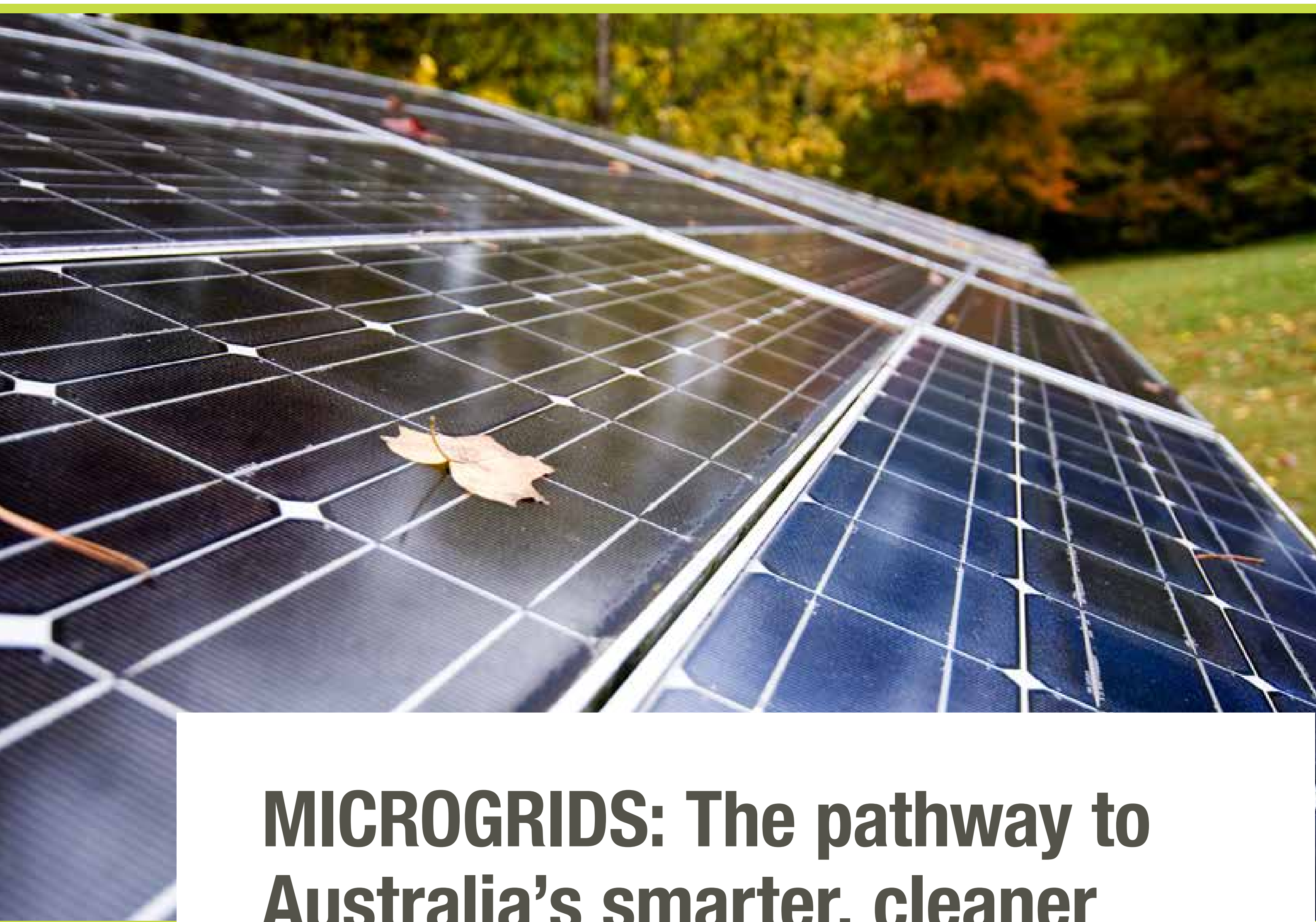

MICROGRIDS: The pathway to Australia's smarter, cleaner energy future

Kristian Handberg

An International Specialised Skills Fellowship

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i. EXECUTIVE SUMMARY

Microgrids are the building blocks of our energy future. Small-scale electricity networks that can operate independently of the surrounding grid, they are a tailored solution optimised for cost, reliability and sustainability. By intelligently networking and managing distributed energy resources and loads, they can achieve efficiency dividends and capture new revenue streams.

The challenge of microgrids lay in their complexity. Technical issues associated with the integration of renewable energy resources form a subset of the overall challenge of coordinating continuously changing inputs and demands. These tasks are normally undertaken at the macro level by large, specialist energy market participants.

This project was aimed at understanding how microgrid projects come into being. Project owners and supporters from around the world were consulted to better understand project types, planning methods and delivery models. These insights were then applied to the Australian context, to identify the drivers, obstacles and likely applications.

Based on the research findings, microgrid project typology was mapped out as follows:

- Standalone (off-grid) applications – enabling energy access for productivity and amenity benefits, most recently in the developing world
- Fringe-of-grid applications – cost-effective, utility-driven alternatives to network augmentation
- Campus applications – precinct-scale, customer-driven projects that deliver improved reliability and sustainability
- Community applications – shared-service models that promote resilience

Through an in-depth analysis of successful case studies, the key finding was that the complexity of microgrid projects necessitates a holistic risk management perspective. In response, projects are being planned and delivered using an incremental approach that begins from known infrastructure and accepted delivery models. By gradually building out the microgrid via bankable sub-projects and re-baselining at each interval, risks can be managed in line with financing requirements.

Drawing on the research insights, the path forwards for microgrids in Australia was evaluated. Costly grid outages caused by extreme weather events are running parallel with mainstream media interest in grid defection due to high electricity prices and the emergence of battery storage. Working counter to this is Australia's generally reliable electrical supply, and our still-evolving framework of demand management incentives, network tariff design and grid connection arrangements.

As the imperatives grow the barriers may shrink, suggesting that microgrids are a likely part of Australia's energy future. Based on the drivers, obstacles and market arrangements, fringe-of-grid, critical infrastructure and embedded networks are felt to be the most likely growth applications.

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Ah amp-hour

CHP Combined Heat and Power

CO_2e carbon dioxide equivalent

DER Distributed Energy Resource

EPC Energy Performance Contract

ESA Energy Service Agreement

hr hour

ICT Information and Communication Technology

kg kilogram (= 1 x 10^3 grams)

km kilometre (= 1 x 10^3 metres)

kVA kilovolt (= 1 x 10^3 volts)

kVA kilovolt-amp (= 1 x 10^3 volt-amps)

kW kilowatt (= 1 x 10^3 watts)

kWh kilowatt-hour (= 1 x 10^3 watt-hours)

OH&S Occupational Health and Safety

LCoE Levelised Cost of Energy

m^2 metres squared

MW Megawatt (= 1 x 10^6 watts)

MWh Megawatt-hour (= 1 x 10^6 watt-hours)

O&M Operation and Maintenance

PCC Point of Common Connection or Point of Common Coupling

PPA Power Purchase Agreement

PV Photovoltaic, as in solar PV

RPS Remote Power System

R&D Research and Development

SAPS Standalone Power System

SPV Special Purpose Vehicle

SWOT Strengths, Weaknesses, Threats and Opportunities

UPS Uninterruptible Power Supply

US United States

USD United States dollar

V volt

VNM Virtual Net Metering

1. ABOUT THE FELLOW

Name: Kristian Handberg

Employment / affilations:

- Manager – Electric Vehicles, AGL
- (formerly) Principal Consultant – DiUS Computing
- (formerly) Business Development Manager – Percepscion
- (formerly) Honorary Research Fellow – Monash Sustainability Institute

Qualifications:

- Masters of Engineering (Project Management), RMIT 2003
- Bachelor of Engineering (Materials, Hons.), Monash University 1994

Biography:

Kristian Handberg has been working in 'clean' technology product and market development for over 17 years. Driven by a desire to 'make a difference', Kristian draws on his engineering training and public policy experience to investigate and establish implementation pathways for technology solutions to society's problems.

Kristian's professional career began in 1994 working in a non-destructive testing and heat treatment services provider for petrochemical facilities. His natural curiosity led him to travel overseas for four years shortly thereafter, during which time he accumulated a range of professional experiences including two years as a manufacturing engineer in an aerospace component supplier to Rolls Royce, General Electric and Pratt & Whitney. More significant were the life experiences acquired during his extensive travel around the world, not least of which was three months travelling solo around India in 1995-96.

Upon his return to Australia he resumed his professional career with General Motors Holden in 1999. Working primarily on the design and development of key engine components, he supplemented his vocational experience with further academic training in the field of project management. In 2003 his role with Holden led to a particularly influential period working as a liaison engineer in Detroit on a global engine design program. It was here that he was exposed to elite decision-makers operating in high pressure situations, providing him with experience and insights that he continues to draw upon to this day.

Having read the signs of terminal decline in the Australian automotive industry, Kristian joined the Environment Protection Authority (Victoria) in 2005. Although a newcomer to public policy, Kristian grew into the role quickly on account of the close alignment to his personal interest in the public good. His commercial/technical background allowed him to deliver a number of very successful projects for EPA, including a heavy-vehicle emissions test capability at a saving of $AUD 1 million on the allocated budget and restructure of the EPA's internal environmental management system. During this time he also worked on environmental regulation of Carbon Capture and Storage (CCS), and led the environmental approvals process for Victoria's desalination plant before his departure.

In 2008 Kristian moved within the environment portfolio of Victorian Government to the Department of Sustainability and Environment. During this time he held briefing responsibility for the Minister for Environment and Climate Change on transport issues, including formulation of the 2008 Victorian Transport Plan. He also took a forthright role in a number of national policy development processes, delivered a hybrid bus trial within the public transport system, and undertook a sustainability assessment of biofuels for Australia in partnership with the CSIRO.

1. ABOUT THE FELLOW

Kristian joined the Department of Transport in 2010 to design and deliver the Victorian Electric Vehicle Trial – a globally significant project in the field and the largest project of its type in the southern hemisphere. Over three years he brought together 80 organisations to establish the foundations of the Australian electric vehicle market. Through relationships formed over this time Kristian continues to be involved in development of the global electric vehicle market to this day.

At the conclusion of his contract, Kristian returned to the private sector in 2013 to take up a consultancy role with DiUS Computing. As part of this role, Kristian was working on business development for DiUS's technology commmercialisation start-up company Percepscion, who specialise in home energy management products. While committed to the success of DiUS and Percepscion, Kristian continued to indulge his passion for the public good with research conducted under the umbrella of Monash University.

In March 2015 Kristian joined AGL Energy, where he is now part of the Products & Pricing team in New Energy. His role focuses on electric vehicles, however he works across energy systems bringing the pieces of the puzzle together to commercialize new business models based on emerging technology.

In combining his technical, commercial and public policy expertise, Kristian is committed to leaving a legacy of a better world for his children and others.

Kristian is married to the beautiful Tamara, with whom he has two amazing sons – Rudy (six) and Thomas (three).

2. AIM OF THE FELLOWSHIP PROGRAM

The Fellowship provided the opportunity to investigate microgrid project development pathway, specifically:

- Characterisation, as an input for planning and delivery
- Planning, focused on preliminary and high-level approaches
- Financing, including key considerations as an enabler for project delivery
- Path forwards for Australia, including drivers, obstacles and near-term applications

The investigation drew on international expertise via a number of avenues:

- Microgrid Forum, Singapore, 11-13 August 2013, was an international conference on microgrid technologies, projects and policy primarily in developing countries
- Phone interviews with a number of international experts, including the UN Foundation Microgrids Working Group
- Structured in-person interviews in April 2014 with two groups of U.S. microgrid project owners and policymakers:
  - » New York State Research & Development Authority (NYSERDA)
  - » Department of Energy and Environmental Protection (DEEP), State of Connecticut

In addition, extensive research was undertaken into supporting documentation associated with the various projects and policies encountered through the investigations above. This research also included additional analyses of relevant aspects of the Australia policy and project environment.

3. THE AUSTRALIAN CONTEXT

Microgrids are small-scale, self-contained electricity networks. They find application in remote/island communities, campus-style facilities such as universities, commercial/ industrial applications such as data centres, or in highly sensitive locations such as military facilities. They are of increasing appeal for their potential to improve system resilience, energy access and reduce environmental impacts. Microgrids based on renewable energy sources are of particular relevance to Australia due to the wide distribution of remote communities and industry across Australian territories, our increasing vulnerability to environmental hazards, and our rapid uptake of renewable energy.

3.1 What is a microgrid?

Microgrids – also called minigrids, isolated or remote power systems, or hybrid generation systems – are small-scale, self-contained electricity networks. They always contain one or more generation sources to service local demand, and may contain some sort of storage capability. Although more complex and occasionally contrasting definitions abound, microgrids are effectively defined by their larger network context in being capable of operating independently of it. Micrograds may range in size from kilowatts to megawatts (noting that one megawatt equals one thousand kilowatts).

Microgrids are both an aspect and outcome of the massive changes taking place across our electricity networks, including:

- Digital metering, sensing, communications and control
- "Big data" combined with predictive analytics
- Distributed energy resources
- Energy storage systems
- Plug-in electric vehicles

The diagram below depicts how the old model of centralised energy generation and distribution is undergoing a technological revolution that will deliver improved efficiency, quality of life and environmental sustainability.

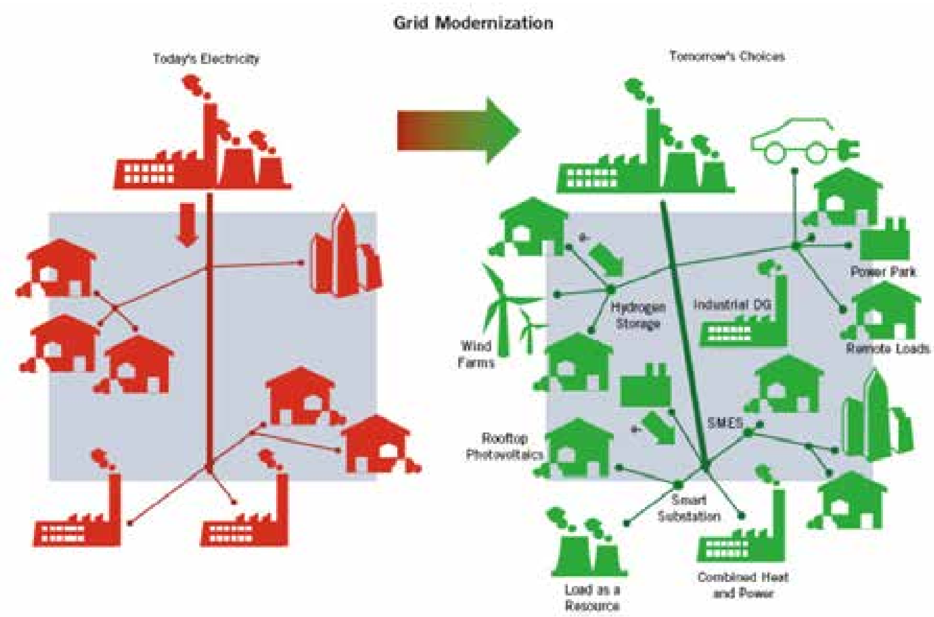


Figure 1. *The Institute of Electrical and Electronics Engineers (IEEE) depiction of grid modernization, including distributed generation, information networks and system coordination, compared to the old centralised generation model.*[1]

Through the use of these technologies, microgrids have become viable. The economics and practicalities associated with design, construction and operation of a small-scale electricity network that services local needs are being transformed by the technological revolution unfolding across our energy systems.

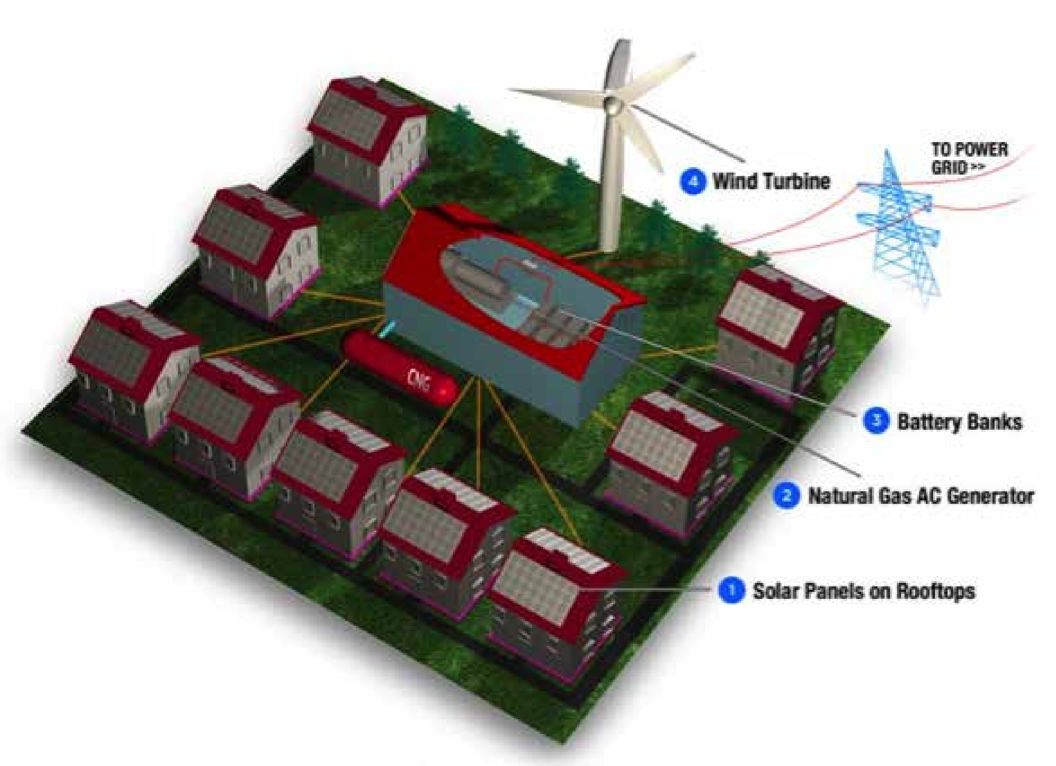


Figure 2. *A simplified depiction of a neighbourhood-scale microgrid, where the wind and solar renewable energy resources are matched with a natural gas generator and battery storage.*[2]

Example microgrid applications include:

- Remote, rural and/or island communities
- Commercial / industrial facilities such as data centres
- Research facilities, such as university campuses or laboratories
- Military installations or other security-related facilities
- Community-level or utility-specific application

Household-scale grid systems with the capability of operating independently from the grid – occasionally described as nanogrids[3] – are another potential microgrid application. Although the challenging economics and large regulatory barriers associated with this concept are currently limiting uptake, insights gleaned from the applications above will inform efforts to promote adoption in future.

