Autonomous Resilience Project

Final Report

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Executive Summary

Electricity supply is a critical service that underpins almost every aspect of modern Australian life. Climate change is a threat to the ability of Australia's electricity system to meet the basic needs of users, especially during and after severe weather events such as bushfires or flooding.

Following the widespread electricity outages caused by recent extreme weather events in Australia, there is a strong desire across the community to understand what can be done to improve the resilience of energy systems.

This report investigates how households and small businesses in areas likely to be impacted by the increasing frequency and intensity of severe weather events can take practical (and preferably low cost and low emissions) steps towards increasing their individual and community energy resilience.

There are a number of measures that government, regulators and related stakeholders can take to further empower energy consumers to improve their energy resilience. These measures range from funding the purchase and ongoing support of community-based energy resilience technology, to investigating new technical approaches and standards for consumer-grade solar and battery systems, that could improve the application of these systems as an energy resilience appliance.

The options available to a consumer to improve their own energy resilience are very diverse, ranging from large solar and battery systems, to portable charger devices. Which particular technology or appliances are appropriate will depend heavily on the consumer's living circumstances and what they consider are critical energy loads. Despite such diversity, there are several key recommendations that can be made to most consumers, that would make a significant difference in reducing the risks they face after an electricity system outage. These include:

1. Understand how much energy your appliances need, and which ones will be the most important to keep operating during a prolonged blackout.
2. Buy a windup or solar powered combined torch, radio and battery, so you can stay in touch with the outside world (including charging your mobile phone).
3. Have a backup source of electricity ready, or perhaps some alternative appliances that don't need grid electricity to operate.
4. If you are able to buy a home battery to store rooftop solar energy, make sure it can also operate as a backup power supply.
5. Likewise, if you are thinking of buying an electric vehicle, think about getting one which can power plug-in electricity appliances (Is capable of "vehicle to load" or V2L).
6. Talk to your neighbours and local council about what loads are critical to keep operating during blackouts (eg evacuation centres, health facilities and emergency services), and how this might be achieved.
7. As with other disaster preparations, it's important to practice what you would do in an emergency, and to make sure that the relevant equipment is working safely and is charged or primed for deployment at short notice.

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1. Introduction

The provision of reliable electrical power is a basic foundation of modern society. Typically, this service is based on largescale electricity grids, using infrastructure that includes large, centralised electricity generators, transmission and distribution lines, switchyards and substations. This infrastructure is at risk of interference by severe weather events- power lines can be toppled during storms, substations flooded or equipment may need to be disconnected due to the risk of bushfire. The electricity outages caused by such events have a profound impact on the community: without electricity, telecommunications and payment systems fail, fuel for vehicles can't be pumped, refrigeration is not available to preserve food and medicines, and buildings are at risk from the unavailability of key infrastructure such as pumps or fire protection systems.

In 2016, a storm event damaged key transmission infrastructure, causing a blackout across the entire state of South Australia and affecting 850 000 people [1]. In the summer of 2019/2020, equipment damage from bushfires across South-Eastern Australia left 130 000 households without power, some for many weeks [2]. More recently, in 2022 floods in north-eastern Australia left over 60 000 customers without power, limiting their access to key services, in many cases for multiple days [3].

Climate scientists advise that the frequency and intensity of extreme weather events will increase over coming years [4]. This makes it likely that power interruptions will be a growing challenge for Australian energy consumers, businesses and communities. A variety of studies have considered how to improve the resilience of energy systems when faced with a range of increasing threats. However, most of these studies take a "top down" approach to improving energy resilience. For example, a recent investigation by the Victorian government on how to improve energy resilience in that state recommended measures such as strengthening electricity distribution systems, considering liquid fuel supply chain dependencies, and enhancing communication between the energy industry and incident response teams [5]. Whilst important considerations for improving the resilience of the energy system as a whole, such measures provide little guidance or solace to end consumers.

Interviews with people impacted by the 2019/2020 bushfires showed a strong desire by individuals to understand what they could do to improve their own energy resilience:

> *"It also became apparent that the crisis experience had for many people heightened their desire to secure a self-sufficient energy source. This desire was not only an effort to safeguard the technologies (mobile phones, emergency service apps) that underpin access to critical information in the midst of an emergency but also provide a sense of security and self-sufficiency in the event of other crises, such as* [electricity] *network infrastructure failure"* [6].

This report considers how individual households, small businesses and local communities might improve their own energy resilience, with particular consideration given to the maintenance or restoration of electricity supply after a grid outage.

2. Scope and Definitions

The objective of this project was to develop an understanding of how households and small businesses in areas likely to be impacted by the increasing frequency and intensity of severe weather events can take practical (and preferably low cost and low emissions) steps towards increasing their individual and community energy resilience.

This project focuses on technology measures available to, and controlled by, the end consumer. The resilience of energy systems when faced with the impacts of climate change is a major area of work around the world. Many studies and electricity network operators are considering technology measures such as microgrids or network augmentation, or the undergrounding of critical infrastructure, to improve reliability of supply. These "grid" based resilience measures are out of scope for this project: the focus here is the opportunities or options that a household or small business may pursue themselves, independent of their local network operator.

This project focuses on responding to "acute" weather events such as bushfire, flooding or storms that cause electricity or energy system outages. Climate change will also cause "chronic" events such as a gradual increase in energy usage, which may make energy supply unaffordable for some houses. These issues are not considered in this report.

Whilst technology is a key enabler for energy resilience, it is not a panacea: studies such as [6] have found that energy "*…resilience was as much about the individual and community relationships and networks, and trust-based engagement with local services providers, as it is about the "hard" infrastructure…*"

It is clear that organisational design, community-based response procedures, government strategy, policy and other "soft" measures are very important for improving energy resilience, but these are not the focus of this report, and are left for further study.

3. Changing Climate & Energy Resilience

Australia's climate is changing. A recent Bureau of Meteorology report [7] summarised the impacts of climate change as shown in Figure 1. Almost all these impacts have a relevance to electricity systems: whether through the risk of damage to electricity network infrastructure, or by causing significant changes in electricity usage patterns, which can strain the electricity network and result in demand related outages.

Figure 1. Climate related hazards driven by the effects of a changing environment. Courtesy of the Australian Bureau of Meteorology [7].

These risks were further explored in a 2022 report published by Electricity Networks Australia [8], investigating the climate change related hazards for different types of electricity network infrastructure. As shown in Figure 2, almost all infrastructure is at risk.

Figure 2. Electricity network infrastructure vulnerable to climate-related hazards. Red squares denote high or medium risk. Courtesy of Energy Networks Australia [8].

Clearly, as the risk of physical damage to major infrastructure increases, the likelihood of interruptions to electricity supply also increases. These threats occur in the context of an electricity network that is already stretched, and that faces additional climate change risks from changing electricity consumption patterns. Climate change is forecast to increase the energy consumption of houses in some parts of Australia by over 100% [9]. This additional demand is most likely to occur at times that the electricity network is already physically stressed: high ambient temperatures mean greater electricity demand, but they also cause operational challenges for electricity network infrastructure. These threats combine to pose another very significant challenge to electricity network reliability.

