RENEWABLE ENERGY DISSERTATION

A Techno-economic and cost benefit analysis of the Ultrabattery for residential applications with solar photovoltaics in Western Australia.

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Neil Salam

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LIST OF ACRONYMS AND ABBREVIATIONS

SWIS: South-Western Interconnected System.

CSIRO: commonwealth Scientific and Industrial Organization

PV: Photovoltaics

ARENA: Australian Renewable Energy Agency

EXECUTIVE SUMMARY

In this report I will summarize the key findings from modeling and literature review on the Ultrabatteries technology from a Techno-economic analysis perspective. Key findings:

- The Ultrabattery has fewer technical obstacles than Lithium as presented.
- The Ultrabattery may have a payback of as low as 5 years compared with Lithium's 7 years as modeled under assumptions.
- There is scope for this technology and potential for residential storage growth in the WA market.
- Developments in the market in economics of electricity and the photovoltaic (PV) and energy storage system improvements in cost will help the growth of the market.

1.0 Introduction

The reason for this project is to explain the background of why Western Australian markets need energy storage for solar photovoltaic (PV) and to look at the Ultrabattery as an option for energy storage in solar PV systems. As batteries become more and more economical, and as electricity prices continue to rise, they will continue to increase in popularity. For solar PV systems in residential areas in Australia an area of key interest and growth is in energy storage. This section of the project will look at some of the popular technologies for residential purposes. Batteries are needed to store excess energy for when it is needed. Energy storage is very useful for solar PV systems, whether residential or commercial.

The research question deals with the Ultrabattery: the research is to find specific examples where the Ultrabattery may be used in residential applications with solar PV for use in Western Australia (W.A.). The Ultrabattery is an advanced lead acid battery technology. It combines improved capacitor technology with a longer life battery using shallow recharge capability. The battery was invented by Dr. Lan Lam and supported through CSIRO in its development (Lam and Louey 2006). It comes into development at a time of growing battery competition and the growth of battery technology generally. It is also to see how it compares with other energy storage and PV systems in the presence and absence of batteries with solar PV. The Ultrabattery currently does not have any suppliers in W.A.; however, it is well established in the Eastern states and has been used in some telecommunications and residential uses (Stone et al. 2013). Solar PV is increasingly used in residential areas to offset increasing electricity prices and for environmental reasons. Similar modelling has been done for different parts of Australia and shown savings.

The aim of the project is to look at the technical, economic and cost benefit analysis for Ultrabatteries in comparison to other current battery systems in the market used for solar PV systems. The project covers Lithium, Sodium, Vanadium and Zinc-Bromine or flow battery technologies. In this project my objectives will be to:

1. Have an in depth knowledge and understanding field to prevent blackouts and brownouts by showing the potential of batteries.
2. Develop the battery storage industry in Australia further.
3. Increase knowledge available more publically for these energy storage technologies.

Many brands are now seeking niches in residential, commercial and utility applications. There is research into the cost benefits of and techno-economic analysis of these new systems (Moshövel et al. 2016); however, currently there are gaps in the research for specific applications and comparisons in a more localised context.

1.1 Background

The solar PV industry continues to grow in W.A. Perth has one of the largest percentages of solar PV residential systems in Australia. With the growth in adoption of battery storage technologies and retrofits for solar PV systems with energy storage, a techno-economic comparison of some of the alternative energy storage options for residential uses is valuable. With the falling costs of battery technologies and the wider public discourse on these systems there is potential to increase the affordability of using battery systems. In W.A. there are already several solar farms including the Greenough River Solar One facility. Residential and commercial solar systems continue to grow, including in rural areas, amongst families and seniors. Now newer residential developments such as apartments are also considering micro grids with solar and battery storage as new residential developments like Alkimos start to include solar and battery storage systems in W.A.

1.2 Solar Photovoltaics

1.2.1 What are solar photovoltaics

Solar PV consist of solar cells which make use of solid state devices which convert sunlight into electricity via the photovoltaic effect.

Benefits of solar photovoltaics in Western Australia

Solar PV systems could enable households to have cheaper and more reliable electricity in specially designed systems with energy storage. Solar PV makes good use of the great solar resources available in W.A. Solar PV makes use also of available solar tariffs and tax incentives/ rebates for solar PV systems in W.A. Western Australian battery industry growth supported by subsidies and rebates would help to increase renewable energy penetration and increase the adoption of residential solar energy. In Australia and W.A. in particular a solar rebate scheme using Small Technology Certificates and a solar tariff helped to increase the adoption of solar PV in Perth and the growth of the industry. Western Australia has good resources for solar photovoltaics. The solar resources available in W.A. are amongst the best in the world as shown below in Figure 1.

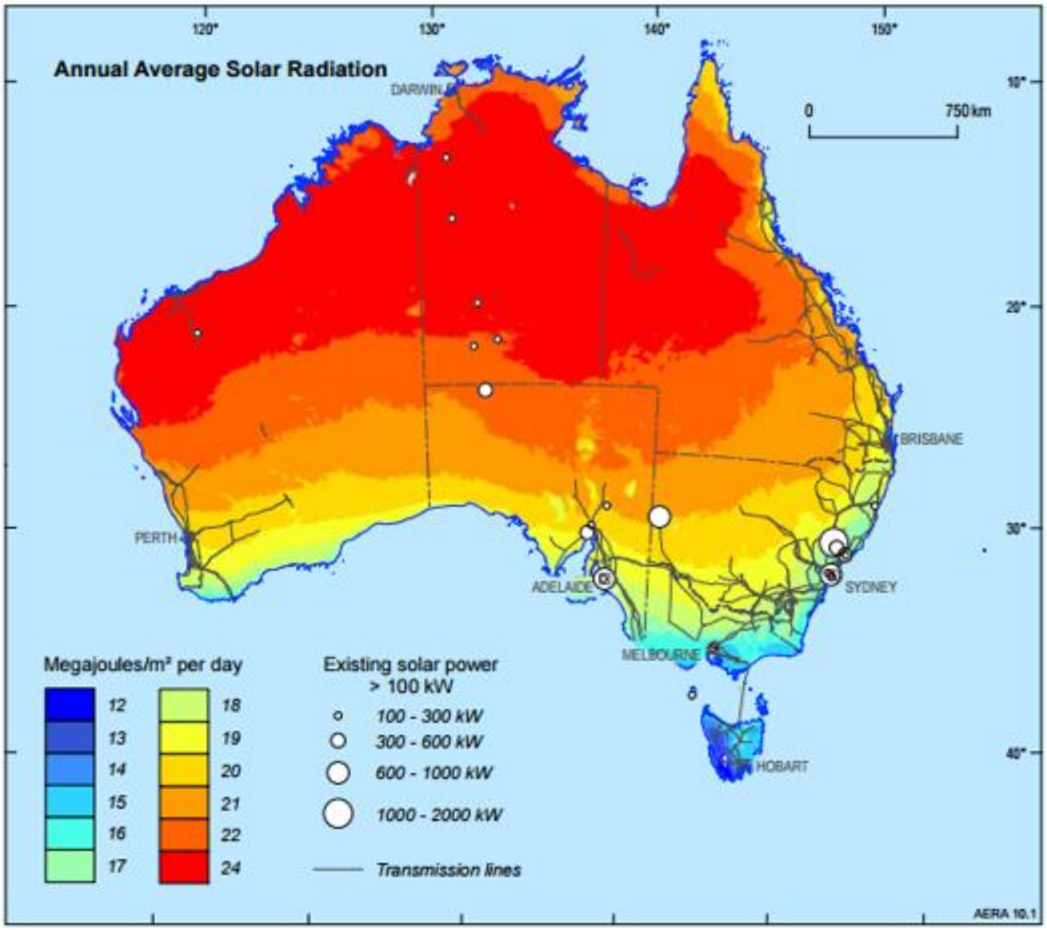

Figure 1: Annual average solar radiation (in MJ/m2) and currently installed solar power stations with a capacity of more than 10 kW (Bureau of Meteorology 2009).

1.2.2 Comparing solar with hydropower and wind for residential consumers in W.A.

Solar is cheaper and more plentiful than hydropower potential in W.A. Hydropower for sufficient storage and power relies on enough rainfall. Wind power is a very good resource for W.A.; however, wind power is currently more suited for non-residential areas while solar photovoltaics are readily available for residential purposes. Currently there are few regulations for domestic size wind power and standards for residential wind power.

In terms of the scientific perspective, solar photovoltaics have enough efficiency to be effective for residential power generation with some incentive economic policy batteries could become very popular as a way to ensure security of supply. Electricity prices are rising currently in W.A. More money is being invested in electrical infrastructure (Laschon 2017). As solar tariffs are reduced and battery costs fall there is a need for research in this area to see how this transition could be done and the advantages of this opportunity (Kathryn 2016). “Pumped hydro, on the other hand, is a relatively inexpensive storage technology (already at around A$100 per kWh) as it can store large amounts of energy using a very inexpensive material” (Dargaville 2016). Pumped hydro would not be sufficient for individual residential areas due to the large area required. Solar PV continues to grow in W.A. and there is much interest in Lithium batteries. It is especially interesting that W.A. also has one of the largest reserves of Lithium in the world among the top three producers and that Lithium mines have expanded in W.A. As stated by Dargaville, “in the same way that rooftop PV has gained more popularity than large-scale solar (even though the latter should be cheaper), distributed storage in the form of lithium ion batteries may be the eventual winner, not because of economics but because of human behaviour” (Dargaville 2016).

1.2.3 Physics and the efficiency of solar

In terms of efficiency typical crystalline solar panels may have efficiencies of 15-18%. The manufacturing costs are falling for solar PV systems and as labour costs also fall solar PV systems will be more available to more consumers. Solar PV and energy storage for residential solar generators of electricity for residential uses are some different uses for these systems in residences. Solar rebate schemes and small micro-grid solar are other residential uses for solar Photovoltaics and energy storage. These uses include apartments, old age care homes and small residential micro grids. Such examples include the Alkimos suburb scheme and a recent apartment scheme supported by Curtin University. These systems could be financed differently and also share the costs among residents.

"Most solar PV is distributed on rooftops throughout the grid, the antithesis of the central generation model. Another significant change, still in its earliest stages, is the consumer-driven decision to install home battery storage systems. More than 1.5 million solar PV systems generate electricity from the rooftops of Australian homes" (Department of the Environment and Energy 2016). According to the Now switching over Solar PV and looking at Electricity Network Transformation Roadmap: Final Report - April 2017, intermittent energy from solar needs to be stored. It recommends energy storage of which the two leading residential energy storage technologies are lithium and lead acid batteries. "forecasts suggest that by FY2035 there will be approximately 1.1 million battery storage systems installed alongside new rooftop solar PV systems in households across the NEM" (Department of the Environment and Energy 2016). Solar PV is also an intermittent energy source and as a report by CSIRO 2012 finds "A number of mechanisms can be employed to manage the impact of intermittency on electricity networks. Some of these include: using short-term energy storage systems". The report discusses the importance of energy management systems, the flexibility that energy storage gives for PV systems and electric vehicles and energy storage with photovoltaics being used in conjunction (CSIRO 2012).

1.2.4 Why is solar PV system use growing in W.A.?

Solar photovoltaics are growing in W.A. because:

- Solar PV located on consumers' premises has become a partial alternative to traditional grid-supplied electricity in Australia. Australians households have invested several billion dollars in such systems over the past decade.
- Rooftop solar PV combined with battery storage can save consumers money. Instead of selling excess electricity to the retailer during the day at low feed-in prices they can store the excess and avoid purchasing electricity in the evening and night at higher retail prices.
- Advances in batteries and other storage technologies are likely to make it cost-effective for increasing numbers of residential and commercial consumers to partially or even fully disconnect from the grid and operate independently, or be supplied by a micro-grid (for example, small-scale local generation and storage supporting an entire town or suburb using its own separate network).
- Digital meters, using the 'Internet of Things' and energy management software can help consumers trade, track and control their electricity usage to manage their electricity costs.

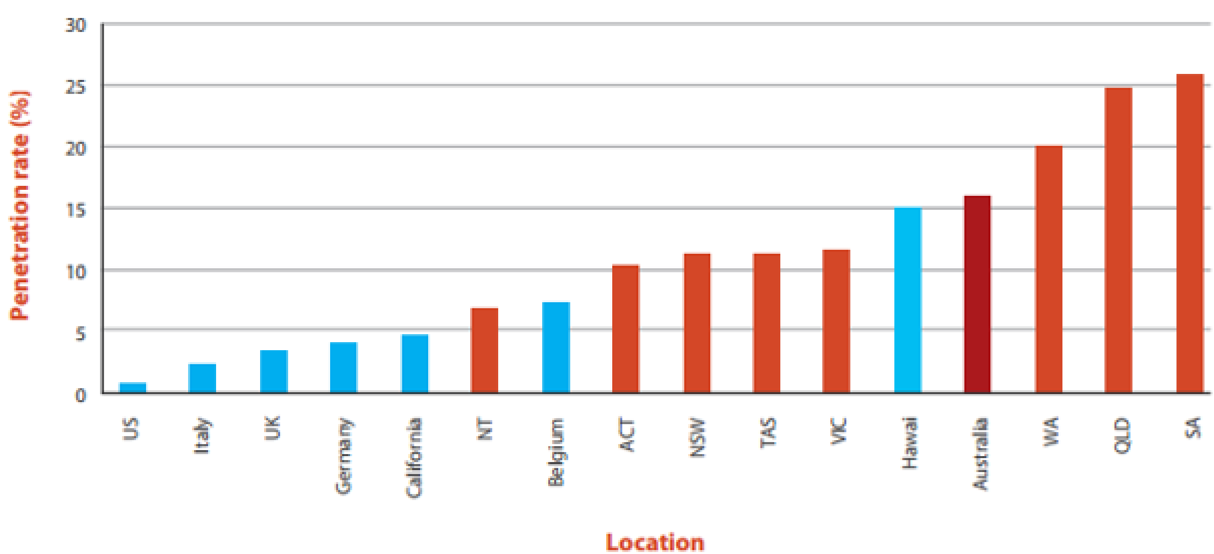

Figure 2: Rooftop PV penetration rates as a percentage of households (Department of the Environment and Energy 2016).

Residential vs. Commercial:

Residential solar PV systems are growing at 2GW this year (Department of the Environment and Energy 2016). Rooftop penetration is quite high in Australian states as shown in Figure 2. Household and commercial solar PV growth continued steadily, with many solar businesses now targeting the 30-100 kW section of the market. With power prices rising and the cost of solar technology continuing to fall the business case strengthens each year. The fastest-growing sector of the solar market is commercial systems between 75-100 kW, which helped to push up the average size of solar power systems to 5.56 kW at the end of 2016. Commercial systems between 30-100 kW are particularly popular in the ACT, New South Wales, South Australia and the Northern Territory, where they make up about 30 per cent of sales. Australia is one of the sunniest continents in the world. Given a stable policy environment, there is massive potential for solar PV to make a significant contribution to electricity generation in Australia over the coming decades. (SunWiz Consulting 2014) Figures 3 and 4 below show the expected growth in PV installations.

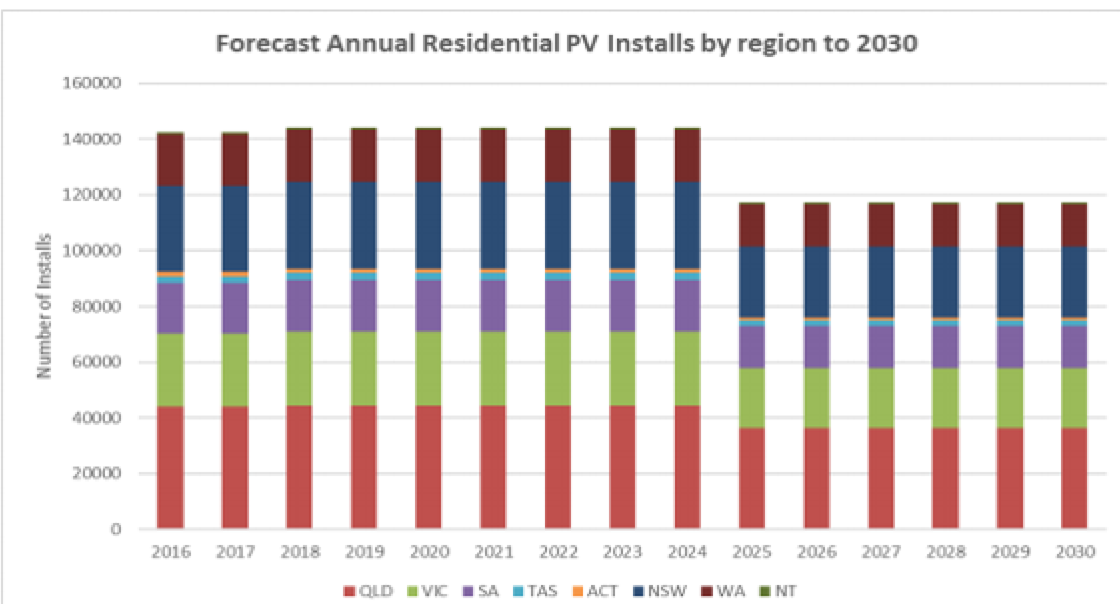

Figure 3: Forecast PV Installs by region out to 2030 (Ainscough 2016).

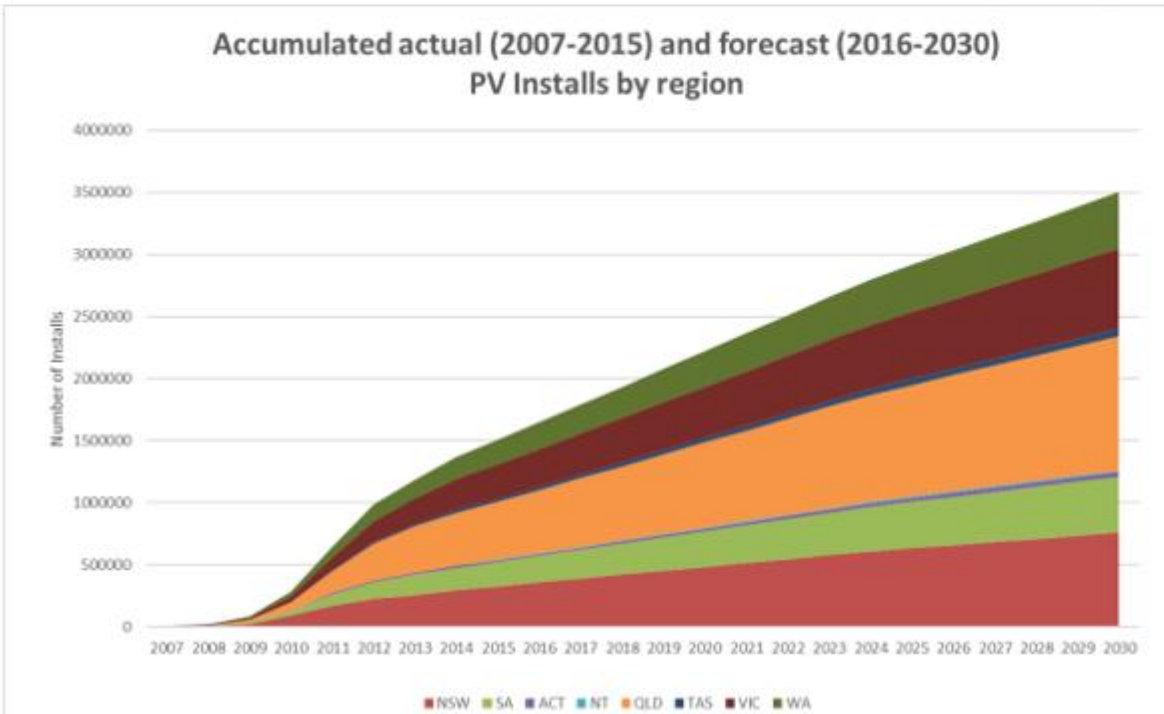

Figure 4: Forecast PV Installs by region out to 2030 (Ainscough 2016).

1.2.5 Seasonal effects in W.A. on Solar PV systems

The summer and winter resources are very good for solar PV systems. There needs to some allowance for the lower Peak Sun Hours in winter and the increased amount of electrical appliances used in winter. As this project will be looking at grid connected solar PV systems these systems will not necessarily cover the entire electricity bill of a household. There will be variance also in different parts of W.A. with some areas having even better solar resources than in Perth.

1.3 Energy Storage

Energy storage is a key area of interest in the West Australian market. There is increasing interest with the changes in the SWIS electricity grid with the coming closure of coal power plants in the south west and increasing investments in the grid leading to increasing electricity prices. Perth is currently one of the highest adaptors or residential PV. With the coming changes in the PV tariff there and the decreasing prices in batteries there is an increasing interest and growth in the battery market for residential PV systems. “A number of factors in Australia’s electricity market are now combining to produce favourable conditions for residential battery storage uptake out to 2030. These factors are: decreasing battery prices, increasing forecast grid electricity prices, the removal of state based premium feed-in tariffs and the continued willingness of Australian households to reduce their electricity costs through installing solar” (Ainscough 2016). Recent interest in storage has grown nationally with the release of the chief scientist report, by Alan Finkel, called “Independent Review into the Future Security of the National Electricity Market” which discusses battery storage systems for both residential and commercial sectors.

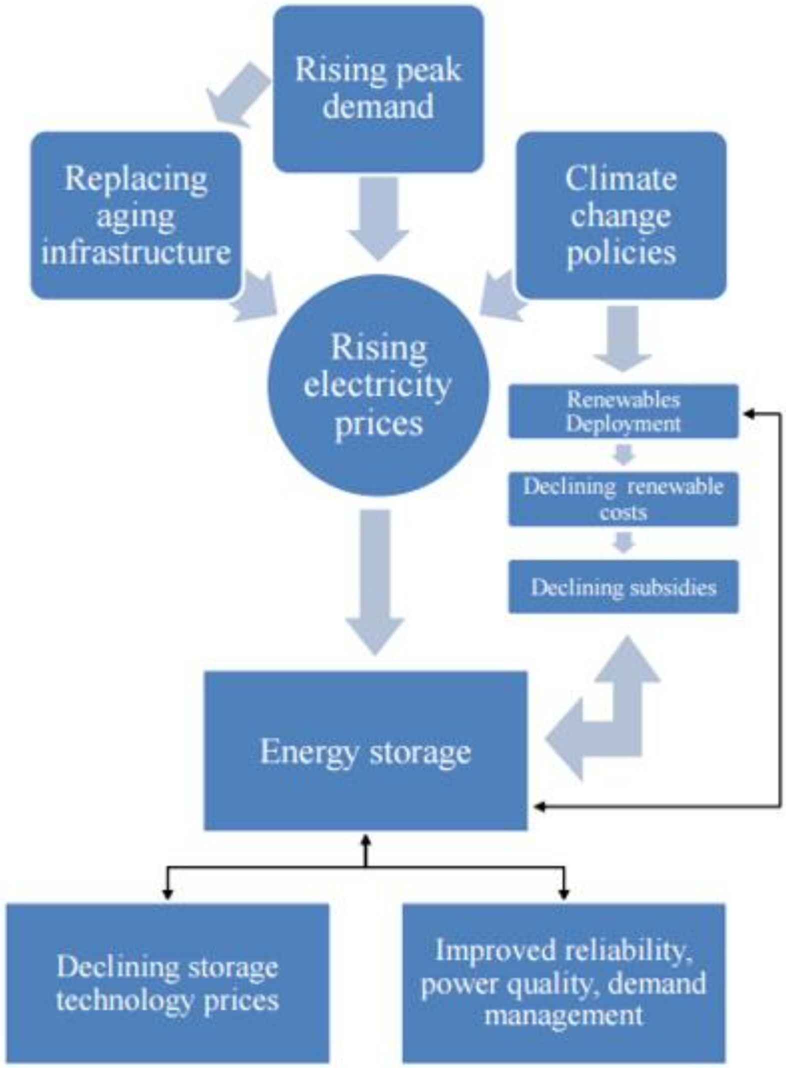

Figure 5: System drivers for energy storage (Hector 2015).

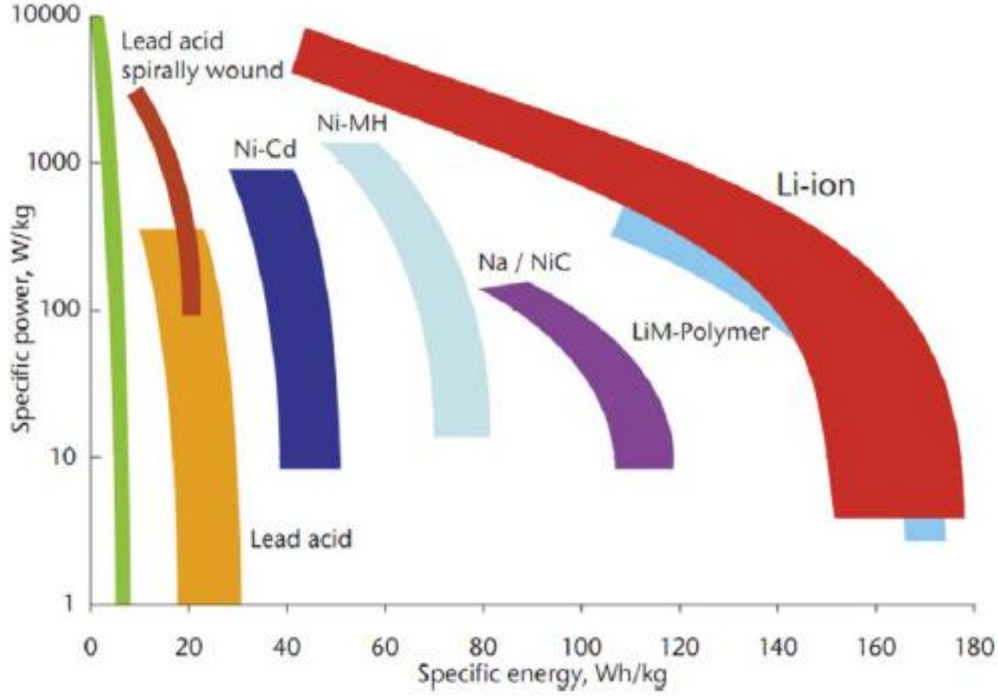

Figure 6: Schematic diagram of battery energy (IEA 2011).