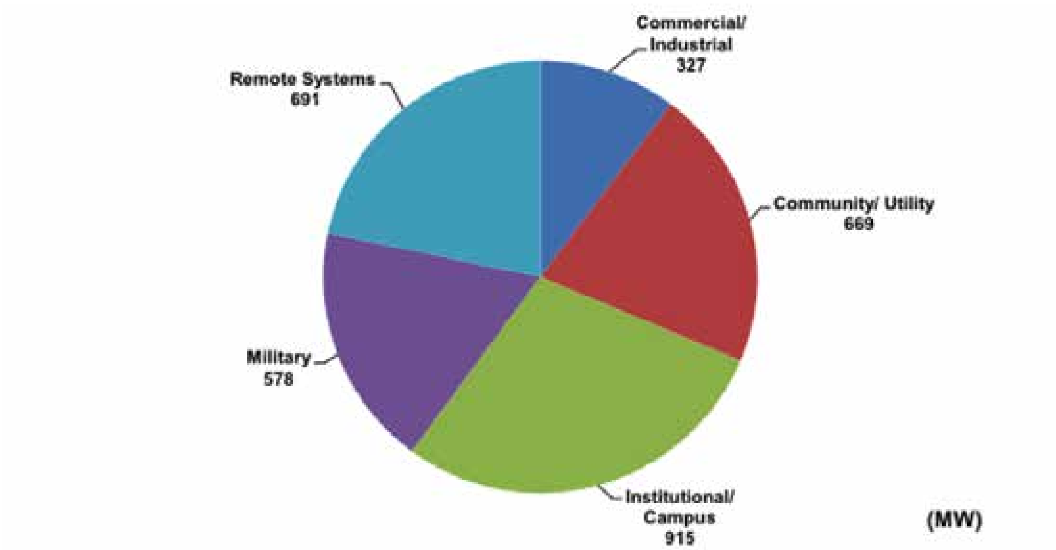


Figure 3. *Global microgrid capacity (MW) for 405 projects either in the pipeline or fully operational as of fourth quarter 2012, broken down according to market segment.*[4]

With reference to Figure 3, the total microgrid capacity worldwide remains relatively low at around 3,180 MW. By way of comparison, the combined total capacity for the Loy Yang A and B power stations in the Australian state of Victoria is 3,250 MW, or 70 MW more than all the microgrids planned, proposed, under development or fully operational worldwide as of September 2012.

While each of these applications is more commonly serviced by large-scale generation and regional-scale transmission and distribution infrastructure, there are a range of reasons as to why local microgrid solutions hold appeal.

3.2 Why microgrids?

Electricity is a vital input for modern society, be it for cooking and heating, lighting and communications, or mechanical power for an almost unlimited number of uses. Energy access has been identified as a key issue for global development and wellbeing, and energy security is a critical component of modern, productive society. Accompanying these benefits is the need to manage the environmental impacts of energy production and use.

The prevailing model of energy supply is the current day grid, revolving around centralised generation connected to a vast array of end-users through a complex network. This approach is an outcome of the century-long evolution of our networks, where the initial goal was to simply supply electricity – refer to Figure 4. While this model represents one of history's most significant engineering achievements, it is not without its disadvantages:

- *Efficiency and environmental impacts* – transmitting power over long distances can result in significant losses, reducing system-wide efficiency; newer, more environmentally-friendly technologies can be a challenge to accommodate within even modern systems
- *Costs and leadtimes* – design, financing and construction of large, centralised networks is hugely complex and costly, which can create significant barriers and long leadtimes for the supply of energy to new, remote or poor communities

- *System resilience* – while the interconnection of electricity networks has improved wider system reliability, having a single solution for such a crucial need creates a vulnerability for individuals, businesses and society more generally; this vulnerability is amplified by the range of possible avenues to which such a large and diverse solution is open to attack/failure, and by the cost/reliability trade-off which is resolved for most end-users but not all

Figure 4. *The evolution of electricity networks for industrialised nations.*

As a result, energy supply solutions tailored to local needs – microgrids - have inherent appeal. While the issues above have existed for some time, there are a range of drivers that are promoting interest in microgrids:

- *Technology cost reductions* – renewable energy technology (particularly solar photovoltaic), energy storage technology and advanced energy monitoring and control systems are continuing to decrease in price and are driving huge change across energy markets around the world
- *Heightened awareness of system vulnerability* – the degree to which modern society is susceptible to environmental threats or cyber-attack on our electricity networks is increasingly understood and being acted upon
- *Environmental awareness and protection commitments* – community understanding of the environmental impacts of energy is increasing the expectation of and interest in more sustainable solutions
- *Promotion of affordable, clean energy for economic development* – sustainable energy access has been identified as a development priority for the world's poor

As a result, microgrids utilising renewable energy generation sources are of increasing interest to address known challenges for our electricity systems.

3.3 How are renewable microgrids relevant for Australia?

Although all the attributes and emerging opportunities for microgrids outlined above are of relevance to Australia, there are three areas which are of particular significance:

1. **The tyranny of distance** – Australia's vast landmass and geographical distribution of communities and industries favours the economics of microgrids over centralised generation and distribution;
2. **Environmental hazards and the risk of attack** - microgrids present a potentially cost-effective solution to promoting system resilience in the face of Australia's increasing vulnerability to environmental hazards such as bushfires and cyclones; and

3. **The growing use of renewable energy** - Australia's rapid uptake of renewable energy is increasing understanding and acceptance of localised energy solutions that are the basis for microgrids.

3.3.1 The tyranny of distance

Australia's huge but sparsely populated land-mass creates major challenges in providing affordable, reliable and sustainable energy to remote communities and commercial operations. The high costs of extending the centralised generation network along with the increasing costs of diesel are making distributed energy systems based upon renewable energy generation more and more appealing.

Horizon Power in Western Australia services the largest area for the least amount of customers in the world.[5] Although Horizon maintains two interconnected networks, they also maintain 30 standalone Remote Power Systems in towns and communities that might be thought of as microgrids.[6] Although these systems predominantly use diesel fuel trucked in at significant expense, Horizon commissioned solar-diesel power stations in 2010 at two locations – Marble Bar (Figure 5) and Nullagine.[7]

Figure 5. *Horizon Power's Pippunyah power station in Marble Bar (Western Australia), which combines a single axis tracking 1.16 MW solar farm with diesel generation and kinetic flywheel energy storage.*[8]

Ergon Energy in Queensland faces similar challenges to those of Horizon Energy above with a network consisting of approximately 150,000 kilometres of powerlines and one million power poles, servicing around 700,000 people over an area of around one million square kilometres.[9] Figure 6 below shows the location of the 33 isolated power stations that could be described as microgrids. While the vast majority of these power stations use automotive diesel as fuel, two also use renewable energy – Thursday Island (wind) and Windorah (concentrated solar photovoltaic).

Figure 6. *Ergon Energy's power station location map, including 33 isolated power stations that provide electricity to communities which are isolated and too remote for connection to the national grid.*[10]

The Australian Government Renewable Energy Agency (ARENA) has recognised the immense potential for renewable energy in remote and regional locations through their Regional Australia's Renewables (RAR) program.[11] RAR comprises two components – the RAR Industry program (I-RAR), and the RAR Community and Regional Renewable Energy (CARRE) program – with the aim of increasing the use of renewable energy solutions once they become affordable. Expressions of interest for funding were sought in the period up to the end of 2013 for trials of renewable energy based hybrid systems in rural and remote locations.

Noting the ever-improving economics and understanding of renewable energy systems (refer below), renewable microgrid solutions are of increasing relevance to remote communities and industrial facilities across Australia.

3.3.2 Environmental hazards and the risk of attack

Bushfires, cyclones and flooding are growing in frequency and severity, challenging our dependence on electricity during and after these events. This dependence also heightens both the risks and consequences of physical or cyber-attack. Network-scale solutions must strike a balance between reliability and cost, thereby favouring locally-tailored solutions such as microgrids for sensitive and/or critical loads.

Recent events highlight our vulnerability to environmental hazards.

During Victoria's 2009 Black Saturday bushfires the community ability to respond to these fires was severely hampered by the loss of power:

Once power was lost at the Beechworth DSE office, the incident management team struggled without lighting, air conditioning and the Commander™ phone system; a back-up generator was obtained but it was barely able to support computers and other systems. At Murrindindi the local radio station, UGFM, lost transmission once the power at the main transmitter site went off. Loss of power also affected community water supplies and delivery systems at Buxton.[12]

These challenges continued beyond the immediate threat into the aftermath and clean-up. Residents reported being without power for weeks which, combined with the roadblocks and loss of telecommunications, compounded the sense of isolation.

Queensland residents have reported similar experiences in the aftermath of tropical cyclones. With reference to Figure 7, more than 200,000 residents of North Queensland were without power after Cyclone Yasi in 2011, while some residents went without power for up to four weeks after Cyclone Larry.[13]

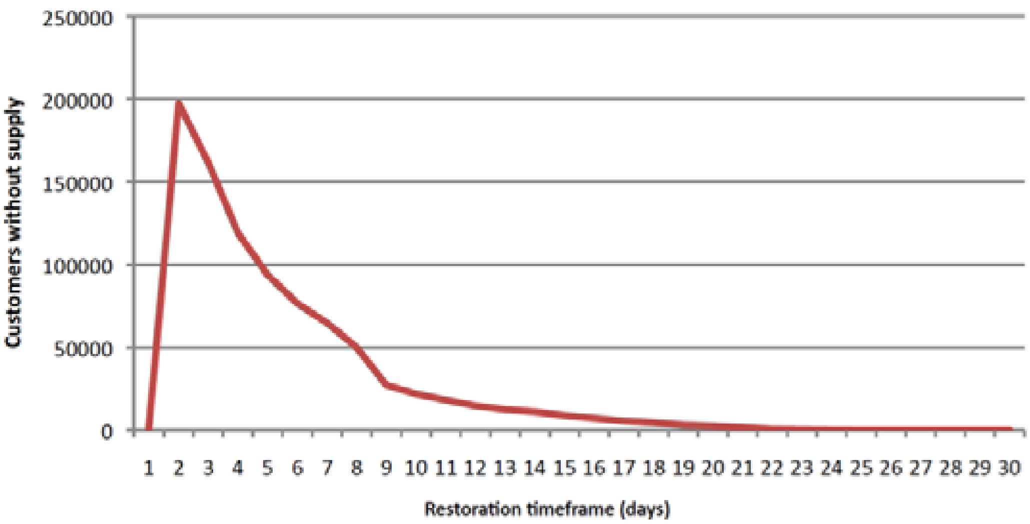


Figure 7. *Ergon Energy's restoration of electrical supply following Cyclone Yasi in 2011.*[14]

In aggregate, the cost of electricity outages is immense. On 16 January 2007 around 690,000 Victorian electricity customers, including 70,000 businesses and public infrastructure services such as transport, telecommunications and healthcare, experienced electricity supply interruptions as an outcome from a fire in the northeast of the state in the vicinity of transmission lines.[15] Despite there being no direct loss of life and a mere 7 homes lost to the bushfires themselves,[16] the total economic impact on the state has been estimated at $500 million[17] due to the supply interruptions alone.

To understand the supply-side infrastructure risks at the national level, the Australian Government undertakes a regular assessment of energy security. The latest review from 2011 noted the increased significance of the risk of cyber-attack:

3. THE AUSTRALIAN CONTEXT

Online electronic systems can be vulnerable to remote attacks, as physical proximity is no longer needed to inflict damage on infrastructure. Such attacks could pose significant risks to the reliability of our physical energy networks. The reliability of our energy sector in the face of cyber security threats is difficult to assess, but a moderate assessment would be consistent with the Australian energy sector having been impacted by known cyber security incidents and a growing concern of further vulnerabilities and expected attacks.[18]

In support of efforts to be better prepared for these risk scenarios, in 2010 the Australian Government released a national *Critical Infrastructure Resilience Strategy*[19] in response to a range of threats including natural disasters, pandemics, accidents, negligence, criminal activity and terrorist attack. The Strategy highlighted the numerous public and private sector stakeholders involved in the operation and protection of Australia's critical infrastructure, and set out a range of framework for coordination across these entities based primarily on information sharing through the Trusted Information Sharing Network (TISN).

In 2012 The Climate Institute published a climate risk assessment of Australia's infrastructure that provides a summary of the obstacles to greater system resilience.[20] In observing a case study of the complicated and highly regulated nature of Australia's electricity sector, they noted efforts by Victorian distribution network service providers to address climate risk in the period from 2011-15 by upgrading components of the network. The Australian Energy Regulator (AER) was unpersuaded by the companies' submission, and so declined the request for additional funds for climate-proofing activities within this period.

Also in Victoria, legislation was passed in 2009 which created deterrents to man-made threats to the electricity sector aimed primarily at protestors against coal-fired power stations.[21] Notably, these measures fail to address the more immediate consequences for the state should the system come under more concerted attack as has occurred in the U.S. and Europe.[22]

Observations made during the 2009 Victorian Bushfires Royal Commission highlight the need for increased system resilience at the electricity end-user:

Past inquiries and fire inquests have clearly demonstrated the importance of independent water and power supplies. Poor planning and lack of preparedness for interruptions to electricity or water supply were highlighted after the Canberra bushfires of 2003. Despite this, the Commission heard that on 7 February reliance on mains power and water was again a concern for fire agencies and those who stayed to defend their properties. This is worrying. Although land-use regulation can help to redress this problem, more effort is obviously required to ensure that houses in bushfire-prone areas have independent access to water and electricity.[23]

As lead of the TISN energy sector group, the Australian Energy Market Operator (AEMO) has published guidance on how business might prepare for power interruptions:

Create a business continuity plan that identifies critical areas of your business requiring support during power supply interruptions. Back-up power supplies (e.g. uninterrupted power supplies (UPS) or stand-by generators) may be appropriate.[24]

Anecdotal evidence suggests that Victorian businesses largely ignore this advice despite being reminded of it at the outset of each summer period.[25]

Building on this, the Queensland Government has published a guideline to improving the resilience of electrical infrastructure during flooding and cyclones including the following advice:

It is recommended that the relevant bodies undertake a review to identify the power supply security of critical infrastructure including the following: evacuation centres; medical centres; schools; water treatment facilities; sewerage pumping stations; telecommunication sites; significant shopping *precincts. It is crucial that the relevant bodies work together to determine the appropriate strategies to be included in local government contingency plans for the most efficient restoration of power supply to critical infrastructure sites. Supply security for critical infrastructure sites should be given priority in each local government business continuity plan.*[26]

As the risks and consequences of electricity supply interruptions are growing, the onus is on end-users of critical need to respond – microgrids provide a potential solution. Following the 9.0 magnitude earthquake and accompanying tsunami that hit northeast Japan in March 2011, an experimental microgrid in the city of Sendai continued to provide electricity to the university and nearby hospital for two days while the rest of the city remained without power.[27] And as the facility included a Combined Heat and Power system, the hospital's patients were kept warm through northern Japan's cold March nights.

Drawing on learnings from experimental microgrids such as that in Sendai, various organisations and governments around the world are pursuing strategic microgrid solutions as a means of achieving cost-effective system resilience.

By way of example, in October 2012 power outages in the United States cost an estimated $USD 14-26 billion as an outcome from Hurricane Sandy[28] - refer to Figure 8. As part of efforts to improve system resilience, Connecticut has invested $USD 18 million in 9 microgrid projects,[29] while the New Jersey Transit system is investigating microgrid solutions after experiencing $USD 400 million in damages from Sandy.[30]

Figure 8. *An electrical transformer explosion lights up a corner in Lower Manhattan surrounded by darkness one day after Hurricane Sandy's landfall.*[31]

3.3.3 The growing use of renewable energy

Cost reductions, technological evolution and increased acceptance and understanding are promoting uptake of renewable energy by individuals, business and communities. Localisation of energy production is providing a foundation for a customer-driven move towards microgrids. Electricity utilities, at risk operationally and financially from the growth in renewables and distributed generation, have and will continue to vary in their response.

Renewable energy, while still a minor contribution to the overall grid mix, is growing rapidly:

- In 2012, a record 13.14 per cent of Australia's energy was renewable[32]
- The one millionth rooftop solar power system was installed in March 2013, with more than 10 per cent of Australians now using solar power in their homes[33]
- Globally, the cost of producing solar panels has decreased by 75 per cent in the period between 2008-11[34]

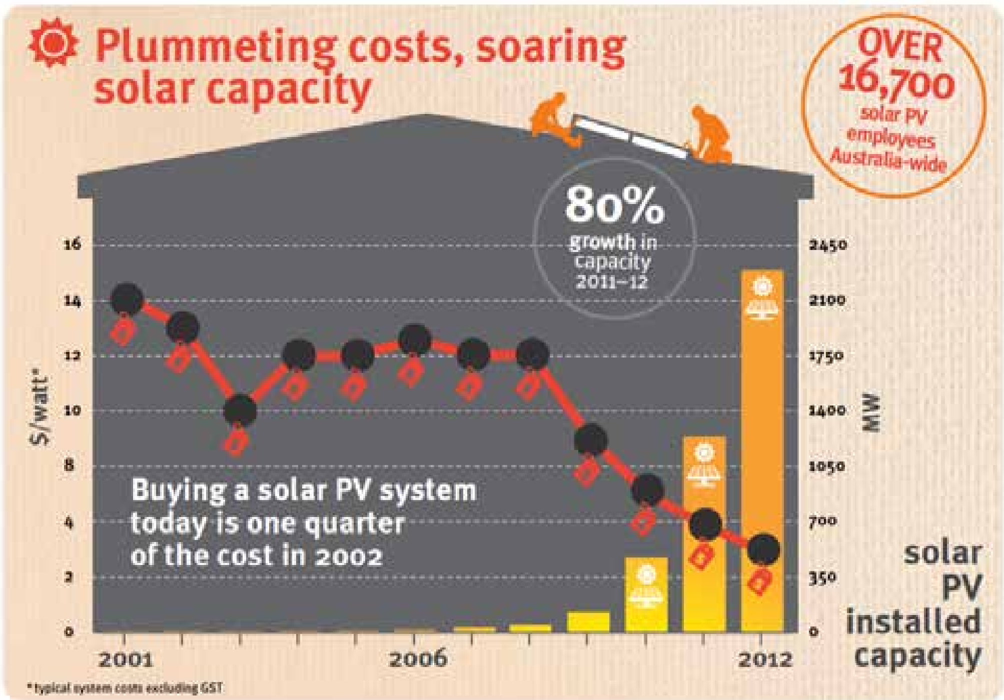


Figure 9. *A decade of change in Australian grid-connected solar PV (grid-distributed and centralised), expressed in terms of installed capacity (MW) and unit costs ($/W).[35]*

And from here the renewables story keeps getting better:

- The medium-term outlook for renewable energy globally is 40% growth over the period from 2012 to 2018, with the total contribution from renewable sources expected to surpass that from gas and be twice that from nuclear by 2016[36]
- The Australian Government has legislated a mandatory renewable energy target to ensure that 20 per cent of our energy will be from renewable sources by 2020[37]
- By 2030 some renewable technologies, such as solar PV and on-shore wind, are expected to have the lowest Levelised Cost of Electricity[1] of all generation technologies in Australia[38]

Alongside this there exist opportunities and challenges in adapting our electricity system to accommodate renewable energy. Positive impacts on grid operation, such as reduced network flows and hence reduced losses and voltage drops, can be offset by negative impacts such as voltage fluctuations, voltage rise and reverse power flow, power fluctuations, power factor changes, frequency regulation and harmonics, unintentional islanding, fault currents and grounding issues.[39] Many of these impacts are compounded by the intermittent nature of most renewable sources – solar energy is obtained only when the sun shines, wind energy only when the wind blows. This creates an inevitable, ongoing and fast-changing mismatch between renewable energy supply and end-user demand that must be managed to avoid power outages or worse.