Summarising these trends, the Grattan Institute suggested in 2019 that

> *"If networks continued to spend what they spend today on maintenance and investment, global warming of 1 degree would indicatively increase average outages by 26 minutes per customer per year…Customers would likely be willing to spend a significant amount of money to avoid these additional outages – potentially as much as $450 million"* [10]

4. Approaches to Energy Resilience

In modern society, electricity outages are not just an inconvenience for the end user- because the electricity system is closely intertwined with many other critical services, an electricity outage can affect telecommunications, water, traffic, electronic payment and a myriad of other services.

With the threats faced by the electricity system increasing, and the cost of electricity outages very significant, a key response is to investigate how to improve the *resilience* of the electricity system and the devices or services that rely on it. This report focuses on measures to improve a household's or small business's *own* energy resilience. Research into resilience suggests a system's disaster resilience can be evaluated by considering four fundamental properties [11]:

1. Robustness: what is the inherent strength of the system against threats?
2. Redundancy: does the system have alternative options or substitutions when there has been a failure, or the system is under stress?
3. Rapidity: how quickly can the system restore priority service?
4. Resourcefulness: what is the system's capacity to mobilise resources and services needed to respond to a failure?

In the context of energy resilience for a household or small business, these properties can be reframed as:

1. What electrical loads or services are critical to keep supplied, to minimise further losses?
2. Is there a source of backup power available? Or can a critical service be provided another way?
3. How quickly can electricity be restored, or the core service provided another way?
4. Can the household or small business do something themselves, or are they relying on a third party?

When faced with the possibility of an increased number and duration of outages on the electricity system, these questions are important for every energy user to ask themselves. They underpin the analysis throughout the rest of this document.

5. Critical Loads

The first step in working to improve one's own energy resilience is to identify what particular electricity-related services are critical to their situation, and then understand the energy characteristics of those services. Some electricity-related services can be provided in a multitude of ways: for example, a house may usually use electric heaters to keep warm in winter, but there are a variety of other ways to heat a house, some of which don't need electricity. On the other hand, some critical services can only be provided by one particular machine or electricity load: for example, a continuous positive airway pressure (CPAP) machine may be considered a critical service, and for most users there's no alternative way to obtain the service provided by that machine.

What loads are considered critical in one house or business may be quite different to another house or business. For some consumers, having a way to keep a mobile phone charged, and provide a modest amount of lighting during the night may be all they need to consider themselves energy resilient. For other consumers, having a way to continue to power critical medical appliances, or operate water pumps, may be essential.

The range of potentially critical appliances is quite broad, and each of these appliances may have quite different electricity demand characteristics. For any appliance, when considering the energy requirements of that appliance, there are two key characteristics that need to be understood:

- The peak power demand of that appliance: the maximum power used by the appliance at any short instance in time.
- The total energy required by that appliance: the energy the appliance will use over a (for example) 24-hour period.

These characteristics are further explored in Appendix A. As an example of the diversity of energy requirements, several appliances, their peak power demand and 24-hour energy consumption are listed in Table 1.

Appliance	Peak Power Demand (W)	Estimated Operating Time Per Day (hours)	Energy Consumption Per Day (kWh)
LED light bulb	5	5	0.025
Mobile phone charger	15	3	0.045
Portable camping fridge/freezer: 108L	50	8	0.4
CPAP medical device	75	8	0.6
Septic system aerator	120	24	2.88
Sump pump	600	2	1.2
Domestic pressure pump	850	2	1.7
Induction stove	1200	2	2.4
Household refrigerator: 380L	280	8	2.24
Fan heater	2400	4	9.6
Large split-system air conditioner	3600	4	14.4

Table 1: Peak power demand and 24-hour energy requirement of various common appliances.

Lastly, note that Table 1 does not include fixed-telecommunications equipment such as needed for the National Broadband Network (NBN) Internet and phone service: if there is an electricity grid outage, even if a backup power solution was available for the NBN device in the home, in many installations service would still not be available due to a lack of electricity supply to broader NBN infrastructure [12]. Thus, if there is a failure on the electricity grid, for most consumers, the main source of Internet and phone connectivity is their mobile phone.

6. Resilient Supply: Distributed Generation

Having determined what loads or services are critical, the next step in improving an end-user's energy resilience is to identify an alternative way to provide that service, or a backup source of electricity that can supply that load even if the wider electricity grid has failed. As one farmer said of their experience in the 2019/20 bushfires:

"We are totally reliant on the main energy grid…There was no mobile service and the radio was almost useless. People need to realise that you need to have your own power supply." [6]

Today, distributed generation and storage technologies such as rooftop solar and batteries are proliferating across the electricity system. In most cases, these devices operate in coordination with the electricity grid: the end user sources their energy from both the electricity grid and their own distributed generation device. As a generator that is permanently connected to a building, owned and managed by the consumer and capable of supplying a significant amount of energy, distributed generation technology seems well-suited to the goal of autonomous energy resilience. The following sections consider the energy-resilience opportunities from grid-connected distribution generation systems such as solar and wind generators, and batteries.

6.1 Grid-Connected Solar Systems

Over 3 million solar systems have been installed on rooftops around Australia [13]. These systems take energy from the sun and provide electricity to power loads in the building adjacent to the solar system. These systems are "grid-connected": if the solar system cannot provide sufficient electricity to meet building loads, then electricity is imported from the electricity network to meet the shortfall. Conversely, if the solar system generates more electricity than is needed to meet building loads, the excess electricity is exported into the electricity network.

A typical residential rooftop solar system may have a peak generation capacity of 5kW, which is more than enough to power many typical residential appliances. Given the solar system is a local electricity generator, it seems reasonable to expect that a rooftop solar system can improve energy resilience, acting as a backup source of electricity: that is, if there is a failure on the electricity network, on a sunny day the solar system could be used to power local electricity loads. Unfortunately, for the vast majority of solar installations, this isn't the case: for most grid-connected solar installations, if there is a power outage on the electricity network, the local solar system also stops supplying electricity.

The main reason a grid-connected solar system cannot (by itself) help with energy resilience is due to a functionality called "anti-islanding". Anti-islanding is a key safety feature required of small-scale grid-connected solar systems: it ensures that, if electricity workers disconnect an electricity line from the broader electricity system for maintenance, the solar systems connected to that line also shut down, meaning the line should be safe to work on. Without anti-islanding, there is a risk that, even if an electricity line was disconnected, solar systems connected to that line could keep exporting electricity into that line, meaning the line is "live" and unsafe to work on.

Anti-islanding works by the inverter in a solar system sensing that the electricity grid is not available: when it senses this, the inverter shuts down, and only turns on again when it has detected grid supply has returned. A solar inverter cannot differentiate between a grid failure due to natural disaster, or a grid failure due to power line maintenance: in either case, the solar inverter senses the local electricity grid has shut down and will stop the generation of solar energy.

