two-way network, this 'energy internet' distributes power and liquid fuel in a cyber-physical network that operates in more than one direction. This is a new framework for conceptualising our energy systems, that allows distributed power sources and networks to behave in accordance with prioritised, adaptive goals derived from direct real-time feedback about consumer need. It brings together power supply networks that flow in more than one direction (with a mix of power sources and storage technologies), ensures security of our liquid fuel supply system and is framed in a context of a digital platform akin to the Internet of Things.

Engineering expertise and collaborative planning to energy-proof communities and businesses

In the context of an Australian E-Net, we can consider the supply, transmission, storage and consumption of energy in a way that recognises the interconnected dependencies of technological innovation, resource management and security, demographic shifts and effective governance. However, increased complexity of the electricity system requires technical expertise to avoid risking unnecessary costs being borne by consumers, as market-based rules are not sufficient to balance the instantaneous supply required. Earlier Jack Bryant described the nature of frequency stability where conflicting market network methodology has compromised good engineering and operational practices. This report calls for policies determined by good engineering practice and forethought, to identify investments that can best unlock value of existing and new sources, and to expedite collaborative planning that can energy-proof our communities.

Recommendations

This section makes five recommendations:

- That the Energy Security Board sustain a focus on mapping expertise for near term and future needs – thus ensuring recognition of sustained and timely access to technical capability as a driver for effective planning of the increasingly complex electricity system.
- That future system planning be facilitated by the formation of national work streams to develop appropriate solutions for the Australian context that achieves both coordination and optimisation at a macro level, whilst also coping with distributed energy networks. These streams include standards (to ensure interoperability); technology adoption and new business models; cyber security; and future workforce development needs.
- That the COAG mechanism be reinforced to integrate and improve federal, state and local government planning and procurement processes to foster better and more cost-effective choice of new technologies, models and energy generation options.
- That cooperative research investment be made into our national universities and CSIRO to harness the power of artificial intelligence to promote energy independence, efficiency and resilience for consumers.
- That the federal and state governments deliver improved policy and funding action in the 'E' of STEM (Engineering) through facilitation of the education and skilling, retraining and upskilling of the future workforce and by a mapping of current workforce capacity to core capabilities required by an Australian E-Net.

The challenge of achieving energy resilience in Australia is best served when we integrate approaches of engineering, business and social solution. The views and ideas expressed by a new generation of engineers in this report bode well for the collaborative and creative thinking essential for us to choose the right path forward.

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ACRONYMS AND ABBREVIATIONS

AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
ARENA	Australian Renewable Energy Agency
CPI	consumer price index
ENA	Energy Networks Australia
ESB	Energy Security Board
GDP	gross domestic product
GMP	Green Mountain Power
HPR	Hornsdale Power Reserve
IEA	International Energy Agency
IP	intellectual property
IPCC	Intergovernmental Panel on Climate Change
ISP	Integrated System Plan
NEM	National Electricity Market
PV	photovoltaic
SDI	sustainability-driven innovation
SII	Sustainability-informed innovation
SOI	sustainability-oriented innovation
SRI	sustainability-relevant innovation
STEM	science, technology, engineering and mathematics
VPP	virtual power plant

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