Under Australian electricity market rules, grid operators are obligated to meet reliability standards lest they be financially penalised. In addition, operator revenues are a product of fixed tariffs based on forward projections of demand and the actual amount of electricity subsequently sold.

On this basis, customer-driven renewable energy generation poses a threat to grid operators on a number of fronts. This reality was highlighted by Queensland operator Energex in their 2012/2013 annual report,[40] who noted that the changes unfolding "will have wide-ranging implications for the way the distribution network is planned, build and operated, as well as for our ongoing business sustainability".

This issue may also be impacting upon grid connection standards and processes, which though designed to safeguard reliability of supply, may also reflect the monopoly position of the operator and the financial risks they're exposed to.

The Alternative Technology Association investigated customer experience in connecting renewable energy sources to the grid issue in 2006 as part of efforts to reduce the barriers to uptake of small-scale grid-connected embedded generators. Their survey highlighted the inconsistency and resistance from utilities to renewable/distributed energy:

The universal experience of the respondents to ATA's study was one of frustration at the lack of information available, conflicting advice given, excessive and complex technical regulation and minimal protection for system owners.[41]

The 4.1 MW Hepburn Wind project in central Victoria provides a vivid example of these challenges. Connection of a wind farm of this size to a 22 kVA powerline had largely not been attempted before, and ultimately grid connection costs for the project blew out from $210,000 to $1.8 million – despite the initial estimate being informed by expert opinion:

Detailed grid studies were initiated after the turbines had been selected, which was relatively late in the project development phase. The grid studies identified two issues that had significant impact on connection costs:

1 Levelised Cost of Electricity or LCoE = the minimum cost of energy at which a generator must sell the produced electricity in order to achieve its desired economic return

- *reactive power control — in order to maintain voltage control, Powercor mandated a tight power factor range (0.85 – 0.87 absorbing), requiring the installation of significant reactive power control capability*
- *remote regulator monitoring and control — in order to ensure reliable operation of the two automatic voltage regulators on the feeder, significant investment in custom regulator control and monitoring system was mandated.*

The complexities associated with the remote regulators exacerbated the delays in securing the full grid connection agreements. In order to move the project forward, the grid connection process was split into two phases.

The Phase 1 Augmentation Agreement, signed on 12 August 2010 and costing $868,588 includes augmentation of power lines immediate to the wind farm, hardware upgrades within the Powercor network (particularly at the Bungaree and Muskvale automatic voltage regulators) and network access fees.

Due to technical challenges unrelated to the wind farm project, the upgrades at Bungaree will not be complete until the end of 2011 at the earliest. Until these works are complete the wind farm output is capped to 2.6 MW, resulting in a reduction of project revenue.

At the time of writing, Phase 2 is in progress and is expected to cost $40k - $60k. Phase 2 involves the software and testing of the voltage control solution and once complete will allow the wind farm to operate at its full 4.1 MW capacity.[42]

Figure 10. *Hepburn Wind 4.1 MW Community Wind Farm.*[43]

While stories such as this are discouraging for renewable energy developers, other examples of more innovative approaches being taken within small-scale networks that are a model for microgrids.

The King Island Renewable Energy Integration Project (KIREIP) off the coast of Tasmania has sought to reduce the island's dependence on diesel generation while ensuring a reliable and stable electricity supply . The outcome will be to deliver over 65% of the island's power needs from renewable sources, and reduce greenhouse gas emissions by 95%. In July 2013 the project achieved a significant milestone in achieving a sustained period of zero diesel operation, such that the island can now be expected to be running on 100% renewable energy during overnight periods when demand is low and high-wind periods during the day.[45]

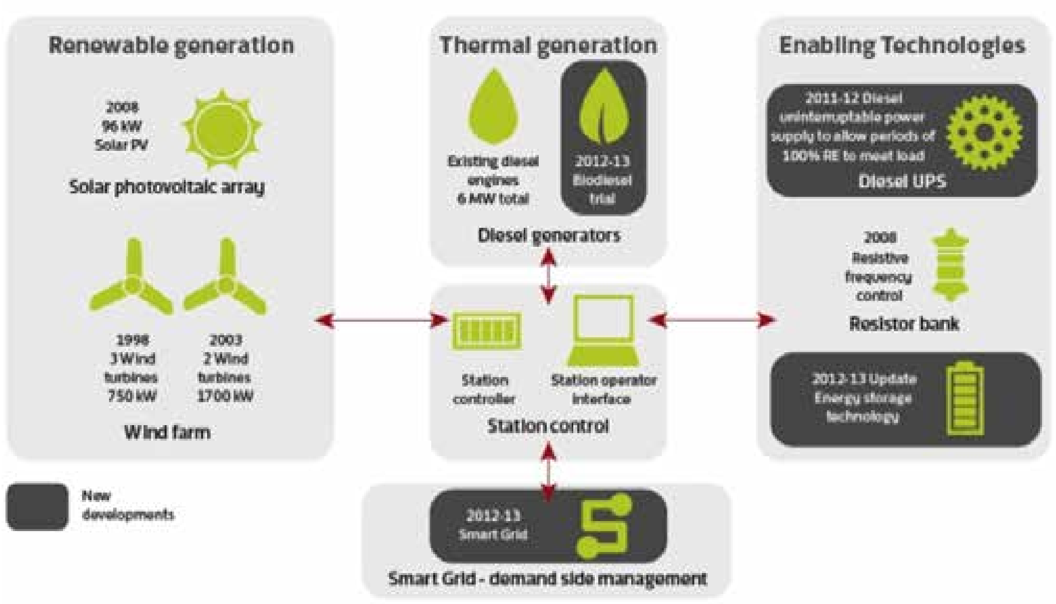


Figure 11. *King Island Renewable Energy Integration Project (KIREIP) schematic.*[46]

Magnetic Island is located approximately 8 km off the coast of Townsville, Queensland. It is connected to the Townsville network by two 11 kV, 12 km long undersea cables which by 2003 had been identified as an emerging capacity constraint requiring an investment of $18.6 million to upgrade (2006 Australian dollars).[47] In 2006 Magnetic Island applied to participate in the Australian Government's Solar Cities program (refer to Figure 12), following which uptake of distributed PV systems reached a relatively high penetration of 22% of households on the island (measured as a ratio of PV capacity to peak load). The main issue experienced by the distribution network operator Ergon Energy is excessively high voltage levels during peak generation periods, however these have been addressed by Ergon through new technologies and procedures.

Figure 12. *Magnetic Island 100kW Solar Skate Park.*[48]

Projects such as those on King and Magnetic Islands highlight the growing knowledge base relating to integration of renewable energy into the grid. Through this improved understanding, the potential for high proportions of renewable energy to be accommodated within customer-driven projects such as microgrids is fast becoming a reality.

3.4 SWOT analysis

A systematic analysis of microgrid strengths, weaknesses, opportunities and threats (SWOT) is presented below.

3.4.1 Strengths

- **Energy security / reliability** – microgrids provide secure, reliable electricity supply for applications or locations where this may be either challenging or critical
- **Centralised supply alternative** – compared to regional-scale grid infrastructure, microgrids can be established quickly and cost-effectively
- **Renewable energy integration** – larger amounts of renewable energy may be accommodated within smaller-scale, tailored microgrids
- **Efficiency** – system-wide losses can be reduced by more closely locating and aligning supply and demand
- **Local business development / job creation** – microgrids generate economic value within the area that they serve

3.4.2 Weaknesses

- **Cost** – the financial commitment to design and construct a microgrid can be significant
- **Energy storage** – the market for which is continuously evolving and proprietary in nature, such that there is a wide variety of solutions accompanied by potentially significant expense and risk
- **Complexity** - inherent to both the design and operation of microgrids generally, and in microgrid design for the specific application/location
- **Information** – there is an absence of information about microgrid design and operation within the public domain
- **Regulatory issues** – due to the lack of standard operating procedures, quality standards and OH&S standards specific to microgrids, and to facilitate interconnection with the surrounding grid where desired
- **Technical expertise** – the relevant technical expertise may be difficult to obtain and retain at the local level
- **Investor risk** – uncertainty over microgrid performance, user behaviour etc deters investment in microgrids

3.4.3 Opportunities

- **Technology cost reduction** – renewable energy and energy storage technologies are and will continue to rapidly decrease in cost
- **Improved understanding** – on all aspects of microgrid design and operation emerging from a wide range of pilot projects
- **Automation** – design and operation of microgrids is increasingly automated through the use of advanced/custom software
- **Policy** – governments are increasingly identifying microgrids as a potential solution for various issues, leading to policy support in the form of regulatory reform and grant assistance; Australian Government policy is shifting away from renewable energy, promoting interest in standalone solutions for individuals/companies/communities
- **Macrogrid support** – microgrids can provide back-up to the rest of the grid or cost-effective ancillary services, including in response to increasing environmental risks (climate-related or from foul-play)
- **Electricity price increases** – heightening the interest and appeal of distributed energy generation
- **Diesel fuel price increases** – as the cost of diesel increases, the business case for renewable energy to replace diesel generation as back-up power or for rural/remote/isolated locations improves
- **Grid modernisation** – is providing a more accommodating environment for microgrids, and is also facilitated incrementally by microgrid roll-out

3.4.4 Threats

- **Investor preferences** – for projects with known financial performance supported by established electricity network operators within a certain regulatory and policy environment
- **Utility pushback** – on account of the potential threat microgrids pose to the utility business model, inadequate or inappropriate standards/regulation, and a lack of understanding about microgrids generally
- **User acceptance / behaviour** – engaging would-be users in the design of supply standards (quality and reliability), rate structures and demand management is a challenge to cost-effective and successful microgrid design and operation

4. IDENTIFYING THE SKILLS AND KNOWLEDGE ENHANCEMENTS REQUIRED

4.1 Definition of a required skills enhancement area

A required skills enhancement area is where a demand for labour has not been recognised and where accredited courses are not available through Australian higher education institutions. This demand is met where skills and knowledge are acquired on-the-job, gleaned from published material, or from working and/or study overseas.

4.2 Identifying and defining the required skills enhancement areas

Australia has some tradition in the design and operation of Remote Power Systems (RPSs) for rural and remote locations. There are however significant differences between these and the emerging area of renewable microgrids. For instance, reliance on renewable energy sources and energy storage is relatively novel in RPSs, as is project design for improved system resilience.

While there are a number of international and a smaller number of local companies who may provide professional services to assist with project design and delivery, project owners must conduct an initial feasibility assessment before expert service providers can be engaged. For would-be microgrid project owners within remote/rural communities, commercial/industrial facilities, university campuses, military installations or community-level applications, this first step may seem insurmountable.

Accordingly, the scope of this fellowship has been refined to address the skill deficiencies for would-be renewable microgrid project owners seeking to undertake an initial feasibility assessment:

1. Establish a microgrid project characterisation framework:
   - Project types based upon context and objectives
   - Differences in approach based upon project type
   - Examples to illustrate microgrid typology and differences in approach

   Action: Survey a range of microgrid projects

   Action: Define project categories based upon key objectives

   Action: Provide a series of case studies for each project category

2. Propose a planning method for microgrid projects:
   - High-level project development process
   - Electricity demand
   - Delivery context
   - Electricity generation and storage
   - Design framework
   - Managing uncertainty

   Action: Analyse project development pathways

   Action: Investigate demand-driven design principles and methods

   Action: Consider key influences on demand forecasts as a project design input

   Action: Examine the socio-cultural issues that may impact upon project design, delivery and operation

   Action: Survey the key system features

Action: Propose high-level preliminary design methods for different project categories

Action: Identify key design inputs and examine methods for handling uncertainty

3. Explore finance strategies for microgrid projects:
   - Finance strategies
   - Emerging financial instruments and innovations

   Action: Survey finance strategies for a range of microgrid projects based upon category

   Action: Consider emerging financial instruments and innovations

   Action: Identify key influences on the choice of finance strategy
4. Consider the path forwards for microgrids in Australia:
   - Drivers
   - Obstacles
   - Applications

   Action: Assess the drivers for microgrid adoption

   Action: Assess the obstacles to microgrid adoption

   Action: Identify likely near-term microgrid applications

5. CHARACTERISATION

The diversity of microgrid projects presents an initial barrier for would-be project owners. Understanding the key attributes that influence project design is a necessary first step to reducing the complexity and establishing a case to move forwards.

To address this issue, a survey of microgrid project types was undertaken and the results characterised according to the key design influences. From here, the high-level planning process specific to each project type was ascertained via expert interviews.

Action: Survey a range of microgrid projects by scale and objective/s

Action: Define project categories based upon key objectives

Discussions with a wide variety of project owners and sponsors have informed an understanding of the key objectives that underpin microgrid projects:

- Energy access, as a foundation of economic development
- Affordability, as an alternative to grid augmentation
- Reliability, as a means of ensuring business continuity
- Sustainability, as an enabler for higher proportions of renewable energy
- Resilience, particularly in the face of climate risk

One or other of these objectives generally provides the foundation for a microgrid project, even if more than one objective may feature in the project design.

The range of projects surveyed could also be categorized according to context, each category for which roughly aligned with a specific objective. Table 1 below provides a summary of microgrid project categories, while a more detailed description including relevant applications and considerations for Australia is provided in the text that follows.

Category	Key characteristics	Key objective/s	Example
Standalone (off-grid)	Supply-constrained	Access	Sandwip Island, Bangladesh
Fringe-of-grid	Utility-driven	Affordability Reliability	Frost Valley YMCA, New York State, USA
Campus	Customer-driven	Reliability Sustainability	Wesleyan University, Connecticut, USA
Community	Shared services	Resilience	Parkville school cluster, Connecticut, USA

Table 1. *Microgrid project categories*

5.1 Standalone (off-grid) applications

These projects are conceived primarily as a means of providing access electrical supply where it is not technically or economically feasible to provide it through an extension of a regional grid. By far the most common microgrid project type, having existed for some time under the banner of Standalone Power Systems (SAPS) or Remote Power Systems (RPS), off-grid projects are increasingly providing energy access to remote and island communities the world over.

Many standalone microgrid projects in developing nations were reported to draw heavily on economic development funding from government and/or intergovernmental agencies. While these projects achieved their nominal objective of providing energy access, many were compromised in their ability to provide a reliable supply of energy into the future. Dr Ali Askar Sher Mohamed, Chief Operating Officer from the Sustainable Energy Development Authority in Malaysia, described problems with off-grid projects carried out by that country's Ministry of Rural Development:

- *Unreasonably high Energy Performance Contract (EPC) cost*
- *Quality issues*
- *No ownership of the project after completion:*
  - » *In many cases, utility will not take over the off-grid project because they are not familiar with the technology, it's costly to maintain, logistics problems, etc*
  - » *Study carried out in 2010 found that most of these off-grid projects failed within a few years due to lack of O&M*
- *Even where the utility does take over the project, there are still O&M issues:*
  - » *Utility staff are not trained in the technology*
  - » *Site is remote*

A recurring theme with many of the projects in developing nations was the absence of measures that would ensure electrical supply could support increased demand into the future. For example, Dr Sher Mohamed stated that demand in Malaysian off-grid projects had been found to increase by fifty percent within the first two years of operation. Design considerations observed in more sustainable projects that help address this are described in section 7.2 "Electricity demand" below.

Although examples of standalone microgrids abound, one of the more notable observed through the course of this research was on Sandwip Island, Bangladesh. The objective to provide energy access is summed up in the following quote sourced in relation to the project:

Swapan Saha, sub-inspector and in-charge of the Sandwip Police Station, said following the power connection, he no longer feels that he is in a remote village.

"When I first came here, I found out that there was no power at the station and the policemen had to work at night using kerosene lamps," he said.

"It was too cumbersome working without electricity and it certainly affected the performance of the policemen posted here."

"Now we work at night at ease and efficiency at the office has also increased," he said.

Figure 13. The 100 kW solar minigrid on Sandwip Island, Bangladesh – standalone (off-grid) project that has provided energy access to this remote community using innovative project design (Image: Ahsanul Hoque).

Particularly noteworthy features of this project include:

- Demand-driven design (demand-driven design is discussed further in section 7.2.1 below)
- High proportions of renewable energy - the generation sources for the project are two solar PV installations of 60 and 40 kW backed up by a 40 kW diesel generator, which also provides an equalisation charge for the battery bank
- Early-market application of battery storage – a total of 96 batteries in four battery banks provide a total of 12,000 Ah of storage capacity at 48 V, which is sufficient to cover the evening load of the local fresh food market with average insolation
- Innovative project financing – the KfW Development Bank provided 50% of the $USD 650,000 project budget via a grant that was linked to selection of a German technology provider, Asantys Systems

Building on this, a more recent project that highlights the significance of renewable microgrids for the economic development of remote communities was announced in May 2014 for an island off the coast of the West African country Equatorial Guinea:

Annobón Province has a population of approximately 5,000 residents. Today, the residents have reliable electricity for up to five hours per day and spend an average of 15-20 percent of their income on supplemental power. The solar microgrid in development will eliminate this expense entirely and provide reliable electricity 24 hours a day, seven days a week.[49]

As described in section 3.3.1 under the heading “The tyranny of distance”, Australia has an extensive history with off-grid projects which are largely dependent on diesel generators. In contrast, the emergence of cost-competitive renewable energy is increasingly providing the cornerstone for affordable energy access in the developing world. Insights from these projects, particularly in relation to financing (section 8), are likely to be of relevance to remote Australian communities who are currently encumbered with a reliance on high-cost diesel.