For a solar system to operate during a grid outage, it needs to be able to operate in "islanded" mode, isolated from the electricity grid. Solar systems that can operate in islanded mode are commercially available: when there is a grid outage, such systems are physically separated from the local electricity line, thereby they don't post a safety issue, and can continue to generate electricity for their local loads. This separation can happen either manually, through a switch a person would operate when they realise there's been a grid failure, or automatically, through an automatic control system that senses the status of the grid. When the electricity grid supply returns, the solar system will be reconnected to the local electricity line, and resume grid-connected operation.

The technology required for an inverter that can operate in islanded mode is more complex than a typical grid-connected solar inverter, therefore inverters capable of islanded operation are significantly more expensive than a regular grid-connected solar inverter. Some inverters address this issue by providing a limited "islanded" operation- they can supply a single power-point (usually installed adjacent to the inverter) if it is sunny.

A fundamental limitation to the use of islanded solar systems for backup power is that the solar resource is variable: factors such as the position of the sun and clouds in the sky cause dramatic fluctuations in the output of a solar system. These output fluctuations mean there is a high chance that a solar system will not be able to supply sufficient energy to power the local loads in a building: so, for example, as a cloud passes over a solar system the output may stop, meaning loads such as fridges and pumps would also stop.

The solution to the variability inherent in solar power is to add energy storage to the system: when the output from the solar panels drops, the difference is made up by energy sourced from the energy storage system. When there is excess energy available from the solar panels, this is used to add energy to the energy storage system for later use. Today, a typical energy storage technology for use with solar panels is the battery system.

6.2 Wind Generators

An alternative to solar panels as a source of renewable energy is the wind generator. Small wind generators are available that can provide a source of electricity to power building loads. As wind is also a variable source of energy, just as for solar power, a wind generator will normally need to be partnered with a battery system to be used as an energy resilience solution.

Whilst small wind generators are commercially available, their uptake around Australia is relatively small and, compared to solar-based solutions, wind generators are much more limited as an energy resilience option. Disadvantages of wind generators include:

- They are noisy. Small wind generators make noise when operating, so are not suitable for installing close to where people live and sleep.
- Most wind generators require uninterrupted wind flow if they are to work reliably. This means most wind generators need to be installed up high, on a tower away from objects such as neighbouring buildings and trees that can interrupt wind around the turbine. It also means they are unsuitable for installing in urban areas.
- They are relatively expensive. A 2kW wind generator is many times more expensive than a 2kW solar system.

With these sorts of limitations, for small to medium energy demands, wind generators remain a relatively niche solution, suitable for remote areas with lots of space, and where solar is not a suitable technology for electricity generation.

6.3 Grid-Connected Batteries

A wide range of grid-connected battery systems for residential or small-medium enterprise applications have been available in Australia for the last 6 years or so. The primary application of these systems is to reduce the consumer's energy expenditure: they store energy to be used at some time later, usually when electricity prices are higher. Many commercially available battery systems can also help with energy resilience, by providing some form of backup power.

Fundamentally, a grid-connected battery system that can provide backup power will charge using grid-connected electricity (if the grid is available), or solar energy. If there is a grid outage, the energy stored in the batteries is available to supply local loads. In some systems, during the grid outage, the battery can be charged using electricity produced by adjacent solar panels, and so if it is sunny, the battery can provide a relatively uninterrupted power supply to some loads.

Not all grid-connected battery systems can provide backup power. For those that can, there are a variety of ways the system can be configured to provide backup power. These include:

- Power all loads in the building. In theory, a battery system can be installed that could power all loads in a building, and recharge from solar energy. In practice, such systems are not very common, due to the total power and energy demands of a typical building. For example, a typical grid-connected solar/battery inverter has a maximum power capacity of 5kW, which is less than the total power demand possible in a whole house, which can exceed 10kW. Similarly, the energy storage required to supply all loads (including air conditioners, ovens, etc) in a house for any useful length of time is far greater than the size of common commercially-available battery systems. Whilst multiple batteries could be installed to meet this large energy demand, the costs of this approach are prohibitive for most customers. Configuration of such a "whole building" system requires a range of unique equipment- this includes an inverter capable of operating islanded from the grid, and, depending on the configuration of inverter, isolation switches that electrically disconnect the house from the grid. These switches may be manually or automatically operated.
- Power a "critical loads" or "essential services" circuit in a building. A more common backup power configuration is for a battery to be installed to only supply a few critical loads in a building: for example, refrigeration and lighting. In this situation, a number of power outlets in the building will be nominated as "critical", and these outlets (only) wired to the battery for backup power provision. As the number and type of loads connected to the system is limited, the total energy and power demands should better match the capacity of the battery system. Such an installation requires specialised configuration of the electrical wiring in the building, which can be relatively expensive. Retrofitting such a configuration to existing buildings is usually even more complex and expensive.
- Power a single "backup power" outlet. To avoid the expense of specialised wiring configurations, an alternative approach to backup power provision is to install a single "backup power" outlet, usually located nearby the battery. The system owner knows that if there is a grid outage, there is a single power outlet where electricity is still available. They can then move mobile appliances to that outlet to run during a grid outage or use an extension cord to power an appliance such as a fridge or a water pump. Whilst the "backup" functionality of such an approach is limited, it is relatively simple and cheap to install, and likely to match the energy and power capacity of the battery system.

Broadly, grid-connected battery technology is well suited for improving the resilience of houses and small buildings: the technology is relatively well-known by consumers, the supply chains are widespread and mature, and, used carefully, a typical residential battery system, partnered with typical rooftop solar installation, could provide backup power to loads such as refrigeration, small appliance chargers and lighting for multiple days. The challenges to the wider uptake of grid-connected battery technology for energy resilience purposes include:

- Capital expense. A typical "whole-house" sized solar + battery installation costs $10 000 or more. Whilst such systems provide a range of economic benefits, as an energy resilience solution alone they are relatively expensive.
- Equity of access. As an installation that is relatively permanently installed, it is difficult for renters to access most solar + battery technology. As an item involving significant capital expense, it is relatively difficult for low-socioeconomic communities to access such technology.
- Understanding of the inherent limitations of the technology. A typical residential-building sized solar + battery system is constrained in the number and type of appliances it can provide backup power to. Many consumers lack an understanding of the power and energy demands of typical appliances, and thus the suitability of the battery for powering these appliances. This can result in, at times of grid outage, the battery being drained very quickly, and backup service becoming unavailable.

Lastly, as a permanently-installed device, a stationary battery system is only useful as an energy resilience solution if it is not damaged during the event that caused a loss of grid electricity. For example, if a stationary battery system is located at ground level and this area floods, wetting the battery system, the battery will not be able to provide backup power. Similarly, if the battery system is damaged by fire, it won't be available to provide backup power. Given these possibilities, consideration should be given to having some form of portable backup power supply also available, that can be moved out of harm's way and operate independently of the building wiring.

6.4 Community Batteries

A new concept in the Australian electricity system is that of the community battery, where a single medium-scale battery is shared in a local neighbourhood, allowing those connected to the battery to access the multiple benefits the battery can provide.

Community batteries are typically used in a similar way to standalone grid-connected batteries located at individual houses: the battery is used to store local solar or grid-supplied energy for later use, usually discharging during periods of peak electricity price or demand. A typical community battery may store enough energy to operate at its peak power rating for a few hours at most. In providing this service, those connected to the battery (either economically or electrically) benefit from lower electricity costs. There are a variety of funding arrangements possible for community battery projects: the battery may be purchased through funds raised from individual community members, or a community organisation. Or the battery may be purchased through funds sourced from a public entity or electricity network stakeholder.