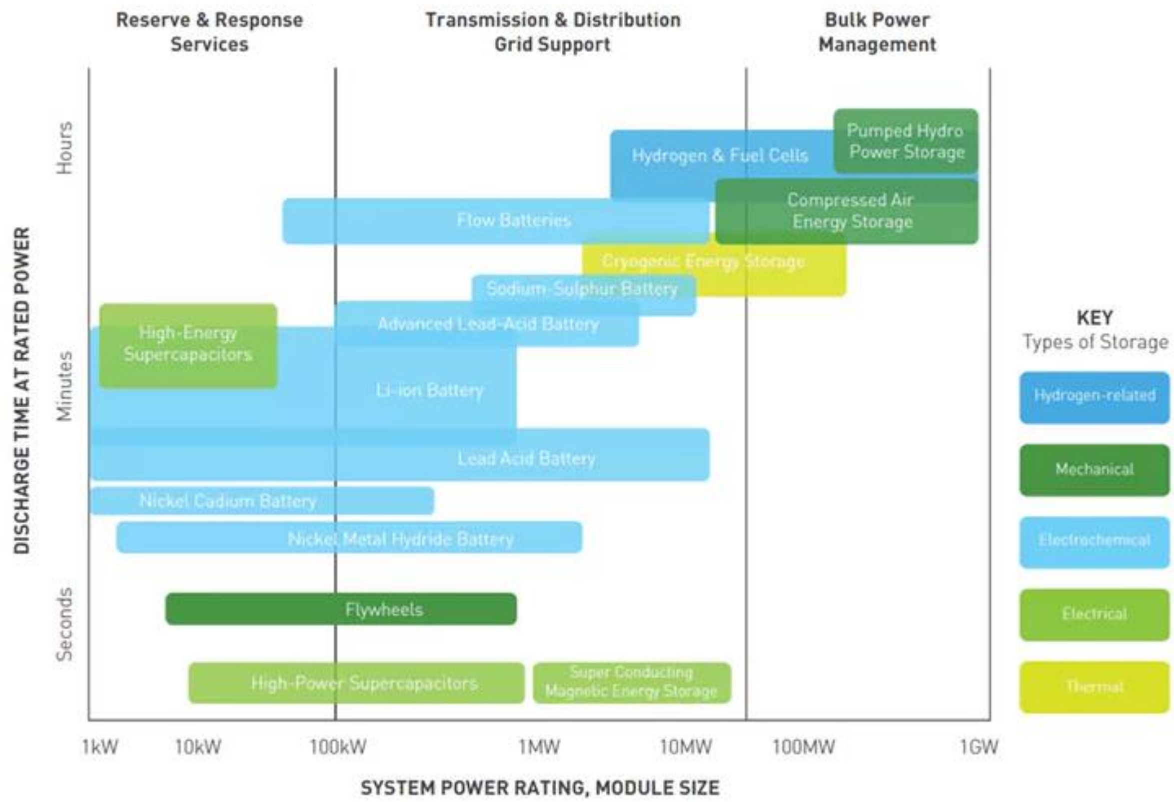

Figure 7: Storage characteristics (Dargaville 2016).

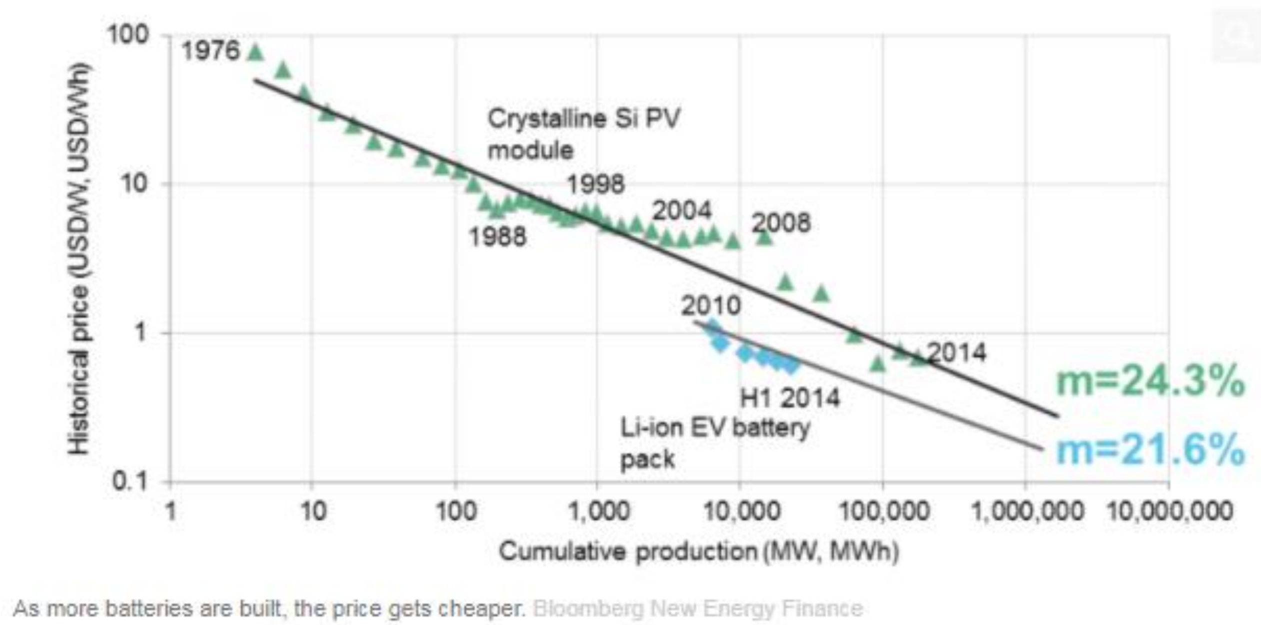

Figure 8: Historical Price (USD/Wh) of Lithium batteries vs. Cumulative production (MW, MWh) (Dargaville 2016).

(Figures 5 to 8 show the place in terms of price and characteristics of the different technologies for energy storage.)

1.3.1 Advantages and Disadvantages of Energy Storage

Advantages:

- Cost savings.
- Peak shaving.
- Smoother and more stable supply of electricity.
- Security of supply.
- Enable the usage of potentially wasted energy, increase autonomy and, therefore, improve the reliability of the energy supply for a household.

Disadvantages:

- Initial capital costs.
- Maintenance costs.
- Using the right system for the right situation.

Why choose batteries?

- Utility Load Levelling (correction of mismatch between production and consumption of electricity) as seen in Figure 9.
- For using solar and wind energies continuously and reliably.
- For emergency and backup power supply.

Advantages of Batteries:

- They store and release electrical energy directly.
- Fast response.
- Being modular, they can be used flexibly; (depend on demand).
- Easy to locate near load site.
- They are largely free of environmental problems.
- They typically have a short lead time in manufacture.

1.3.2 Battery management Systems

Energy storage requires effective battery management systems (B.M.S.) to enhance and improve energy storage solutions. Reliable load profiles, knowledge of peak loads and battery management systems that can operate in the case of interruptions are important. A B.M.S. enhances the reliability of a PV system which is important for residential customers. As mentioned in NREL 2008 reports, residential load modeling, energy modeling and project case studies are important for improving existing energy storage solutions and ensuring the best system solutions are selected. Battery attributes, size and functionality are important for residential customers as each system is designed to customer specifications and locations. Payback period is a very important factor as is reliability. Cost remains the most important factor to consumers. “Cost was unsurprisingly the most important factor in consumer decision making. However, its influence is moderated when considered in conjunction with the interaction effects of battery size and payback period” (Agnew and Dargusch 2017).

1.4 Battery Technologies

Residential customers in Western Australia wants energy storage for solar PV systems for electricity during the night, security of supply and cost savings for electricity. Security of supply and cost savings are bigger motivators in W.A. than selling electricity to the grid for profit.

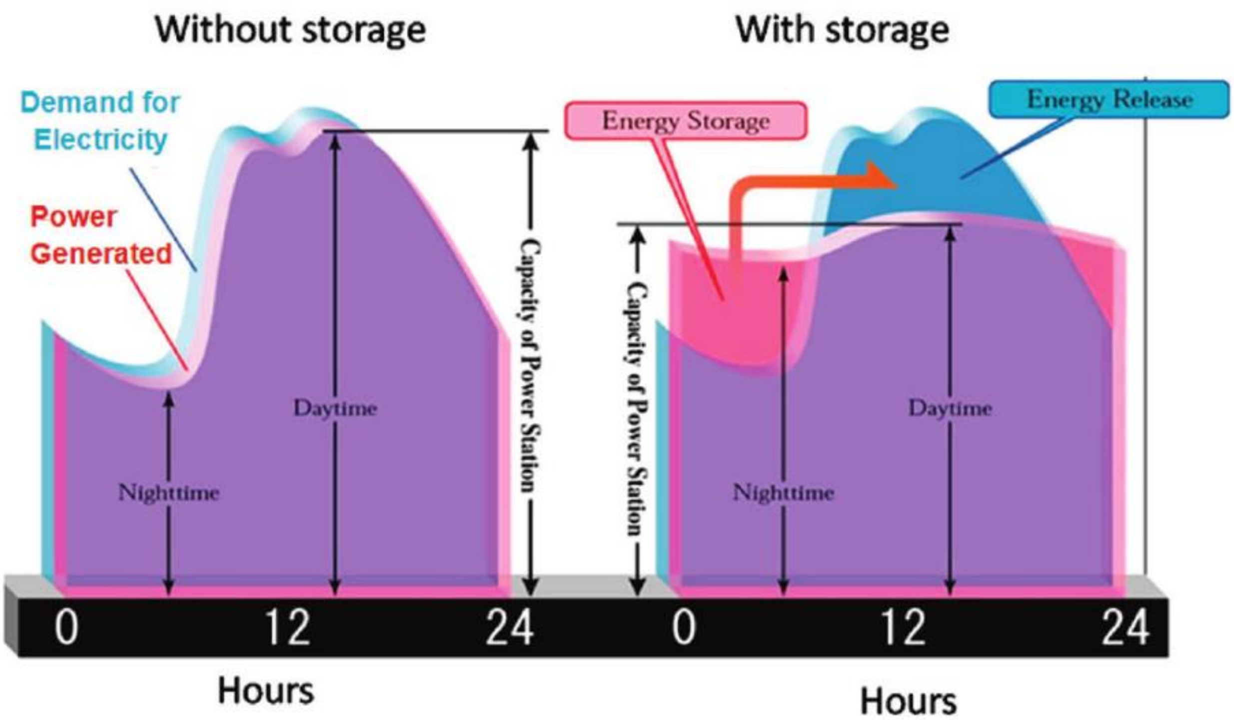

Figure 9: figure for load profile with and without storage (Sundaram 2017).

There are many other types of battery technologies available and in development. There are other growing technologies in the field such as flow batteries and various group 1 metal batteries. In this project I have chosen to focus these three types of batteries because Lithium and lead-acid batteries are leading battery technologies. The aim of this project is to compare the Ultrabattery with leading competing technologies in the field in W.A.

1.4.1 Conventional Lead Acid battery

Lead acid (Pb-A) batteries are a mature technology used for many applications including PV systems. Deep cycle lead acid batteries are used commonly in Solar PV systems and have been used successfully in PV systems in W.A. They can be easily accessed and there are a range of brands available. They are heavier batteries and in some applications compete with NI-Cd batteries. "The lead-acid battery is the oldest and most mature technology that has been used for electrical energy storage and is currently a front-runner for use in distributed generation application." (Garimella and Niraj 2009).

"Pb-A batteries were first created in the 1860's and are one of the most mature, least expensive and widely used rechargeable battery technologies in the world today. Decades of research and development have been spent on all aspects of the Pb-A battery including plate design, active material composition, electrolyte composition, separator materials, and case design" (Leadbetter and Swan 2012). Lead acid batteries remain the most widely used batteries for solar PV applications and is the most mature technology. There have been a range of improvements in its capacity and efficiency.

1.4.2 Advantages and disadvantages of Lead Acid batteries

"The defining characteristics of lead-acid batteries include relatively low cost, technological maturity, low energy density, and limited cycle life" (Leadbetter and San 2012).

Table 1: Advantages and disadvantages of lead acid batteries (Sundaram 2017).

Advantages	**Disadvantages**
They store and release energy directly.	Lead is toxic and Sulphuric acid is toxic and corrosive.
They have a fast response and good high rate performance.	Lead acid batteries are very heavy.
Good temperature performance.	They need electrolyte maintenance.
High cell voltage.	Stratification of electrolyte.
Batteries are modular and can be used flexibly depending on their demand.	Low utilisation of active materials.

Batteries are easy to locate near load sites.	Need to follow correct charge procedures.
Batteries typically have a short lead time to manufacture.	Corrosion of grids.
Mature technology.	Need to charge.
Lower cost.	Shorter cycle life.
	Limited rechargeability.

Options in the market for Deep cycle solar Lead Acid batteries in W.A.:

- Panasonic.
- Century.
- Drypower VRLA.
- Ritar VRLA.

Why use the advanced lead acid battery?

The battery is a hybrid device containing an ultracapacitor and a lead-acid battery both sealed in a single unit sharing a common electrolyte – a technology combining trusted, world-class, lead-acid batteries with fast cycling capabilities and partial charge operation to suit modern energy storage needs.

Competition for Lead Acid battery

Nickel Cadmium batteries are comparable to lead acid - they have good power density, maintenance free over a wide temperature range, long cycle life and acceptable self-discharge.

1.4.3 Lithium batteries

"Li-ion batteries are a recent technology with roots based at Bell labs in the 1960's and the first commercialization by Sony in 1990" (Leadbetter and Swan 2012). Lithium batteries are a very popular technology with a lot of research going into the battery type and many brands now available in the West Australian market. It is lighter and has a higher energy density as well as being able to operate at lower states of charge. Lithium batteries do require a BMS as they have the challenge of thermal runaway. Also there are fewer recycling options and disposing of the batteries can be expensive. As well as this they are more expensive than lead acid batteries and do not have as good payback periods as other technologies. Western Australia actually has very good Lithium resources currently being further developed by companies such as Tianqi and Talison Lithium. As there is more demand and there are more companies producing Lithium batteries the cost is expected to decrease further.

Options in the market for Lithium based technology batteries:

- SonnenBatterie.
- Tesla Powerall.
- Enphase (modular lithium-ion phosphate).
- Samsung SDI.
- Panasonic LJ-SK84A.

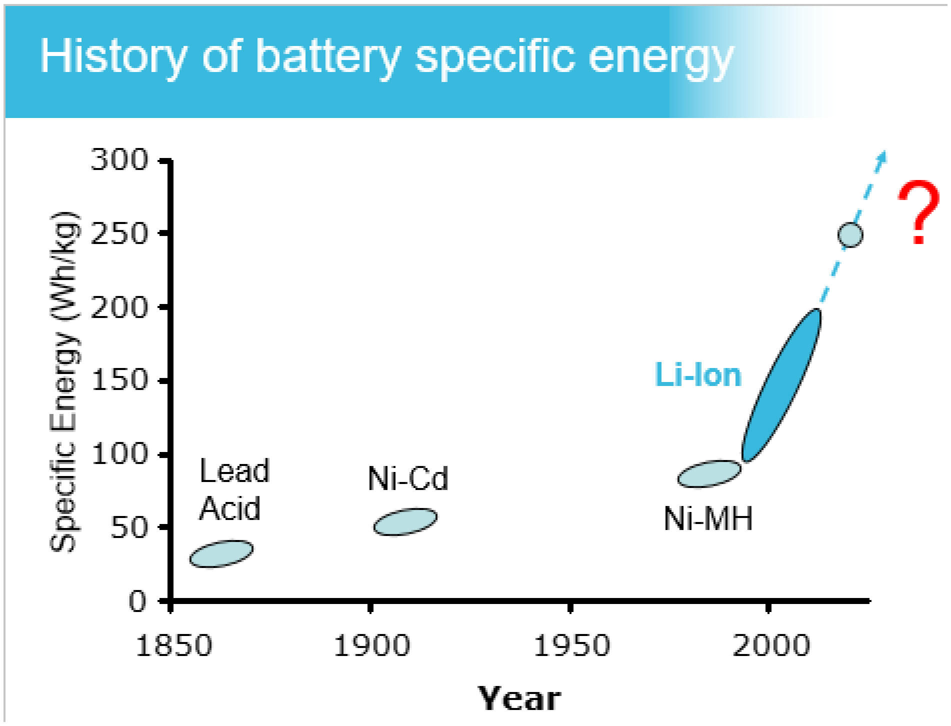

Figure 10: History of battery specific energy (Sundaram 2017).

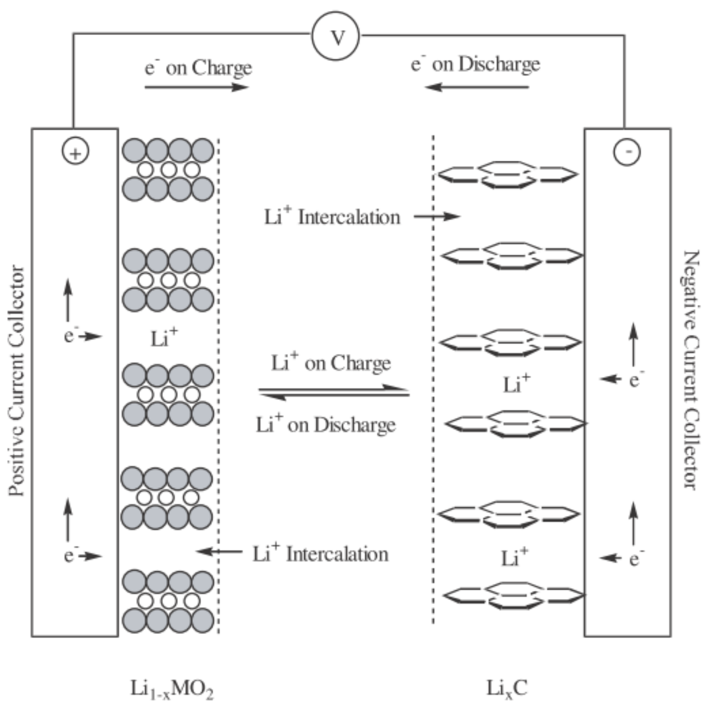

Figure 11: Schematic of the electrochemical process in a Li-ion cell (Linden and Reddy 2002).

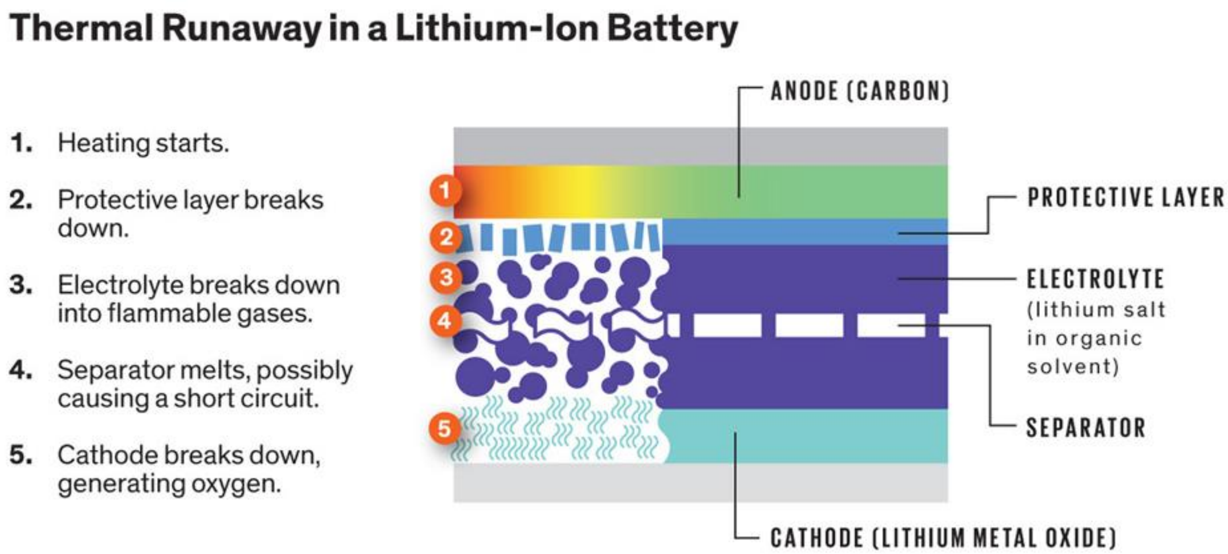

Figure 12: Thermal Runaway schematic (Sundaram 2017).

Safety issues of Li Ion Batteries

- **Safety issues**: occur if a cell exceeds the critical temperature above which the increase of temperature is irreversible due to the heat produced by the cathode, anode, and electrolyte and their interactions above the critical temperature.
- **Excessive ambient temperatures**: excessive ambient temperatures will lead to electrolyte heating, thus increasing the exothermic chemical reactions.
- **Overcharging**: All Lithium ion (Li-ion) batteries are equipped with protective circuitry to avoid overcharging, but if the protective circuitry fails, Lithium ions will build up on the graphite anode, forming a lithium dendrite. If the charging continues, the dendrite will grow until it penetrates the separator, creating a short circuit by connecting with the cobalt oxide cathode.

- Safety problems begin with flammability and electrochemical instability of (non-aqueous) electrolyte.
- Li-ion batteries die quickly if operated at 60 ^{o}C and explode at 80 ^{o}C.

1.4.4 Lithium Ion Battery Advantages and Disadvantages

Lithium ion battery advantages

There are many advantages to using a li-ion cell of battery. These li-ion battery advantages include:

High energy density: The much greater energy density is one of the chief advantages of lithium batteries. The much higher power density offered by lithium batteries is a distinct advantage over other technologies.

Self-discharge: One challenge with batteries is that they lose their charge over time. This self-discharge can be a major issue in battery usage. One advantage of lithium batteries is that their rate of self-discharge is much lower than that of other rechargeable cells such as Ni-Cad and NiMH types.

No requirement for priming: Some rechargeable batteries need to be primed when they receive their first charge. Lithium batteries don't require this.

Low maintenance: One major lithium battery advantage is that they do not require maintenance to ensure performance.

Variety of types available: There are several types of lithium battery types available. This advantage of lithium batteries can mean that the right technology can be used for the particular application needed (Poole 2017).

Lithium ion battery disadvantages

Like the use of any technology, there are some disadvantages of lithium batteries that need to be balanced against the benefits. The lithium battery disadvantages include:

Table 2: Lithium battery disadvantages (Poole 2017).

Disadvantage	Details
Protection required	Lithium batteries are not as robust as some other rechargeable technologies. They require protection from being over charged, being discharged too far and they need to have the current maintained within safe limits. One lithium battery disadvantage is that they require protection circuitry incorporated to ensure they are kept within their safe operating limits. Fortunately, with modern integrated circuit technology, this can be relatively easily incorporated into the battery or within the equipment.
Ageing	One of the major lithium ion battery disadvantages for consumer electronics is that lithium ion batteries suffer from ageing. This is time dependent and dependent upon the number of charge discharge cycles that the battery has undergone.
Transportation	Lithium batteries have certain restrictions placed on their transportation, especially by air. Lithium batteries must be protected against short circuits by protective covers.
Cost	A major lithium battery disadvantage is their higher cost. Typically, they are around 40% more costly to manufacture than similar batteries. This is a major factor when considering their use in mass produced consumer items where any additional costs are a major issue.
Immature technology	Lithium ion battery technology is a developing technology. This can be a disadvantage in terms of the fact that the technology does not remain constant. However as new lithium ion technologies are being developed and it can also be an advantage as better lithium battery solutions are coming more readily available.

1.5 Ultrabattery (Advanced Lead Acid battery)

The Ultrabattery is an advanced lead acid battery technology. It combines improved capacitor technology with a longer life battery using shallow recharge capability. The battery was invented by Dr. Lan Lam and supported through CSIRO in its development (Lam and Louey 2006). The battery is shown in Figure 13 below.