5.2 Fringe-of-grid applications

Fringe-of-grid microgrid projects are emerging mainly in the developed world as a more cost-effective alternative to extension or augmentation of the regional network. They are being increasingly considered as a means of ensuring energy affordability and reliability for remote or isolated communities.

Towards the extremities of a regional network costs increase as customer-density decreases, increasing the appeal of microgrids as a means of addressing any or all of the following challenges:

- Population and/or household income growth – both drive increased demand for electricity, along with expectations for the reliability and quality of supply
- Reliability and/or resilience – susceptibility to storm damage and other environmental hazards tends to increase with the length of the network extension
- Environmental sensitivity – many remote communities lie within or adjacent to areas of high environmental value, inconsistent with the presence of overhead powerlines

An example fringe-of-grid project was described by the New York State Energy Research and Development Authority (NYSERDA) for the Catskill Mountains area of New York State. This project has delivered against primarily the objectives of reliability and resilience:

Prior to considering the microgrid as a solution for an on-going reliability problem, analyses of four options to improve reliability were reviewed. The analyses concluded that construction of a microgrid would be the best solution to the ongoing outages in the Frost Valley area of the service territory. The microgrid system has been called upon for emergency operation seventeen times project-to-date. One event was a severe system-wide snowstorm that began on February 23rd, 2010. This event ended on March 4th, 2010. All of the components of the microgrid functioned without error for a period of seven consecutive days.[50]

Figure 14. *Frost Valley YMCA building that is the site of a microgrid system established in 2010 to address electrical supply reliability issues in the Catskill Mountains, New York State (Image: Riding the Catkills blog).*

As fringe-of-grid projects form part of the regional grid, they are generally led by or delivered in close partnership with the regional grid operator (e.g. Borrego Springs delivered by San Diego Gas & Electric in California[51]). As a result, electricity market regulations must allow for and promote consideration of microgrids as an alternative to regional grid solutions. This is an issue in Australia where 'ring-fencing' guidelines tend to preclude monopoly network operators from offering services within a contestable market, such as would be the case for a community-scale microgrid that contains distributed generation assets.

At the time of writing this situation appeared to be ripe for change:

- Consideration of non-network solutions is being promoted through reforms that have either been recently implemented[52] or are under consideration and likely to be implemented[53]
- Discussions with many Australian network operators have highlighted a strong interest in 'non-network solutions' for fringe-of-grid applications in particular
- In early-2014 Ergon Energy successfully submitted for a waiver of ring-fencing obligations to allow it to own and operate generation infrastructure to serve the Queensland city of Mount Isa[54]

Based on this evidence and experiences elsewhere, the opportunity for renewable microgrids to provide affordable, reliable, clean energy for Australian fringe-of-grid communities may have arrived.

5.3 Campus applications

Campus-style microgrids are precinct-scale installations that serve one or more customers behind a single "Point of Common Connection" (PCC) to the surrounding grid. These projects have been behind much of the recent interest in microgrids on account of them being customer-driven and the source of research findings that are promoting microgrid adoption more generally.

Although the business case design can vary significantly from project to project, the driver for the recent interest in this application has been resilience. For research institutions and commercial enterprises that place a premium on business continuity, the service reliability and quality provided by the regional-scale grid may necessitate back-up power systems such as diesel gen-sets and/or Uninterruptable Power Supplies (UPSs). Microgrids may provide a better return-on-investment through one or more benefits beyond improved asset utilisation from the site electrical infrastructure.

A pertinent campus microgrid example is that operated by Wesleyan University in Connecticut – the first rolled out under that state's resilience program. Wesleyan hosts around 5,000 full-time resident students on a campus property of around 320 acres with 3 million square feet (= 280,000 m^2) of buildings. Their microgrid project is the culmination of a long history for the university's energy infrastructure that began in 1860 with the development of their first power-plant for the generation of hot water. In 2008 they commissioned a gas-fired Combined Heat and Power (CHP) system which carried around 75-80% of the campus electrical load. This was done in parallel with an aggressive efficiency program that reduced their energy consumption by 50% over 10 years.

Alan Rubacha, Wesleyan's Director of Plant Infrastructure, described the rationale that underpins their energy infrastructure planning and investment in the following terms:

Our priority really is a balance of economics and the environment … we're not afraid to spend money on technology that maybe is unproven, too. Wesleyan's very good about that, about having an administration and a student body that supports experiments…

… Resiliency had never been that important to Wesleyan until we lost power for the first time that anyone could remember in 2011 in a huge snowstorm… so then we decided we would supplement our generation on campus and extend our grid to become a FEMA distribution facility.

Figure 15. *Wesleyan University's director of plant infrastructure Alan Rubacha inspecting part of their campus microgrid equipment, which was the first project commissioned under the state of Connecticut's resilience program.*

The $USD 4 million microgrid project added a 676 kW CHP plant and interconnection to the university's existing infrastructure, which included a 2.4 MW CHP plant, three solar-PV systems totalling 250 kW, and two geothermally-heated student residences. In doing so, it has provided Wesleyan with one of the most efficient, environmentally-friendly college campuses in New England – a region that includes Harvard, MIT and Yale.

Discussions with the New York State Energy Research and Development Authority (NYSERDA) highlighted the prominent role universities have played in the emergence of microgrids within their region. Institutions such as NYU, Cornell and Ithaca College have all pursued microgrid projects on the back of objectives that related to more than financial returns on investment. Michael Razanousky from NYSERDA's Smart Grid program described his outlook on campus facilities as the pathway for more widespread adoption of microgrid technology:

I think personally the campus model that NYU and Cornell use can be duplicated throughout every campus-style setting in our state or in the entire country. And when I say campus, I don't just mean a college. We have some (hospitals who) are putting in their own CHP system now, creating their own microgrid because they legally have to have a back-up power source anyway.

While project economics work differently in Australia due to the significantly different energy input costs, insights relating to campus microgrids are likely to be of relevance. In particular, Australian universities have much in common with their North American brethren – triple-bottom-line business cases, long-term financial outlook, research interests in advanced energy infrastructure, high value placed on business continuity etc. For these reasons much of what follows in the remainder of this report should be of interest to Australian universities who are owner-occupiers of their own campus facilities.

5.4 Community microgrids

Community microgrids serve a subset of separately metered customers within a regional network context. They represent the most radical application of microgrid technology, due to their conflict with electricity market regulations which are designed around a distribution monopoly. Interest in community microgrids is being driven the evolution of Distributed Energy and Smart Grid technologies as enablers, and increasing interest in more tailored solutions than the "one size fits all" approach underpinning traditional distribution network design and performance.

The starting point for consideration of a community microgrid is distributed energy generation. By serving more customers and larger demand, distributed energy facilities owners benefit from economies of scale that have traditionally favoured the centralised generation model, while retaining control over their grid design and performance attributes. The emergence of community microgrids may be interpreted therefore as the bridge between the two extremes of grid design.

While this sounds appealing in theory, the challenges within community microgrid models relate primarily to their relationship to the surrounding market. The natural monopoly of electricity distribution has traditionally been addressed with regulated price controls and protections that provide certainty for distribution businesses. In delivering electricity across a public right-of-way, a community microgrid creates an alternative distribution model incompatible with the regulatory framework for monopoly distribution. As a result, community microgrids only exist where regulations permit and encourage.

As a reflection of climate risk for that state's electrical infrastructure, Connecticut passed an amendment to legislation covering utilities in 2013 that permitted electricity to be distributed across public streets as long as the generation source does not exceed 5 MW. The state's microgrid grant program then provided funding towards a $USD 3 million project in the town of Parkville which aims to connect a 600 kW natural gas CHP generator located in a school with a local supermarket and "gas" (service) station – refer to Figure 16.

Figure 16. *The community microgrid being established in Parkville, Connecticut – electricity generation infrastructure based at the Parkville Community Elementary School also serves the Senior Center and Public Library that are in the same building, along with the C-town supermarket opposite and the Shell service station further up the same street. A distance marker has been included for scale.*

The Parkville Neighborhood Microgrid will provide a place of refuge along with food and fuel distribution for the community during extended power outages. The microgrid electricity distribution infrastructure runs parallel to and can “island” (disconnect) from the parent network. Tony Matta, Department of Public Works Architect with the City of Hartford, described the project as follows:

…in the Parkville community we found that there is a fair amount of power outages … there were times nowhere … you could find gas, nowhere you could find a grocery store … there was a real, real need, and it was a social need before it was a financial need. So we looked at trying to serve our people and … creating this public/private partnership … with the Parkville microgrid that accomplishes a whole bunch of important processes for us.

Our microgrid is actually up 24/7 … it only goes back onto the grid when it needs repairs and stuff. We looked at partnering with energy companies to design, build and eventually operate, and through a power purchase agreement this microgrid will actually offer the energy back to both the city and the two private companies. The reason we looked at it that way is that, unlike Wesleyan, we don’t have a lot of resources to do a lot of the energy stuff.

… the City looks at it more of an opportunity to provide necessary services and an effective cost model, because one of the things we are putting into the contracts is that the energy that’s going to be sold back to us has to be better or equal to the rate that we are getting from our overall city power purchase agreement provider.

Under the current Australian framework, a community microgrid would be likely delivered via exemptions from various requirements that apply to regional-scale network operators and market-participating electricity retailers. The Australian Energy Regulator (AER) provides guidance on registration exemptions for parties that are distributing and/or selling electricity, and maintains public registers of exemptions granted for these activities.[55,56]

Exemptions may fall into different classes based upon the activities being undertaken. Conditions relating to the exemption become more significant as the activities increase in scale and complexity as a reflection of the activities of and requirements for registered network service providers and authorised retailers.

While this guidance suggests that exemptions for relatively small-scale community microgrid projects (e.g. the Parkville Neighborhood Microgrid) may be granted with minimal conditions attached, each exemption application is considered on its merits. For this reason the exemption arrangements entail uncertainty and risk for community microgrid projects in Australia, with corresponding implications for project planning and finance.

An alternative approach may be for existing market participants to offer community microgrids as an alternative model. Based on conversations with Australian market participants, this scenario seems unlikely in the near-term. Issues raised include:

- Regulatory constraints on offering both network and retail services
- Organisational culture and/or business strategy
- Uncertainties relating to the commercial viability of the model

Notably, in June 2014 the New York State Public Service Commission received an application for permission to offer microgrids as a customer service from Central Hudson Gas & Electric (CHG&E), one of that state’s electricity distribution businesses.[57] Given that Australian market participants are subject to similar influences as CHG&E, this development may be a portent of things to come.

6. PLANNING

For would-be microgrid project owners understanding where to start is an intimidating thought. Enlisting the help of experts may be an obvious course of action, however the deliberations that go into even that decision are a perceived deterrent.

To assist would-be microgrid project owners, the development pathway for a range of project types was analysed to identify priority areas for consideration. In addition, the key strategies that underpinning successful project delivery were assessed for inclusion in project planning decisions.

Action: Set out a high-level planning process for each project category

6.1 Incremental project development

The complexity of microgrid projects can be significantly reduced by dividing the project into "digestible chunks". Furthermore, a logical sequence exists for design and implementation as a reflection of project risk and finance considerations.

The majority of microgrid projects originate from existing investments in energy infrastructure. The exception to this may be standalone microgrids that are established to provide energy access where previously there was none, however even these projects may unite existing end-users of electricity and their infrastructure.

While a distribution system effectively defines a network, a source of distributed generation has been found to be the most common foundation for the microgrid projects investigated. The wisdom acquired through ownership and operation of the generation resource appears to provide the appropriate foundation for consideration of a microgrid by reducing the project risk (perceived or real). Enhancing the investment in distributed generation is usually a more palatable approach than starting a blank sheet of paper – for both the project owner and their finance provider/s.

Although distributed generation may instigate consideration of a microgrid, the first phase of a microgrid project is focused on demand optimisation – refer to Figure 17. The reason for this is simple – the Distributed Energy Resource (DER) investment requirement increases with the size of the load to be served. By reducing overall demand and smoothing out peak demand, less generation capacity is required and more efficient utilization of assets can be pursued.

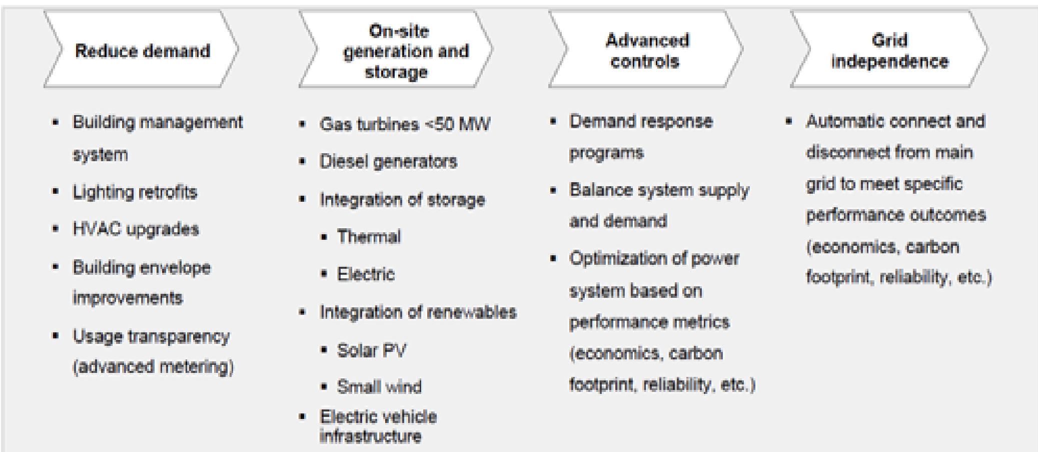


Figure 17. *An idealized representation of microgrid project evolution.*[58]

Additional benefits from pursuing demand reduction at the outset include:

- Reduced operating costs – energy efficiency delivers immediate returns in the form of reduced costs, while peak demand management can deliver reduced operating costs from (e.g.) reduced peak demand charges levied by the regional network operator; both measures can provide excellent returns on modest investments that can be financed off the balance sheet or through a variety of low-cost loans (see also section 8)
- Improved stakeholder engagement – both energy efficiency and peak demand management can be implemented in relatively short timeframes; early wins for the project help to gain support and spur additional commitment

Despite the benefits, many would-be project owners overlook demand reduction in favour of higher-profile, more-visible distributed generation. For community microgrid projects in particular, building a wind or solar farm represents the “moon shot”. Maintaining support for the project can be challenging if the initial focus is on less-glamorous, incremental improvements rather than the big breakthrough.

These expectations may be partly managed by highlighting the relationship of the distributed energy resource strategy to the characteristics of the load being served. While the natural progression for the project will be from demand reduction to distributed generation and storage, it may be more palatable to start the conversation from the other direction.

An additional consideration with regards the load characteristics relates to reliability requirements. Critical loads within the demand mix need to be identified along with the maximum outage interval. These insights are not only crucial to the rest of the project design, but may actually be the main motivation for pursuing a microgrid at the outset.

Once demand has been analysed and optimized, the second phase of the project will focus on the DERs. Noting the observation made at the outset, this will be most likely a “brownfield” activity that draws on existing investments. Renewables, gas-fired generators and diesel gen-sets may be individually or all present, and will form part of the solution. Additional generation and storage resources will be conceived and implemented alongside existing resources, even if at this stage of the project they may not be managed in concert. Information on the DER strategy can be found in the section that follows.

The final stage for a microgrid project is where the vision finally comes to life with interconnection and centralized control of the various network resources. For microgrids containing significant proportions (> 20 per cent) of renewables, grid-stabilising infrastructure will be required along with sophisticated control systems that permit islanding. Commissioning of the microgrid can be said to have occurred once the facility has operated independently of the surrounding grid, including successfully re-joining it for grid-connected facilities.

Although dedicated microgrid controllers are emerging as a derivative of regional-scale Smart Grid control systems, the unique attributes and objectives for each microgrid entail a lengthy connection, commissioning and optimization process. Regional-grid operators must themselves gain confidence in the safe, reliable and predictable operation of the microgrid before islanding/re-joining can take place. Optimization of the microgrid operation under various scenarios is likely to continue beyond the facility being commissioned into service as the desired balance between competing objectives is established.

6.2 Electricity demand

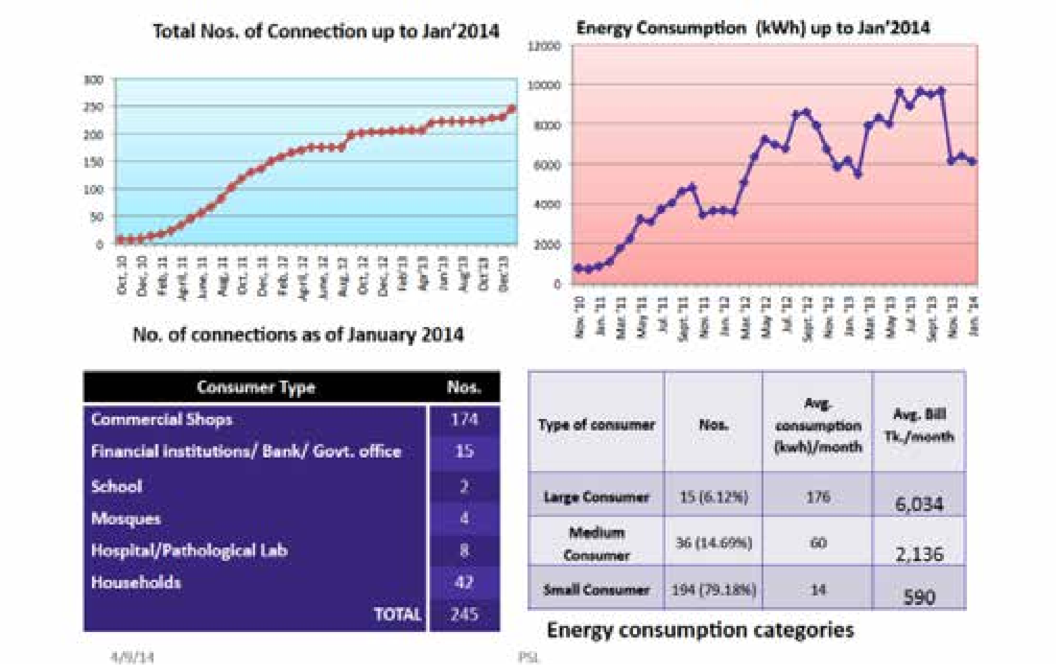
As for electricity networks more broadly, microgrid design and operation is strongly influenced by the load being served. Characterisation of existing and forecast demand is one of the most important tasks at the outset of microgrid project planning. Optimising demand through efficiency and peak-smoothing measures helps minimize the upfront investment requirement in generation. Management of demand helps realise outcomes envisaged in the project business case, including those arising during periods of emergency operation.