Community batteries have the potential of offering an energy resiliency solution, as a source of backup power during a wider electricity grid outage. Broadly, there are two likely scenarios for realisation of backup power with a community battery:

- The community backup provides backup power to all buildings electrically connected to it. Given the peak power and energy demand of multiple buildings is quite large, in this situation the community battery is likely to only provide a few hours of backup power at most. Furthermore, such a solution has the risk of conflict between community members if some use more energy than others.
- When the electricity grid fails, the community battery ceases to provide electricity to the individual buildings that are electrically connected to it. Rather, it provides backup power local to the battery itself- so during an electricity grid outage, the community can source electricity adjacent to the actual community battery installation. This electricity may be used to power an emergency response centre (discussed further in the next section), or to recharge community member's mobile phones or other critical mobile loads.

Community batteries are just now being deployed in a variety of demonstration projects. Energy resilience does not appear to be a service provided by any of the current demonstrations.

7. Resilient Supply: Alternative Options

Given the limitations of grid-connected solar and battery systems, it is important to identify a range of energy resilience options beyond solar and/or battery technology that is permanently installed or fixed in place.

Energy resilience options beyond grid-connected solar and battery systems range from portable battery units, to using a car to provide power to a building. One key difference many of the options below have compared to grid-connected solar and batteries is that they are relatively mobile. As such, they can be moved out of harm's way. Similarly, they can be moved to be adjacent to the location of a particular critical load.

The following are commercially available technologies for improving a consumer's energy resilience.

7.1 Portable Solar Chargers

For those looking to spend less on their energy resilience plan, or who are renting and unable to install permanent solar and battery solutions, the recreation/caravanning/camping industries offer a plethora of appliances and energy storage systems that are designed with off-grid operation and energy supply in mind. Many of these products are also well-suited to energy resilience applications.

One of the simplest and lowest-cost energy resilience options is the portable solar panel/charger. These devices take energy from sunlight and can be used to recharge a battery or appliance. Portable solar chargers are available at a range of sizes: from very small devices designed to charge a mobile phone, to large solar panels designed to charge a camping battery or large portable power pack. Some panels can be grouped together to provide even greater charging capacity. Two examples of portable solar charger are shown in Figure 3.

Figure 3. Two portable solar chargers. The unit on the left is 10W maximum output, with a USB connector for recharging mobile phones or similar devices. The unit on the right is 160W maximum output, with cable connectors for recharging a car/caravan/camping battery or similar device. Courtesy of Jaycar [14].

Portable solar chargers are relatively affordable, easy to move to place in sunlight, and do not require any maintenance or service. Generally, a portable solar charger needs to operate with a battery: they are used to recharge an appliance's inbuilt battery (for example, a mobile phone or rechargeable camping lantern), or to recharge a mobile battery solution, to which other loads are plugged into.

7.2 Portable Battery Packs

As described in section 6, whilst grid-connected stationary battery systems can be useful for energy resiliency, they are expensive, difficult for some members of the community to access, and at risk from flooding or fire damage. There is a wide range of portable battery solutions available that can help with energy resilience, are mobile and much cheaper than grid-connected stationary battery systems.

Figure 4. Portable battery pack and solar charger. Courtesy SolarPowerChargers [15].

At the small end of the size and cost scale are portable batteries designed to recharge a mobile phone or similar appliance. These devices may have enough energy capacity to recharge a mobile phone 2-3 times and can cost less than $100. An example of such a portable battery is shown in Figure 4 that also includes a light and inbuilt solar for charging itself.

In the middle of the size and cost scale are 12V deep cycle batteries (as shown in Figure 5) that are intended for powering a variety of purpose-built 12V appliances such as fridges, fans and lights. These are widely available at a range of capacities and price points. For energy resilience purposes, such a battery usually needs to be partnered with an appropriate 12V appliance, and then recharged from a portable solar panel as described in the previous section.

Lastly, the most expensive portable battery systems are units with inbuilt batteries and a 240V inverter. The 240V inverter means these units be used as a backup power source for regular 240V appliances: they have a power outlet built in, so can be used identically to a regular power point. Such units will generally have sufficient storage capacity to operate small-medium household appliances for a few hours and are sometimes known as “portable power stations”. Examples of two units are shown in Figure 5. These units can typically be recharged from a portable solar panel, a generator, or the electricity grid. They are an excellent energy resilience solution in that they can power a wide range of appliances and are quite portable, but they are relatively expensive. Further details on the capacity and cost of various batteries for backup “grid” power supply are shown in Table 2.

Figure 5. From left to right: 12V deep cycle battery (courtesy Outbax [16]), Bluetti portable power station (courtesy OKSolar [17]) and EcoFlo Delta portable power station (courtesy mwave.com.au [18]).

Battery Device	Cost	Energy capacity (kWh)	Household Fridge (days)	Phone Charger (days)	Sump Pump (days)	Fan Heater (days)	Split System Air Conditioner (days)
Bluetti Portable Power Station	$2699	2	0.92	45	1.7	N/A	N/A
EcoFlo Delta Pro Portable Power Station	$6599	3.6	2.2	80	3.0	1.5 hours	N/A
Tesla Powerwall 2	$13750	13.5	6	300	11.3	1.4	0.9
Hyundai Ioniq 5 EV V2L	$71900	72.6	32.4	1613	60.7	121	N/A

Table 2. Various battery backup-power products, and the approximate length of time (in days) they may be able to run different appliances, based on the appliance energy consumption data in Table 1 of this report. Where "N/A" is listed, the battery does not have sufficient peak power capacity to operate the appliance.

7.3 Portable Generators

Portable generator sets are a single unit that brings together a reciprocating engine and an electricity generator, that are a widely available backup power solution. Units are available across a very broad range of sizes: from highly-portable 1kW capacity, to 5kW units that require two people to move. Modern units that are labelled as based on "inverter" technology are suitable for supplying all modern electricity loads.

Portable generators are readily available across Australia, relatively affordable, and a well-known technology. They are one of the most economical forms of energy resilience: for example, a 2kW generator can be purchased for approximately $500. A 2kW solar system would cost approximately $2000, and that's without any batteries, which realistically are a critical item for energy resilience. As shown in the previous section, a portable battery solution suitable for solar input could add another

$2000 or more, meaning a solar + battery system that can provide similar backup power functionality to a 2kW portable generator may cost over 8x the price of the generator. Portable generator sets are also relatively easy to move, so can be kept out of the way of damage from fires or flooding.