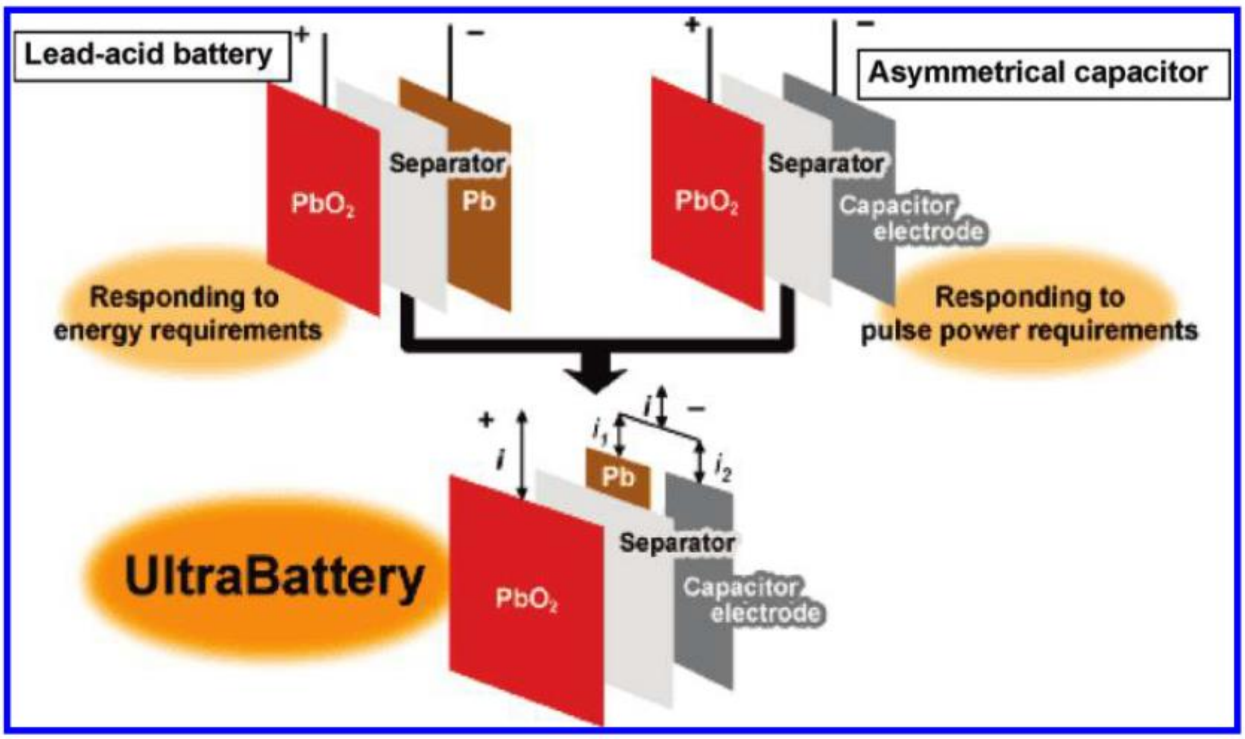

Figure 13: Diagram of the Ultrabattery (Sundaram 2017).

1.5.1 Advantages and disadvantages of the Advanced lead acid battery

Advantages include:

- The reduced cost of tower ownership for telecommunications.
- Increased generator life for remote users.
- Reduced diesel haulage and use due to energy storage.

• Increased generator efficiency due to energy storage.

• Longer battery life compared to conventional lead acid batteries.

• High temperature tolerance suitable for Australian conditions.

• Higher safety standard due to stability of the battery.

• Reduced generator maintenance.

• Reduced hours spent visiting site.

• Reduced site diesel emissions due to less diesel being needed.

• Reduced site noise levels due to less diesel generator use.

• Closed loop manufacturing for high sustainability.

• Proven renewable integration.

Disadvantages of the Advanced lead acid battery

- Expensive compared with lead acid batteries.
- Fewer suitable battery management systems for this type of battery.

Advanced lead acid battery Options in the market:

Ultrabattery

"A new lead acid battery developed by a consortium with the CSIRO is being trialed on off-grid conditions, including as storage for intermittent renewable energy. Called the Ultrabattery, it takes the 150-year-old lead-acid battery technology, like those used to start cars, and adds a super-capacitor" (McHugh 2016).

1.5.2 Why use the Ultrabattery?

Table 3: Key Benefits and Features of the Ultrabattery (Ecoult 2017).

Key Features	Benefits
Modular Design.	Flexible sizing for different power and energy requirements – good for residential requirements.
Available in a pre-installed or pre-wired for ease of use on site.	Reduced labour costs and quicker installation time.
Small footprint – uses less space – 1 m x 0.6 m.	High power for less space on site needed.
Passive thermal design – Maximized battery life by using airflow to operate within optimum temperature limits.	Suits different applications, operating environments (indoor and outdoor) and maximizes the return on investment.
Ultrabattery monitoring system.	Helps to achieve the greatest longevity and allows remote monitoring.
Over-current Protection - Protects the system from high currents and faults.	A safety feature and helps the longevity of the system. It helps the battery operate within performance limits.

Competition for the Ultrabattery

Competition is based on cost and application. The other batteries discussed as the main competitors were considered.

1.5.3 Comparison between the Ultrabattery and the lead- acid battery

"Examination of the UltraBattery against its conventional counterpart revealed improvements in performance using the conventional tests, mainly related to Ah capacity and overall internal impedance" (Fairweather, Stone and Foster 2013).

Case studies of the Ultrabattery:

- Remote telecoms base station (N.S.W., Australia).
- Small commercial peak shaving and solar self-consumption (N.S.W., Australia).
- Health Retreat (N.S.W., Australia).
- PNM 'Prosperity' Project (New Mexico, United States).

- Hampton Wind Farm (N.S.W., Australia).
- Ecoult Grid Energy Storage and PJM Interconnection (Pennsylvania, United States).

(Ecoult 2016).

1.5.4 Advantages and disadvantages of battery technologies for residential applications

Table 4: Advantages and disadvantages of lead acid batteries, Lithium batteries and the Ultrabattery (A. A. Franco 2015; Mckeon, Furukawa and Fenstermacher 2014; Energy Networks Australia 2017; Summer et al. 2012).

	Lead Acid batteries	**Lithium batteries**	**hybrid/advanced lead acid (Ultrabattery)**
Advantages	• Cheapest technology. • Mature technology. • Has been used successfully in residential PV systems the longest. • Lead acid batteries can last up to 15 years with 70-75% discharge rate.	• Highest energy density. • High efficiency (nearly 100%). • Relatively long cycle life. • Widespread use and good performance. • Lower weight. • Longer cycle life. • Maintains its voltage throughout the entire discharge cycle. • No maintenance. • High rate and high power discharge rate. • High coulombic efficiency.	• Combines the benefits of a capacitor and a battery. • Charged much faster than conventional lead-acid batteries. • Most of the benefits of lead-acid batteries. • The Ultrabattery is cheaper than Tesla batteries. • The Ultrabattery has more cyclability than the other two batteries.
Disadvantages	• Short cycle life. • Limited rechargeability.	• Not adequate for many applications. • High cost. • Need special packaging, internal overcharge protection circuits. • Thermal runaway, safety issues with fire.	• Higher cost compared with conventional lead acid batteries.

		• Degrades at high temperature. • Tesla has a 12 year payback which is longer than its current warranty.	

1.5.5 Table of typical values for comparison of the three types of batteries

Table 5: Typical values for comparison of the three types of batteries Lead acid, lithium and hybrid/advanced lead acid batteries (A. A. Franco 2015; Mckeon, Furukawa and Fenstermacher 2014; Energy Networks Australia 2017; Summer et al. 2012).

Typical values	Lead acid battery (flooded, AGM or Gel)	Lithium batteries	Hybrid/Advanced lead acid (Ultrabattery)
Energy Density	90-160 Wh/kg	130-200 Wh/kg	3 to 4 times conventional lead acid batteries.
Cost	$100-300 /kWh	$400-600 /kWh	CSIRO, claims “The UltraBattery is about 70 per cent cheaper to make than batteries with comparable performance and can be made using existing manufacturing facilities”
Cycle Life	800-5600	1200 - 2600	UltraBattery will last about three to four times longer than a conventional VRLA battery.
Specific Energy	180 Wh/kg	100-265 Wh/kg	80 Wh/kg
Charge/discharge efficiency	50–95%	80-90%	DC–DC efficiency of 93–95%
Lifecycle	10-20 years	2-7 years	UltraBattery will last about three to four times longer than a conventional VRLA battery.
storage temperature	25°C	-40-50°C	25°C

1.6 Software Used

1.6.1 What is HOMER

HOMER (Hybrid Optimization Model for Electric Renewables) software is a software that simulates micro power systems to find the lowest Net Present Cost (N.P.C.) combinations. In this project it will be used for residential area PV with battery systems. HOMER is a micro-grid software that does optimization and sensitivity analysis on renewable energy systems. HOMER can also model a power systems physical behavior and life cycle cost (capital cost, replacement installation and maintenance) to look at performance and cost parameters to aid in making decisions in selecting systems. It can carry out a quick feasibility study and can simulate different system configurations top generate a list of feasible solutions based on lowest NPC. HOMER has access to NASA databases for solar resources data and the ability to input battery data for simulation.

How HOMER works

HOMER is a micro-grid software by HOMER Energy that optimizes micro-grid design. It uses three tools in one software product that does engineering and economics functions: sensitivity analysis, simulation and optimization. It also can be customized with up to 9 individual models for modeling needs (HOMER Energy 2015).

1.6.2 What is SAM

SAM (System Advisor Model) is software that analyses performance and is also a financial model. It will make performance predictions and cost of energy estimates based on costs and design parameters that are specified as inputs. It can simulate grid connected PV and battery systems as well as financing options. SAM has access to the NREL databases and can include more financial input data. It has been used in a previous study for the W.A. as well, “NREL's (National Renewable Energy Laboratory) modelling software, System Advisor Model (SAM), was used to determine energy production for rooftop and 1-axis tracking of PV.” (Lu, Blakers and Stocks 2017) SAM has also had changes to the PV with battery storage model and case studies of economic analysis of battery energy which will prove helpful.

How SAM works

"SAM makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model. Projects can be either on the customer side of the utility meter, buying and selling electricity at retail rates, or on the utility side of the meter, selling electricity at a price negotiated through a power purchase agreement (PPA)" (National Renewable Energy Labs 2010).

How software will help

The software will help simulate various combinations currently used in W.A. and the three battery types in practice and compare costs. There is currently available literature using these software packages to model similar systems in other parts of the world. These papers will help in creating these software simulations as well as the software case studies available on the respective websites. The software will help to simulate all the combinations will be looking at using real life costs and allow us to look at optimal solutions for feasibility.

Why software will be used

Software will be used to calculate the energy generated money that would be saved and payback periods. It can also include any current rebates and use W.A. conditions for the simulations. The software will also help to analyse the current feasibility of the three battery energy storage solutions.

System inputs

SAM

SAM System Inputs:

- Weather Data
- Financial and economic inputs
- Incentives
- System performance
- Costs

HOMER

HOMER System Inputs:

- Load details
- Component details
- Resource details
- Sensitivity variables

1.6.3 Modeling batteries (Lithium and Advanced lead acid batteries)

1.6.4 SAM modeling batteries

SAM is able to model residential systems with lead acid and lithium ion battery chemistries. SAM is able to model system lifetime analysis (including battery replacement costs), it models terminal voltage, capacity and temperature and can model dispatch controllers as well (DiOrio 2015).

A study in modeling Lithium ion batteries in SAM models a Tesla Powerwall in the following way:

- Lithium-ion nickel manganese cobalt.
- An assumed cycle full 6.4 kWh down to 20% of state-of-charge over 10-year warranty.
- Assume the battery degrades ~20% over 10 years.
- Full installed capacity is then: 6.4 kWh/ 0.8/ 0.8 = 10kWh

(DiOrio 2015).

Modeling the batteries in SAM can be done with a PV and battery model which has been made available. Case studies have been made using lithium batteries with assumptions to model these batteries in the SAM software.

1.6.5 HOMER modeling batteries

In the paper Micro power system modeling with HOMER as stated by Lambert, Gilman and Lilienthal, "HOMER models a single battery as a device capable of storing a certain amount of dc electricity at a fixed round-trip energy efficiency, with limits as to how quickly it can be charged or discharged, how deeply it can be discharged without causing damage, and how much energy can cycle through it before it needs replacement." Assumptions have been made and simplifications based on battery behaviour and user behaviour for modelling purposes. "Concerns arising due to the variability and intermittency of renewable energy sources while integrating with the power grid can be mitigated to an extent by incorporating a storage element within the renewable energy harnessing system. Thus, battery energy storage systems (BESS) are likely to have a significant impact in the small-scale integration of renewable energy sources into commercial building and residential dwelling." (Garimella and Niraj 2009). All of the batteries modeled will rely on BESS and will most likely continue to be in use as it is more convenient and leads to better system results.

"Optimisation and sensitivity analysis algorithms used by HOMER allow for evaluation of economic and technical feasibility of technology options and account for uncertainty in technology costs, energy resource availability and other variables" (Garimella and Niraj 2009). HOMER has been used already in many studies of battery system behaviour with results that are comparable to real life systems in addition it is suited for economic analysis. "HOMER can model a single battery or an entire bank of batteries, which HOMER treats as a DC storage device." (Lithium ion battery modeling in HOMER paper (Alexis 2012)). "The system designer is able to select the number and size of the batteries that HOMER is to consider in its system analysis. If the user is unable to find a suitable battery in the library, HOMER does have the option of allowing the user to create a battery, and select the way that battery is modelled" (Alexis 2012). The size of the batteries could be used from previous studies into the West Australian market with current and predicted trends for costs. "Currently, there are two models that HOMER uses in its calculations, the KBM and the simple battery model. The KBM is much more robust and detailed than the simple battery model" (Alexis 2012). From the literature the KBM model could be used for battery usage and the simplified model for economics.

Load and Resource inputs

For this project the load and resource inputs will be based on data from Perth and costs from current systems used in Australia. Sizes to be considered for PV will in include 5 and 6.5 kW. Using the below simulation graph as a guide for sizes and retrofits from Ainscough's 2016 paper the simulation looked at 5kW and 4kW with retrofits.

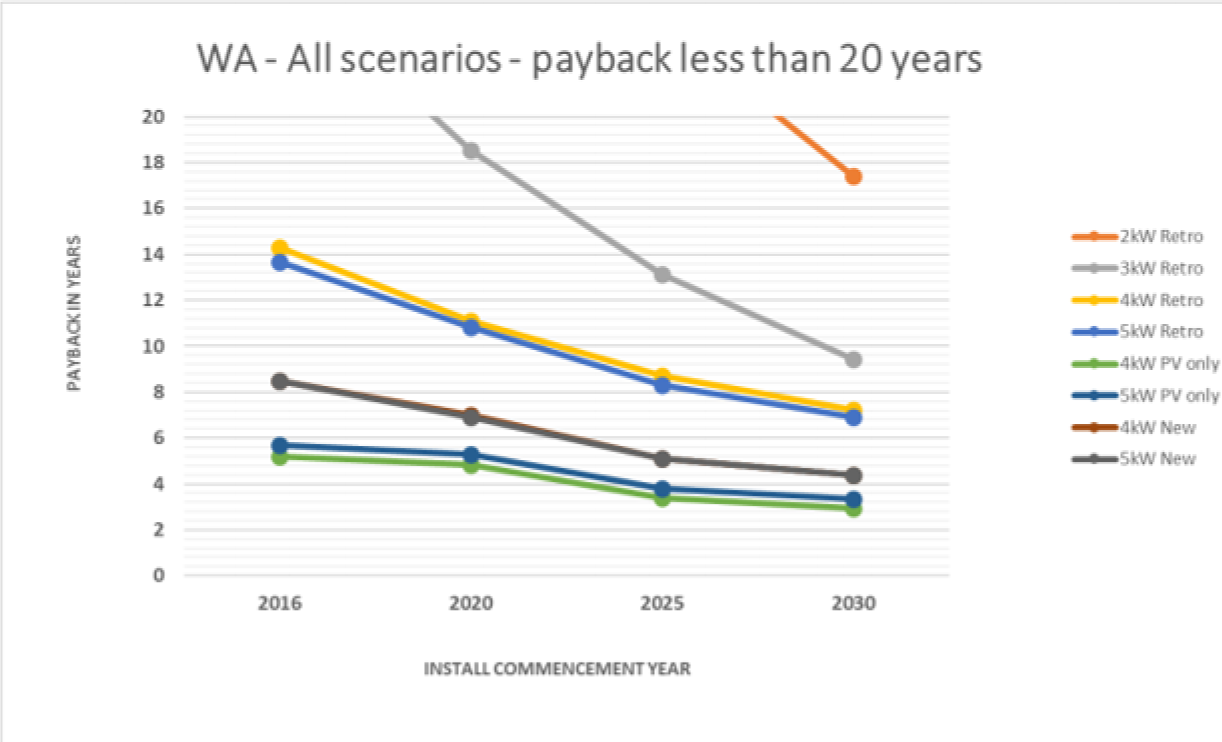

Figure 14: Paybacks for W.A. scenarios limited to 20 years' payback. (Ainscough 2016).

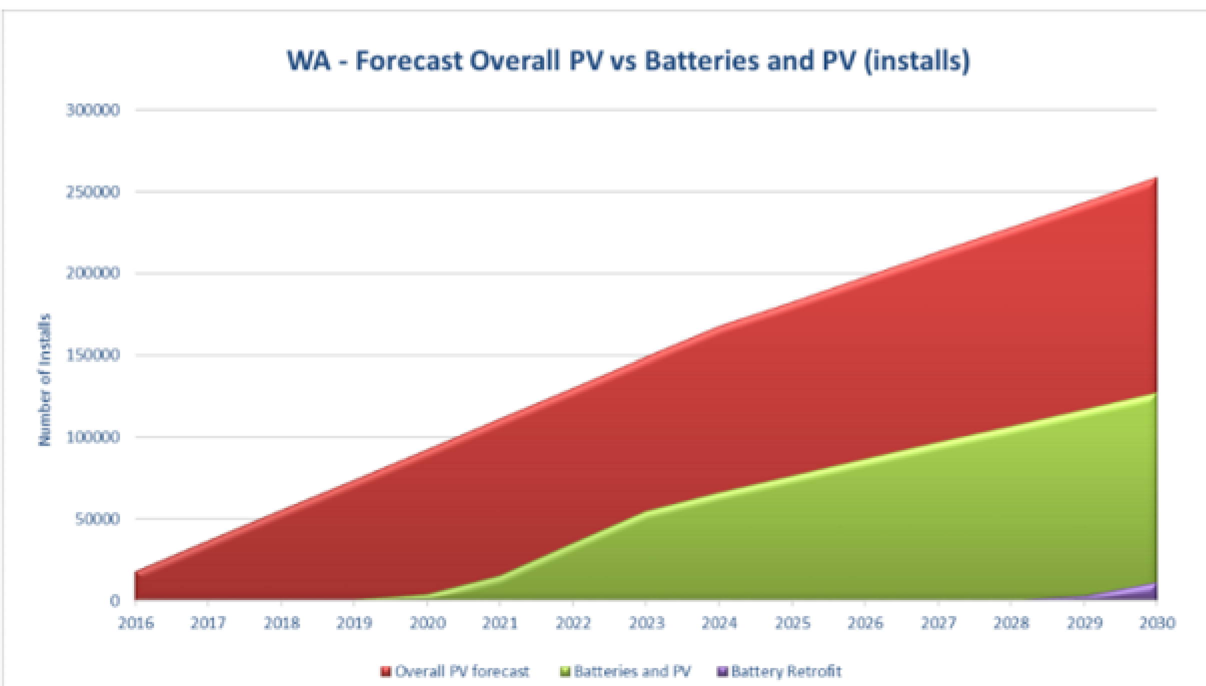

Figure 15: W.A. – forecast PV and battery vs overall PV installs (Ainscough 2016).

From Figures 14 and 15, we can see the rise in expected W.A. PV and battery installs and the decreasing payback for PV systems and retrofits of batteries to these systems especially as the size of system increases.

1.6.6 Advantages and disadvantages of using the different software packages

In Table 6 below is detailed further information of the software packages relevant for modelling these scenarios that were considered.

Table 6: Advantages and disadvantages of SAM and HOMER (Okedu and Uhunmwangho 2014; Tozzi and Ho Jo 2017).

	SAM	HOMER
Advantages	• Can produce P50/90 reports, stochastic and parametric calculations. • Can choose different physical models. • Can choose different ways to simulate for optimal outcomes other than lowest NPC. • Uses the NREL databases. • Simpler battery models.	• HOMER can input new equipment into the database. • HOMER can input weather data manually. • The program can simulate hybrid systems. • Simulates a list of real technologies, as a catalogue of available technologies and components. • Very detailed results for analysis and evaluation. • Determines the possible combinations of a list of different technologies and its size. • It is fast to run many combinations. • Results could be helpful to learn a system configuration and optimization.
Disadvantages	• Fixed equipment databases. • Simulations can take a longer time for comparable results. • Harder to input details for newer battery models.	• The program sorts systems by NPV only – it cannot sort by multi criteria analysis. • Homer cannot do stochastic or P90, P50 calculations.

	SAM	**HOMER**
		• Quality input data needed (sources). • Detailed input data (and time) needed. • An experienced criterion is needed to converge to the good solutions. • HOMER will not guess key values or sizes if there are missed. • Could be time consuming and onerous.

1.7 Updated technology and the effect of the current market

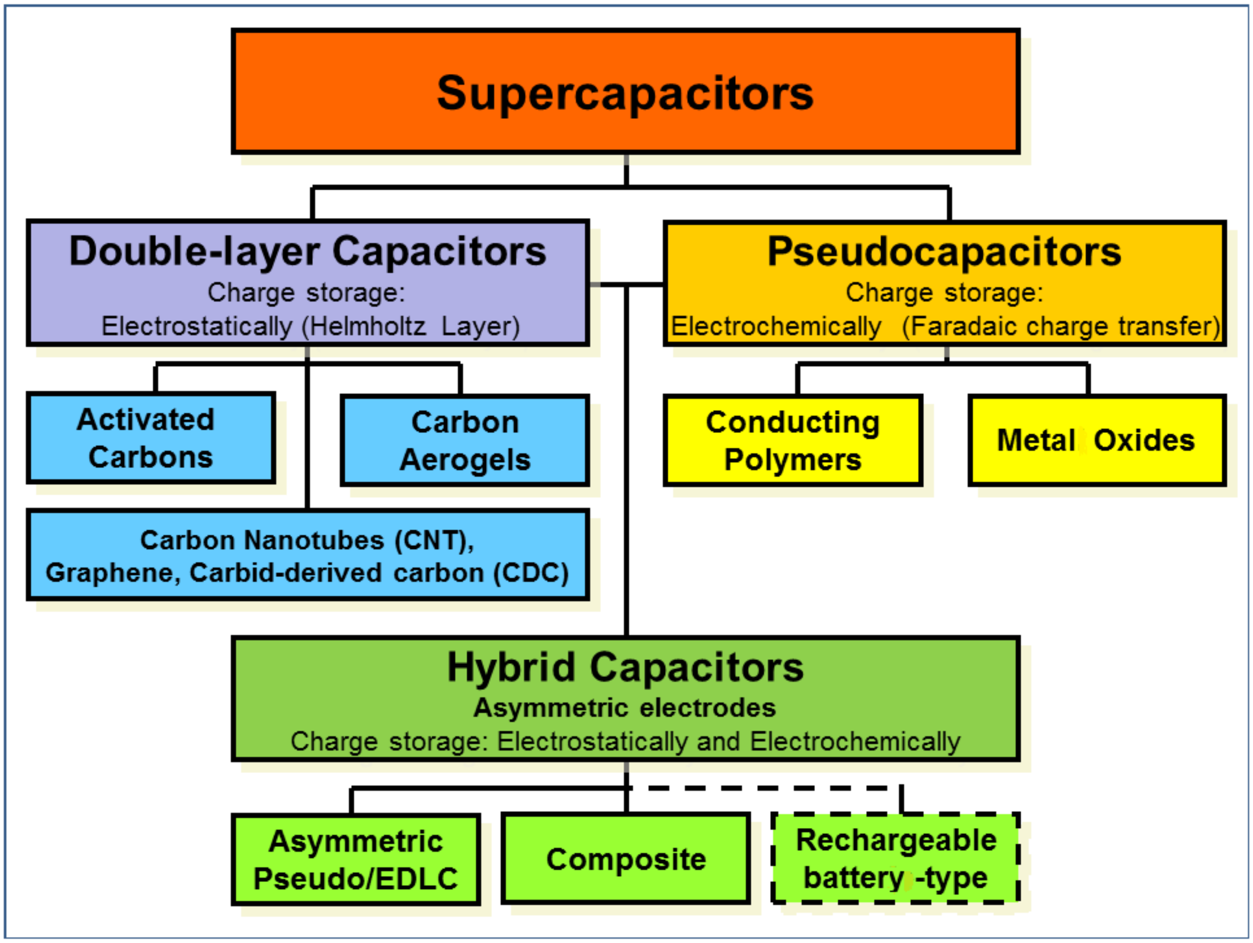

Figure 16: Schematic of supercapacitors and hybrid rechargeable batteries (Sundaram 2017).

New Battery Technology

"Public investment in energy storage research and development has led to significant cost reductions. However, additional efforts (e.g. targeted research and development investments and demonstration projects) are needed to further decrease energy storage costs and accelerate development" (IEA 2014).

New battery markets and uses

Grid storage, residential micro-grids, powering electric and hybrid cars are all possible growth factors for solar PV and energy storage systems. As the Solar and storage trial at Alkimos Beach residential development website states “This project involves developing, deploying and testing the commercial feasibility of a new energy retail model. It will combine community scale battery storage, high penetration rooftop solar PV and energy management within a new residential development at Alkimos Beach, Western Australia” (Australian Renewable Energy Agency 2015).

Decentralised Energy Exchange (deX)

There are moves within the local power utility to consider energy exchanges for retail residential electricity. These may increase the growth of community owned solar systems which can then trade electrons on such systems. These systems have been made possible with the increasing integration of the Internet of Things (IoT) and new software which allows such an exchange to exist as well as new regulation on such exchanges. “deX is a prototype online marketplace that will provide a way for households and businesses with rooftop solar and battery storage systems to be paid for allowing electricity network businesses to access their rooftop solar and stored electricity to strengthen the grid” (Australian Renewable Energy Agency 2017).

Electric cars and solar photovoltaics systems with energy storage

Following trends with all major car manufacturers and companies such as Tesla and Volvo there is an increase in both hybrid and electric vehicles which will be within the cost range of a greater majority of residential customers. There are currently companies in W.A. that provide home charging systems which are integrated with solar PV battery systems. Whether these systems become more popular and add to the growth of solar PV with battery storage in W.A. will be seen in the coming years.