Demand optimization can often yield cost savings at the outset of a project – quickly and with minimal investment. Demand reduction and smoothing also serve as the foundation for optimization of subsequent investments. The understanding of these issues varies wildly across would-be project owners, with community microgrid participants in particular prone to overlooking demand optimization in favour of the greater allure of generation infrastructure.

6.2.1 Demand-driven design

Approaches to demand characterisation vary according to project type. For off-grid locations and/or community microgrids, assessments are likely to include paper surveys of community members. Demand types must be identified and understood in terms of how they will impact the aggregate demand profile. “Willingness to pay” studies not only help with demand estimation and forecasting, but tariff structure design, revenue estimation and project financing. Experience in the design and interpretation of these studies is crucial to ultimate project success.

By way of example, “best practice” for a standalone microgrid design was described by Mahmood Malik from IDCOL in Bangladesh.[59] An initial survey of businesses and the community on Sandwip Island suggested that potential consumers were eager to pay for reliable grid electricity services beyond the expensive diesel-based supply used by select commercial customers. Once the decision was made to locate the facility nearby to the local market, potential consumers were notified that the solar minigrid would provide electricity for lighting, fan, computers, television and other small domestic appliances. Following product research, high efficiency fans, lights and televisions were made available to consumers through the market. Tariff packages were designed as a reflection of the load types, system costs and customer willingness/capability to pay. Low, medium and high tariff bands were designed to optimize the socio-economic development return on investment. Based on the projected demand and accompanying revenue over a 20-year project life, finance was obtained for the microgrid construction. Since it was commissioned in 2010, there has been a steady increase in the number of customer connections and revenue as the reliable power supply became evident. Up to January 2014, the project has generated more than 320 MWh and displaced diesel generation which would have produced 222,230 kg CO2 – refer also to Figure 18.



Consumer Type	Nos.
Commercial Shops	174
Financial institutions/ Bank/ Govt. office	15
School	2
Mosques	4
Hospital/Pathological Lab	8
Households	42
TOTAL	245

Type of consumer	Nos.	Avg. consumption (kwh)/month	Avg. Bill Tk./month
Large Consumer	15 (6.12%)	176	6,034
Medium Consumer	36 (14.69%)	60	2,136
Small Consumer	194 (79.18%)	14	590

Figure 18. *A breakdown for the standalone solar PV microgrid project in Sandwip, Bangladesh.*[60]

For fringe-of-grid and campus applications metering data is likely to be available. While aggregate demand profiles are the most commonly available meter data, characterisation of different load profiles and types is crucial to the microgrid design, including optimization of the technology mix and control strategies under different scenarios.

By way of example, critical loads are a subset of the aggregate load that must be supported during emergency events where the microgrid may be disconnected from the regional network. These loads should be on a standalone circuit and characterised in accordance with how long they must be maintained – from a matter of minutes to several days.

Planning of the distributed energy resource mix will build out from the critical load profile as the baseline for the microgrid design. Energy storage and/or diesel generation capacity will increase with the size and duration of the critical load profile. Should islanded operation be required for potentially a 24-hr period for a grid-connected microgrid, the design may begin to resemble that for an off-grid location.

6.2.2 Energy efficiency

Minimising the total load to be served is "low-hanging fruit" for most projects. Energy efficiency projects often have low investment requirements, short payback times, and reduce the investment requirement for generation. Grant funding or low-cost finance is often available, along with well-established financing arrangements such as Energy Performance Contracts that minimize risk. Energy conservation victories increase support and buy-in from project stakeholders and sponsors alike.

As described under "Campus microgrids" in section 6.3, Wesleyan University in Connecticut has an outstanding track record for energy efficiency. Notably, Wesleyan cited their successful implementation of grant-funded energy efficiency initiatives as proof of their commitment and capability within their ultimately-successful microgrid grant funding application.[61]

Despite its enormous potential, energy efficiency is often undervalued and overlooked. This can be explained by a number of issues, not least of which are the information barriers relating to analysis of energy data and identification of savings opportunities. The familiar adage of "you can't manage what you don't measure" looms large in the space - interpretation of aggregate demand data is challenging even for experts, and installation of submetering equipment and collection of data can take time. Significant gains may require the implementation of a diverse range of incremental improvements, none of which have the allure of a large solar array or highly-visible wind turbine.

The good news is that for those willing to commit there is plenty of help available. Independent, expert auditors can be engaged to conduct comprehensive assessments, often drawing on funding made available by various levels of government. Equipment and buildings can often be benchmarked against alternatives using well-established rating schemes that are widely recognised and increasingly understood by buyers and sellers alike. Case studies from within industry sectors or geographic regions are available for those unsure of where to start or what's possible.

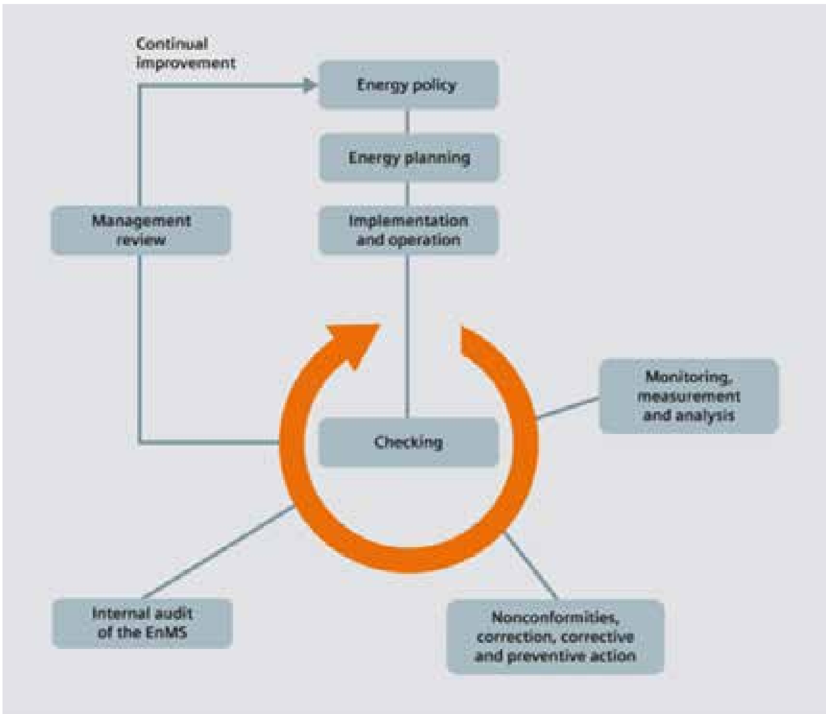


Figure 19. *Energy systems model as defined by ISO 50001:2011 Energy management systems – Requirements with guidance for use.*[62]

For organisations seeking to effect change, the most effective measure is to set targets and make the relevant staff accountable for energy efficiency improvements. Performance plans and rewards for (e.g.) facilities managers should be linked to energy efficiency outcomes, and encouragement and support provided to seek help where needed. Most energy efficiency initiatives pay for themselves, and with outside assistance commonly available, the excuses for not achieving savings are few.

6.2.3 Demand management

Demand management is a crucial aspect of microgrid design and operation. High peak-to-average demand ratios translate to suboptimal investment and poor utilization of assets. Excessive use of higher-priced energy sources to meet demand peaks may undermine the project business case and translate to financial loss. Exceedance of system capability may result in supply failures, significant financial impacts and potentially worse.

This was particularly the case for standalone microgrids, where project failure was often attributable to unmanaged demand alone. Andre Susanto from PT Imprima (Indonesia) and Ali Askar Sher Mohamed from SEDA Malaysia provided numerous examples of off-grid projects in their countries where supply capabilities were exceeded as actual demand surpassed the forecasts underpinning the system design.

Demand management may be achieved through technical and/or non-technical solutions:

- Identification and management of "deferrable" loads should be undertaken as part of the demand-driven design activities – this can be done intuitively and manually, or using more advanced methods such as intelligent demand/energy management systems that can match demand to the supply of intermittent resources from solar and wind generation (an increasingly important opportunity in the context of battery storage systems)
- Critical load circuits – where only the highest priority loads exist on specific circuits from the point of centralised electrical supply and/or control – provide the physical means of easily shedding load under emergency scenarios
- Dynamic tariff structures where the unit costs of electricity vary for end-users according to the time of day/week are a highly effective means of smoothing demand, even if they should be complemented with information on how to achieve the desired outcomes for all parties
- Demand charges often apply to large business users during periods of high network demand, such that the cost savings that can be made from demand management/reduction serve as an input for the project business case more broadly (e.g. for investment in on-site storage)
- Consumption limiters constrain peak and/or daily energy use for individual customers to ensure the system operates within its capabilities, but require user education on how to manage this, may be subject to tampering in the absence of penalties, and may be too expensive for some applications
- Pay-as-you-go systems and pre-payment meters combine financial and technical measures for individual users and have been proven to be effective at managing demand and delivering revenues relative to the project design inputs; while improved design and understanding of these approaches is increasing their effectiveness, the equipment, installation and operating costs may be prohibitive for many applications

Although support for demand management is not as mature or accessible as for energy efficiency, it can often be obtained through the same avenues, e.g. independent, expert auditors. Consideration of both in parallel may be effective at the outset, even if the solutions that are ultimately implemented diverge.

6.3 Delivery context

Set out a microgrid customer needs assessment framework:

- Social and cultural factors

Action: Examine the socio-cultural issues that may impact upon project design, delivery and operation

Although microgrids may be thought of as the ultimate expression of customer-driven energy solutions, the motivations and objectives of microgrid stakeholders can vary wildly. Understanding and accommodating these socio-cultural influences may be crucial to successful project delivery.

This issue has relevance for standalone (off-grid) microgrids in particular. Andre Susanto from Imprima (Indonesia) highlighted that social and cultural issues were more difficult to solve than technical issues – particularly in the emerging markets of Asia and Africa. Specific issues Mr Susanto highlighted for consideration included:

- Partner selection
- Theft
- Jealousy
- Greed
- Capacity building and a sense of ownership
- Violent social conflict
- Rich versus poor

In one case study Mr Susanto explained how the local village chief insisted he be exempt from the demand limiters applied to the rest of the village before allowing the contractor to finish installation and commissioning of the village microgrid. As a result, the system ran out of power every day as a result of the chief's excessive use of electricity relative to the demand forecast that underpinned the system design.

Another vivid illustration of these issues arose in the Indian state of Bihar around a Greenpeace demonstration project. While the project was carefully conceived and delivered as a reflection of the goal for it to "showcase a new approach for energy justice",[63] a series of local protests only weeks after its launch gained international media attention:

Slogans such as "Hamen nakli nahin, asli bijli chahiye (We do not want artificial energy, give us the real one)" greeted former Chief minister Nitish Kumar, as he went to the village to see how the long forgotten region, devoid of electricity since 1981, looked after dusk.

… Though the former chief minister tried to put up a brave front, asserting how the inexhaustible solar power would become the main source of energy in the future, he eventually promised the villagers that "real electricity" would be provided to them shortly.[64]

This project was delivered within the context of heavily-subsidized grid electricity in neighbouring areas, which was ultimately extended to the village thereby undermining the microgrid business case.[65]

Remedies suggested by Andre Susanto included:

- **Community involvement** (via local contractors or volunteers) – this approach will help create a sense of community ownership that will reduce the likelihood of push-back, sabotage or theft
- **Picking the right partner** – someone who knows the local culture, understands local issues and is knowledgeable of the technical challenges specific to the area

- **Demand management** – via limiters for each user, noting that these can be expensive and potentially circumvented by users who are not on board
- **Education** – developing a sense of understanding of the relationship between the affordability and reliability of electricity supply, and training people in productive uses of electricity as a cornerstone for economic development
- **Building capacity into the project** – ensuring system components such as inverters are future-proofed for foreseeable increases in generation capacity
- **Managing the losers** – understanding who will lose out as a result of the project and pre-empting their response, e.g. diesel fuel distributors/sellers

While much of this advice is mainly relevant to standalone/off-grid applications, the delivery context is important for microgrids regardless of where they're employed. The business case for most microgrids will generally contain assumptions that should be tested against changes in the operating environment, e.g. policy changes that jeopardize key revenue streams or business case inputs. Robust project design requires sensitivity and scenario testing at the outset to help identify risk and the appropriate management strategies.

6.4 Distributed Energy Resource (DER) planning

Detailed design of the distributed energy resource strategy is outside the scope of this report and should be undertaken by skilled experts. This analysis should combine technical and financial modelling using tools such as HOMER from the U.S. National Renewable Energy Laboratory (NREL),[66] and should address various outcomes including avoided costs from unplanned outages and environmental performance over the project lifetime in comparison with grid-sourced energy. Where relevant, the analysis should be broadened to include consideration of wider benefits, such as local economic development arising from reduced energy costs to households or jobs created through the project (e.g. via local harvesting of biomass).

In the face of this complexity it is useful for would-be project owners to understand some of the basic characteristics for each resource, and in doing so help refine their selection at the outset.

6.4.1 Combined Heat and Power (CHP)

As the name suggests, Combined Heat and Power (CHP) systems deliver both thermal and electrical energy. Natural gas is the most common fuel input, but biogas is also widely used making it a potentially renewable source of generation. Electricity is produced via an energy conversion unit – typically a turbine but potentially a reciprocating engine or fuel cell (more about these below) – from which the waste heat is also recovered, ensuring high levels of energy efficiency. Co-generation is a term used to describe CHP systems that produce electrical and heat energy only, while tri-generation also provides cooling energy via an absorption chiller operating on the waste heat.

CHP is well-suited to serving large/stable baseload demand which includes thermal energy loads along with a need for a highly reliable source of power. Example applications include hospitals, military facilities, data centres and 24/7 manufacturing facilities.

Gas supply inputs and price projections must be reliable and support the project business case, the latter also benefiting from grid-support payments as means of ensuring adequate asset utilization and investment efficiency. While low gas prices and grid-support payments are relatively commonplace in the U.S., this is not currently the case in Australia.

The NSW Government has produced a guide and modelling tool for cogeneration that are an excellent starting point for would-be Australian CHP project owners.[67]

6.4.2 Renewable energy resources

Renewable energy resources for microgrid applications generally focus on solar photovoltaic (PV) and wind turbines, even if small-scale hydro and biogas-fuelled generators may also find application in predominantly rural locations. Across the various microgrid projects benchmarked for this report, solar PV was by far the most common renewable energy technology featured.

Being reliant upon energy inputs from the surrounding environment, site characteristics are the strongest influence on the selection of renewables for microgrid applications. Renewable resource potential including adequate real-estate may be a constraint for any significant installation capacity, which for wind turbines may reflect the local planning approval requirements associated with impacts on local amenity.

As renewable energy resources cannot be "scheduled for despatch", the business case for renewable microgrids should mostly reflect self-use rather than the sale of excess energy back into the surrounding grid. Similarly, complementary resources such as diesel gen-sets or energy storage will likely be required to account for the intermittency of generation.

The widespread adoption of residential solar PV entails that Australian expertise in this technology is world-leading. The Alternative Technology Association provides an excellent modelling tool that will help assess the economic feasibility for a solar system.[68] More detail on hybrid solar/diesel microgrids can be found under "Reciprocating engines" below.

Wind farms are a highly politicized topic as is illustrated by the divergent and continuously-changing approaches taken by various state governments in the planning approval frameworks for these projects. Embark provides an excellent account of these experiences delivering the Hepburn Wind project , however it should be noted that many of the insights within this wiki are applicable to renewable energy projects more generally.

Bioenergy is a diverse topic due to the large number of possible feedstocks and processing routes that might be taken through to the final energy conversion. Guidance from the International Energy Agency[70] and the U.S. National Renewable Energy Laboratory[71] is complemented by the wealth of material provided by the Australian Government Rural Industries Research and Development Corporation.[72] Although it is outside the scope of this report to delve more deeply into any particular technology, a unique characteristic of bioenergy that should be noted is the potential economic development benefits associated with realising value from waste products and localised employment through the production process.

Micro or small-scale hydropower is challenging in Australia given the variable and often sparse flows in our inland waterways, however sites near catchments or in high rainfall areas may be able to harness this energy source. An introduction to the topic is provided by the U.S. Department of Energy,[73] which sits alongside more detailed guidance from the European Small Hydropower Association.[74]

6.4.3 Energy storage

Although storage may include thermal, flywheel, pumped hydro and compressed air, interest in on-site storage is increasingly focused on battery technologies. Cost reductions and the increasing uptake of solar PV is driving much of the interest in battery storage for microgrid applications.

Battery storage technology choice varies according to the project objective. For example, renewables integration will generally favour technologies with short response times such as lithium-ion batteries, while extended back-up power needs may be better served by flow batteries based on vanadium or zinc bromide electrolytic cells. Due to the proprietary nature of various battery technologies, vendor consultation in the early stages of project development is necessary to ensure the appropriate selection can be made.

Battery storage is currently expensive, but costs are likely to decline significantly over the next five to ten years. Additionally, electricity market reforms are expected to open up the “benefits stack” which will deliver additional revenue streams into the storage business case. Notably, customer-sited storage solutions are showing signs of emerging from regional network operators who can realise benefits from the storage investment alongside revenue gained through the customer service agreement. An additional input into the storage business case relates to provision of emergency back-up power in place of the traditional diesel gen-sets, which are a sunk cost, dirty and often unreliable.

The rapid evolution of the battery technology and the associated market likely to unfold over the next five to ten years entails close attention to the risks associated with storage investment. Early-stage technology risks associated with most battery technologies may create project financing challenges (see Section 8), however these may be addressed through vendor financing and/or warranty arrangements that allocate risk appropriately, along with consideration of R&D/innovation funding sources. Similarly, procurement decisions should favour reliable vendors that are backed by a large parent organisation with the appropriate longevity.

For the microgrid projects benchmarked there was a mix of battery storage technologies in use. Pb-acid systems were the most popular for projects that had been in operation for a number of years, while Li-ion systems were becoming more commonplace within more recent projects. Flow batteries were not observed in many applications, likely due to their relatively recent commercialization, high cost, bias towards larger scale applications of over 1 MW, and longer charge/discharge times that prevent them from being used for voltage/frequency regulation. Composite Energy Storage Systems (CESSs) that combine and offer all the advantages of a number of battery technologies were felt to offer much potential, however their design is complex and needs to be tailored to the application. The overriding insight was that battery technology was a fast-evolving space dominated by proprietary technologies which require close engagement with vendors.