Disadvantages of portable generators as an energy resilience solution include:

- They require fuel to operate. If fuel supplies are unavailable, the generator doesn't work. Fuel can be stored on site, but fuel goes stale over time, is flammable and needs to be stored carefully, and needs to be refreshed. During a largescale grid outage, fuel service stations may be inoperable, or roads impassable meaning additional fuel supplies are unavailable.
- They require regular maintenance. Generator sets need ongoing checking and servicing to ensure their reliability. If they are not maintained, there is a strong possibility they will not work when called upon.
- They are environmentally damaging, as they usually burn fossil-fuel, producing carbon and particulate emissions. Whilst the use of 100% biofuels means a generator can operate close to carbon-neutral, 100% biofuels are not widely available.
- They can only be operated outdoors, making their use as a backup power solution for appliances that must remain indoors challenging.
- They are noisy.

7.4 Largescale Mobile Power Units

At the other end of the size spectrum from portable battery packs and small portable generators are largescale mobile power units that are designed for providing a mobile, high-capacity (10kW or more) grid-equivalent electricity supply. Such solutions are often truck or trailer based, and so can be moved to a particular area to provide energy supply. Largescale mobile power units may be procured by one individual consumer to meet their own significant energy demands, or they may be deployed as a community-based energy resilience solution. In the latter case, largescale mobile power units are often deployed to a community emergency response centre after a natural disaster, providing a centralised source of electricity, and derivative services.

The most common example of largescale mobile power units are diesel-powered mobile generator sets, which are available from tens-of-kW capacity, to 1MW+. Units are available for purchase or rental from many suppliers across Australia. The main advantages of such technologies are they can provide grid-equivalent power supply and are widely available, at a broad range of capacities. The main disadvantages of such units are identical to those for portable generators: they are fossil fuel based, require regular maintenance, are noisy, and for long term operation require an ongoing source of fuel.

Largescale mobile power units based on solar power and/or battery storage are appearing in the market in growing numbers, from a variety of vendors. The simplest of these solutions are based on a diesel generator as the main source of energy, but include some amount of solar generation that reduces (but not eliminates) the use of diesel fuel. These units use less fuel (and thus produce less emissions) than a generator without solar but are designed so that the generator needs to operate continuously, and so apart from using less fuel for the electricity they produce, they otherwise have the same disadvantages as other portable generators.

More complex largescale mobile power units are designed to rely predominantly on solar and battery technology. An example of such a unit is the Solar Qube, as shown in Figure 6. This unit is sold by Boundary Power [19] and provides grid-quality electricity supply in a mobile container that folds out to deploy solar panels upon arrival on site. The Solar Qube also includes a backup diesel generator: so if there is insufficient sunlight available to supply loads or recharge the onboard batteries, the system will start the generator to meet the local energy demand.

Figure 6. Solar Qube, from Boundary Power [19]

Another example of a solar-based largescale mobile power unit is that provided by Self-Sufficient Australia, shown in Figure 7, which includes 14kWh of batteries, a 5kW solar array, and can supply up to 10kW of demand [20].

Figure 7. Self-Sufficient Australia Portable Power Station (the backup generator shown is an optional extra) [20].

Units like the Solar Qube and Portable Power Station can provide backup power to an entire house or building or ensure power supply to a range of larger critical loads. They can also be deployed as a "resilience centre" or "recovery centre" for a community. Another title for such systems is an "emergency distributed energy" solution [21].

The main disadvantages of solar + battery based largescale mobile power units are:

- Their availability: such units are not widely available, nor held in stock awaiting purchase or deployment. Currently, such units tend to be built-to-order, and then installed as a relatively permanent solution for a particular location. Thus, such systems are not commonly available as an energy resilience solution available on short notice for deployment to a particular location.
- Their capital cost: a system such as the Self-Sufficient Australia Portable Power Station costs over $70 000, without the optional backup generator [20].

7.5 Microgrids

Even further along the size scale from largescale mobile power units are microgrids, which bring together multiple distributed energy devices, linking them to provide reliable power in a network that resembles a smaller version of the electricity grid. A microgrid would typically include multiple solar installations, battery storage, and perhaps a fossil-fuel or wind generator. These are often spread out across a geographical area and linked together with loads through an electricity distribution system. They require a dedicated control system to coordinate the variety of assets involved. A microgrid may be installed to supply a village, a university or commercial campus, or outlying island. They may operate connected to the main grid, or completely separate, permanently islanded from the broader power grid. If grid-connected, for energy resiliency purposes the microgrid will be able to island from the blacked-out grid and operate autonomously with local supply.

Being based on a combination of devices, microgrids are particularly well suited to maintaining electricity provision during an electricity outage: there are many examples internationally where a microgrid has continued operation after a natural disaster, maintaining local power supply despite the wider network being inoperable.

Microgrids are large, complex systems: as effectively a "micro" version of the electricity grid, their design, procurement, installation and operation should be considered a major project. A privately-owned microgrid requires significant technical expertise and capital resources, and is a significant "in advance" approach to energy resilience, as opposed to a rapidly-deployable response to a recent disaster.

7.6 Bidirectional EV Chargers

An electric vehicle can be considered a "battery on wheels" that is very large compared to the batteries usually deployed for building purposes: the battery in a typical electrical vehicle stores more than four times the energy of the battery in a typical residential grid-connected battery system. Recognising the energy stored in an electric vehicle battery could be very useful for other applications, the "vehicle to grid" (V2G) and "vehicle to home" (V2H) concepts were born, which are based around taking electricity out of the vehicle battery to power electricity loads outside the vehicle. V2H and V2G require the use of a dedicated bi-directional charger, which is different to the standard charger supplied with an EV. The charger is permanently installed into a building's electricity system and plugged into the vehicle through the regular charging port. It can either charge the batteries in the vehicle using electricity from the grid, or discharge the batteries in the vehicle, providing electricity to the building.

Today, bidirectional chargers are expensive (estimates are $5000-6000), and only currently available in Australia through participation in some limited trials, which are focused on grid support, rather than resilience applications [22]. At the time of writing, only two EVs available in the Australian market (from Nissan and Mitsubishi) currently support such chargers. Whilst there are expectations that bidirectional chargers will drop in price, the functionality of such chargers during electricity grid outage is unclear: EVs and bidirectional chargers have been used in Japan to provide backup power during grid outages, but this functionality does not appear to be available from the bidirectional chargers sold in Australia.

7.7 Vehicle to Load

Vehicle to load is another technology designed to take advantage of the very significant energy storage capacity of an EV battery. Vehicle to load (V2L) is a feature of some EVs and hybrid vehicles, where the vehicle features a power outlet that portable appliances can be plugged into: it allows the vehicle to be used as a portable power source, to (for example) power electrical tools on a worksite, or equipment when camping. Vehicle to load does not require a unique charger or other major interface external to the car: as shown in Figure 8, the power outlet is typically built into the car body, or an adapter that plugs into the car's charging port, and using that outlet is identical to using a normal power point. In many ways, vehicle to load technology provides a similar service to a portable generator: appliances up to 3.6kW may be powered, and a typical EV battery could run these appliances for many days.

Vehicle to load is an excellent energy resilience solution, as a relatively portable, high-capacity source of backup power. Vehicle to load has some significant energy resilience advantages over vehicle to grid technology: the backup power source is very high capacity, but portable, so it can be moved to where energy is required, such as powering a fire-fighting pump. It is also an energy resilience solution that doesn't require extra equipment, using the equipment inherent in the vehicle itself.