Power Purchasing Agreements

Power purchasing agreements with PV and battery storage in W.A. are being trialed following examples from the USA and Europe. How to model Power purchasing agreements in SAM and HOMER – both have the option to do this and this may help to reduce the costs of PV/battery systems. In the present and future power trading programs using block train transactions are becoming more popular. As the Power Ledger website explains: “Our technology enables the sale of surplus renewable energy generated at residential and commercial developments (including multi-unit/multi-tenanted) and at homes and businesses connected to existing electricity distribution networks, or within micro-grids” (Power Ledger 2016).

1.8 Conclusion

In conclusion from the literature the gaps appear to be with the new hybrid lead-acid batteries and their use in residential solar PV with energy storage systems in W.A. Modeling for these systems have yet to be done in SAM or HOMER from the available literature so this project will examine this. In this project the software can cover this gap in in terms of the limits in the research by modeling in SAM and/or HOMER Ultrabatteries in comparison with the two leading technologies (Conventional Lead-acid and Lithium Ion batteries). SAM and HOMER both have the capability to model these systems and newer battery models are also being implemented.

The research suggests the project use an existing methodology for modeling such batteries which inputting existing data bases and using researcher’s techniques as a guide to approximate these batteries. For this project the project will restrict the terms to these limits in order to focus the research and look at the technical and economic aspects in real residential terms. In W.A. currently there is growth and interest in the solar PV field and a growing uptake of energy storage with such systems. With the current existing societal (acceptance of Solar PV and growth of energy storage) and environmental factors (good solar resources) it appears this would be a good area of further developed research. Existing software can be used to help model the economic and technical aspects of these batteries effectively to give consumers and retailers better information with which to make better decisions. It still remains with the consumer what needs they will have for their residential systems and the wider society trends that this technology may be influenced by. In fact, energy providers such as AGL have "plans to have 1,000 smart, connected energy storage devices installed at homes and small businesses in Adelaide. Less than six months into the trial more than half the systems have been sold and a substantial fraction of these are already installed and operational" (Department of the Environment and Energy 2016).

2.0 Research Design and Methodology

For this project several computer modelling papers on SAM (System Advisor Model) and HOMER were reviewed to use as a guide for methodology. Similar studies have been carried out with newer versions of the software that allow for more diverse battery technologies to be modelled with assumptions in the software. Sources of data for the project was an important aspect.

2.1 Research Design

Research Questions

1. Is the UltraBattery suitable for residential applications in W.A?
2. What are the benefits of this technology compared with Li Ion and conventional lead acid batteries?
3. What can be found through computer modelling of the economic and cost benefit of the Ultrabattery compared with Li Ion and conventional lead acid batteries?

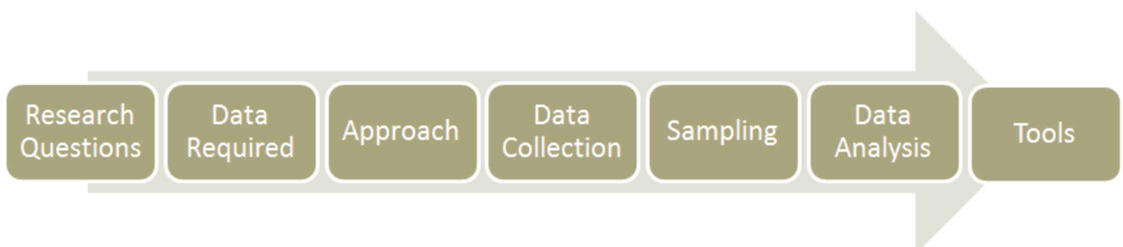

Figure 1: Research Design

For this project the project will look at the research questions, the tools and the data required for answering the research questions. Our approach will be to use a modelling approach as suggested by Bahramara, Moghaddam and Haghifam 2016. The data will be collected from quotes and readily available data from papers on modelling in the Australian context using SAM and HOMER as well as NASA and NREL databases. The results will be analyzed using these tools and the results will be explained, analyzed and discussed in context.

Methods

The purpose of this project is to provide one Solar Home System (SHS) solution using Ultrabattery batteries for Western Australian residential applications to cover the power needs for residents and compare this with other system technologies in similar situations. Thereby a clear understanding of the techno-economic aspects of this solution within the time scope will be provided. The project will include a literature survey, modelling the costs and understanding the cost benefits from this information. The following method is to achieve the mentioned objectives:

1. The state of the art of the Ultrabattery (lead acid hybrid battery) and comparison systems will be summarised with a special emphasis on the technological transitions and potentials based on previous literature (Malhotra 2016).

2. Modelling inputs for the Solar Home Systems (SHS) components to be analysed and compared will be found and provided.

3. The modelling and optimisation of the SHS in the presence and absence of batteries is performed for different reference technologies (Linssen, Stenzel and Fleer 2015; Lahnaoui, Stenzel and Linssen 2017).

4. The results for the different systems economic feasibility within the Western Australian context are developed.

5. Useful conclusions from the proposed SHS techno-economic and cost benefit analysis.

2.2 Aim and Objectives

My research objective is to create further knowledge on the applications of Ultrabatteries for residential PV systems in W.A. compared with two other popular energy storage technologies (Lead acid and Lithium batteries). My objectives for this project are to increase knowledge and understanding in this field to prevent blackouts and brownouts by showing the potential of batteries, develop the battery storage industry further and increase knowledge available more publicly for these technologies.

2.3 Data Required

Data was provided by the programme, from quotes, company and scientific literature. Refer to the Appendix.

2.4 Modelling Approach

The modelling approach was based on papers and the literature of NREL (developers of the SAM programme) and HOMER the website.

2.5 Modelling Inputs - data

Both programs require sources of data for modelling. This project will gather this data from databases, quotes and papers. For the quote data three solar retailers were chosen and for load data the author's own data and data from papers as explained in the literature review were used. (Refer to the Appendix.)

System inputs SAM

SAM System Inputs included:

- Weather Data – use program data.
- Financial and economic inputs – available as preset.
- Incentives – estimated using calculation.
- System performance – was modelled using quote data.
- Costs – estimated from quotes directly.

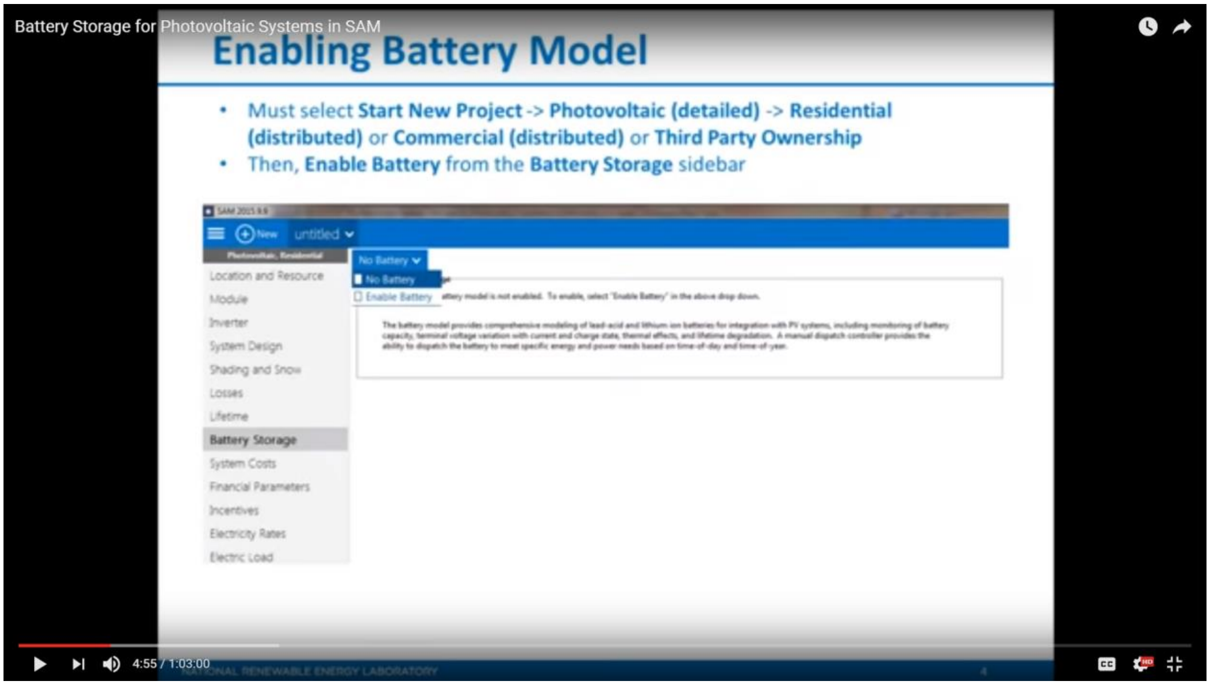

Figure 2: SAM Steps for enabling the battery model (DiOrio 2015).

For the data for SAM I followed the steps in Figure 1 and the video shown in figure 2 using already available data for Perth from the SAM program. The idea was to look at payback periods and compare the battery technologies.

HOMER

System Inputs included:

- HOMER System Inputs.
- Load details.
- Component details.
- Resource details.
- Sensitivity variables.

2.6 Approach - Research Methodology

2.6.1 Steps in Modelling

Modeling a PV-Battery System in SAM:

- SAM and battery modelling capabilities.
- Designing a battery system.
- Downloading applicable electricity rate data.
- Programming the dispatch strategy.
- Optimal sizing approach.
- Viewing and interpreting results.

HOMER

1. Inputs Data.
2. Simulation and Optimization.
3. Sensitivity analysis.
4. Uncertain parameters.

2.6.2 Dispatch Storage Strategy for Battery use

The dispatch strategy for a battery system determines its charging and discharging parameters as well as it use throughout the day. The dispatch strategy for battery use is important to model for all of the batteries concerned. I will use papers created by the creators of the SAM and HOMER programmes as the well as some other similar studies as a guide for what dispatch strategy to use.

2.7 Modeling Inputs Values

Residential areas considered and resource data sources:

The project will consider the Perth residential area as this is a growth area. These are more heavily populated areas with growing populations and represent northern and southern population areas. W.A. does have a larger area to consider; however, the project will not consider the northern areas or more country areas. Data sources will come from the local Perth BOM, NREL and NASA databases. This will be based mainly on the data available to SAM and HOMER.

SAM

2.7.1 SAM Lead Acid Performance Models:

- Capacity Model.
- Parameter determination
- Charge Transfer.

2.7.2 SAM Lithium-ion Performance Models:

- Default Chemistries.
- Capacity Model.

Lithium Ion Battery System

- Model battery similar to Tesla Powerwall
  - Lithium-ion nickel manganese cobalt
  - Assumed can cycle full 6.4 kWh down to 20% of state-of-charge over 10 year warranty.
  - Assume battery degrades ~20% over 10 years.
  - Full installed capacity is then: 6.4 kWh / 0.8 / 0.8 = 10 kWh

Property	Value
Capacity	6.4 kWh (100% DoD)
Power	3.3 kW
Efficiency	92%
Voltage	350 – 450 V
Current	9.8 A
Weight	97 kg
Dimensions	1300 mm x 860 mm x 180 mm
Warranty	10 years

Image from teslamotors.com/powerwall

Figure 3: Lithium Ion battery model in SAM Assumptions (DiOrio, Dobos and Janzou 2015).

2.7.3 SAM Ultrabattery Performance Model

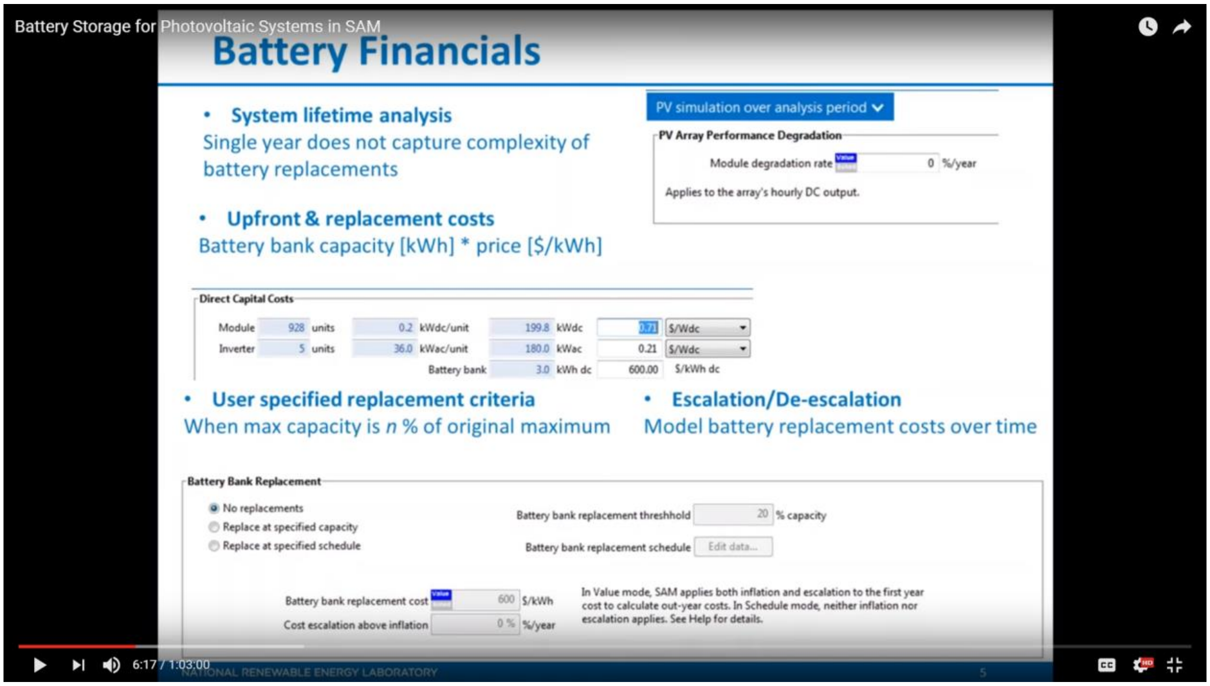

Figure 4: SAM Battery financials model (DiOrio, Dobos and Janzou 2015).

The main data for the simulation was filled as needed and following steps from DiOrio, Dobos and Janzou 2015 and are included in the Appendix. Battery Bank Replacement was estimated at 7 years. For user specified replacement criteria no cost of removal was estimated.

HOMER Values and Inputs included:

- Capacity.
- SOC (State of Charge).
- Cycles.

Modeling was based on a standard LG Chem Lithium battery, a model lead acid battery and a model for an Ultrabattery based on the lead acid model provided with cost and operation modifications. The values in Figure 3 below were either estimated, taken from the program or from the battery specifications.

Nominal capacity (Ah)
Nominal voltage (V)
Round trip efficiency (%)
Min. state of charge (%)
Float life (yrs)
Max. charge rate (A/Ah)
Max. charge current (A)
Lifetime throughput (kWh)
Suggested value (kWh)

Capacity curve

Current (A)	Capacity (Ah)

Lifetime curve

Depth of Discharge (%)	Cycles to Failure

Figure 5: Battery inputs (HOMER Program).

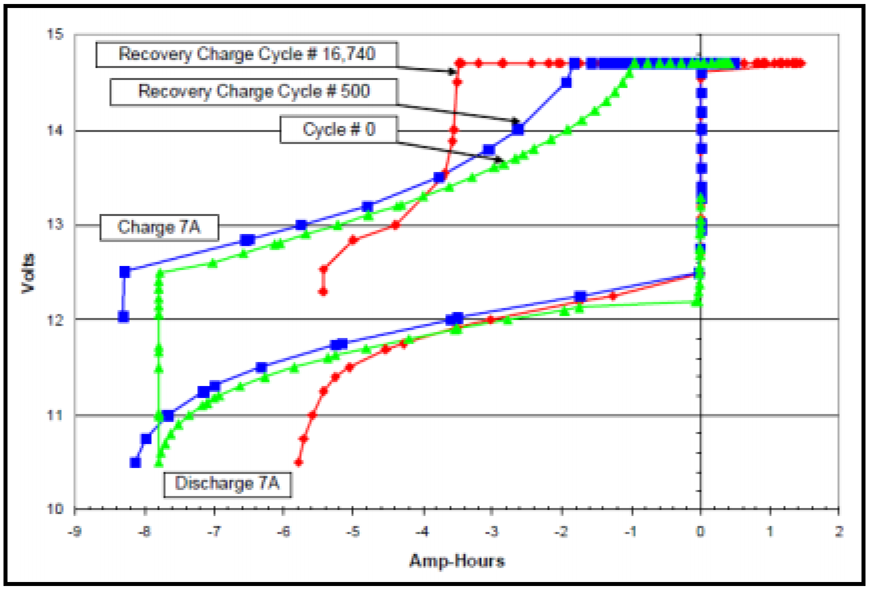

Figure 6 : Ultrabattery capacity curve at 0,500 and 16,740 HRPSoC (High Rate Partial State of Charge) Utility Cycles (Mathews 2015).

Values for the charge cycles were taken from graphs such as Figure 4 or based on existing customer usage data.

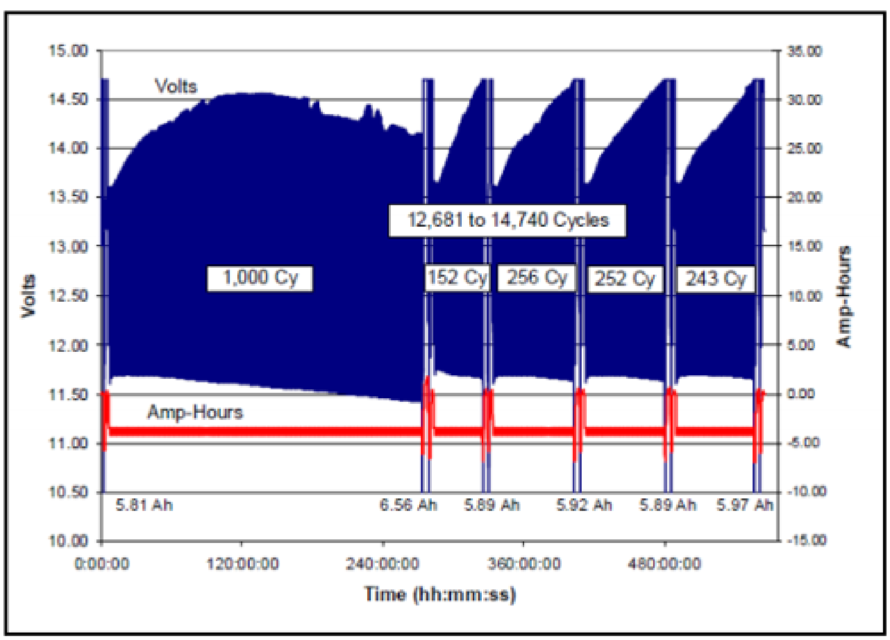

Figure 7: Ultrabattery HRPSoC Utility Cycle Accelerated Rise (Mathews 2015).

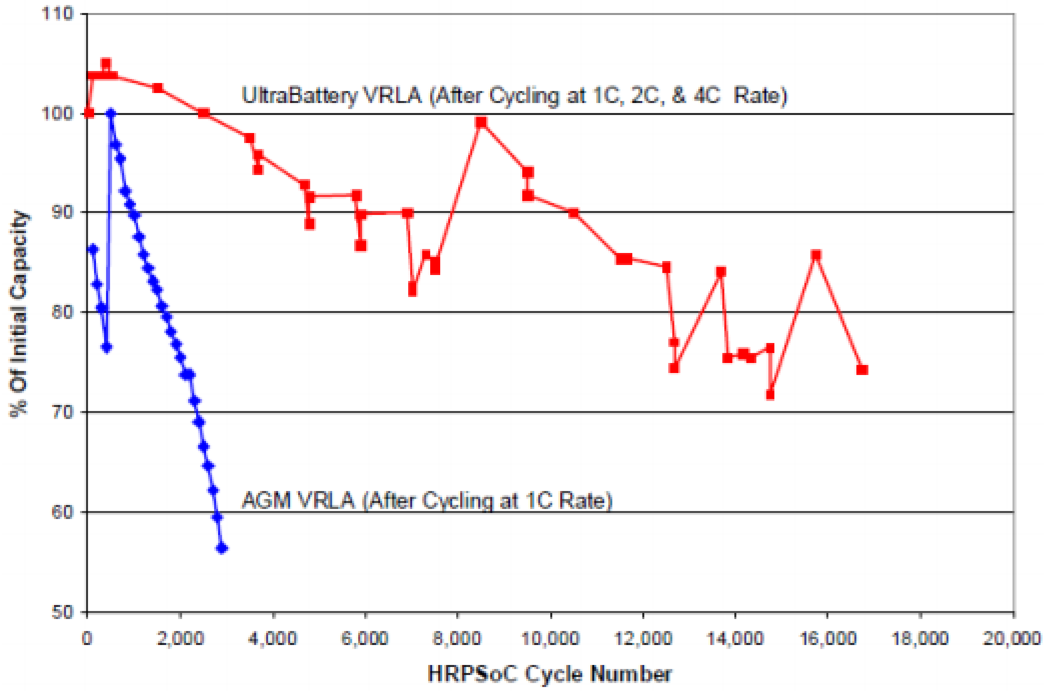

Figure 8: Ultrabattery HRPSoC Utility Cycle Aging Effect (Mathews 2015).

2.4.1 Lithium-Ion

Daily-cycle lithium-ion nickel manganese cobalt oxide (NMC) batteries similar to the Tesla Powerwall batteries or LG Chem batteries were selected for the lithium-ion battery bank. Table 1 shows properties for a single battery pack.

Table 1: Battery Specifications (DiOrio, Dobos and Janzou 2015).

Property	Value
Price	$3000
Capacity	7 kWh
Power	2.0 kW continuous, 3.3 kW peak
Efficiency	92%
Voltage	350 – 450 V
Current	5.8 A nominal, 8.6 A peak
Weight	100 kg
Dimensions	1300 mm x 860 mm x 180 mm

This analysis assumed that 7 kWh of energy can be cycled daily within the minimum and maximum state of charge limits, which are assumed to be 30% and 100% respectively. This implies a full capacity of 10 kWh which is assumed to cost $3000, implying a price of $300/kWh. The project assume this cost includes installation and permitting, but additional analysis would be required to incorporate these costs at a specific site. This analysis assumed that the battery begins with 7 kWh of daily cycle life and is replaced once the maximum capacity has degraded to 70% of the original value. As detailed lifetime cycling information is not readily available, the project assumed that the batteries can be fully cycled daily for five years beyond the stated 10-year warranty period before the battery capacity degrades to 70% of the original installed capacity, at which point the battery bank must be replaced. This implies about 365 cycles per year, for 15 years, or 5475 cycles. (DiOrio, Dobos and Janzou 2015).

2.4.2 Lead Acid

Deep cycle valve-regulated lead-acid (VRLA) absorbed glass mat (AGM) batteries were selected for the lead acid battery bank similar to the Outback Energy Cell. Table 2 shows the Outback EnergyCell properties.

Table 2: Outback Energycell 200RE Specifications (DiOrio, Dobos and Janzou 2015).

Property	Value
Price	$425
Capacity	1.680 kWh (4 hour discharge)
Power	420 W (4 hour discharge)
Efficiency	Unlisted
Voltage	12 V
Current	35 A (4 hour discharge), 30 A (charging)
Weight	60 kg
Dimensions	320 mm x 551 mm x 126 mm

The lead-acid system was similarly allowed to cycle from 30% to 100% state-of-charge, or approximately 1.18 kWh per battery at a four-hour discharge rate. The cost of one battery was found to be about $425, implying a price of $255/kWh. This cost again assumes that installation and permitting are included, though additional analysis would need to be performed for a specific site. No efficiency was listed for the battery, so single point AC/DC and DC/AC conversion efficiencies of 92% were assumed. These efficiencies were chosen to remain consistent with the lithium-ion system. The battery bank is assumed to be replaced when the maximum capacity has degraded to 70% of the original value. The following cycling information was used from the battery spec sheet.

Table 3: Outback EnergyCell 200 RE Lifetime (DiOrio, Dobos and Janzou 2015).

Average Depth-of-Discharge (%)	Cycles Elapsed	Relative Maximum Capacity (%)
10	6200	80
20	5700	80
50	1800	80
80	600	80
100	425	80

As the battery is allowed to consistently discharge 70% of its energy, the expected lifetime before degradation to 70% of maximum capacity and replacement is about 1400 cycles, as shown in Table 5. The "Relative Maximum Capacity" is the maximum capacity of the battery relative to the original maximum capacity, which changes over time as cycles elapse (DiOrio, Dobos and Janzou 2015).