Although the situation is changing rapidly, Australia has relatively limited experience of emerging battery technologies. Notably, while a number of distribution network service providers are trialling grid-scale (generally Li-ion) batteries as part of the Demand Management Incentive Scheme, the results from these projects are not reported in a consistent fashion.

In contrast, Sandia National Laboratories in the U.S. are the focal point for much of the storage research and information-sharing,[75] and maintain a handbook, project database and feasibility assessment tool which are all available for public use.

6.4.4 Fuel cells

Stationary fuel cells are beginning to emerge as a viable choice for backup power, power for remote locations, standalone power plants for towns and cities, distributed generation for buildings, and as the energy conversion units within CHP systems. They use a fuel (typically hydrogen in pure or derived form) and oxygen to create electricity by an electrochemical process.

Fuel cells are inherently quiet, and provide emissions-free, critical systems performance. They may use pure hydrogen, natural gas or renewable fuel in the form of biogas, and can deliver reliable electricity and heat within CHP systems at up to 90 percent conversion efficiency.

As for battery storage, fuel cells are expensive and bring reliability concerns due to the relative immaturity of the technology and lack of field exposure. Management of these issues should follow the approach outlined for battery storage above.

None of the microgrid projects benchmarked utilized fuel cells, however case studies highlight that they are finding use in commercial-industrial applications in the U.S. in particular.

Experience with fuel cells in Australia is relatively limited. It has been suggested that fuel cells are being trialled in defence applications for ICT support in remote locations,[76] however the results from these trials are unlikely to be made publicly available.

The U.S. National Renewable Energy Laboratory (NREL) runs a technology evaluation program that analyses and reports on the performance of stationary fuel cell systems operating in real-world conditions.[77] Also in the U.S., the Oak Ridge National Laboratory published a guide for government facility managers on procuring fuel cells for stationary power.[78]

6.4.5 Reciprocating engines

While reciprocating engines as diesel gen-sets represent the "business-as-usual" option for microgrids in many applications, it should be noted they may be operated on various blends of renewable biofuels. They may also be supplemented or even replaced by storage, fuel cells and/or CHP units, including for backup power.

Reciprocating engines are a mature, low-cost technology that is generally reliable. They have traditionally been the main or sole source of power for standalone or off-grid applications in remote areas. While this may be the cheapest way to provide energy access in terms of upfront investment, the high costs of transporting diesel to remote locations often translates to high electricity costs for poor communities.

For this reason, renewable sources are increasingly displacing diesel as the technology costs come down and technical solutions are developed/accepted for increasingly high penetrations of renewable energy.[79]

Shuin Chen from Sarawak Energy in Malaysia described how his state-owned corporation was increasingly using hybrid solar/diesel microgrids to provide electricity to remote communities. He highlighted the investment challenge associated with minimizing operational costs for poor communities through greater percentages of renewables accompanied by higher capital expenditure.

Solar PV technology cost reductions are shifting the balance on this issue in favour of reducing operating costs. In recognition of this the Power and Water Corporation (PWC) of the Northern Territory has developed a handbook for solar/diesel mini-grids that provides an overview of design considerations including the various issues relating to diesel engines, along with modelling software for technical and financial assessment.[80]

More generally diesel gen-sets are used for backup power in grid-connected applications.[81] The Australian Trusted Information Sharing Network for Critical Infrastructure Protection has authored a useful guide to diesel fuel supply and backup generation.[82]

As costs go down, alternatives to diesel backup generation such as CHP, fuel cells and (particularly) storage are of increasing interest as evidenced by many of the projects benchmarked for this investigation. Notably, this is also due to the various limitations of diesel backup power which include:[83]

- Backup diesel generators are rarely called to operate and might not start and run when needed
- Diesel fuel deliveries can be difficult or impossible to arrange during a widespread disaster
- Storing large quantities of fuel imposes high costs and risks of fuel leakage or fuel degradation
- Diesel engines used for backup service typically have high emissions and are permitted for limited use

As highlighted by the quote from MIT researchers within an assessment of U.S. Department of Defence facilities, consideration of the alternatives fits within a more holistic approach to energy supply which may deliver equivalent or better reliability using distributed energy resources. Additional benefits include operational cost savings and avoidance of the sunk costs associated with diesel backup generators.

Existing solutions typically use dedicated backup generators to service each critical load. For large installations, this can result in over 50 small generators, each servicing a low voltage feeder to an individual building. The system as a whole is typically not well integrated either internally, with nearby renewable assets, or to the larger external grid. As a result, system performance is not optimized for efficient, reactive, and sustainable operations across the installation in the event of a power outage or in response to periods of high stress on the grid.[84]

While the commentary on bioenergy set out in section 6.4.2 Renewable Energy Resources is pertinent is pertinent to consideration of reciprocating engines operating on biofuels, there are specific issues that relate to generators powered by biodiesel. And as these issues tend to have reliability implications, biodiesel generators should not generally be considered for backup power applications.

The tendency of biodiesel to act as a solvent for compounds that may be the basis of various engine components entails restrictions or warranty limitations from engine manufacturers[85] for use with specific blends of bio- and regular diesel.[86] A detailed understanding of these issues should be sought as part of any consideration of biodiesel for extended use.

Furthermore, biodiesel properties can vary significantly according to feedstock and processing route. Biodiesel blends may also be seasonal due to their temperature sensitivity. For this reason the biodiesel supply-chain should be understood and managed as part of any commitment to operate gen-sets on biodiesel.

6.4.6 Microgrid controllers

Monitoring, communications and control tasks are centralised in the microgrid controller – a software platform that serves as the user and grid interface, and is the brains behind the microgrid operation. As this part of the system is crucial to the microgrid project success, it is important that a well-considered project brief be put together at the outset, and that a range of issues be considered through the product and vendor selection process.

Advice from project owners suggests that microgrid controllers are largely bespoke solutions at the project implementation level. The specific needs and objectives of the project combined with the large number of variables that must be dealt with drive project-specific implementations even if starting from a common platform. As an indication of where this complexity stems from:

- Each DER may have its own integration requirements that relate back to not only what it is, who designed and installed it, and when
- The interaction of various DERs in each project will create unique and continuously changing requirements for the microgrid controller to manage in terms of maintaining the quality and reliability of the energy supply
- The threshold issue of the grid connection agreement must be addressed within the unique requirements identified by the regional network operator

The microgrid controller must address all of these issues, as well as deliver cost-effective, reliable operation in potentially challenging conditions. For these reasons the microgrid controller commissioning and test process will be crucial to avoiding potentially disastrous consequences down the line.

As a starting point for consideration of product choice, preferred options should include those with actual field exposure on similar project applications. Would-be project owners are likely to identify analogous projects already in operation through their research. If possible, contact should be made with these project owners to discuss their experience, particularly in relation to their choice of microgrid controller. The effort invested in benchmarking experiences and products may be the difference between a successful project and a painful and costly failure.

For grid-connected projects the regional network operator should be consulted in the specification of the microgrid controller and subsequent selection process. Preferably, the network operator should have a previous working relationship with the vendor, and even the product. If this is not possible, the shortlisted vendors should be prepared to engage with the regional network operator and take ownership of the issues identified as part of the connection agreement.

Vendors are entering this market from a number of possible directions. Smart Grid controllers, building automation, energy efficiency technologies, storage energy management – basically any technology offering that is connected to building or energy management – is serving as a starting point for microgrid controller design and evolution.

In terms of vendor choice, large industrial solutions providers who offer generic microgrid controller platforms include:

- ABB
- Caterpillar
- Eaton
- GE
- Honeywell
- Ingersoll Rand
- Johnson Controls
- Lockheed Martin
- National Instruments
- Schneider
- Siemens

Outside of these, there are a number of smaller, specialist and/or start-up businesses who have developed microgrid controller platforms through the early stages of the market development – examples include:

- GreenSync (Australian)
- Optimal Power Solutions (Australian)
- Pareto Energy
- Power Analytics
- Princeton Power
- Schweitzer Engineering Laboratories
- Spirae
- Viridity Energy

As for any emerging technology, the market expands rapidly with competitors from all directions pursuing rapid product development cycles to establish a competitive advantage. As the better products and players emerge, others will fall away and the market will consolidate around a dominant few.

In this fast-changing environment characterised by uncertainty, would-be project owners need to be aware of the various risks they face in their choice of technology and vendor:

Issue	Description	Remedy
Interoperability	Where gaps in standards, differences in their interpretation and/or proprietary systems create problems in the interactions across system interfaces	• Demonstrated experience working with similar technologies • Familiarity with proprietary systems • Prioritize the most important integrations in assessing prior experience
Obsolescence	Where the chosen product becomes obsolete (e.g. due to a lack of backwards-compatibility for new product releases) or unsupported (e.g. due to closure of the originating business)	• Use widely recognised standards wherever possible • Good contract design that ensures ongoing product support/ compatibility • Ensure that the software source code can be accessed under certain circumstances
Warranty	From unforeseen eventualities that may be excluded, consequential losses, and for unsupported products originating from businesses who leave the market	• Expert legal advice in the appraisal of product warranties • Ensure that the software source code can be accessed under certain circumstances
Switching costs	Excessive barriers to migration from the incumbent platform to a newer/preferred alternative	• Use widely recognised standards and APIs wherever possible • Prioritize the most important integrations in considering potential exit strategies

While it's hard to safeguard against these issues as new technologies rapidly evolve, one approach is to work with an established vendor who isn't going anywhere. Unfortunately, this may work counter to the need for continuous, on-the-ground support of the type that is best delivered by a specialist, local provider.

6.5 Project approvals

There are a range of approvals likely to be required for any project. Connection agreements, development approvals, OH&S reviews and more will need to be addressed and are a significant source of project risk.

For microgrids or even DERs that are connected to "the grid", a connection agreement will need to be obtained from the distribution network (grid) operator. This is a threshold issue for most projects, and is one often underestimated by project owners and sponsors.

The primary purpose of a connection agreement is to minimise the cost and reliability impacts to the network. At face value these impacts are characterised as potential deviations from the regulated power quality specification – voltage dips and sags, frequency variations etc – arising from customer-sited distributed energy resources. Power quality deviations outside the range of acceptance may cause damage or breakdowns to other equipment in the surrounding area, and as a result network operators are financially penalized for any failures to meet these requirements.

In parallel with this are the financial impacts arising to the network operators arising from decreased electricity demand. As the tariff determinations made by the regulator reflect the expected electricity demand, increased use of distributed energy resources may create shortfalls in the cost recovery by the networks, and with this an incentive to obstruct connection agreements. This issue will be further compounding through the advent of energy storage, which may have additional financial impacts on the network operator through arbitrage of energy within the regulated tariff arrangements, i.e. customer pay-outs for supplying cheap off-peak power from energy storage facilities back into the system during peak periods.

While the network connection application and review process is regulated, it remains a significant source of project risk. For project owners, the technical design requirements for the network connection agreement application create an almost impossible situation:

- The level of understanding underpinning the technical design requirements for the network connection application necessitates significant project investment be made before the network connection application can be lodged
- The application process is not a negotiation – the network operator is a monopoly enterprise, they are incentivized to avoid risk, and are entitled to transfer all risk back onto the project owner through a very costly connection agreement
- Efforts to ameliorate unforeseen costs may be stymied by a lack of transparency in the network operator's deliberations, and by the need to revamp the design and effectively start at the beginning before any further deliberations will be made

While still challenging, there are some simple approaches available to help reduce the frustrations arising from the connection agreement process:

- Ensure that the project team includes expertise and experience with the network connection agreement process, and preferably with the relevant network operator
- Understand the network operating environment by examining any publicly-available information such as annual network planning reports
- Engage the network operator early on in the project design, particularly for projects which are innovative or challenging with the specific network operating environment
- Utilise an incremental project design of the type outlined previously to help obtain a sufficient level of confidence in the project, particularly in the operation of the DERs
- Identify 'islanding' scenarios and consult on how these may be accommodated by the network operator – understand how these are handled for critical infrastructure that may already be present in the system, and demonstrate how the islanding/re-joining process will be handled safely and reliably

For many of the projects investigated these issues were addressed through the close involvement of the regional network operator – as a project delivery agent, supporter or key stakeholder. This was particularly true of standalone or fringe-of-grid projects, as these were often delivered under the influence of a regulated service obligation on the part of the network operator. For campus applications and community microgrids, close engagement between project owners and network operators unfolded alongside the incremental project development process, which allowed the network operator to gain confidence with the project design through the DER connection agreements and subsequent operation.

6. PLANNING

6.6 Design framework

Propose a preliminary technical design method for microgrid projects:

- High-level system architecture
- Key input variables
- Handling uncertainty

Action: Survey the range of system architectures applicable to different project categories

Action: Propose high-level preliminary design methods for different project categories

Action: Identify key design inputs and examine methods for handling uncertainty

While the context and objectives of a microgrid project will strongly influence the design framework adopted, three features emerged as common to successful projects – good data, a risk management perspective, and the expertise of the project team.

6.6.1 Data

Data is the starting point for all projects. Identifying and characterising the various system elements will draw on a range of inputs including location, geography, user needs and preferences, technology specifications and costs, energy inputs and the regulatory environment. Time-series forecasts for many of these variables will also be required for the project lifetime, and range estimates that reflect the uncertainty in key variables will be required for sensitivity analyses. Good data reduces risk, but can cost money.

While this may seem overwhelming at the outset, the incremental project development method described earlier allows the task to be broken down. The first step is to define the project scope, in terms of what buildings or loads will sit within the microgrid. The project must then be characterised in terms of the total system demand and key sources of demand. These may be large, isolated loads with their own unique demand profiles (e.g. a central heating or cooling facility), or an aggregation of loads that behave in a similar fashion (e.g. residential dwellings).

Monitoring data should be obtained for validation and further analysis. While gas and electricity bills are the most common source of information, additional monitoring is likely to be required for most projects. At the outset, the monitoring strategy should reflect the management level for key system resources – at the building level or within this for key demand or generation resources. If the majority of the total system demand profile cannot be accounted for through characterisation of the key loads and generation resources, the initial analysis should be revisited to identify the missing inputs.

Once the system demand is characterised, additional inputs can be gained for scenario modelling. Technology vendors will often provide free quotes that can be used as a starting point for further analysis. Modelling tools such as HOMER include libraries which allow a basic model to be constructed from built-in DER profiles. Literature reviews of peer-reviewed journals can identify studies of microgrid systems that may be analogous to the project at-hand or allow a sense-check of data inputs.

Some attempt should be made to benchmark against multiple sources of information relevant to the project scope. By way of example, discussions with facilities managers have highlighted outdated views on the viability of solar PV systems in particular, where technology improvements and cost reductions have rendered project modelling from just a few years back redundant. Storage technologies – expensive and risky right now – are undergoing an even more rapid evolution. Vendor information will likely be more up-to-date, and so it is worth sourcing to sense-check inputs obtained from literature etc.

The objective at this point should be to obtain sufficient data to undertake a 'back of the envelope' analysis before engaging paid experts. The would-be project owner should subject their idea to a 'sniff test' which will tell them whether the project is a bad idea before they start investing real money. Finance providers will require an objective analysis by paid experts before they arrive at a funding agreement. This analysis will draw on the monitoring data in particular, so it is a wise to start gathering this information then use it as an input for a preliminary assessment.

6.6.2 Risk

At this juncture a risk management perspective should be applied to the project. Sources of project risk should be identified and addressed before making the decision to proceed. The cost of finance is proportional to project risk, so the whole project should be viewed through the eye of a pessimist at the outset.

For enthusiastic project-owners it can often be hard to see the thorns on their rose of an idea, so a structured, collective risk assessment process should be undertaken. Project risk assessment methods are widely available on-line, but their application is mostly down to the discipline of the project participants. The goal should be to find the right project rather than invest a lot of time and effort into trying to make the wrong project succeed.

Risk is never eliminated, but simply managed to acceptable levels. Where a risk likelihood cannot be reduced, the source of that risk should be compartmentalised so as to reduce the consequence. The incremental design philosophy reflects this outlook, whereby initial investments target initiatives with fewer variables and a higher degree of confidence in the underlying business case. Successful delivery of these initiatives will de-risk later investments at the network scale (where the uncertainty increases) and in costly technologies (where the consequences of failure are much greater).

Example risk mitigation measures that can be adopted at the outset:

- Actual monitoring data should be prioritised over estimations
- Proven technologies should be preferred to emerging
- 'Hard' (technology-based) control strategies should be selected in favour of 'soft' (behavioural)
- Experience should be prioritised in the project team over enthusiasm
- Sensitivity analyses should be used to address areas of uncertainty

Getting the right foundation for the project should be a priority over expedience to take advantage of a funding application. Bad projects generally cost far more than any grant agreement they may have sourced, and smear the reputation of those involved for future projects.

6.6.3 Team

A key issue for would-be project supporters relates to the experience and capability of the project team. Expertise trumps enthusiasm every time.

By way of example, this report is targeted at enthusiasts rather than experts. Reading this report may help educate enthusiasts, but should also highlight the limits of their expertise. The goal should be to recruit sufficient expertise to the project team so as to guarantee the project success.

While the project specifics may require particular areas of expertise, there are a range of issues common to most projects:

- Technical design – for the energy technologies being proposed for the project

- Grant applications – for potential sources of funding relevant to the project
- Regulatory approvals – for connection agreements and retail exemptions pertinent to grid-connected projects
- Finance – for project design and engagement with finance providers
- Legal – for contract design and review

Recruiting capable participants to the project with experience in the areas above is perhaps the highest priority for any project. Unfortunately attracting this talent to the project is no small task. Residents/customers for the end-project are the most likely pool of "free labour" to draw upon, however the odds are against having sufficient expertise within this pool. Outside of this there may be altruistic, capable people who can be recruited through community collectives, not-for-profits, professional networks, research institutions and even technology vendors.

Once gained, this experience should be respected no matter how bad the tidings that they may deliver. Second opinions should be sought as a last-resort before dismissing opinions that don't conform to the expectations of other project participants. The relationships formed and/or soured over individual projects may be crucial for other projects that are destined for success.