Whilst vehicle to load technology requires the vehicle battery to have sufficient state of charge to operate the connected electrical loads, the risk of a vehicle not having sufficient energy to provide some form of backup power is relatively low: for example, a typical EV with a battery state of charge of only 10% would still have useable energy capacity many times greater than the portable power packs described earlier in this report.

The main downside of vehicle to load technology as a form of energy resilience is its current lack of availability: at the time of writing there are only two EVs with V2L technology available in Australia: the Hyundai Ioniq 5 and Kia EV6. Many EV manufacturers have announced upcoming vehicles that will include the technology, and it has been suggested by industry insiders that eventually all EVs offered on sale will include the technology [23].

Figure 8: Vehicle to load adapters. Left picture shows Hyundai Ioniq 5 adapter (courtesy of Hyundai [24]), right picture shows Ford F-150 Hybrid adapter (courtesy of Ford USA [25]. The Ford F-150 Hybrid is not currently available in Australia).

7.8 Portable Devices Powering a Building

In the event of an electricity system failure, it would seem appealing that a portable electricity generator or battery could be “plugged in” to power a whole building, but in practice such a concept is not straightforward to achieve. If a consumer was able to connect their portable generator, battery, or EV with V2L functionality to their house, this would simplify getting backup electricity to any appliance in the building. From a hardware point of view, such a concept seems relatively straightforward to implement- it requires a basic power plug inlet (also known as a “caravan inlet”) to be installed adjacent to the building’s switchboard, and a changeover switch that switches electricity supply from the grid to the plug inlet. In the event of a blackout, the householder would switch the changeover switch to generator supply, plug in their generator or battery into the inlet, and then have supply across the building. When the grid returns, they reverse this procedure to return to grid operation. Whilst apparently simple, there are significant risks and complexity to this approach. These include:

- The limited power capacity available. For example, a typical portable generator may have a maximum capacity 2kW. The homeowner needs to be very careful not to exceed this capacity, given the diversity of loads available across a building.
- The risk of a consumer plugging in a local generator or battery when their house wiring is faulty or damaged from a flood or similar event.
- The risks associated with having an extension cord running from the portable device to the house.
- Depending on how the generator and meterbox/switchboard are wired, the risk of electrocution may be higher than if the house was grid connected.

7.9 Approaches That Don’t Need Electricity

Some services that usually rely on energy from external electricity source can be provided by a different appliance, that uses an alternative source of energy. Having a “backup appliance” to provide these services, independent of an outside electricity source, is another approach to energy resilience. Such appliances include:

- Self-powered radios and lights/torches. Such appliances may be powered by cranking a handle on the torch or radio to charge an internal battery. Alternatively, they may have a small solar panel built into the unit, that can charge an internal battery.
- Refrigeration. Absorption fridges use heat to provide refrigeration. Gas-powered absorption fridges are widely available for camping or caravanning purposes, and use regular LPG gas bottle supply to operate, without any electricity needed. A typical 9kg BBQ gas bottle can fuel an absorption fridge for many days. Kerosene fuelled absorption fridges are rarer, but still commercially available.
- Heating. Gas and kerosene fuelled room heaters are widely available.
- Stoves. Gas and liquid-fuelled stoves are widely available. Liquid-fuelled stoves may operate with a range of liquid fuels, including methylated spirits, kerosene and diesel fuel.
- Lighting. Gas and kerosene fuelled lights are widely available.
- Ovens. Gas ovens are widely available.
- Solar cooking appliances. A variety of solar-driven cooking appliances are available, including solar ovens, solar kettles (for boiling water) and solar BBQs. These devices only work effectively on sunny days.
- Solar hot water solutions. A variety of solar-driven hot water appliances are available: at the large end of the scale are permanently installed solar hot water systems. So long as it is sunny and there is a water supply available, solar hot water systems where the water tank is mounted on the roof work without needing any grid electricity at all. Solar hot water systems where the water tank is mounted below the roof will not work during an electricity grid blackout, as they require electricity to pump water up to the roof-mounted solar collector. At

the smaller end of the scale, a variety of portable solar water heaters are available, designed for camping applications. Two examples of such systems are shown in Figure 9.

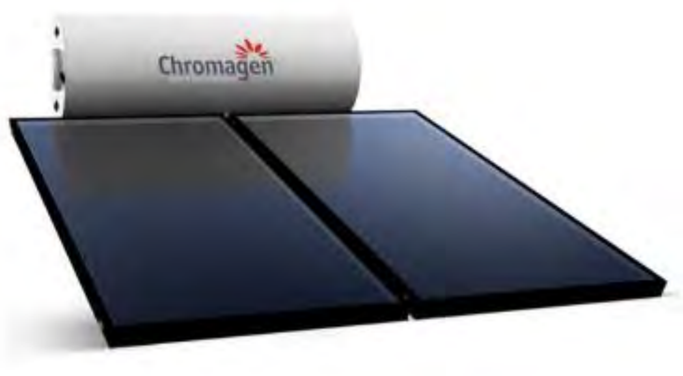

Figure 9. Two solar hot water devices. The unit on the left is a system designed to provide hot water to a house (courtesy of Enviro Friendly [26]). The unit on the right is a "solar kettle" and can heat up approximately 1L of water. It is about the size of a large drink bottle (courtesy of Amazon [27]).

Improving the thermal efficiency of a building can reduce the reliance on external systems for heating or cooling, and thereby improve energy resilience. Thermal efficiency can be improved by reviewing the building materials and structure of a building, and then considering measures such as glazing, shading (including trees or awnings), insulation, or the sealing of gaps to improve the building's energy efficiency.

The fossil-fuel powered appliances in the list above have similar downsides to portable electricity generators- whilst a viable source of "backup" service, these appliances produce significant emissions with the use of fossil fuels, and that fuel can be expensive. Furthermore, if the fuel is not available (or the supply chain has been disrupted), then the backup service is not available.

8. Novel Approaches, Not Commercially Available

Given the experience of the Advitech team with energy resilience issues, the following novel technology concepts may further help improve end-user energy resiliency. These are not commercially available products or technologies: rather, they are alternative concepts, presented here for consideration, but that will need further exploration and development.

8.1 Extra-Low Voltage Solar Output

As described in section 6, whilst a rooftop solar system has the capacity to power many typical building loads when it is sunny, by themselves rooftop solar systems are not an energy resilience option, due to their anti-islanding functionality and the lack of energy storage in a standalone solar system. Whilst adding a permanently-installed battery system and inverter/charger can allow a rooftop solar system to provide backup power, there are disadvantages with this approach, as outlined in section 6.3.

The Advitech team have been investigating alternatives to expensive stationary batteries, that would allow standard rooftop solar systems to provide some form of energy resilience. One concept worthy of further consideration is combining a (usually) grid-connected rooftop solar system, with an affordable portable power bank.

Portable power banks as described in section 7 are a relatively affordable energy resilience solution, some of which store enough energy to run an appliance such as fridge or lights for several hours. In this new concept, a portable power bank could be recharged by connecting it to an extra-low voltage output linked to the existing (usually grid-connected) solar panels on the roof of a building.