SAM Storage Dispatch Strategy and Inputs:

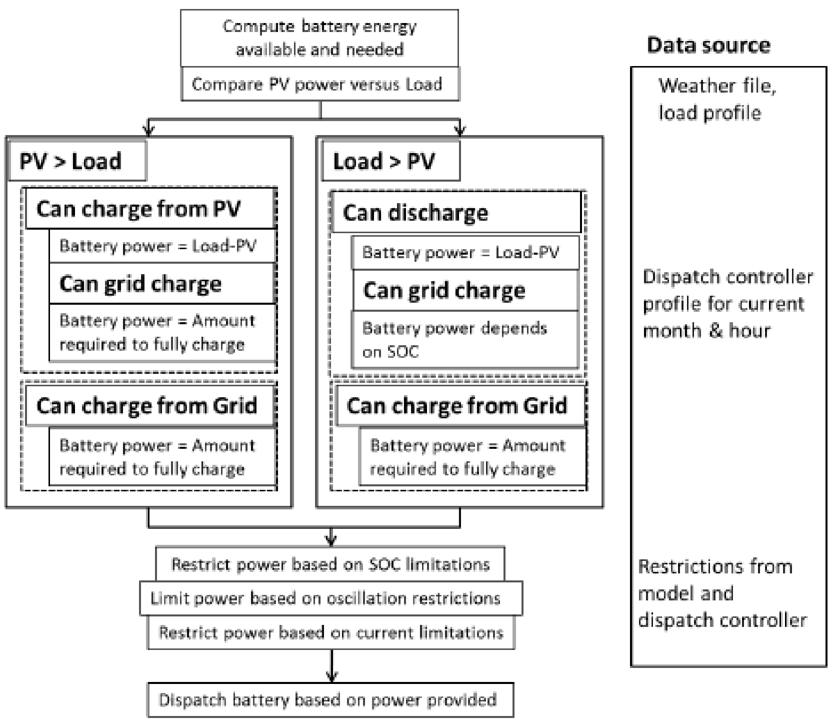

Figure 9: Algorithm description - Dispatch Control Strategy (DiOrio et al. 2015).

It will be important to model different controller strategies to represent different systems. The project will concentrate on some common schemes for this project**:**

State-of-Charge Controller

The state if charge controller will look at the state of charge in the battery to determine whether it should be charged or not first.

Switching Controller

The Switching controller will have set limits when the charging will be switched on.

Current Controller

This controller will charge depending on the current which depends on the MPPT on the panels.

Battery Economics

Battery costs will consist of maintenance and initial capital costs. Higher initial capital costs will affect the viability of systems and is one of the main reasons that such systems are not more commonly used with PV in residences. Modelling these costs along with the effect of cycles and state of charge modelling will determine lifespans of the batteries which can be used for payback calculations. The better the payback period on the batteries the better the economic value which increase that systems viability.

Financial Analysis

A table of data was required with values estimated for the following: $/kWh, Battery shed, and Battery system miscellaneous initial cost.

2.7.4 HOMER battery models

The analysis framework was as follows:

I. Site specification.

II. Derivation and verification of modelled data sets.

a. Solar energy.

b. Temperature.

c. Load demand.

III. System analysis and operational performance impact.

(Halabi et al. 2017).

2.7.5 Battery Degradation Modelling

"Important mechanisms resulting in battery capacity loss are generally divided into two main areas: electrodes degradation modes and electrolyte degradation modes" (Hamedi, Hamedi and Rajabi-Ghahnavieh 2016). The project can model the Ultrabattery degradation from the advanced lead battery research.

System Costs and Financial Parameters

For the analysis there are many financial parameters to be considered which could impact the value of installing a battery system. Battery costs are captured on a $/kWh basis as reported by vendors. Installation labor, margin, operation and maintenance, and other costs are captured as a function of the size of the installed PV system using the defaults in SAM. The battery bank is assumed to be DC connected such that battery power output is inverted to AC using the same inverter as the PV system.

Table 4: System costs for equipment (DiOrio, Dobos and Janzou 2015).

Variable	Value
Module cost	0.71 $/Wdc
Inverter cost	0.21 $/Wdc
Battery cost	$300/kWh Lithium Ion $255/kWh Lead Acid
Balance of system equipment	0.57 $/Wdc
Installation labor	0.15 $/Wdc
Installer margin and overhead	0.75 $/Wdc
Permitting	0.06 $/Wdc
Operation and Maintenance	20 $/kW-yr

Modeling procedure:

SAM Steps:

1. Photovoltaic Performance model.
2. Irradiance and Weather Data.
3. Sun position.
4. Surface Angles.
5. Incident Irradiance.
6. Effective POA Irradiance.
7. Self-Shading Algorithm.
8. Module DC Output.
9. Array DC Output.
10. Inverter AC Output.
11. System AC Output.

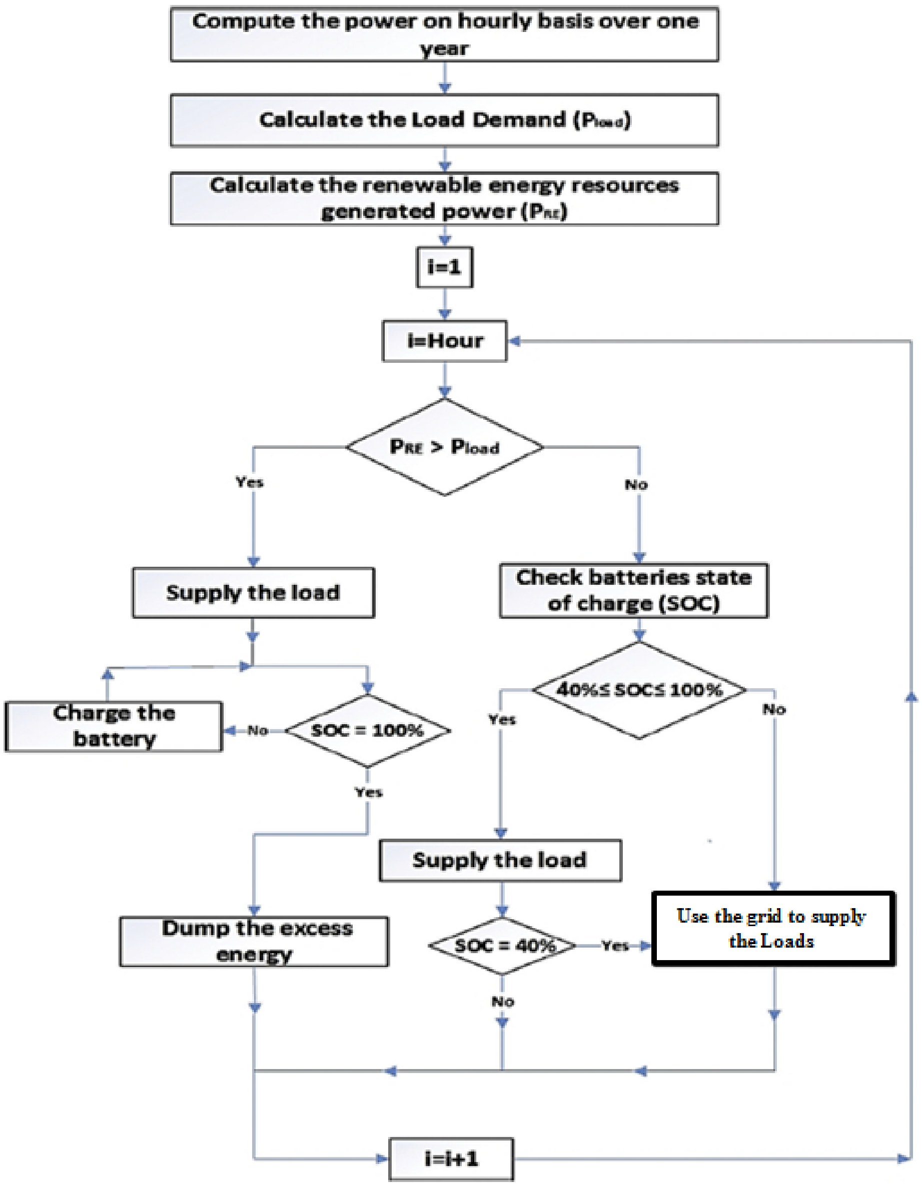

Figure 10: Flow chart of system operation in various scenarios.

Based on a schematic from (Halabi et al. 2017).

A Techno-economic model for behind-the meter residential, commercial, and third-party ownership systems will include also:

- Lead acid and lithium ion battery chemistries.

- System lifetime analysis including battery replacement costs.
- Models for terminal voltage, capacity, temperature.
- Manual dispatch controller algorithms/schedule.

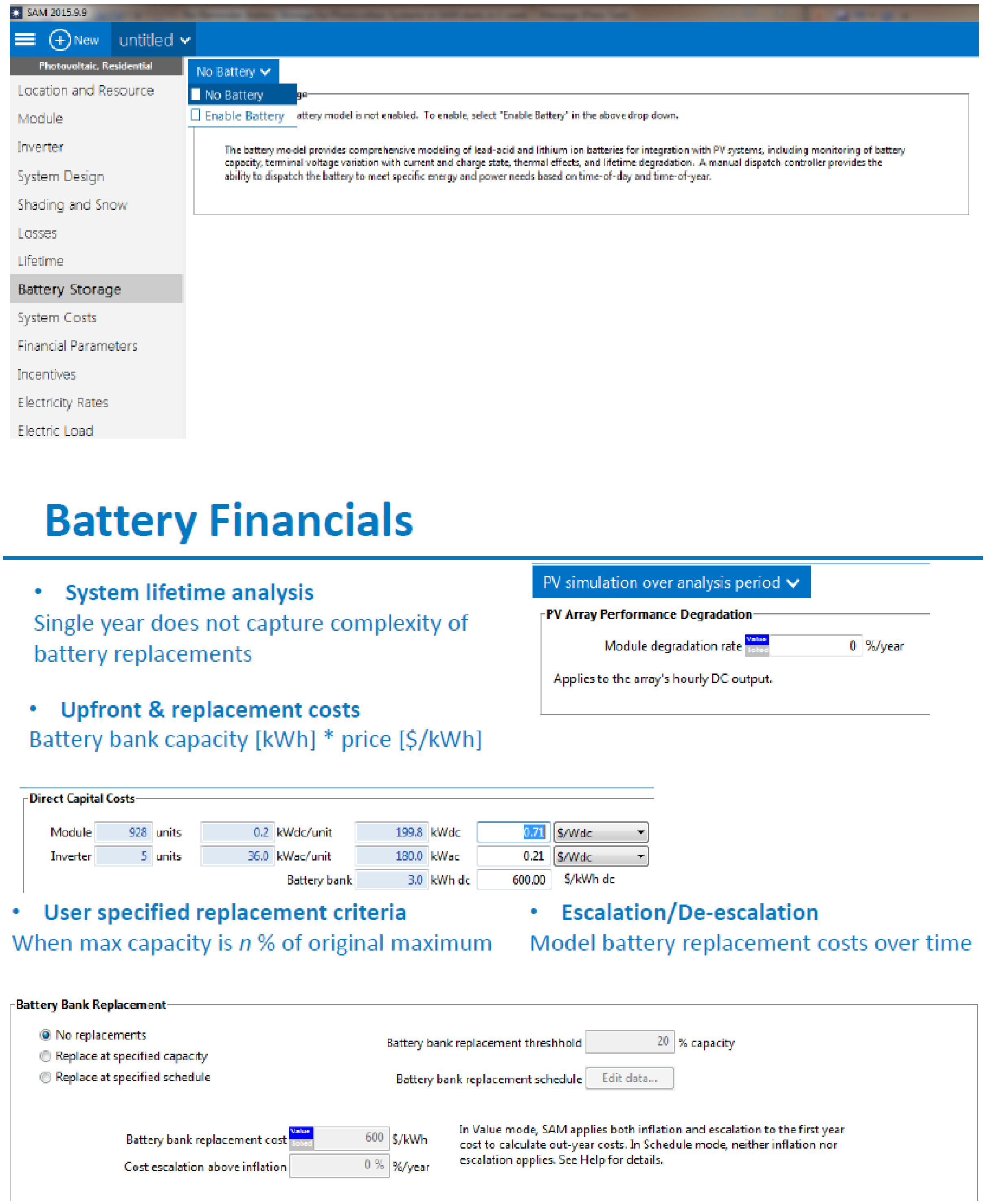

Figure 11: SAM PowerPoint slides showing battery details (DiOrio et al. 2015).

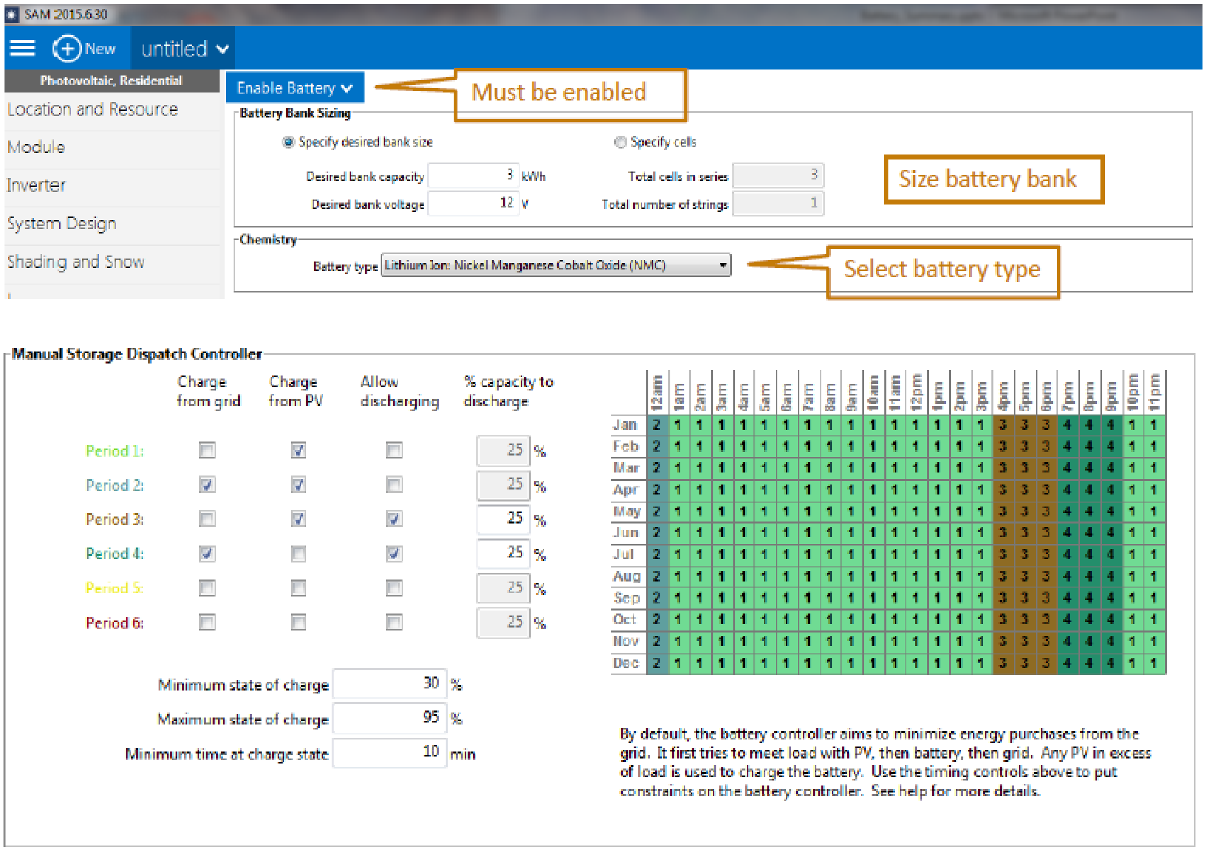

Figure 11: SAM PowerPoint slides showing battery dispatch (DiOrio et al. 2015).

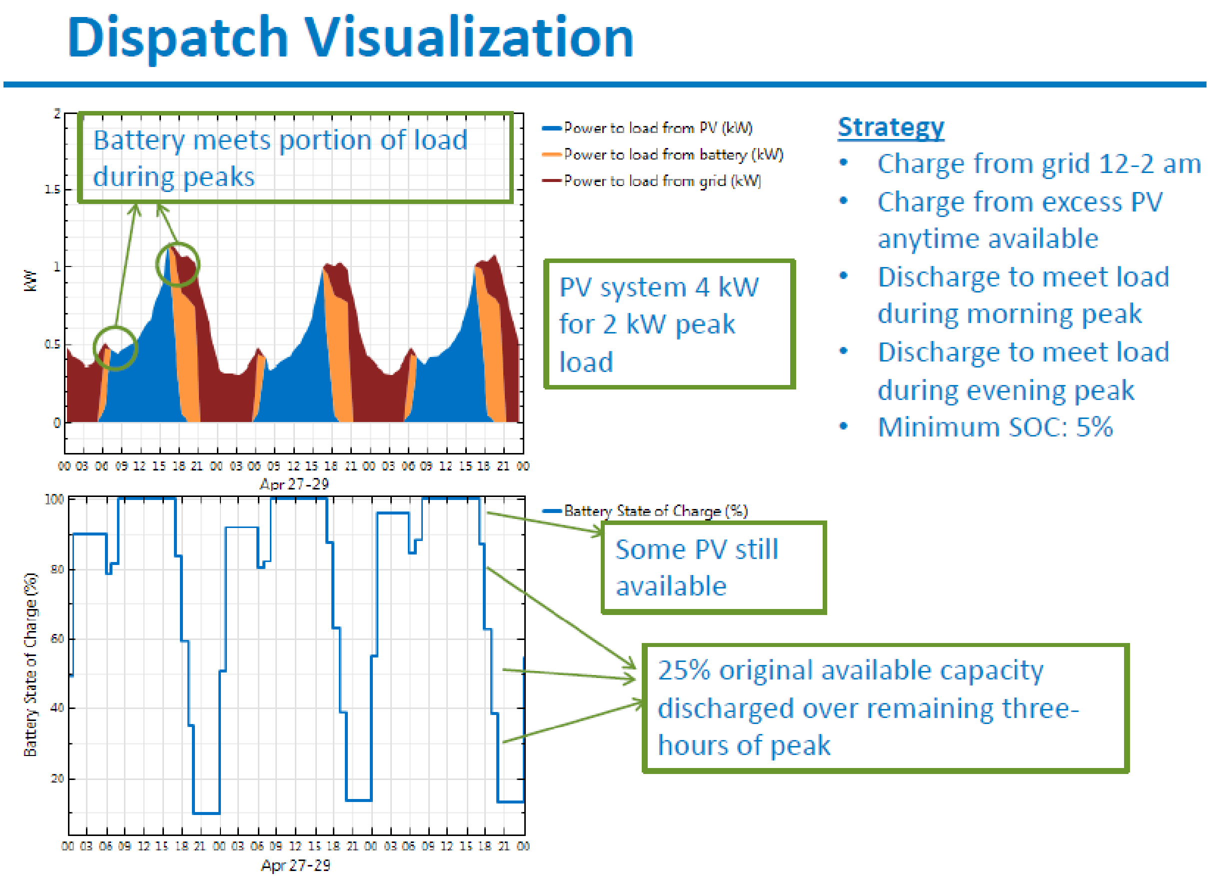

Figure 12: Dispatch Visualization for batteries (DiOrio et al. 2015).

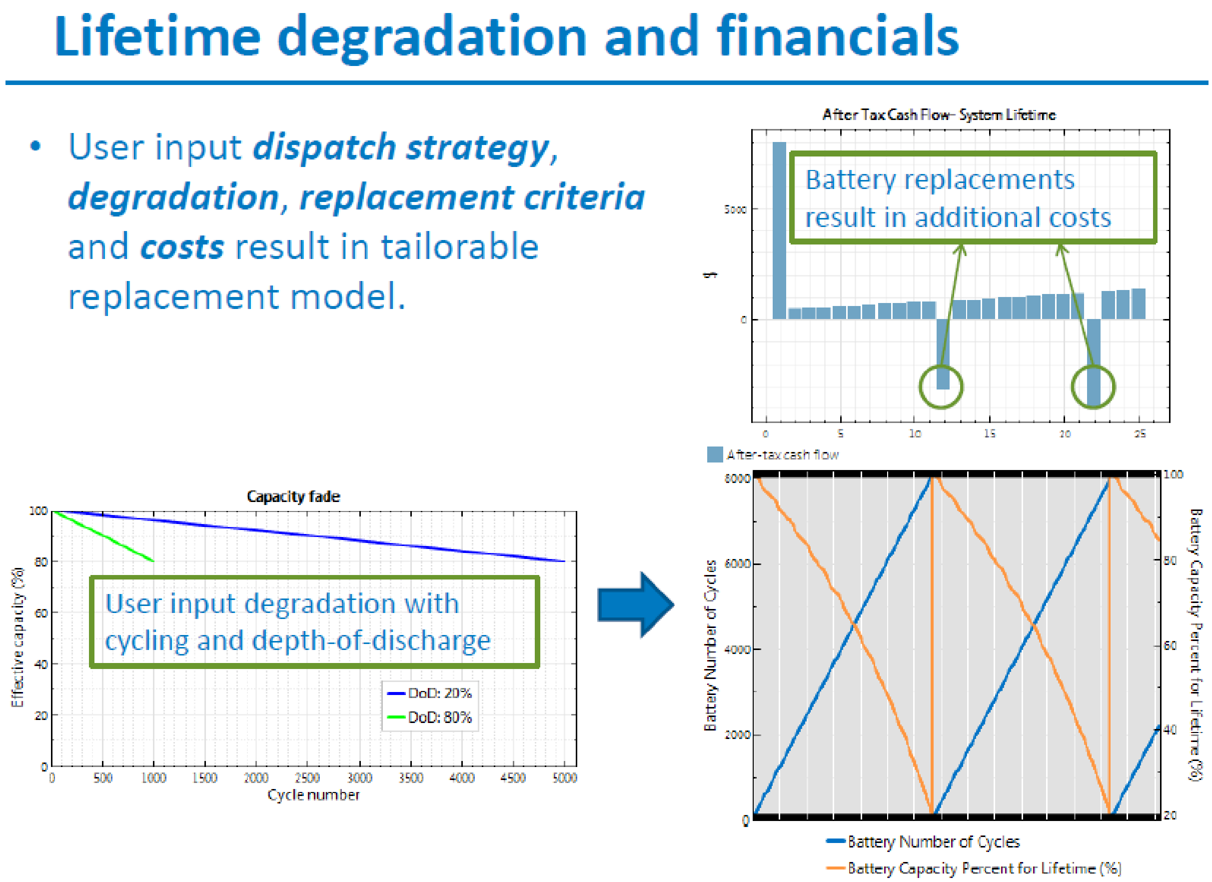

Figure 13: Lifetime degradation and financials (DiOrio et al. 2015).

Figures 10 to 13 show us what new features the SAM Program has for battery simulations has as well as different parts to consider for the battery simulation. Further information can be found on the SAM website and in the SAM program as well as in the Appendix.

Steps shown in Figures 10 to 13:

1. Create a detailed PV case with Commercial financial model.

2. Input details about location, PV system, battery system.

3. Tailor dispatch strategy to electricity rates.

4. Compare payoff period to no-battery case.

(DiOrio 2015).

2.8 Research Methodology Flowchart

Flowchart Diagram:

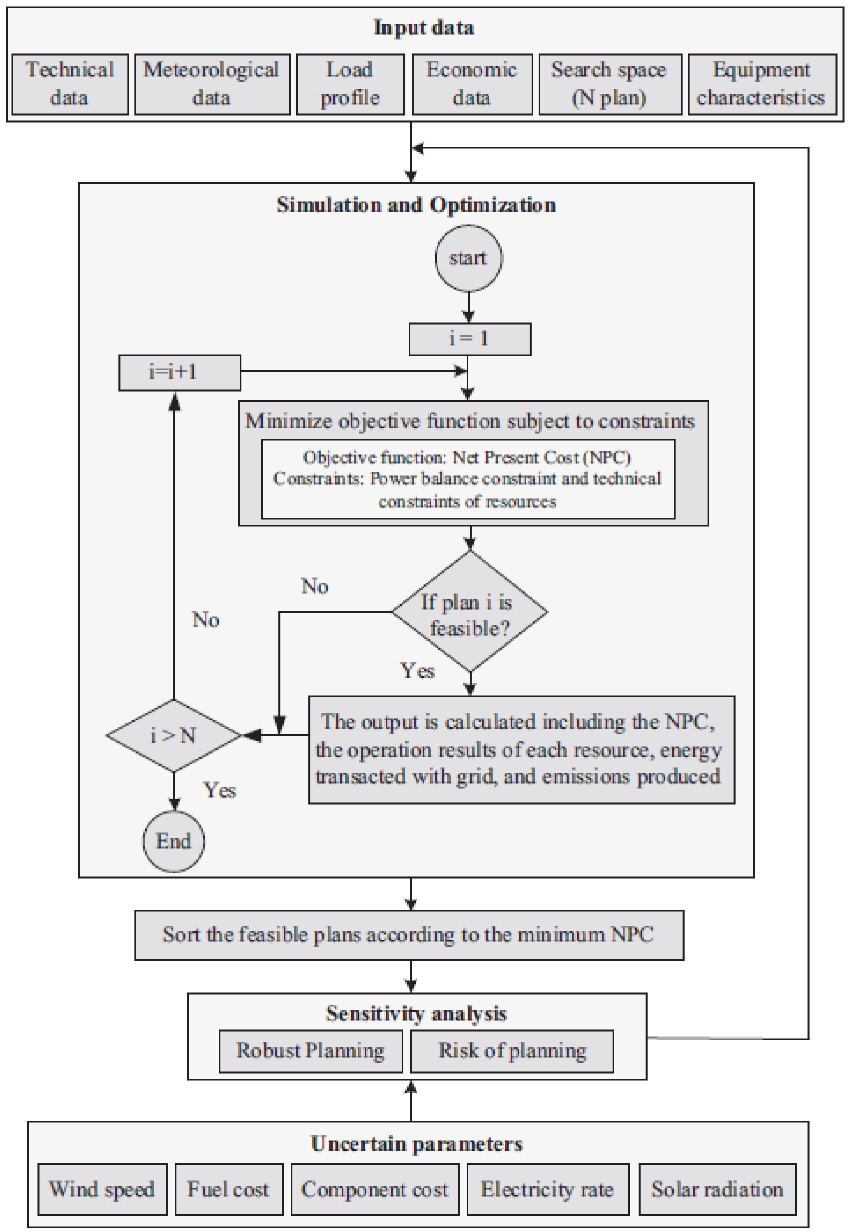

Figure 14: The comprehensive framework of HOMER optimization PROCEDURE

(Bahramara, Moghaddam and Haghifam 2016).