6.6.4 Project-specific issues

Standalone microgrids are "closed systems" that draw on a vast body of practical experience in their design, build and operation. Hybrid diesel/renewable power systems are the evolutionary next-step of those based solely on diesel gen-sets. Design approaches reflect this evolutionary pathway by promoting consideration of renewable energy technology in systems that would otherwise be based solely on diesel generation. Financial analyses that allow the upfront costs of renewables and possibly storage to be compared with diesel operating costs are the starting point for determining the system architecture. Additional considerations relate to the selection of proven, reliable technologies that can operate with the available support. Numerous examples were quoted at the Microgrid Forum 2013 event that highlighted the pitfalls associated with system design and deployment by experts detached from the operating environment.

Beyond single-user applications, standalone microgrid projects that serve multiple users are prone to issues arising from the "tragedy of the commons" – independent users acting in their own self-interest exceeding the system capabilities through their collective action. These risks are increasingly able to be managed through the consideration of the demand management methods and contextual issues outlined previously. Outages arising from demand exceeding supply can be avoided by incorporating 'soft' and 'hard' management strategies into the project which will help ensure the performance targets are met and the business case realised in practice.

Fringe-of-grid, campus and community microgrids are "open systems" complicated by their interaction with the surrounding network. The first step is to define the scope for off-grid operation or the "closed system" boundary conditions – what loads must be supported, under what scenarios and when. Once these items have been appraised, demand-driven design methods allow the generation and storage inputs to be modelled and specified.

As the majority of these projects are 'brownfield', a gap analysis against existing infrastructure should be undertaken to identify additional requirements. Supplementary generation and storage should be specified to meet the microgrid performance objectives. Networking of the critical loads either on a single-circuit or through demand management of non-critical loads will also be required.

7. FINANCING

The overwhelming majority of microgrids will be delivered using "third-party financing" (generally referred to as "financing") rather than "self-funding" by the project owner. Obtaining financing is both challenging and requiring skill-sets that are often separate to the technical design process that has been outlined earlier. The good news is that project financing options are expanding via innovative financial mechanisms being developed by both the public and private sector.

The purpose of this chapter is to outline the basics of project financing before exploring some of the emerging financial instruments that were encountered during the course of this research. While some of these instruments may not be available in the Australian context, their design may prove instructive for microgrid project owners and supporters alike.

7.1 Basics

Explore basic financing strategies for microgrid projects:

- Financing strategies

Action: Survey the influences on project financing

Action: Identify the basic information required for financial modelling

Action: Outline the basic approach to financial modelling

7.1.1 Influences on project financing

The most significant influence on project financing is risk. Risk determines both the likelihood and cost of project financing. As outlined earlier, a risk management perspective should be taken at the outset of the project so as to improve the likelihood and reduce the cost of obtaining financing. Identifying key sources of project risk at the outset allows mitigation strategies to be adopted that will help ensure the project success.

A key source of risk from a financier's perspective relates to the project team. The qualifications and credit worthiness of those involved in the project may often be more important than the merits of the project itself. While the project team composition was touched on previously, financing providers will look closely at the team's experience, expertise, honesty and commitment. The credit risk of the project owner will be assessed, with preference given to entities that can be relied upon to pay back the project debt regardless of whether the project succeeds. Preference will also be given to project teams that have a history of delivering successful projects with the financing provider. While deficiencies in the project ownership and team may not preclude financing, the costs of financing will increase with the perceived risk from the financier's perspective.

For the project team, the involvement of the regional network operator is a key influence on project risk. Project models may involve the regional network operator as either the owner (100% utility ownership), co-owner (hybrid/public-private partnership), or be delivered independently of them (100% non-utility ownership). Regulatory risk is generally reduced according to the involvement of the regional network operator, making this a key risk area for 100% non-utility owned projects. A summary of the pros and cons for the different models of regional network operator involvement can be found below, some points of which are explained further in the sections that follow.

Ownership model	Pros	Cons
100% utility ownership	• Avoids disincentives • Simple business structure • Easy access to capital • Avoids franchise and right-of-way issues	• Raises service equivalency, cross-subsidy issues • Precludes service innovation and price competition
Hybrid/public-private partnership	• Reduces disincentives and service equivalency challenges • Avoids franchise and right-of-way issues • Allows service innovation and price competition	• Complex business structures • Limited pool of financing options
100% non-utility ownership	• Avoids disincentives • Simple business structures • Large pool of financing options • Allows service innovation and price competition	• Raises franchise and right-of-way issues • Reduced support from regional network operator

Table 2. *Project ownership models as influenced by the involvement of the regional network operator* [87]

Vendor choice – for project or technology sourcing, installation and operation – will also be a key source of project risk. Reputable vendors with a history of successful project delivery will be strongly favoured, even more so for analogous projects in terms of context or content or delivered with the same financiers. If an innovative new-entrant is preferred over conservative incumbents, a risk management perspective can still be taken by compartmentalizing their responsibilities to smaller or later stages of the project and ensuring that low-risk decisions are made elsewhere.

Technology risk not only relates to the technology options outlined in the previous chapter but also the complexity of their operational and maintenance requirements within the context of the project. Standalone or fringe-of-grid projects should generally use mature technologies with known performance characteristics for the operating environment in question.

Project risk generally decreases in line with the project development. Furthermore, investment partners often prefer to stick with their chosen risk level and deal size. For these reasons the financing strategy across the project lifetime should be considered – refer below for a simplified project lifecycle.

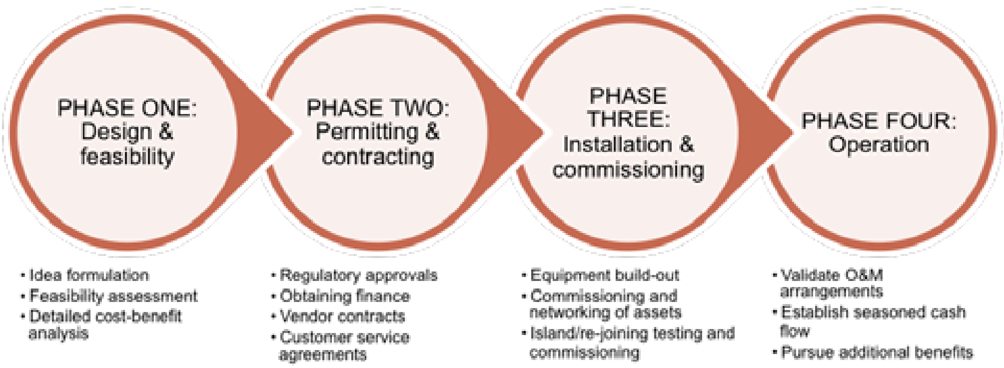


Figure 20. *Simplified project lifecycle, where risk and the costs of financing generally decrease as the project evolves*

At the outset of the project during the feasibility stage when the risk is highest, zero or low cost funding in the form of grants should be investigated from public or philanthropic bodies. In the design and construction phases, vendor financing may be obtained and paid back as the project moves towards commissioning. Once a seasoned cash flow is established, the reduced project risk may now make it more attractive to pension funds, insurance companies and other low-risk/long-term investors. This is easier as the project matures towards the operational phase where returns are guaranteed over a long period.

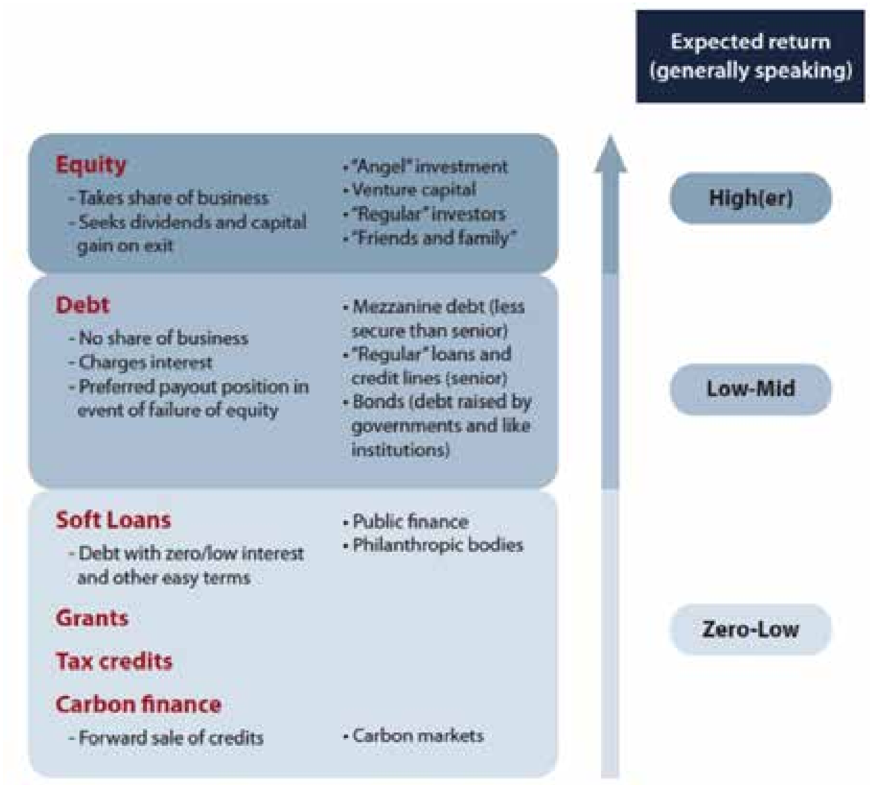


Figure 21. *Types of financing and risk appetite* [88]

Aside from risk, an additional issue to consider is the preference of the project owner for off or on balance sheet financing. These terms relate to how the project assets and liability are handled – off or on the company's balance sheet. Off balance sheet is when the project assets and liability are not listed on the company's balance sheet, such as operating leases where the payments are made from the operating budget and the equipment is effectively rented (not owned) by the project owner. For on balance sheet financing the project asset and liability must be listed on the company's balance sheet, as is the case where the equipment is bought via a loan. As the choice of off or on balance sheet financing may be influenced by contextual issues such as the overall lending ratio for the business, it is important to understand the project owner's preference before investing time exploring financing options.

Additional issues for consultation with the project owner that are of immediate relevance to the financial modelling include the expected debt to equity ratio, project lifetime and discount rate/expected rate of return.

Another consideration in the selection of financing options is the scale of the project. The high set-up costs for more complicated financial instruments or those originating from institutional investors are generally appropriate for major projects worth millions of dollars. For these a "Special Purpose Vehicle" (SPV) may be adopted, where the project is incorporated into a standalone company. The SPV can be set up in line with the specific needs of the project separate from balance sheet constraints of the supporting business/es.

For smaller projects, financing programs that focus on projects or sub-projects with a standardised, repeatable structure are becoming increasingly available. These include energy efficiency programs, solar PV financing and financial instruments that parallel emerging regulatory definitions and standards. In some cases, the originating financial structure for these programs may be a SPV such as those created for securitization of solar PV.

7.1.2 Project costs & funding

In line with the incremental planning approach, project costs should be broken down into phases and discrete work packages.

With reference to the simplified project lifecycle illustrated in Figure 20 above, the first phase relates to project design and feasibility. Costs during this stage should include engineering costs arising from the detailed technical design, financial modelling and cost-benefit assessments, regulatory requirements studies and other tasks that form part of the project feasibility assessment.

Some effort should be made at this stage to aggregate the project elements into logical work packages that can be executed discretely according to the incremental planning process outlined previously. The investment requirements during the design and feasibility phase are generally met using equity financing from the project owner (sweat and dollars), and grant funding from public or philanthropic bodies.

Project costs grow significantly in the second phase. This is where lawyers must be engaged to design and negotiate the various aspects of the commercial arrangements. Allowances must be made for regulatory approvals including siting and permitting, project financing arrangements, vendor contracting, and customer service agreements.

A mix of project funding may be drawn on in the approvals and permitting stage according to the work packages identified as part of the incremental planning process. Renewable generation resources may be easily addressed through standardised approaches such as vendor financing. Conversely microgrid networking, control and service is not yet widely recognised and may therefore require grant funding to execute.

Phase three: installation and commissioning should draw on the cost estimates developed at the outset and refined through the approvals process. Capital expenditure on assets is concentrated in this phase and paid for using the financing arrangements established in the preceding phase. Additional costs may include warranty and insurance arrangements to safeguard against various issues that may occur during the build.

Once the project is commissioned and operational, the final stage can take place where the business case is validated and financing arrangements may be transitioned to lower-cost options as per the project plan. Costs will include debt obligations, O&M overheads as well as fuel inputs if applicable. Additional effort may now be invested in 'outlier' opportunities that draw on reliable performance data.

7.1.3 Project savings & revenues

The financial viability of most projects is generally dependent on cost savings and generation revenues from the increased use of distributed energy resources. The enhanced reliability and energy market services from microgrid operation are challenging to quantify and realise in practice. The incremental planning process recognises this by targeting discrete work packages that are least-risk/greatest-return at the outset, such as energy efficiency initiatives and solar PV installations.

For both energy efficiency and renewable energy projects, the key benefit is avoided energy purchases. Standalone microgrids are closed systems that are increasingly switching to renewable sources due to the cost savings from avoided diesel generation. Grid-connected microgrids allow customers to reduce or avoid consumption of grid-sourced electricity that includes wholesale generation, network and retail costs. In both instances the cost projections ultimately require expertise in both energy markets and financial modelling, so that the project business case will be accepted by investors.

Revenue projections reflect the demand for the energy generated and the customer willingness to pay. For the preliminary analysis, the potential revenues from energy sales can be assumed to reflect the current and projected demand from customers within the microgrid system at a unit cost that is less that the existing and future alternatives (i.e. grid energy). This assumption can then be validated through assessment of the Levelised Cost of Energy (LCoE) over the project lifetime, which should come in under the grid tariff.

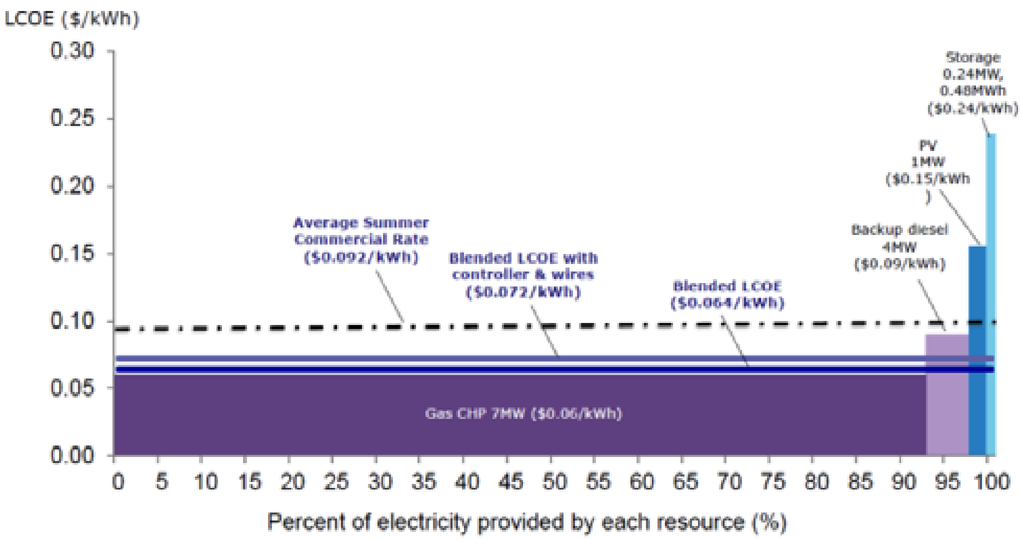


Figure 22. *Graphic illustration of a Levelised Cost of Energy (LCoE) calculation for the Twenty Nine Palms microgrid project, showing how the project ("Blended LCoE") can deliver energy below the cost of that from the grid ("Average Summer Commercial Rate").*[89]

Payments for excess energy are often available under regulated net metering models. For larger DER projects, negotiated Power Purchase Agreements (PPAs) and Energy Service Agreements (ESAs) underpin the sale of excess energy to other market participants.

Other revenue inputs familiar to renewable energy systems include upfront or ongoing payments for environmental benefits, such as renewable energy credits, emission allowances or emission reduction credits. While renewable systems have O&M overheads that should be captured as part of the operating costs, there may also be O&M savings from the reduced use of reciprocating engines.

Microgrid projects have the potential to generate additional revenues beyond those realised from more conventional DER projects. To date, the primary driver for grid-connected microgrid projects has been the avoided costs from outages. While these can be difficult to quantify, methods borrowed from the insurance industry are increasingly able to be applied to analysis of microgrid projects.[90] A key consideration in the design of these projects is ensuring continued operation of the microgrid at the required performance levels during grid outages. This will require more robust design and operating strategies, such as pre-emptive islanding and demand management of the microgrid in the lead-up to extreme weather events.

As energy markets evolve, additional benefits can be realised from the advanced monitoring, communications and control capabilities. Demand Response (DR) payments are increasingly available for curtailing grid-sourced energy demand during peak periods. Voltage and frequency regulation can deliver power quality benefits both to the microgrid users and the surrounding grid, capturing payments for ancillary services. Energy sales across community microgrids that don't require distribution network payments may be possible under Virtual Net Metering (VNM) models successfully negotiated with the regional network operator.

7.1.4 Determining bankability

As microgrids are systems with a range of influential input variables as outlined above, demonstrating their "bankability" – or financial and commercial viability – is complicated.[91] Financial viability – securing an acceptable rate of return on capital – is the minimum threshold for consideration. However to be truly bankable, a project must also address all commercial considerations or risks that could threaten financial returns. The uncertainty associated with each input variable multiplies and acts as a deterrent for investors in greenfield microgrid projects.

This issue lies at the heart of the incremental planning process, and is addressed through the discrete work packages which can be more easily and reliably modelled. For energy efficiency and distributed energy resource projects there is a wide range of business case modelling tools available. Financing programs focused on the project type of interest often prescribe tools to applicants in an effort to streamline the assessment process.

For would-be microgrid project owners, a recent example of this is the cost-benefit analysis tool prepared by The New York Prize competition for assessment of microgrid projects[92] - refer to Figure 23. The tool has been built in Microsoft Excel and is supported with a number of data capture questionnaires and extensive user guidance. While this tool is an excellent resource for anyone undertaking modelling of a microgrid business case, the various assumption built into the model need to be understood given that it has been designed for project proposals in the state of New York.