Such an outlet would be permanently installed in the building and could act as a power supply and fast-recharge solution for a portable power bank. In theory, such a solution could provide backup power to a limited number of loads for many days, without needing the expense of a permanently installed battery system.

This concept is not currently available with commonly available grid-connected solar systems. However, it is a concept that could be relatively straightforward to implement, requiring very minimal changes to solar system hardware and design. One potential way of realising this concept would be to add additional wiring to a single solar panel on the roof, and then run this wiring to an appropriate extra-low voltage (defined by Australian standards as <50V AC or <120V DC meaning it is relatively safe) DC outlet near the solar inverter. Then, during a grid outage, when it is sunny this DC outlet could be used for powering or recharging portable power banks and the appliances connected to them.

This concept has not been thoroughly investigated, and further effort is needed to verify its safety, and consider its implementation amidst the various Australian Standards for wiring and solar installation. Further work is also needed to standardise a safe DC outlet design and broader installation approach.

8.2 Battery Libraries

In an electricity grid outage associated with a largescale natural disaster, a common response is for the community to gather in an emergency response centre that may provide services such as safe shelter, potable water, communications and perhaps a form of backup electricity. Whilst largescale mobile power units as described in section 7 are an excellent energy resilience option for such centres, they can only provide backup electricity in one location, adjacent to the energy source. As the disaster response progresses, the community may be able to leave the emergency response centre and safely return to their homes or businesses, but can be hampered by a lack of electricity at those locations.

An alternative approach to community-based energy resilience would be a "battery library". Such a system would be a variation of the solar + battery based largescale mobile power unit. In the battery library concept, a centralised energy resilience solution is still located at the emergency response centre, but the system is based around multiple portable batteries, rather than one large stationary battery. These portable batteries can be taken to local houses or businesses, where they may provide 1-2 days of backup power to critical appliances. When the portable batteries are empty, they are returned to the emergency response centre for recharging, in exchange for a fully charged battery. Individual batteries are recharged at the emergency response centre using large solar panels, or perhaps a generator. As per largescale mobile power units, the entire system would be trailer or container based, and designed to be self-contained and mobile: the solar panels would fold up for transport, and individual portable batteries would slot into racks on the battery library for recharging and remain there during storage and transport.

This battery library concept is not currently available in Australia. However, the concept is based on commercially available technology, and it would be a relatively straightforward system-integration and engineering project to design the system and bring the individual components together for a final product.

A collection of battery libraries could be kept available as a public disaster-response facility, stored ready for deployment to the location of a natural disaster. They could offer an energy resilience solution to the end consumer that is relatively easy and straightforward for disaster response authorities to manage. The biggest challenges to realising the battery library concept are likely to be issues around who would fund the development work and subsequent procurement, and who would have ownership and ongoing responsibility for the collection of battery library systems.

8.3 High-Capacity Mobile Battery Recharger

As described earlier in this report, the energy storage capacity of a grid-connected stationary battery system, or an electric vehicle battery, can provide significant local-to-the-consumer energy resilience benefits. However, the resilience benefits provided by such systems depend on the ability to recharge them: if such systems are to act as an extended source of backup power, there needs to be a way to recharge their batteries during an electricity grid outage.

In the case of grid-connected stationary batteries, the typical way to recharge such systems during an electricity grid outage is through rooftop solar panels connected to the stationary battery. This only works if it is sunny, and the solar system has sufficient capacity to meet the demand of critical energy loads *plus* recharge the batteries.

In the case of vehicle-to-grid or vehicle-to-load based energy resilience solutions, EVs are designed to recharge from "grid" supplied electricity through a particular interface, and at a high rate. Once the vehicle battery is empty, it is no longer available as a source of backup supply.

The high-capacity mobile battery recharger concept uses a truck-mounted large battery system to recharge grid-connected stationary batteries, or electric vehicle batteries. A truck would visit the consumer's site where the EV or stationary batteries are located (and grid electricity isn't available or working), and then through a cable provide a high-power recharge of the consumer's batteries, ensuring they are charged and able to provide ongoing backup power. The recharge truck would have sufficient capacity to recharge several consumers' EV or stationary batteries before recharging its own batteries elsewhere, where a high-capacity electricity supply is available.

The high-capacity mobile battery recharger would be relatively straightforward to implement for recharging EV batteries: it would use the standard EV high-power charge port to recharge the vehicle, identical to the vehicle recharging of any other high-power street-based charger. As such, realising a high-capacity mobile battery recharger for EV purposes is a relatively simple system integration project to design and assemble the commercially available components into a working system.

Whilst theoretically possible, the high-capacity mobile battery recharger concept is much more difficult to realise for the recharging of stationary batteries designed for grid-connected use. Grid-connected stationary batteries are designed to charge off solar or the electricity grid, and their electricity-grid charging function is of relatively low capacity, meaning they usually take multiple hours to recharge from the grid. Furthermore, they do not have a port that allows the simple connection of an outside charger. These challenges are not insurmountable: a charging interface that facilitates high-capacity outside charging of grid-connected batteries could be designed and standardised for installation on every new battery system, but this would require significant industry and regulatory effort.

Once again, a key barrier to the realisation of the high-capacity mobile battery recharger concept would be the issues around who would fund the development work and subsequent procurement, and who would have ownership and ongoing responsibility for the collection of truck-based chargers.

9. Steps to Improved Energy Resilience: Regulators, Policy Makers and Other Stakeholders

This report focuses on technology measures that may help households and small businesses to improve their energy resilience or respond to a loss of grid-supplied electricity. Whilst such measures are focused on the end-user, there are a number of steps government, energy system regulators and related stakeholders can take to assist here. The following measures would help to empower consumers to improve their own energy resilience, or to take their own actions in response to a major electricity grid outage.

1. When evaluating community battery projects, include consideration of the energy resilience benefits such battery projects may offer. With appropriate design, a community battery could become a source of community backup power. This may be as simple as offering accessible power-points on the side of the battery for powering loads such as mobile phone chargers during an emergency. Or it may be as complicated as providing grid-equivalent backup power to a broader resilience centre or set of buildings. The agencies involved in evaluating grid-connection permission, funding or other support of a community battery

project, should be required to factor in energy resilience considerations into their evaluation process.

2. Instigate a major initiative to secure a stock of mobile energy resilience centres that can be deployed as a disaster response solution. Such systems have clear community benefits, but it is not clear how many should be procured, who can fund them, where they would be located, or who would be responsible for their ongoing management and deployment.
3. Support a detailed investigation into novel resilience approaches such as:
    a. Extra-Low Voltage (ELV) solar output
    b. Battery library
    c. High-capacity mobile battery recharger

    The investigation should consider funding, standards requirements, and the ongoing support/operation of the technology being considered.
4. When considering measures that support EV uptake, realise that such measures may also bring energy resilience benefits. These benefits should be included in the cost-benefit analysis that is performed when considering any EV support measures.

10. Steps to Improved Energy Resilience: The Consumer

The energy requirements of households, small business and other end-users are very diverse: in one situation the only "critical" energy loads needing backup may be a mobile phone, whilst in another situation there may be multiple medical or pumping devices that need uninterrupted power supply. Given this diversity, the following steps are designed to assist the energy consumer determine what their critical energy loads are, and then determine the best options for improving the energy resilience of these loads or services.