With a view to fully understanding the effectiveness of the types of energy storage systems considered, the Hybrid Optimization of Multiple Energy Resources program (HOMER) was used in order to model each storage system with electrical demand and selected renewable resources in W.A. HOMER is a software analysis tool that allows the user to input data in relation to what type of system they want to model. Using complex algorithms, HOMER simulates the designed system and generate results for specified sensitivity cases and also shows the user the optimum system design for the data inputted. The program has also been highlighted in literature as being one of the 'preferred tools' in energy modelling (Chmiel and Bhattacharyya 2015). This tool has also been used by various scholars to model small-scale renewable energy systems (Dodds 2015). This makes HOMER one of the most suitable programs for the modeling of energy storage systems, as its battery calculation methods are very thorough and succinct (Dodds 2015).

2.9 Data Collection

System Schematic:

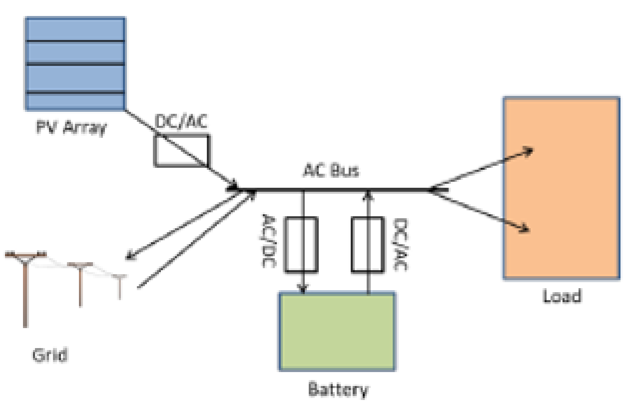

Figure 15: Modelled Configuration (Dodds 2015).

Modelling parameters:

Lithium battery system inputs needed from data were:

- Battery Chemistry model.
- Cells per unit.
- Number of batteries.
- Nominal voltage.
- Bank Capacity.
- Bank Energy.

Lead-acid battery system inputs needed from data were:

- Lead acid battery Chemistry model.
- Cells per unit.
- Number of batteries.
- Nominal voltage.
- Bank Capacity.
- Bank Energy.

Ultrabattery Battery system inputs needed from data were:

- Ultrabattery Chemistry model.
- Cells per unit.
- Number of batteries.
- Nominal voltage.
- Bank Capacity.

- Bank Energy.

SAM Model Limitations:

- Voltage losses.
- Round-trip efficiency.

Types of SAM models:

- Thermal model.
- Lifetime model.

Lead Acid performance models for SAM:

- Built in models allowing for ease of modelling allow comparison.

2.10 Data Analysis

Results that simulations can give for consumers

The results tell us the payback periods and economics of the different systems. They can also model further changes in the market of battery costs and electricity cost changes. The programs are not specifically designed for a battery like the Ultrabattery and so will depend on using the current lead-acid model and modifying it.

What can be learned from the simulation results

The project can learn the economics of the batteries and simplified payback cost.

What answers have this project found for the research questions?

This project has found that Ultrabatteries may payback faster and that batteries will have a more acceptable payback in addition to having many of the benefits of Lithium batteries.

How could these results be used?

The information gained could be used for policy makers, retailers, wholesalers, consumers and the public for education and awareness.

How should the results be viewed and interpreted?

They should be viewed under the caveat that the results are based on assumptions and the limitations of the programs used. Also that the economics may change due to trends and policies in the W.A. market.

SAM Vs. HOMER

Table 1: battery modelling between SAM and HOMER.

	SAM	**HOMER**
Energy to charge battery (kWh)	Simplified model.	Complex model.
Energy discharged to load (kWh)	Simplified model.	Simplified model.
Battery efficiency (%)	Modelled as needed.	Modelled as needed.

2.11 Research Design – Tools

SAM

SAM will be used in this research by to help determine the better options from a battery use viewpoint. SAM also has the ability to show in greater detail the battery usage and dispatch strategy. It can also be used as software to compare the results from HOMER. SAM also allows greater comparison between the systems however it can only do one system at a time.

HOMER

HOMER will be used to help determine the best option from a lowest NPC ranking. It will be able to determine the best batteries to use or combination to use. HOMER can present all the optimal solutions for the different combinations. HOMER is useful as a way to show life cycle costing for each system.

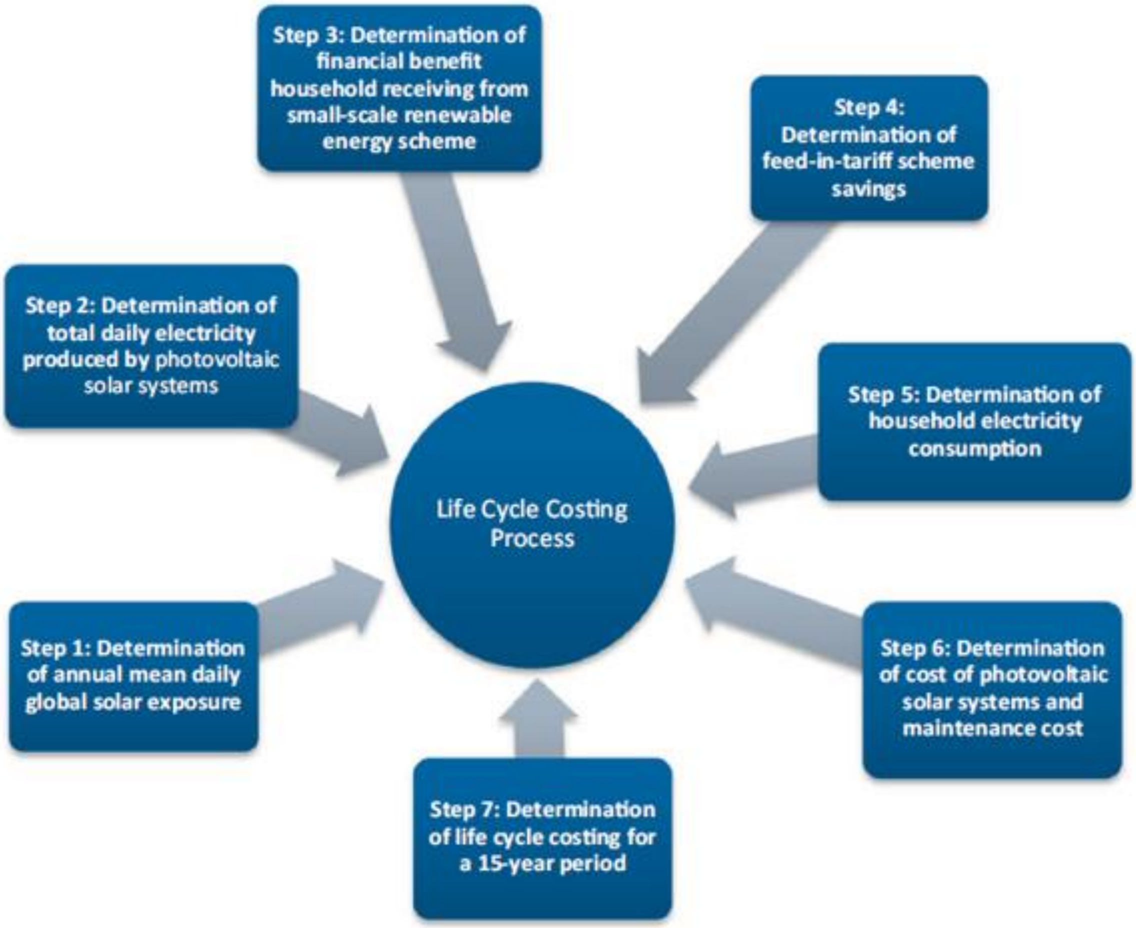

Figure 16: Research methodologies for measuring life cycle costing in using photovoltaic solar systems (Tam et al. 2017).

2.12 Significance and Impact of Research

The significance of this research in the current research is to further the knowledge of the Ultrabattery and hybrid lead-acid batteries as an energy storage option for residential PV systems results were needed as shown in Figure 16. As a cheaper and more effective technology it could expand the viability of PV systems for residential use as well as provide a retrofit option.

2.12.1 Significance and Impact on Society

The significance of this research for W.A. and on society are myriad. There is need for more research into energy storage options for residential and grid electricity for Australia and W.A. With the ongoing trials of "virtual" power plants, newer Power Purchasing Agreements and power sharing agreements as well as decentralized grids this option (for energy storage for PV systems) is still viable for the future and is expanding. The economic and technical viability of newer battery technologies is of interest to society as well as its combination in residential PV systems.

3.0 Comparison of battery and PV systems rebates and differences between the states of Australia

3.1 Comparison with the different states

Solar panels rebates in the state and federal governments

The solar rebate subsidy varies depending of the program and may cover up to 30% of the solar power system cost. The Federal government also allows you to deduct 30% of your solar power system costs off federal taxes through an investment tax credit (ITC) (Solarcity 2017). In W.A you can also be eligible for financial assistance for the cost of a small scale solar system under the Australian Government's Small-scale Renewable Energy Scheme (SRES).

3.1.1 Battery rebates and solar subsidies

Western Australian rules and standards for battery technologies have had a significant impact on the dollar PV take up and also on the local PV/battery market. The solar PV rebates continue to have an effect on the acceptance and growth of PV in the market. Newer factors such as the continuing drop in cost of solar due to subsidies and improvements in manufacturing and installation have also helped to lower costs. Rebates and changes to the documentation or ease of the process of getting solar PV do make changes to its adoption. The changing standard rules for Lithium batteries and its impact on other battery technologies in the market continue to have an effect on the residential storage market. The designations of batteries (payback and lifetime) as well as the power requirements continues to be of interest to consumers. Subsidies on battery technologies as well as well-defined standards have helped battery growth in some states. Lower cost storage of batteries and the systems required to manage them are key to greater acceptance of batteries. In addition, a market for trading electricity, a focus on self-consumption and a change in tariffs to Time of Use have been shown to encourage battery adoption.

"The rooftop PV with battery is most suited for QLD (Queensland) and SA (South Australia). The rooftop PV without storage is most suited for TAS (Tasmania). Furthermore, the analysis implies that the rooftop PV is not suited for ACT (Australian Capital Territory) unless the electricity price rises substantially" (Nicholls, Sharma and Saha 2015). Although TAS has the worst solar insolation conditions, it possesses the fastest payback period amongst the Australian states. This implies that when it comes to obtaining a fast payback on rooftop PV investment, load profile and the electricity price have a significant effect which can offset any shortcomings in the solar conditions. The larger the load profile the greater the effect of PV on a residential household. The greater the $/kWh price the more that solar PV becomes attractive as well as self-consumption of power and therefore batteries.

It is also noted that electricity price has a greater impact than the FiT and variations in the solar exposure levels in determining the economic viability of a PV system. A doubling in electricity price constitutes on average a decrease in Payback period by 60% which indicates that a continual increase in electricity price relates to an increase in PV economic viability. This is contrary to the general perception whereby greater emphasis is placed on the existence of the FiT and the solar conditions for the growth in the uptake of PV systems than on the electricity price. Finally, the PV panels are the main contributor to system set-up cost. A decrease in PV panel costs, possibly due to improved manufacturing processes, will result in a quicker payback period due to a lower capital cost" (Nicholls, Sharma and Saha 2015).

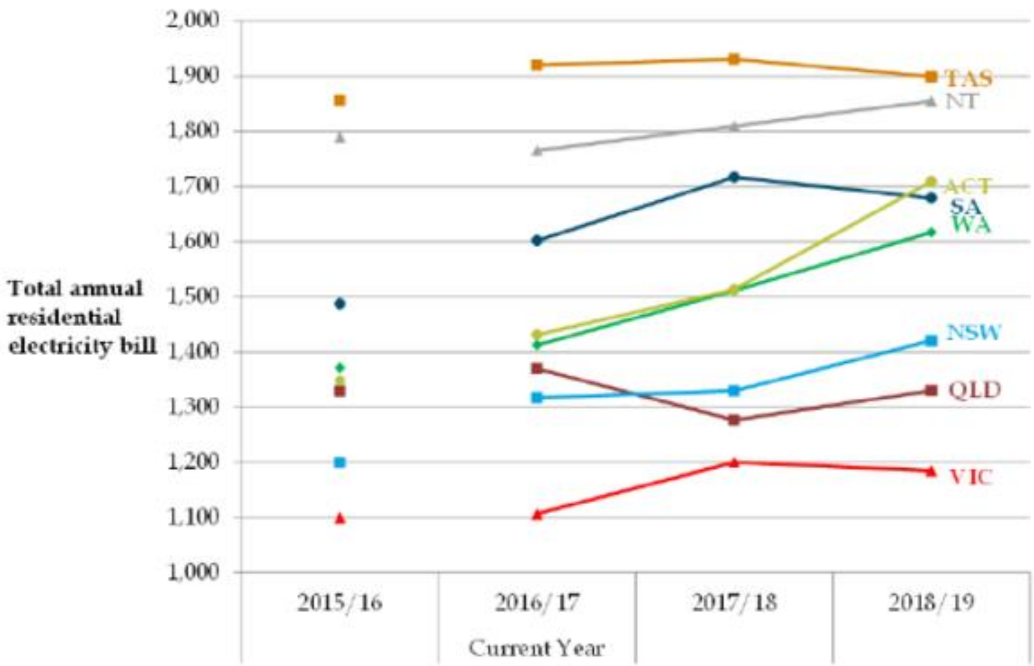

Figure 1: Annual electricity bill trend for a representative consumer across jurisdiction; graph. (Australian Energy Market commission 2016).

As shown in Figure 1, W.A. has had a steadily increasing electricity price which has been a good correlator with the uptake of solar PV. The generally higher electricity prices as well as solar PV policy and better economics would be a better indicator of solar PV uptake. There has been seen with newer battery technologies employed with solar PV a range of factors that can explain the rise in the use of a certain technology. Victoria has the lowest annual residential electricity bill and the worst policy for solar photovoltaics. Even so the uptake of solar photovoltaics in Victoria is still higher due to greater factors in play such as the lower costs of solar photovoltaics, community acknowledgement of savings and community environmental sentiment. “In June 2016, the Victorian Government committed to renewable energy generation targets of 25% by 2020 and 40% by 2025 and a net zero emissions target by 2050” (Climate Council of Australia 2017). “Additional sources of value for storage have been proposed; including electricity network services and taking advantage of variable electricity pricing tariffs, so that electricity can be stored when it is cheap and imports avoided when it is expensive” (Jones et. al. 2017).

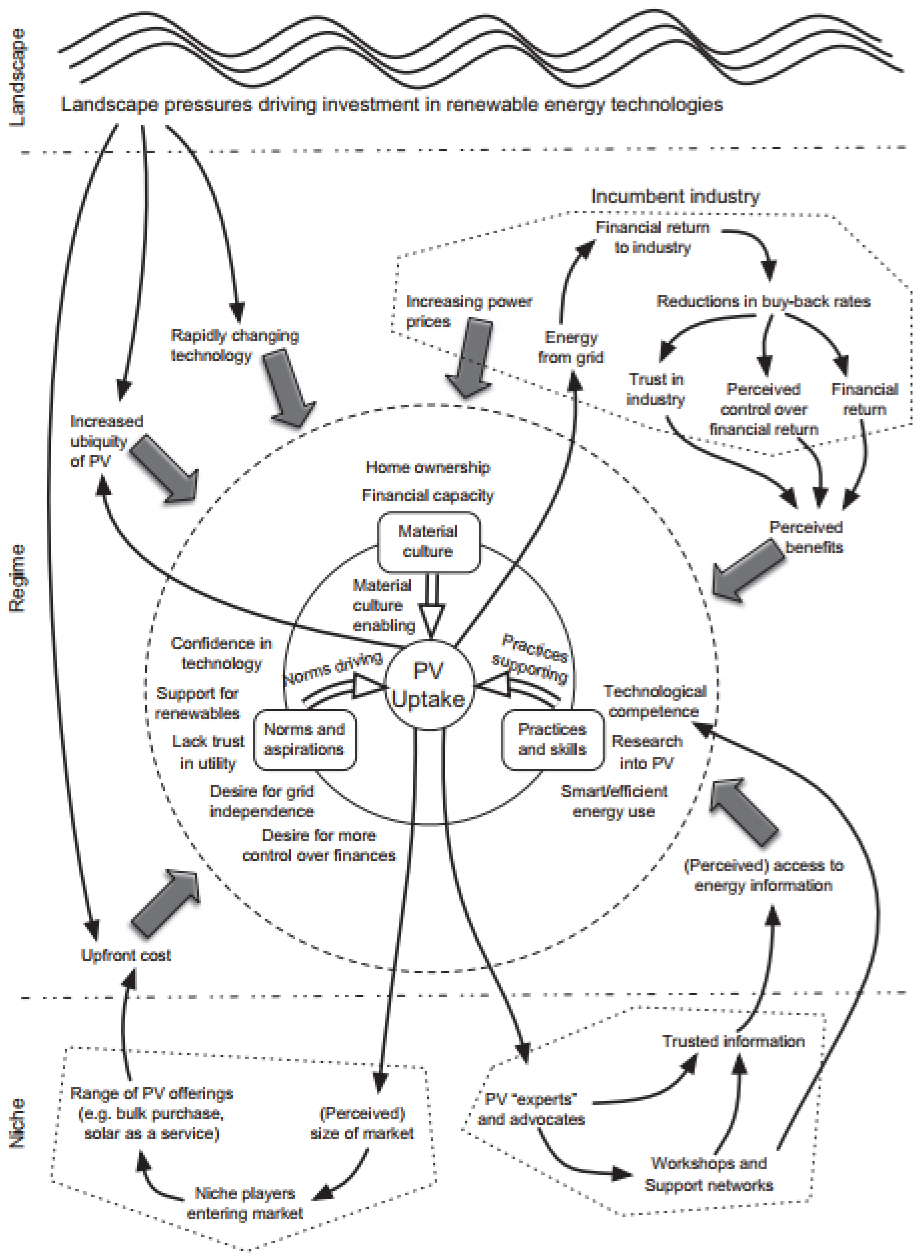

Figure 2: An MLP (Master Limited Partnership)/energy culture reflection on socio-technical transitions (Ford et al. 2017).

Many of the same factors shown in Figure 2 that increased PV systems uptake will also help new battery technology uptake in W.A. The diagram above was based on New Zealand and the same factors may help in Australia due to similar economic and social conditions. For W.A. an incumbent industry including suppliers, manufacturers and trusted information and a lowered upfront cost will help the Ultrabattery in application. The Ultrabattery will need practices and skills as well as norms and a material culture to enable further uptake of PV and battery systems. The Ultra battery will form a niche market and will rely on access to energy information, education on the technology and perceived benefits of the technology.

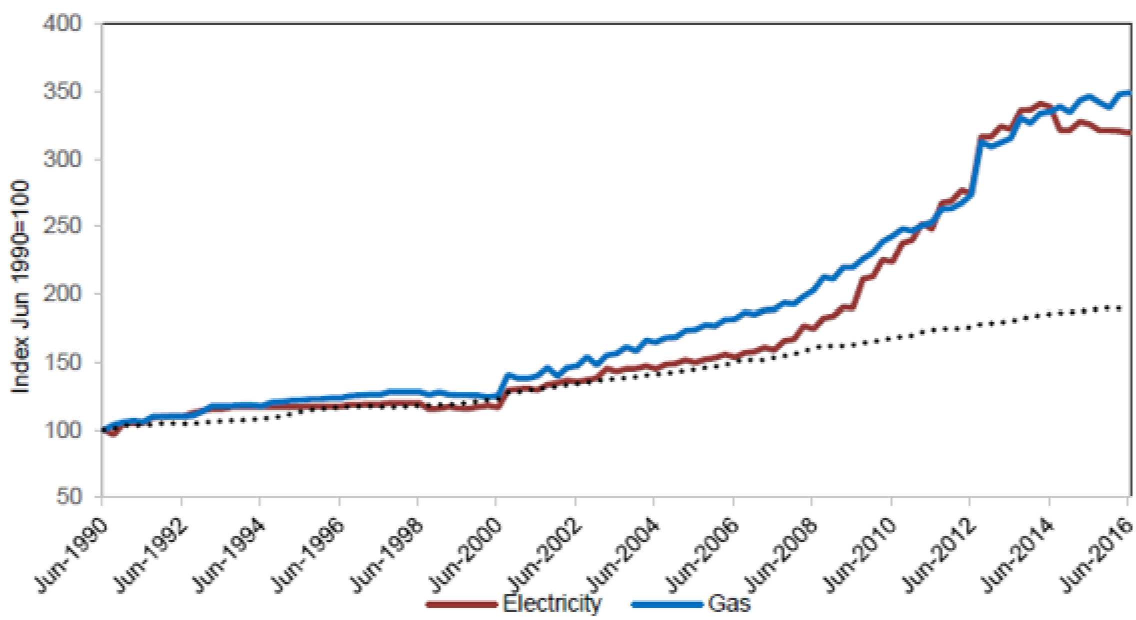

Figure 3: Household energy price index (Australian Bureau of Statistics 2016).

Figure 3, the Household energy price index, shows the close relationship between the household price of gas and electricity showing a correlation. This is an interesting relationship as in Australia the project also use gas to generate electricity. Gas energy applications can also be replaced with electricity. As gas prices have increased especially in the Eastern states this has also led to higher electricity prices which has then had an effect of increasing solar PV usage. Here in W.A. and

Northern Territory (N.T.) while both states do not have gas shortage issues (as both states have readily available off shore gas reserves) there is still great opportunity for solar PV due to the excellent resources; however, W.A. has had a larger degree of uptake of PV due to regulatory and localised economic context challenges (N.T. has more renters and lower income households either unwilling or unable to purchase solar PV). Again incentives for the uptake of PV and batteries is a result of economic and technical challenges.

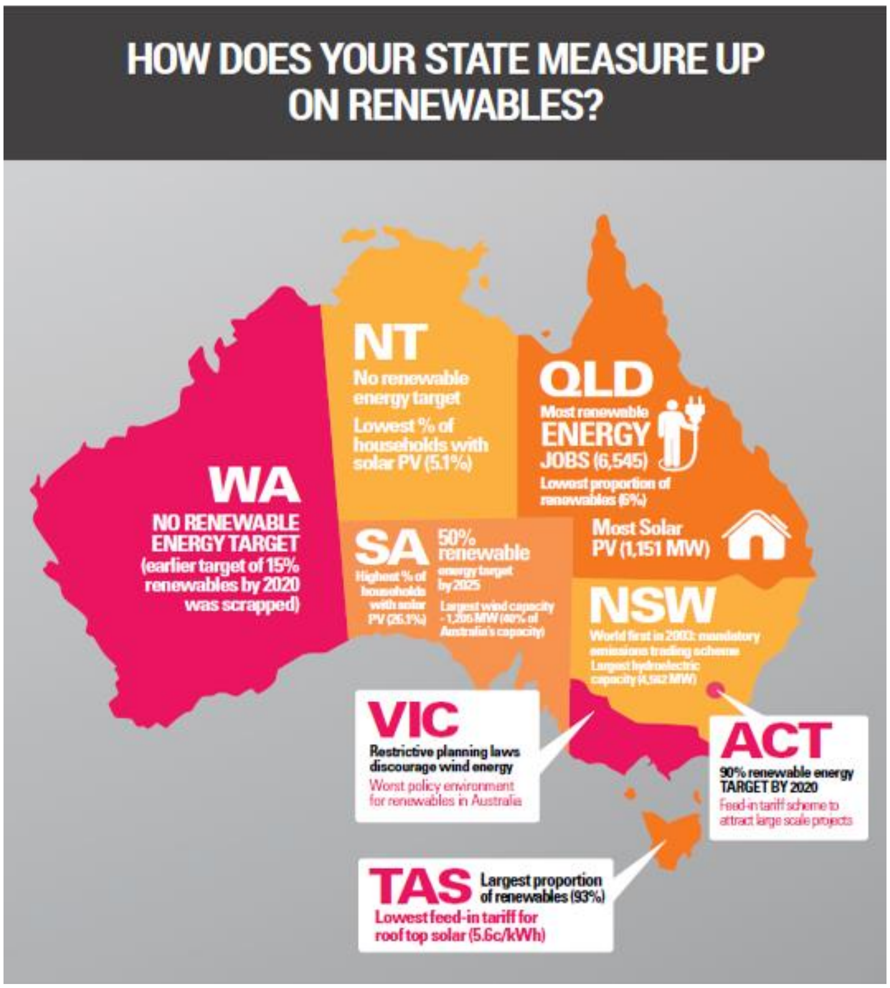

Figure 4: How does your state measure up on renewables? (Data from ABS 2012; ACT Government 2013; Australian PV Institute 2014; Clean Energy Council 2014; Renew Economy 2014).

Figure 4 details the different incentives in each state for solar PV also showing the targets and policy in each state. For batteries also each state has unique incentives and disincentives showing that even for one nation there can be many reasons why battery storage for Ultrabatteries may have a niche or not. Renewable Energy Targets from earlier have been shown to work when the incentives are directly related to the market or the fostering of industries. Restrictive policy or too much or too little regulation has been shown to have a detrimental effect. Western Australia has other policies supporting the solar PV industry. Policies to support the industry, further lowering prices for batteries and increasing electricity prices will help to grow the battery market.