WORKSHEET KEY	NUMBER OF WORKSHEETS
Site Summary	1
Site Inputs	5
Intermediate Outputs	2
Underlying Standard Data	12
Cost Calculations	6
Benefit Calculations	4
Major Power Outage - Fire Station Benefits	1
Major Power Outage - Emergency Medical Services Benefits	1
Major Power Outage - Hospital Benefits	1
Major Power Outage - Police Station Benefits	1
Major Power Outage - Electric Power Benefits	1
Major Power Outage - Wastewater Benefits	1
Major Power Outage - Water Benefits	1
Major Power Outage - Other Benefits	1

Figure 23. *Overview of the New York Prize microgrid project modelling tool.*[93]

HOMER is a financial modelling tool developed by the U.S. National Renewable Energy Laboratory (NREL)[94] that has a large number of users worldwide. Although it is particularly well-suited to standalone microgrid applications, advanced users can build out models with grid interactivity. The affordable, accessible nature of the tool and training, along with the global network of users and peer-reviewed case studies makes it a good starting point for enthusiastic project proponents seeking to develop their own microgrid.

As grid-connected microgrids become more widespread, project modelling approaches will emerge that are accepted by the financial investment industry. Until this happens, the strong likelihood is that the last step for microgrid development – networking of assets and implementation of control systems that enable dis- and re-connection to the surrounding grid – will be funded from research grants and other forms of risk capital.

7.2 Instruments

During the course of this research a range of innovative financial instruments were identified that have the potential to be enablers for microgrid projects. Although many were unique to the jurisdiction in which they were identified, a summary is presented here for the benefit of policymakers, financing providers and would-be microgrid supporters and owners.

7.2.1 Early-market development mechanisms

These instruments are designed to support pre- or early-stage commercialisation of emerging technologies. They address the lack of funding for these technologies from more traditional sources of financing that reflects the uncertainty around their performance and related investment risk.

Would-be project owners should reflect on the list below in the context of the early-stage technology components of microgrids – grid-connected microgrids, microgrid controllers:

- Feed-in Tariffs (more a revenue stream than financing mechanism)
- Renewable Portfolio Standards / Renewable Energy Certificate trading
- R&D grants
- Tenders / reverse auctions

7.2.2 Debt and equity financing mechanisms

Debt and equity financing mechanisms include:

- Public/private sector financing
- Green banks and bonds
- Loan guarantees
- Securitization
- Yield cos
- U.S. Ex-Im Bank

Public sector financing relates to loans from government agencies. Private sector financing includes both debt and equity financing from technology vendors, banks and bond markets. Examples of each of particular relevance to microgrids are public/private sector funds focused on emerging technologies.

Green banks and bonds are variations that focus on clean energy financing.

Green banks are government-sponsored entities that work with the private sector to address financing gaps in clean energy markets. The New York and Connecticut microgrid programs are both closely linked to those states green banks, ensuring that there is financing available for quality projects at various points in the lifecycle where they may otherwise stall or fall over for lack of funding.

Green bonds are fixed income, liquid financial instruments that are used to raise funds dedicated to climate change mitigation, adaptation and other projects with environmental benefits.[95]

Loan guarantees address the reluctance of commercial lenders to take risks on innovative new technologies until they have a solid credit and operating track record.[96] This creates a Catch-22, as without financial backing the technology has little chance to prove itself. Government loan guarantee programs address this through credit enhancements to supporters of eligible projects, which has the effect of increasing their appeal to commercial lenders.

Securitization and yield co's are relatively new instruments that leverage the reduced risk profile of operating projects to access lower cost financing for multiple benefits. They are of most relevance to project developers, however their benefits pass onto end-users.

Securitization is the practice of pooling disparate sources of debt and selling it as a package to investors on the secondary market.[97] It is being used to bundle small, single-business and/or household energy efficiency and solar PV loans into consolidated securities that institutional investors can purchase.[98] The relatively low cost of capital improves the monthly contract (e.g. solar PPA or lease), and by extension the competitiveness of the DER solution with utility rates.

Yield co's adopt a similar approach in that they bundle a portfolio of projects that are already operating into a new corporate subsidiary and sell part of the shares to the general public while keeping proj¬ects that are still under development in a separate entity.[99] The yield co can raise equity at closer to debt rates because it owns de-risked assets that throw off predictable cash flow. The subsidiaries are called "yield cos" because they distribute most of their earnings to shareholders through quarterly dividend payments. In contrast to securitization, yield cos focus mainly on larger projects.

The U.S. Export-Import (Ex-Im) Bank helps mitigate risk for U.S. technology vendors and offers competitive financing to international buyers for the purchase of U.S.-made goods and services. The Ex-Im Bank has an Environmental Export Financing program with a total portfolio of over $USD 3 billion in U.S. exports of energy efficiency and renewable energy technologies.[100] The financing on offer includes:

- Short-term working capital
- Export credit insurance
- Medium-term insurance
- Medium- to long-term loan guarantees
- Project and structured financing
- Long-term direct loans

7.2.3 Tax-based mechanisms

Traditional tax-based mechanisms that may be relevant to various aspects of microgrid project financing include:

- Phase-out of fossil fuel subsidies
- Carbon taxes
- Investment tax credits
- Production tax credits
- Waiver of import duties
- Tax deductions
- Property taxes

A form of tax deduction encountered in the U.S. that may have relevance for Australia are Real Estate Investment Trusts (REITs). REIT is a designation that reduces or eliminates corporate income taxes for a corporation investing in real estate.[101] In return, REITs are required to distribute 90 percent of their income, which may be taxable, to their investors. The REIT model was designed to provide a structure for investments in real estate similar to what mutual funds provide for investments in stocks. To use REITs to invest in energy infrastructure (e.g. renewable energy resources), the infrastructure assets must be characterized as real property assets and pass the relevant income tests. As REITs exist in the Australian context, the model may have potential for application locally.

The Property-Assessed Clean Energy (PACE) model is another tax-based mechanism that can be used to finance energy efficiency and renewable energy projects on private property – refer to Figure 24 below. State and local governments that levy property taxes use the PACE model as the basis of funding programs for property-owners. To access the funding, the property owner agrees to have a new tax assessment applied to their property that captures the energy efficiency or renewable energy investment. Through their property taxes, the owner then repays the assessment over 15-20 years alongside the savings they accrue from the investment itself. As the assessment is tied to the property and not the owner, it removes a barrier for property owners to invest by allowing them to recoup the investment on sale of the property.

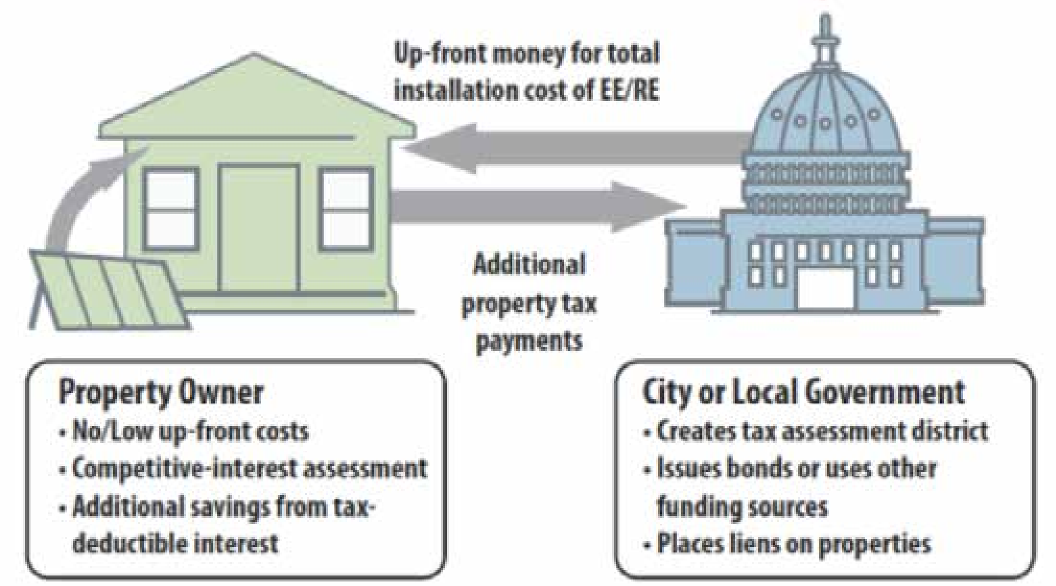


Figure 24. *Basic PACE financing* [102]

7.2.4 Environmental markets

The market-mechanisms below are indirect financial incentives that may be:

- Cap and trade schemes
- Project-based carbon offsets
- Biodiversity credits/trading

7.2.5 Crowdfunding

Crowdfunding is a recent financial innovation that has also been applied to the clean energy sector. While equity-based crowdfunding has seen success in the solar PV market, donation- and loan-based crowdfunding models are making a big difference in the developing world.[103]

8. PATHWAY FORWARDS FOR AUSTRALIA

Reflection on the research insights has revealed a range of implications for microgrids in the Australian context:

8.1 General

8.1.1 Drivers

The extreme weather events at the heart of many catastrophic grid outages are as relevant to Australia as the rest of the world. Towards the end of this research, a severe storm event in Sydney resulted in loss of power to a major IT service provider for many Australian businesses, causing widespread disruption.[104] This was only eight months after the previous major Sydney electricity outage due to extreme weather, which in that case affected 10,000 homes.[105] As the frequency and severity of these events increases with the effects of climate change, consideration of more resilient energy solutions can only be expected to grow.

The high cost of Australian electricity will also continue to provoke debate and consideration of "grid defection". With our high uptake of solar PV, many homeowners are exploring whether they could go "off-grid" once batteries become cheap enough. With these issues at the heart of the "utility death spiral" that will accelerate grid defection as electricity prices continue to rise, Australia is at the forefront of this conversation worldwide. As planned islanding from the grid will be a stepping stone for permanent disconnection, solar plus storage projects will likely serve as a foundation for microgrid project development in this country.

An interesting parallel to the off-grid movement will be efforts by regulators and other energy market players to keep people on the grid. Grid support payments are already being investigated at the Australian household level.[106] As the battery business case improves through grid interactions that open up the "benefits stack",[107] there is a competitive tension emerging between grid-connected and off-grid solutions. Network tariff design will ultimately decide the contest, however microgrid solutions that support grid interactivity are likely to be part of Australia's future energy system.

While much of the debate is unfolding at the household level due to the mainstream media appeal, this research highlights a more compelling financial argument for projects at scale. Due to the specific and complicated nature of the business models, these opportunities are expanded more fully in section 9.2 below.

8.1.2 Obstacles

The reliability of Australia's electricity supply far exceeds much of the rest of the world, including many parts of the U.S. As a result, Australians are more likely to perceive grid outages as "freak occurrences" to be tolerated rather than addressed, particularly via publicly-funded programs that serve as yet more examples of "gold-plating". This may lead to an absence of public funding support for early-stage microgrid projects, and potentially a follow-on effect as private sector financing remains hard to find obtain in the absence of reliable data from early-stage projects in the Australian context.

Australia lags the U.S. when it comes to demand management – on market rules and incentives, business models and products, customer understanding and acceptance. Demand management is a crucial building block for microgrid design, budgeting and revenue. The lack of experience with demand management will likely inhibit microgrid design as uncertainty clouds the design process. This may result in the project being "over-engineered" to deal with excess demand projections. While these issues may be addressed in the incremental design process, a greater issue is the still-forming market for commercial-industrial demand response in this country. Demand charges are a key financial input for many U.S. microgrid projects. Australian project supporters will find it challenging to rely on this input for their own projects.

Potentially the biggest challenge relates to the connection arrangements for grid-connected microgrids. Although much effort has been invested in the embedded generation connection processes[108,109,] the islanding/re-joining functionality for a grid-connected microgrid is a relatively new prospect for Australian network operators. For near-term projects where this functionality is within scope, the involvement of the relevant distribution network operator at an early-stage of the project will be crucial to the outcome. It may be that experience gained from utility-driven fringe-of-grid projects will inform the approach taken to customer-driven projects, however the strong likelihood is that extensive modelling and testing will be required to account for the differences between projects.

8.2 Applications

Drawing on the research insights including the drivers and obstacles above, three specific applications present as a likely focus for microgrid projects in the near to medium-term.

8.2.1 Fringe-of-grid locations

The extremities of Australian distribution networks are already under investigation for operation as microgrids. Our huge landmass and highly-urbanised population have in many cases translated to long distribution network feeders to remote settlements in regional Australia.

As per the description provided in section 6.2, these locations are a technical challenge for network operators. They also require significant cross-subsidisation from the rest of the regulated asset base to account for the relatively small cost recovery possible from the few customers that are being served. Aside from the challenging business case of the existing solution, networks are regulated to test the market for alternatives via the Regulatory Investment Test (RIT) process. Feedback from networks suggests that all of these issues are translating to a strong interest in alternative options.

An unresolved issue is the preferred business model for fringe-of-grid projects. As per the U.S., the Australian market is regulated to address natural monopolies and promote competition where appropriate. Fringe-of-grid microgrid projects are most easily delivered where the electricity supply is from a vertically-integrated provider with generation, distribution and retailing. In these cases, the monopoly provider is more easily able to respond to the incentives that would lead to a microgrid. Conversely in locations where wholesale energy supply, distribution and retail services are ring-fenced, there are coordination issues that may prevent effective action.

For customers, there are a range of reasons that may promote interest in a grid-connected microgrid:

- The microgrid architecture may allow a larger amount of distributed generation – particularly solar PV – to be deployed. This may reduce the operating expenses for communities that are likely to be economically disadvantaged, and align with sustainability objectives that may be above the mean.
- Battery storage will be more cost-effectively deployed in the microgrid architecture – due to be the economy of scale over individual household deployments, and to account for the often variable occupancy of many dwellings (e.g. holiday accommodation).
- Remaining grid-connected will allow the community to get the competitive pricing benefits from the National Electricity Market, and reduce the need to over-capitalise on local energy infrastructure.
- The microgrid islanding capability will promote the reliability of supply and community resilience – potentially an issue in locations that may be vulnerable to the effects of climate change (e.g. increased bushfire risk, storm frequency and severity).

Based on overseas precedents, the strong likelihood is that off-shore or remote locations that are tourist destinations will emerge as the near-term focus for advanced microgrid solutions. A key driver will be the constraints on economic development to support the tourism industry due to issues to do with the electricity supply. The projects will be either driven by the vertically-integrated utility that serves the community, or strongly-supported by them at the behest of governments and the local and state level.

8.2.2 Critical infrastructure

The reliability and resilience benefits that serve as the greatest driver for consideration of a microgrid in the U.S. are most relevant to critical infrastructure. A growing awareness and understanding of weather and security risks in the Australian context is likely to promote a similar response.

In contrast to the fringe-of-grid applications above, critical infrastructure microgrid applications are likely to be customer-driven. Emergency services will identify microgrids as an emerging solution to issues that have been identified in the review of previous disaster events. Trials will likely be undertaken with funding support from policy-makers eager to promote community resilience.

As per fringe-of-grid applications, the preferred business model remains unclear. For facilities operators, there will be a strong attraction for an expert service provider to not only deliver the project, but continue to operate it. This service would be a competitive market offering and therefore outside the mandate of distribution network operators. Conversely, a range of project developers and technology vendors will be interested in supporting the project up to commissioning, but not beyond.

In this context critical infrastructure microgrids look like the early-stage applications for the “network of the future”. Commercial entities will likely emerge from a number of directions to explore “microgrid-as-a-service” models – portfolio building management organisations, network-subsidiary competitive market businesses, electricity retailers and more. At the outset however the likelihood is that individual facilities managers will support their own simplified, microgrid operation.

Based on the U.S. experience, these early-stage projects will likely unfold in campus applications such as hospitals or universities that have disaster management responsibilities. In these locations, the imperatives to ensure reliable, back-up power operation will likely be coupled with large energy bills that include demand charges. Existing distributed energy resources will be available to augment in response to financial incentives and insights gained from elsewhere.

8.2.3 Embedded networks

An embedded electricity network is an aggregation of individual customers on a privately-owned and operated network behind a single point of connection to the surrounding network and market. They are common in multi-tenanted buildings such as shopping centres or commercial buildings, and are also becoming more popular in residential developments.

The natural alignment with campus and community microgrids as described in sections 6.3 and 6.4 means that embedded networks are an existing business model that can be adopted for the microgrid application. The main area of difference between the applications currently currently is the bias of embedded networks towards retail electricity market activities – wholesale market purchasing, metering and retail billing. Most embedded network operators have limited experience and/or interest in distributed energy resources, often inheriting them reluctantly from property developers obligated to build them out as part of their planning approval requirements.

The opportunity here is for existing or new embedded network operators to embrace the commercial opportunities emerging from technological improvement and cost reduction. Solar PV resources will be the likely starting point for this trend, noting also that centralised services such as hot water and HVAC promote systems thinking. Noting the vast skills gap between embedded network and microgrid operation, likely scenarios could be partnerships or subcontracted service delivery models.

The drivers for microgrid adoption under an embedded network model are not quite as clear. The opportunity to address network connection requirements through an integrated energy systems model is countered by its complexity and by extension risk. Furthermore, the imperatives to pursue grid-islanding capability are overshadowed by the likely effort and heartache in dealing with a potentially unhelpful distribution network operator.

Airports are looming as a likely test case, as they are critical infrastructure facilities that often operate embedded networks for their on-site business customers. Sydney Airport has a large trigeneration plant,[110] which likely entails that they have advanced on-site energy management expertise. Many other airports across Australia have or are considering significant investments in on-site generation, so it seems only a matter of time before one extends this to consideration of a microgrid.

University campuses are another likely application. R&D interests, sustainability imperatives and network demand charges are drivers for university interest in microgrids in Australia as in the U.S.

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- To develop partnerships with communities, government and the private sector to prevent irreversible damage to the environment and to encourage the maintenance of biodiversity

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Education and Training

- Canberra Institute of Technology, ACT
- Chisholm Institute of TAFE, VIC
- College of Electrical Training Inc, WA
- Curtin University, WA
- Global Sustainable Energy Solutions (GSES), NSW
- Holmesglen Institute, VIC
- Monash Sustainability Institute, VIC
- Mount Druitt TAFE, NSW
- Murdoch University, WA
- NECA Training, Burwood NSW
- Northern Melbourne Institute of TAFE, VIC
- University of Melbourne
- University of New South Wales
- University of the Sunshine Coast, QLD
- University of Tasmania
- PEER VEET, SA
- Polytechnic West Thornlie Campus, WA
- Regency TAFE, SA
- RMIT, VIC
- Skillstech Australia, QLD
- Sunshine Coast TAFE, QLD
- Swinburne Institute of Technology, VIC
- TAFE NSW, Northern Sydney Institute
- TAFESA Regional Berri Campus, SA
- The Skills Institute, TAS
- Western Institute of TAFE, NSW

Community

- CERES Community Environment Park
- Consumer Utilities Advocacy Centre (CUAC)

Other

- Climate Spectator
- ClimateWorks
- Embark
- International Energy Agency (IEA)
- The Climate Group
- The Climate Institute
- Reneweconomy