1. Appreciate that during an electricity grid outage the only reliable form of telecommunications is likely to be a mobile phone, assuming the mobile phone network is still operable. In this case, the consumer will need a way to recharge their mobile phone during extended electricity outages. A relatively affordable option may be a small solar-based charger.
2. Identify one's own critical electrical loads and estimate how much energy they use. For example, providing a resilient supply of energy for a mobile phone charger, which has relatively low peak power and energy demands, is much simpler than providing a resilient source of energy for a pumping system, which has much higher peak power and energy demands. Steps on how to determine the peak power and energy demands of an appliance are provided in Appendix A.
3. Decide how long they wish to be able to operate without grid-supplied electricity. As a general rule, the longer the consumer's loads are required to operate autonomously without the grid, the more expensive the energy resilience solution will be.
4. Decide what their approach is to ensure the resilience of their critical loads or services. This may include:
    a. Having a backup source of electricity available. There are a wide variety of options here, which include a portable generator, a grid-connected solar + battery system, a portable power pack, or even an electric vehicle that provides V2L functionality.
    b. Having an alternative appliance available that uses a source of energy other than electricity. This could include a gas-powered stove, fridge, or lighting.

c. Using portable self-contained appliances, such as torches, portable radios, or mobile phone chargers. These may be powered by batteries, or rechargeable through physical action (such as cranking a handle or shaking) or have a small solar panel for charging.

5. Appreciate that by itself, a grid-connected solar system will generally not be able to act as a source of backup power during a grid failure, even if it is sunny.
6. If using a backup source of energy, decide what will be their approach to replenishing their backup source of energy. This may include:
   a. Storing fuel for portable generators or gas appliances. In the case of liquid fuels such as diesel or petrol, some method to preserve the fuel when stored long term, or ensure it is fresh, is important to ensure reliable generator operation.
   b. Using solar panels to replenish battery storage. These solar panels may be fixed for large stationary battery systems, or portable for smaller portable battery units.
7. Practice deploying their energy resilience solutions. An energy resilience or backup solution is only useful if it can be deployed with little notice and works on deployment.
8. Recognise that in a significant electricity grid outage, even if they have a source of local backup power, that other key services may be unavailable, and they'll eventually need alternatives to those services, or to evacuate to another location. For example, in a major electricity grid outage, potable water, sewerage and mobile phone services are likely to fail. Similarly, replacement gas or liquid (petrol/diesel) fuel supplies may be unavailable.
9. Appreciate that energy-efficiency measures also help with energy resilience. For example, by reducing the amount of energy needed to keep a building comfortable, that building is inherently more resilient to electricity outages. Similarly, an efficient appliance will operate longer from a backup source of electricity than an inefficient appliance.

11. Conclusion

As our climate changes, the threats posed to our electricity systems will increase, with increasing numbers of bushfires, storms, and flooding meaning the probability of an electricity system outage is also increasing. The experience of recent natural disasters shows that, in addition to measures taken to strengthen the broader electricity network, end-users are keen to understand how they can take action to improve their own energy resilience, or to maintain or restore critical services after an electricity grid failure.

This report examines a range of technology options that are available to end users to improve their own energy resilience. Given fixed telecommunications networks generally do not work during an electricity outage, one critical load for most consumers will be their mobile phone, and, as a minimum form of energy resilience, consumers should have a backup way of charging their mobile phone. Beyond this, what are critical loads, and what are the best ways to maintain this service during an electricity outage depend significantly on the consumer and their particular circumstances. Technology options range from finding a backup source of electricity to identifying an alternative way of achieving a similar service: for example, keeping a portable gas-powered fridge to use in the case of an electricity system failure. Given the variety of options available, this report has presented a number of key steps a consumer can take to consider their energy resilience, and act to improve it.

Whilst this report focuses on energy resilience technologies that are available to an end-user, there are a number of measures that government, regulators and related stakeholders can take to further empower energy consumers to improve their energy resilience. These measures range from funding the purchase and ongoing support of community-based energy resilience technology, to investigating new technical approaches and standards for consumer-grade solar and battery systems that could improve their usage as an energy resilience appliance.

Appendix A

Steps to determining the peak demand and energy requirements of an appliance.

When deciding the appropriate source of backup electricity for an appliance, it is important to determine two key factors for that appliance:

1. The peak *power* demand of the appliance.
2. The daily *energy* consumption of the appliance.

There are a number of ways to determine the peak power of an appliance. These include:

- Read the peak power off the appliance nameplate data. Almost all appliances will list their peak power demand somewhere on their body, as show in Figure 10.
- For plug-in appliances, measure the peak power demand using a plug-in energy meter. These meters measure the instantaneous power consumption of an appliance and are available at hardware stores and other retail outlets. Some councils also provide them to borrow from the local library. An example meter is shown in Figure 11.

The peak power demand of an appliance is typically measured in Watts (W), and this needs to be less than the peak power output of the backup power source. Best practice suggests the backup power source be able to supply peak power demand of at least 1.2x the peak demand of the load[1]. So for example, an appliance with a peak power demand of 300W should only be run by a backup power source that can supply at least 360W.

The daily energy consumption of an electrical appliance is typically measured in kiloWatt-hours (kWh). There are a number of ways the daily energy consumption of an appliance can be determined. These include:

- Getting the yearly energy consumption of the appliance from the appliance's energy rating label, and converting this to an approximate daily energy consumption, by diving by 365. An example energy label is shown in Figure 12. Based on the information in the label, the approximate daily energy consumption of this appliance would be 458 ÷ 365 = 1.25 kWh per day.
- Finding the appliance in the national Energy Rating Database [28], and using the online calculator at that site to get an annual energy consumption, and converting this to a daily number.
- For plug in appliance, measuring the peak power demand using a plug-in energy meter. These meters measure both peak power demand and, over a 24-hour period, the daily energy consumption of an appliance.
- Estimating the number of hours the appliance operates per day and using this to convert the peak power demand of the appliance to a daily energy consumption. For example, a pump with a 300W peak power demand may only turn on for 4 hours per day. The daily energy consumption of this particular pump is approximately 4 x 300 = 1200Wh, or 1.2kWh[2].

[1] This is a crude approximation. Some appliances will be able to be powered by a backup power source of identical rating to the load's peak power rating, others (such as pumps) may require a backup power source with a peak power rating significantly more than that of the load. For most electronic loads, the 1.2x recommendation is conservative and sufficient.

[2] There are 1000 Wh in 1 kWh.

The daily electrical energy consumption of an appliance is used to determine how long a particular battery can run that appliance. For example, a 12kWh sized battery could run a pump that uses 1.2kWh per day for 12 ÷ 1.2 = 10 days.

Figure 10. An example of finding the product nameplate from a TV. The "170W" that is circled is the peak power demand of this TV. Courtesy of Samsung [29].

Figure 11. An example plug-in energy meter. Courtesy of Bunnings [30].

Figure 12. Energy rating label for an appliance, with the annual energy consumption of this appliance circled [31].

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