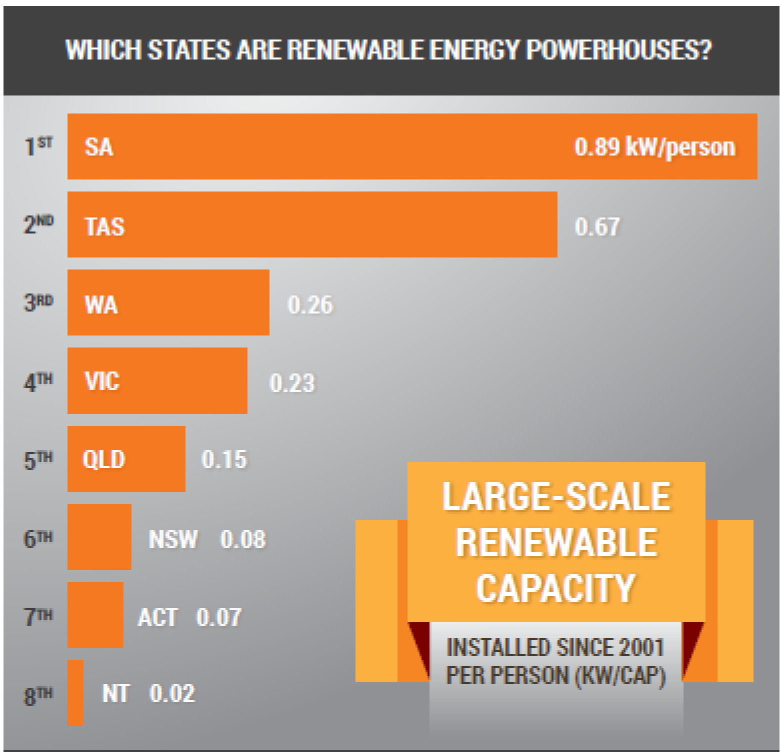

Figure 5: Large-scale renewable energy capacity installed since 2001 per person (kW/cap) (Australian Energy Council 2017; ABS 2012; Commonwealth of Australia 2014).

Shown in Figure 5 above, South Australia has had the largest scale renewable energy installed per person a result of community acceptance as well as a suitable techno-economic environment. South Australia’s government provides generous incentives for residential and large scale PV and has been a very strong proponent of renewable energy. Western Australia despite not have a

Renewable Energy Target (R.E.T.) still ranks third. In fact, some literature suggests that having more education or appropriate standards for solar PV and battery systems helps integration and acceptance (Australian Energy Council 2017).

Cost reductions have been a major factor in acceptance of solar PV in Australia and the same has been shown to be a factor for solar battery storage. Lower cost options such as the proposed Ultrapod Ultrabattery (a residential home storage form of the Ultrabattery) will be a welcome addition to a market now considering metering innovations such as mobile phone apps, net metering with set goals for consumption and the DeX (Decentralised Energy Market) which would be enhanced with the addition of a battery to solar PV systems. Tariff rates in line with or better than electricity prices are another generally good indicator for solar PV uptake; however, lower tariffs have been seen to encourage self-consumption and therefore batteries. Where other parts of the world consistency of electricity supply is an issue cost of electricity is more of a challenge in Australia. Findings "demonstrate how residential consumers are motivated to choose specific storage characteristics and functionality based on drivers for self-sufficiency and grid independence" (Agnew and Bartusch 2017).

Agnew and Bartusch 2017 states, "battery storage could still be poised on the cusp of a similar trajectory" speaking of the rise of solar and battery systems. "International drivers are converging, much like they did for PV, with subsidies in many countries and rapid technology development resulting in price declines and upscaling of manufacturing." This could mean an exponential growth of batteries in W.A. and the whole of Australia due to similar factors influencing growth. Agnew and Bartusch 2017, explains further about the role of the consumer in adopting technology faster and faster, "Understanding the role of the consumer in this transition will help government and industry prepare for and optimise the impending market transformation while enabling a smoother, more efficient pathway for the integration of decentralized, low-emission technologies."

Key Points for the different states in Australia

Western Australia

In W.A. PV systems had/have the advantages of:

- A boost from an initial 47c/kWh FiT and $8000-dollar initial solar rebate from the government which created the solar industry.
- Small Scale Technology certificates (STC's) leading to some of the cheapest solar PV costs in the world.
- Simpler battery regulations.
- Simpler regulations for batteries and accompanying inverters (though single phase inverters are limited compared with other states).
- Some of the best solar resources in the world.

Table 1 shows some key statistics and an idea of the growth of the industry. There is scope for more renewable energy capacity and jobs in W.A. according to the Clean Energy Council 2017 report.

Table 1: Western Australia – key statistics (Clean Energy Council 2017; ABS 2012; Australian PV Institute 2014; Clean Energy Council 2014; Commonwealth of Australia 2014; Department of Environment 2014).

Statistic (measure)	Total	Percentage
Population (million, % of Australian total)	2.43	11
Installed renewable energy capacity (December 2013) (MW, % of Australian total)	936	6
Installed solar PV capacity (December 2013) (MW)	398	/
Dwellings with solar PV (%)	/	18.4
Renewable energy jobs (number, % of Australian total)	1615	8

Queensland

In 2013, Queensland had 2,219 MW of installed renewable energy (Clean Energy Council 2014). Only 682 MW of renewable capacity has been added to Queensland since 2001 (Commonwealth of Australia 2014). Queensland was fifth in terms of new renewable capacity per capita. Almost half of Queensland's renewable energy capacity is solar PV and Queensland has the most installed solar PV capacity (1,151 MW as seen in Table 2) of any state or territory. Hydro and biomass are also significant sources of renewable energy" (Australian Energy Council 2017).

Table 2: Queensland – key statistics (ABS 2012; Australian PV Institute 2014; Commonwealth of Australia 2014; Clean Energy Council 2014; Department of Environment 2014).

Statistic (measure)	Total	Percentage
Population (million, % of Australian total)	4.56	20
Installed renewable energy capacity (December 2013) (MW, % of Australian total)	2219	14
Installed solar PV capacity (December 2013) (MW)	1,151	/
Dwellings with solar PV (%)	/	25
Renewable energy jobs (number, % of Australian total)	6545	31

Victoria

Victoria now has the worst policy environment for renewables in the country. It has few subsidies or regulations that suit photovoltaics. (Australian Energy Council 2017) “Victoria’s state-based renewable energy target (previously set at 20 percent of energy consumed by 2020) was also closed after the introduction of the expanded national RET for 2020” (Climate Change Authority 2012).

Tasmania

Has the lowest amount of PV due to few policies, industry to support and Tasmania has lower insolation values than other states. In addition, Tasmania has a higher renewable energy percentage from hydroelectric power.

ACT

South Australia and the ACT – with progressive renewable energy policies and targets - are winning the Australian renewable energy race. (Australian Energy Council 2017)

Canberra

Has some of the highest tariffs and the largest renewable energy target. It depends on how the federal government decides to implement the target whether it is done through large scale solar, residential or wind power. Only about 10% of the households have solar so there is room to grow (Solargain 2016).

NSW

NSW has a large percent of solar PV and a growing market. It also has a large proportion of hydroelectric power and a mandatory emission trading scheme. This will help for residential adoption of solar PV. There are over 350,000 households in NSW with installed solar PV systems (Planning and Environment NSW Government 2017).

South Australia

South Australia and the ACT – with progressive renewable energy policies and targets - are winning the Australian renewable energy race. A little over a decade ago, South Australia had very little renewable energy capacity to speak of, but is now a leader in renewables after a decade of increasing targets for renewables and supporting policies. “South Australia's solar energy installations have hit a level not seen since 2012, when generous feed-in tariffs were still offered by the State Government.” As stated by Harmsen and McLoughlin 2017, “Nearly 9,000 solar generation units have been sold in SA (South Australia) in the past year, which is more than double the rate of two years earlier. Mr. Johnston said cheaper equipment also made solar energy a more attractive business proposition. "System prices have fallen significantly ... since the feed-in tariff-driven boom," he said. "So people are really taking this up just for the underlying business case rather than trying to rush in to secure some government subsidy, which isn't needed any more.""

3.2 W.A., the Ultrabattery and Lithium

3.2.1 The Lithium market and the “white gold” rush

As Lithium mines and battery factories continue to increase in number and viability the cost of Lithium batteries on the scale of solar storage will decrease. News around the world of larger and larger factories, international competition as well as larger renewable energy storage and grid stability use of batteries have helped to increase public awareness (Lazerson 2017).

3.2.2 Changing Mindset of Australians to battery storage

“Australians love rooftop solar, and most now expect home battery storage to be as commonplace as dishwashers in our homes in a decade, Amanda McKenzie, chief executive, the Climate Council, said in a statement week” (Renewable Energy World 2017). Key factors in the acceptance of battery and PV systems include the cost/kWh, the lower cost of PV systems as a whole and the regulations, standards and costs of batteries. An important factor in addition to these is the mindset and quick acceptance by the Australian community of new solar and battery technology. Contributing causes for the rise of PV systems appears to be the perception of these systems and the cost savings of these systems in the local context.

More Australians expect home storage to be more normal as electricity prices continue to rise amidst political uncertainty in energy policy. Lithium is a rare earth metal and costly so there is a market for competing technologies such as the Ultrabattery. Education of the market and the cost savings appear to be very important to the spread of the technology. In addition, making the process of getting a system easier and the newer battery management systems making the running of the system easier continues to help customers. Since the lead acid battery is a mature technology with mature standards a lead acid based hybrid technology has the advantage of these standards and regulations.

Battery storage and management systems can make use of:

- *Self-consumption of energy* - this is the ability to store excess solar PV produced during the day and used at a later point.
- *Time-of-use billing* - rate shifting is when the system stores solar PV or grid supplied energy for use when electric rates are the highest.
- *Smart home energy management* - which is achieved through an energy management platform, which continuously optimizes the home consumption, solar PV production and state of charge of the batteries.
- *Remote monitoring capabilities* – which is done through the use of either a smart phone or web portal.

(Delony 2017b).

The Renewables subsidy debate

In National government there is a debate on the STC rebates. These rebates have helped to start the solar PV industry. Similar smaller subsidies for batteries exist in the NT and SA and in south Australia are having an impact on battery adoption by the public. An effective subsidy or lowering of battery costs from indigenous manufacturing would help grow the battery market. The growing acceptance of solar and energy storage in commercial and larger scale use has affected residential and societal acceptance. The improvement of standards and increase in viable financial models for projects have also helped to increase the flexibility and acceptance of solar and battery systems.

3.3 Micro-grids and the Ultrabattery

Micro-grids (small power grids which use solar and battery systems) will benefit from the use of battery systems such as the Ultrabattery through the use of control, communication and data functions. There is a growth in Micro-grids across Australia and the world especially in off the grid applications, fringe of grid and suburban trials. Benefits for Micro-grids include:

Availability of Load Data

Providing accurate load data can help with renewable micro-grid design efficiency. Predicting load data for projects is a challenge, especially given the limited amount of publicly available data on load usage.

Long-term Supervisory Control

As the center of smart grids, information technology will help the micro-grid market by allowing intelligent decisions. According to the Delony 2017b, real-time decision making can be supported by the development of control algorithms that balance economically-based decisions with renewables usage. The software algorithms for inverters and battery management systems continue to improve as research and investment are directed into this area.

Improvements in Storage Manufacturing

As one of the key components to renewable micro-grids, storage technologies need to continue to come down in cost for affordable deployments worldwide. Innovations in manufacturing are helping to bring down those costs such as larger scale plants and more efficient use of materials. Advancements in materials are improving energy densities in batteries and weight to energy stored ratios. Delony 2017b said potential advancements in materials include, among other things, elimination of N-methylpyrrolidone and reduction of the electrolyte wetting and solid electrolyte interface layer formation. Whether these advancements can all be done cost effectively is currently being researched. Research is currently being done in these areas as well as other research into battery materials which may bring further cost reductions and efficiency gains.

Inverter Performance

New features for battery inverters will improve their performance and allow smoother interaction with other components. Delony 2017b reports that updates, such as droop control (allowing switching between different operation modes and power sharing between parallel inverters), in the capability of dual-mode inverters will help them shift easily from grid to island mode in black start and seamless forms. Better quality inverters will help battery performance and system efficiency as well as lowering costs.

Power Output

New battery technologies that have higher power outputs and inputs for long time periods can allow renewables to better provide support for power demands that are high for short periods. "The report said that one approach for providing that type of robust service is to include graphene in supercapacitors' electrodes, which will result in power capability that is 10 to 100 times higher than current batteries" (Delony 2017a).

Micro-grid systems in residential areas – the potential growth in the sector and different models being employed in trials and in use

Fringe of grid applications

- 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 power lines.

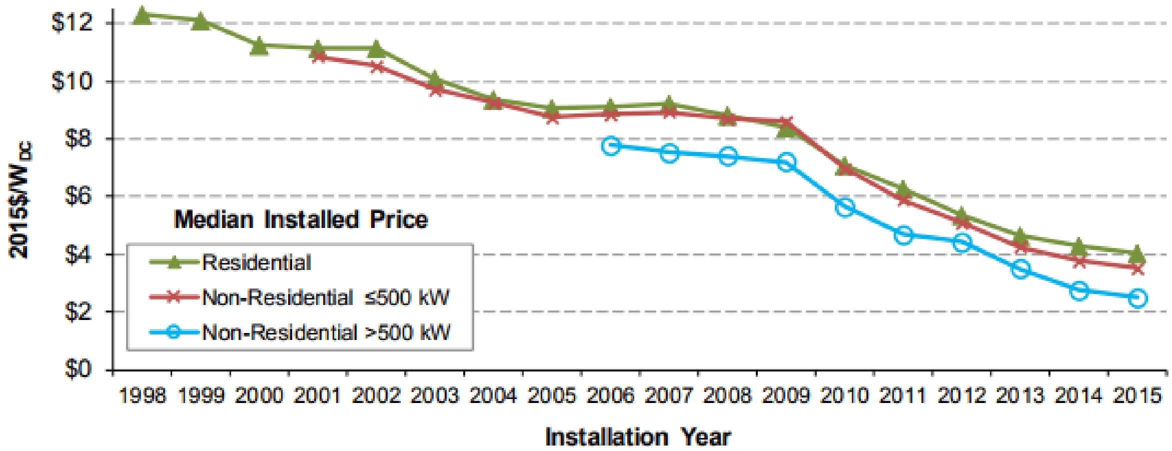

Figure 6: Long-Term and Recent Installed Price Trends (Barbose and Dargouth 2016).

Lower manufacturing costs, shown in Figure 6, demand management awareness in communities, education on the PV systems and building energy capacity has helped to increase solar battery systems.

3.3.1 Financing Micro-grid applications

Micro grid residential applications will include battery and PV systems and these project case studies help with the adoption of the technology. It is also another way this technology can be applied in residential areas in developing newer electrical grids. This application will be applied much more frequently and the lessons learnt will also help to develop these systems and make them better.

Table 3: Project ownership models as influenced by the involvement of the regional network operator (Handberg 2016).

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

3.4 Interest in PV/battery for micro-grids in residential areas

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

• The micro-grid 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 micro-grid 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 micro-grid 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) (Handberg 2016).

State and federal government policy on renewables and the history of rebates in W.A.

State policy has had an effect on the economics of solar PV and battery systems in W.A. This dissertation will not focus on government policy as its focus in on economic and technical issue; however, government rebates on panels through Small Technology certificates and rebates on the panels have helped to foster and grow the industry as did the generous FiT (an economic and policy issue). As the FiT has now been reduced to 7 cents/kWh this has also promoted more self-consumption of power and this is more supportive of battery use.

The Australia Renewable Energy Target (RET) for the different states and targets to achieve them have effected rebates for PV/batteries and their uptake. Indeed, the different states approach to battery technology and PV system uptake for residential areas has led to differing results.

Time of Use Tariffs and Solar/Battery systems

In W.A. there are two major energy retailers: Synergy and Horizon. Under the current system with Synergy, W.A. actually has some of the lowest service charges and electricity prices in Australia with South Australia having some of the highest. Australia does have higher electricity prices than other countries and the Western Australian electricity price has continued to grow though the past years. Synergy has predicted that solar PV and battery systems will grow and will have to adapt to this changing reality (Synergy 2017).

These two Retailers have different approaches for Time-Of Use and fixed rate which have different feed in tariffs for certain suburbs with some of the highest FiT in the Nation (under a Horizon scheme) for some regional areas and a much lower tariff for residential metro areas (7 cents/kWh). Time of Use Tariff plans do exist and would be useful with batteries, currently most residential areas are on the basic A1 tariff with a daily supply charge. The current tariff strategy for Synergy is behind cutting edge pricing controls and will take time to reform. A Solar credit scheme in Melbourne did exist which did help the industry in the state to start; however, Victoria has since lost many incentives for solar and battery systems and now has amongst the least incentives for solar and PV. A rebate on installation in Victoria also did exist which helped lower the labour costs. Horizon regional FiT in W.A. is much higher which is to help reduce the dependence of the grid for regional edge of grid towns. Some model towns now have micro-grids under Horizon which helps reduce grid costs and helps towns to save electricity. Horizon also has been much more accepting of renewable energy applications in farming areas. This could mean more case studies and more applications for PV and battery applications in W.A. Regional areas.

The focus on maximum self-consumption of electricity in Australia

Building and retrofits for energy efficiency and cost savings may include the installation of solar and battery systems. As solar and PV systems and education on energy savings are more widespread these systems will increase and become more popular. Battery and PV systems subsidies must be done with context and with the idea of growing the industry and lowering costs not just subsidising an industry. A focus on education and maximising the use of solar PV will have assisted the growth in the use of batteries.   Numen devices (energy monitoring) and other energy monitoring devices have shown an effect on energy use. In studies in Australia up to 20% of electricity has been saved in households who just had the information to make decisions with (Synergy 2017). Energy monitoring in inverters and battery management systems will help and have been shown to help reduce energy use. Better energy monitoring, matching needs to energy generated and more consumer information will help to increase consumer use of systems such as solar and battery systems.

Comparisons with W.A. and other countries PV/batteries

Western Australia has a range of advantages from great solar resources to a large area of land. Australia also has its own disadvantages from a lack of manufacturing in the industry to an uncertain policy climate. Australia also has challenges with growing the industry however these are not insurmountable challenges. All the states have a solar industry and W.A. has a growing solar industry. The main barrier is from battery costs and this looks to change in the next 5 to 10 years (Clean NRG Solar 2014).

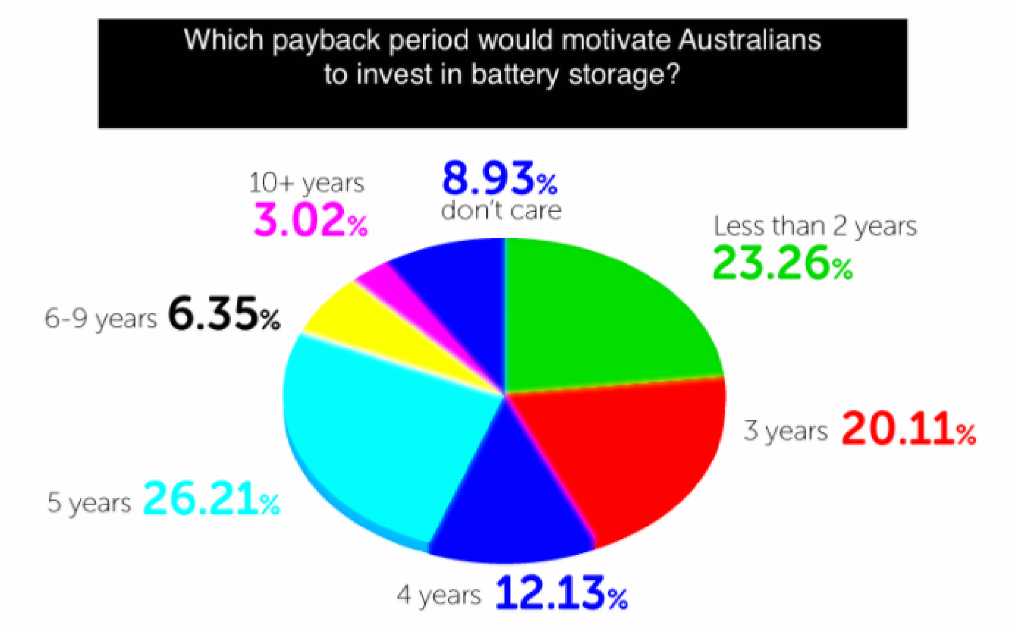

Figure 7: Which payback period would motivate Australians to invest in battery storage (Clean NRG Solar 2014).

Figure 7 above illustrates What payback period is most important to Australians with less than 2 years being the ideal. Electric cars, house charging and PV/battery systems in Australia are another potential growth factor for batteries such as the Ultrabattery. Electric/hybrid cars and solar charging at home is a future need for solar and battery systems in W.A. as the electric charging network grows and the costs of electric cars decreases. Improving battery technology for cars including the Ultrabattery use in cars could lead to synergy in the future.

An Architectural local perspective on trends in solar battery systems

Information from Bassendean: Sid Thoo Architecture and sustainability lecture.

From a live lecture by Sid Thoo, Sunday, September 17 2017 at 12:30 AM. Sustainable House Day in Bassendean, at the Bassendean Memorial Library and hosted by Bassendean Sustainability Network.

From the lecture by Sid solar BIPV (Building Integrated Photovoltaics) could also be another growth area with houses being retrofitted with PV and batteries or built with PV and batteries as part of the design. This is an interesting growth area for the Ultrabattery as it is a lower cost battery that may be more popular with home builders.

In Western Australia:

- Single phase vs. triple phase and battery systems in W.A. – Single phase systems which are the majority have a strict limit to what sort of inverters they can use.
- Increasing efficiency of inverters such as the SolarEdge and increasing warranties have helped to increase reliability of inverters.
- Battery management system and inverters information to consumers are getting better though warranty information could improve further for customers.
- In W.A. there is a maximum of a 5kW system to get the 7 cent tariff which naturally limited the size of usable systems.
- In W.A. there also needs to be a 3 phase inverter for batteries to be used and standards for inverters are not as well defined as other states. This has an effect on the type of battery and PV systems possible in W.A.

Lithium battery standard changes are also currently being considered which may impact on Lithium battery market share. The Lithium standard was challenged in Queensland which lead to increased installation costs to Lithium batteries. These changes will affect the more widespread use of Lithium batteries. Any further changes to Lithium batteries storage standard or safety standard will affect the growth of the technology.

Table 4: States and territories total solar PV installations and 2015 installations (Australian Energy Council 2016)

State / Territory	Population '000 (% of Australian population)	Solar PV systems installed in 2015	Total number of solar PV systems installed (by March 2016)	Share of total solar PV systems installed
Queensland	4,793 (20%)	38,839	470,953	31%
New South Wales	7,644 (32%)	32,522	331,378	22%
Victoria	5,967 (25%)	30,246	282,295	18%
Western Australia	2,598 (11%)	20,024	199,662	13%
South Australia	1,701 (7%)	11,764	194,927	13%
Tasmania	517 (2%)	1,944	26,660	2%
ACT	392 (2%)	989	16,655	1%
Northern Territory	245 (1%)	1,140	5,334	0%
Australia	23,857 (100%)	137,468	1,527,864	100%

As can be seen in Table 4, W.A. had a smaller proportion of solar systems than Queensland, NSW and Victoria and W.A. also has a lower proportion of soalr systems installed. There is consistent growth in this sector and batteries will have a proportion of this growth.

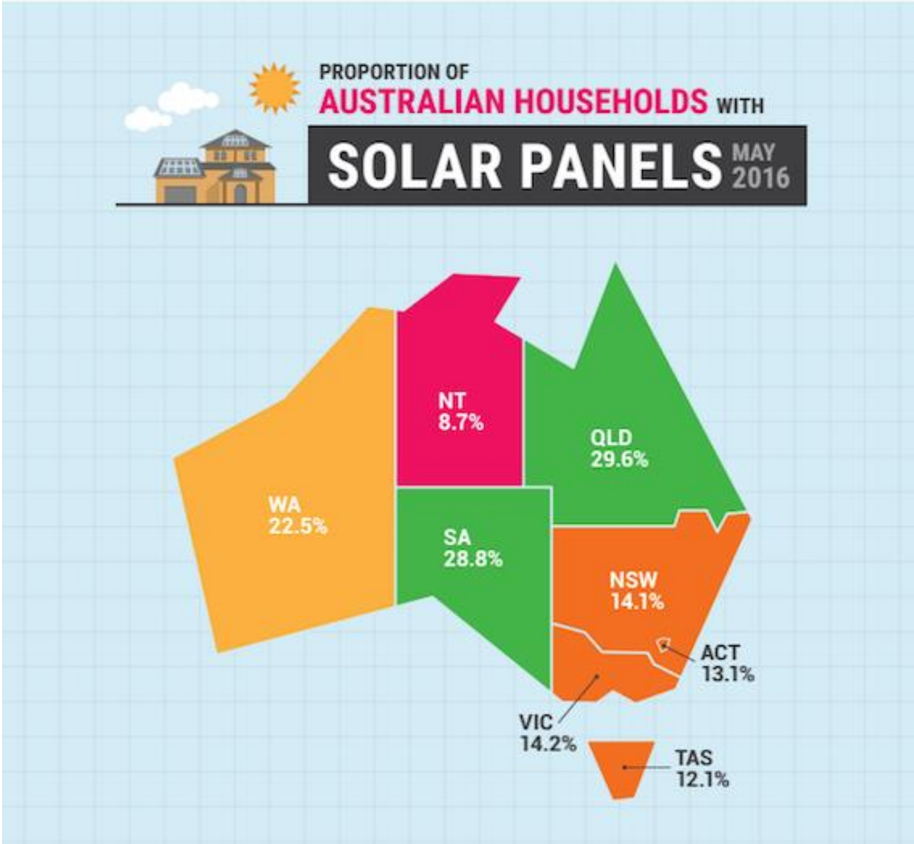

Figure 8: States and territories proportion of households with solar panels. (Climate Council of Australia 2017)

As can be seen in the Figure 8 above, W.A. in May 2016 had the third highest proportion of solar panels. Considering the land area and the space available in W.A. and other information on battery growth there is greater growth available for solar and battery systems.

3.5 Warnings of energy storage market chaos, as industry unites against ban

"The potentially industry crippling home battery installation safety guideline proposed by Standards Australia has again been slammed by the industry, as fundamentally flawed and – if passed – certain to throw the energy storage industry into chaos, both in Australia and overseas"

(Vorrath 2017). The power industry will need to contend with the growth of solar and battery systems. As these systems add to the power generation and energy trading platforms increase there will be disruption to the power utility industry in W.A. and around the world. Energy storage may face opposition in the industry as it may supplant the power utility market. The home battery will have technical challenges from how it will be used in conjunction with the grid as well as economic issue on how they become part of the grid. This may lead to Ultrabatteries used in residential application but not in homes but in larger battery farms depending on the economics. Figure 9 below shows some possible steps for battery introduction for residences.

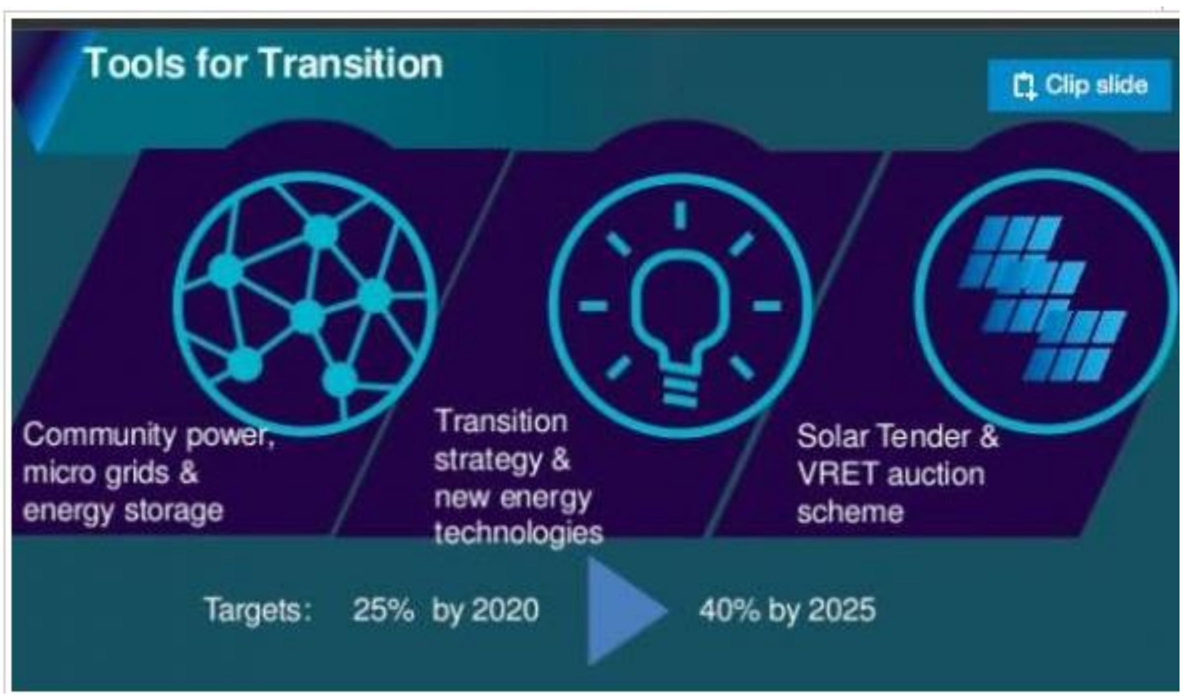

Figure 9: Tools for Transition (Parkinson 2016)

3.6 The History of lead acid batteries in solar renewables and research

There was a lot of early development of deep cycle lead acid batteries for use in telecommunications and remote applications. The first solar batteries were lead acid batteries. Later on as solar was used for residences beyond labs and space stations early use of lead acid batteries with solar photovoltaics was used in Australia. Different brands have been developed specifically for Australian conditions. Later local deep cycle lead acid battery technologies were developed. As the technology became more mature, hybrid batteries have now come to be seen as the forefront. There are challenges to lead acid based technologies for wider use as they are heavy and have lower discharge capability than other technologies; however, the Ultrabattery does not have this disadvantage. The "classic Lead Acid battery in stationary systems should be treated as obsolescent technology and it is expected that it will be exchanged in the near future with the new advanced hybrid Lead Acid Ultrabattery or other technologies, such as Nickel Zinc (NiZn)" (Jarnut, Wermiński and Waśkowicz 2017).

3.7 Lithium battery Risks and Ultrabattery advantages in the local context

- Rare earth metal.
- Manufacturing risk.
- Import risk.
- Ultrabattery manufacturing.
- Common components in lead acid batteries.
- Battle tested lead acid batteries however they are becoming obsolete.

  – Ultrabattery has a chance in terms of performance and cost.

– Fast cycling, efficiency and sustainability.

(Ecoult 2017).

Figure 10: Ultrapod Ultrabattery – An Ultrabattery for residential applications (Ecoult 2017).

Residential products

For residential applications Ecoult supply their UltraPod and UltraFlex products, which can deliver between 4 and 20 kW (4 to 17 kWh) at 48 V.

These products provide:

- CSIRO-developed UltraBattery technology.
- High cycle life, efficiency and power (publicly tested by SANDIA and other world-leading laboratories).
- Increased energy independence.
- High surge power to cover peak moments when several household members turn on appliances and devices at once.
- 50° C temperature tolerance for hot environments.
- Easy installation with indoor and outdoor options.

- Australian-built engineering, software and hardware.
- Batteries manufactured in the environmentally award-winning East Penn plant in the US.
- Sydney-based engineering support team and distributors across Australia.
- The world's most sustainable closed-loop recyclable battery"

(Ecoult 2017).

3.8 Use of smart meters and Time of use tariffs on battery/ PV systems

- Smart metering schemes.
- Feed-in-Tariff schemes.
- Smart tariffs and real time pricing.
- The adoption of PV – battery systems for the management of peak demand and deferment of investments in distribution networks may be a result.

Energy saving devices that are now coming into the market including energy auditing equipment, specialised devices like the "Numen" device and improving Battery Management Systems will help to increase the uptake of battery and PV systems. They may have a greater impact on the market going forward. Maximising self-consumption as an important factor in grid-connected PV-Battery systems. The more power the system uses the more the benefit from a PV and battery system.

The growth in the different states of Australia will depend on factors such as cost (effected by subsidies and electricity prices) and also policy (what will be needed for batteries and solar systems). The different utilities FiT in each state also has an effect. Many of the solar companies I have asked for quotes regarding batteries explain how batteries can also be retrofitted later to PV systems. Education of solar systems is growing as well as awareness. Lowering the barriers to solar systems for different housing populations in Australia is needed. Barriers include expert personnel, availability of different appropriate batteries and the cost of batteries. The easier it is to install a battery, the lower the cost of a battery and installation as well as the knowledge of how a battery can help consumers will increase these systems. The Ultrabattery and other battery technologies have the opportunity to use to increases their market share by taking into account the consumers' needs and knowledge.

The increasing use of smart meters and Time of use tariffs on Ultrabattery and PV systems in W.A. will mean:

- Smart metering schemes are being considered as well as smart meters by Synergy and will be proposed next year.
- FiT schemes will continue in W.A.
- Smart tariffs and real time pricing are currently being trialed and a Time of Use Tariff suitable for batteries already exists.
- The adoption of PV and battery systems for the management of peak demand and deferment of investments in distribution networks. Devices including the Numen device and others on energy use and battery/PV systems will also help to grow these technologies (Bainbridge 2017).

Energy saving devices that are now coming into the market including energy auditing equipment, specialised devices like the Numen device and improving Battery Management systems will help to increase the uptake of battery and PV systems. They may have a greater impact on the market going forward. Maximising self-consumption is an important factor in grid-connected PV and battery systems. The growth in the different states of Australia will depend on factors such as cost (effected by subsidies and electricity prices) and also policy (what will be needed for batteries and solar systems). The different utilities FiT in each state also has an effect. Many of the solar companies I have asked for quotes regarding batteries explain how batteries can also be retrofitted later to PV systems. Education of solar systems is growing as well as awareness. Lowering the barriers to solar systems for different housing populations in Australia is the government policies, economics and market drivers.

4.0 PEN624 Renewable Energy Dissertation Analysis and Discussion

Background

- The battery rollout.
- Renewable energy and the rising cost of electricity.
- What does storage mean for residential customers?
- Customer-side – residential level (backup power, customer energy management, bulk energy shifting, power quality).
- What was chosen for analysis and what will not be considered.

4.1 SAM Modelling results

The results show that Lithium batteries can have a payback of 7 to 10 years depending on the size of the system. For Ultrabatteries have a third of the Lithium battery cost however they may need more capital for pallets so the cost payback could be 5 to 8 years (refer to the Appendix for results).

SAM Model

The SAM battery models were done using guidance form the SAM website and following the same steps.

SAM Modelling Assumptions:

- Data sources – Literature from Ecoult and modelling papers referenced in the literature review.
- Battery costs $/kWh dc – kept this at standard costs for lithium and estimated cost for Ultrabattery based on Literature from the company.
- Battery models in SAM – Used available models.
- Modelling the Ultrabattery – used publically available information.
- FiT, rebate and electricity costs assumptions – used current FiT from Synergy and costs as per a “regular” household.

A fixed FiT was used for the simulations however power prices were varied to see the effect on system payback costs in line with expected increases in the price of electricity. Refer to the SAM methodology in earlier sections for details.

Questions that were asked during modelling:

- Why simulate SAM and HOMER? They were the best tools for Technical and economic focus analysis on a cost and one-on-one basis.
- What was focused on? - Payback costs, local data and relative costs.
- Where this information was found – data sheets from Ecoult, LG Chem and using estimated load profile data.
- How this information is useful for society? Refer to the literature Survey.
- The effects of rebates and FiT in W.A. for battery systems – Solar rebates have the largest effect for W.A. as there are no current battery rebates.

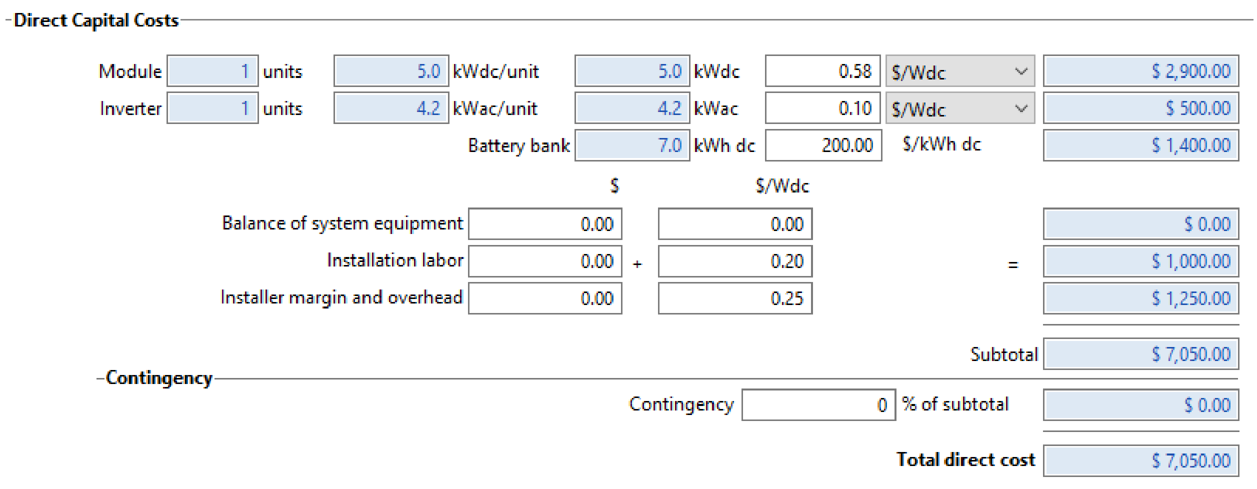

Figure 11: Example Lithium SAM screenshot (SAM Program). (Note that 5kWdc/unit module and 7 kWh dc battery bank do not match due to different prices for the units not sizes)

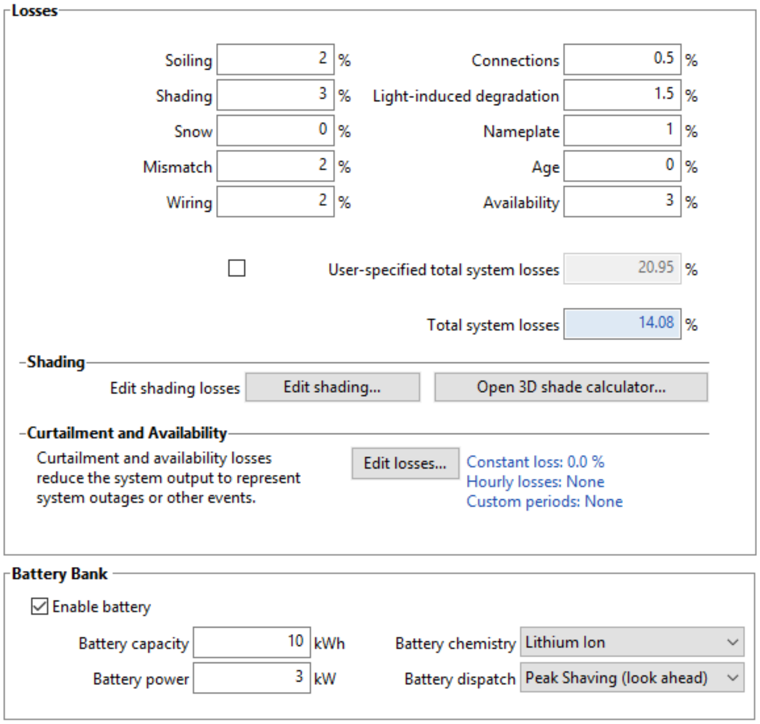

Figure 12: Lead-acid SAM screenshot (SAM Program). (Note that the battery capacity is modelled higher due to program restrictions for Li Ion modelling and is only an example)

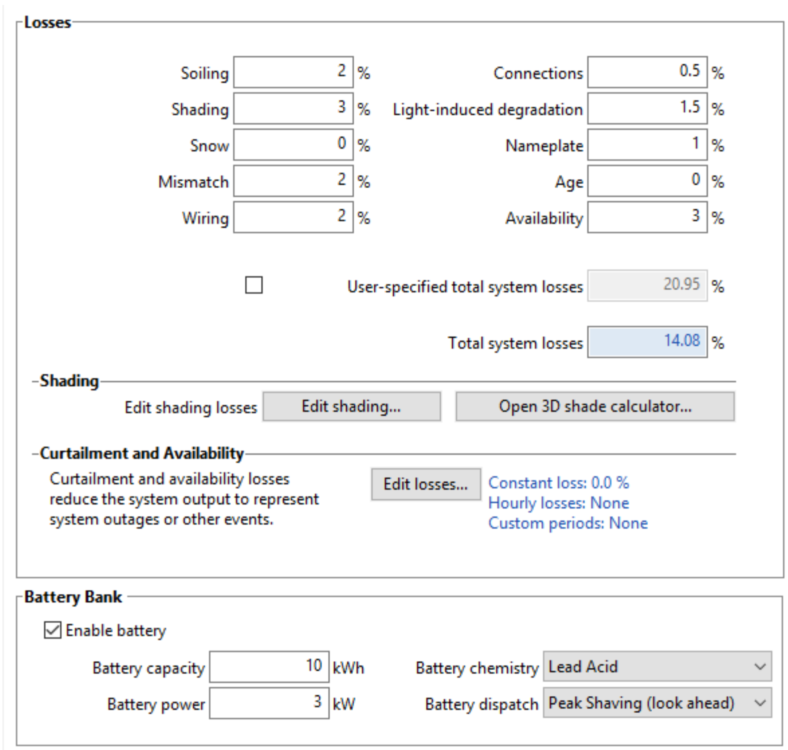

Figure 13: Ultrabattery SAM screenshot (SAM Program). (Note that the battery capacity is modelled higher due to program restrictions as no Ultrabattery model exists)

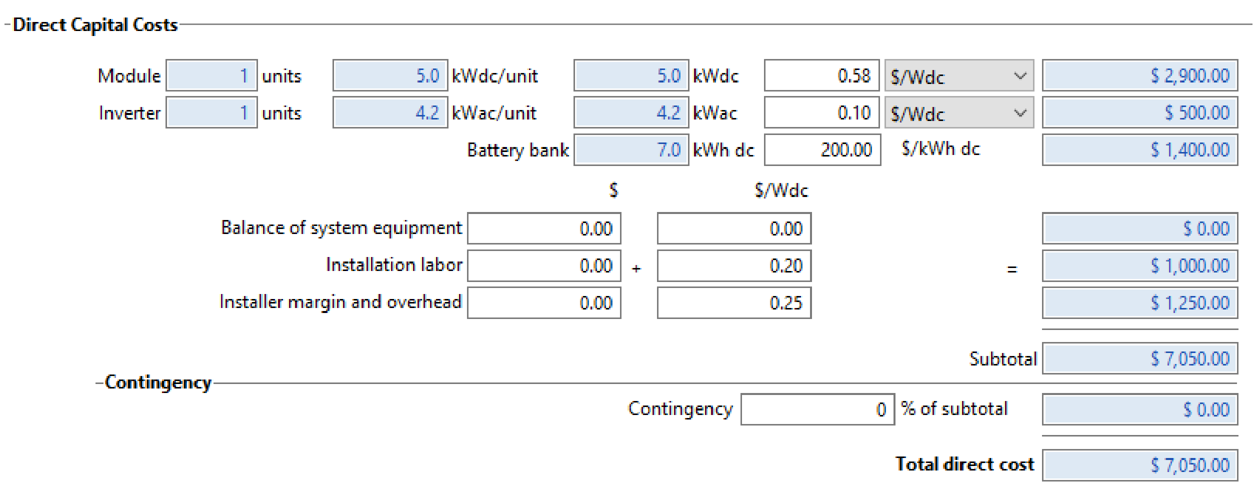

Figure 14: Capital costs in SAM for batteries (SAM Program).

Lithium

The screenshots Figures 11 to 15 show how the data was input into SAM. Costs were important in terms of the size for the simulation. SAM looks more at the technical aspects of the running of the batteries and so the focus is how these batteries differ from Ultrabatteries in terms of payback and lifetime costs.

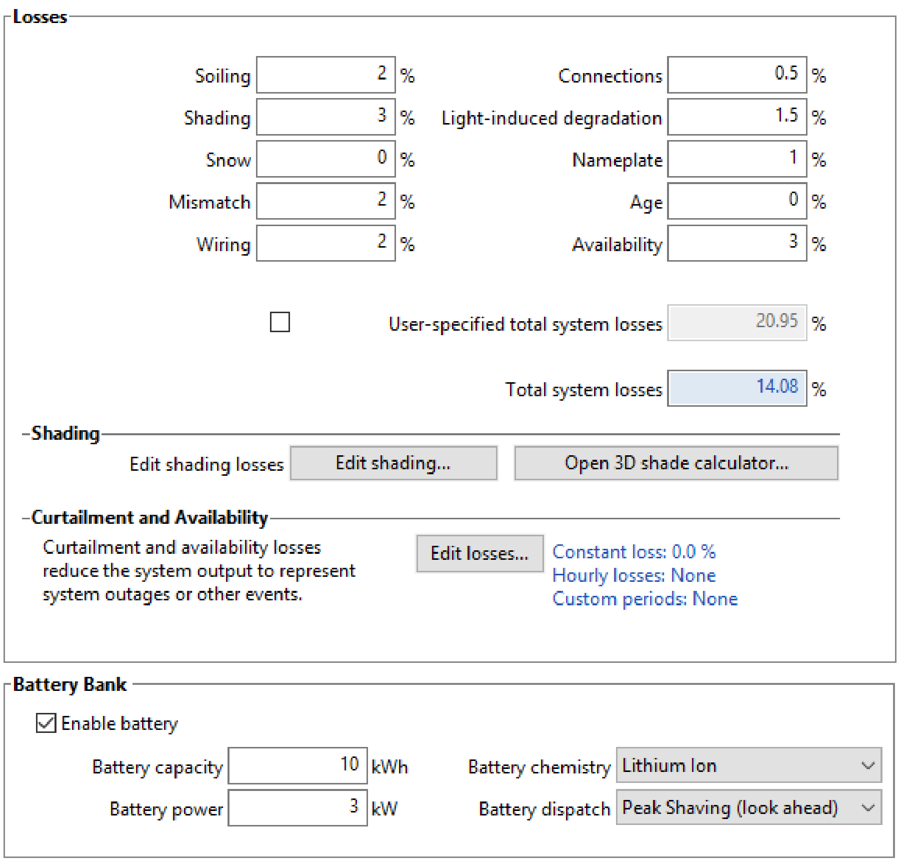

Figure 15: Lithium Battery dispatch and model (SAM Program). (Note that sizes varied for simulations and the above is only an example)

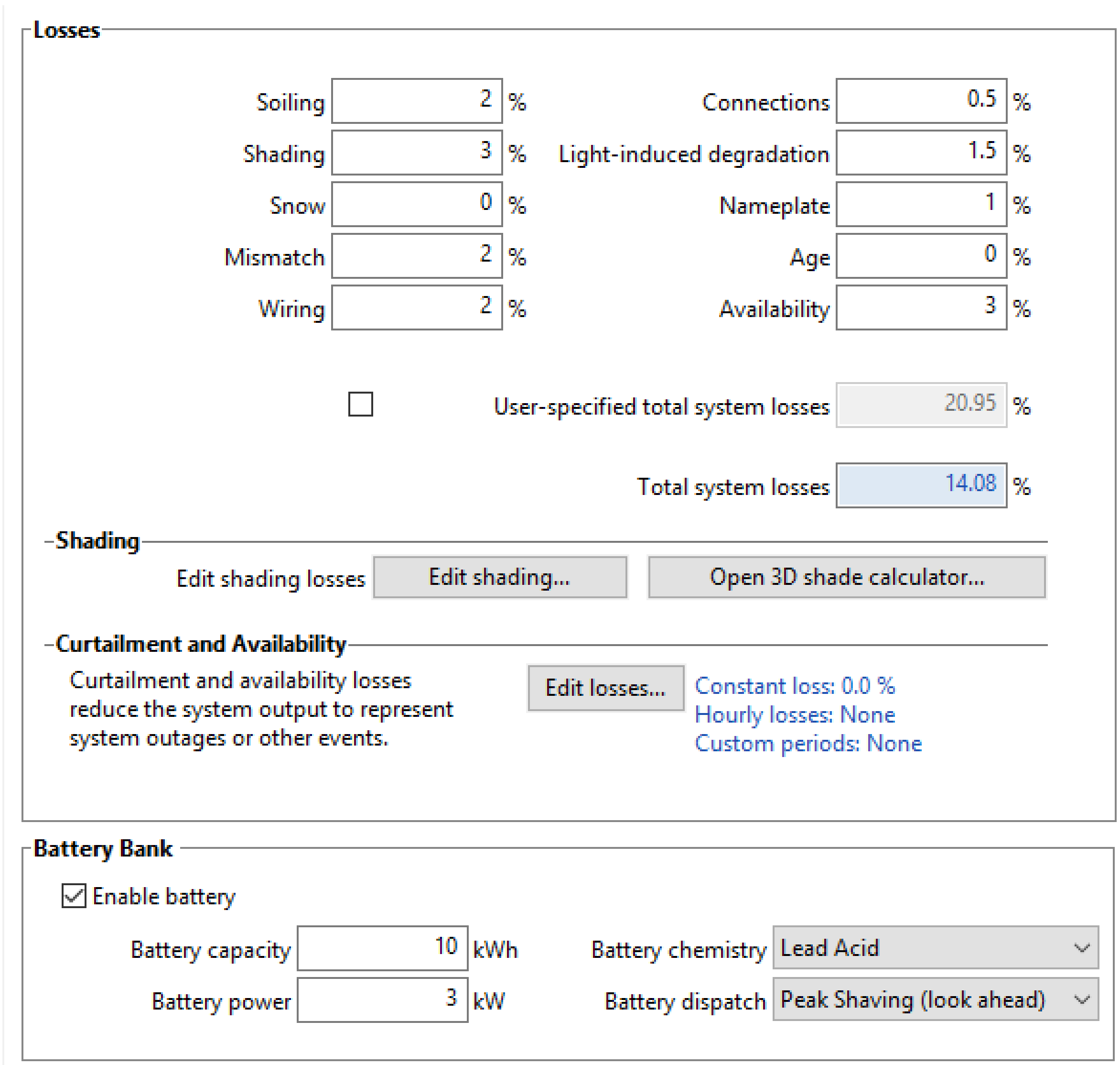

Figure 16: Lead Acid Battery dispatch and model (SAM Program). (Note that sizes varied for simulations and the above is only an example)

As can be seen in the above print screens a lead acid battery is cheaper however the lithium has far more advantages in the model. For the Ultrabattery price and operation controls were modified within the existing models provided according to data available.

4.2 HOMER Modelling results

HOMER Model Assumptions

- Battery costs – from quotes/literature
- Ultrabattery model – from literature
- Lead acid model – from literature
- Lithium battery model – from HOMER
- FiT, rebate and electricity costs assumptions – from existing Synergy data based on the A1 plan (Vikas, Nema and Baredar 2014).

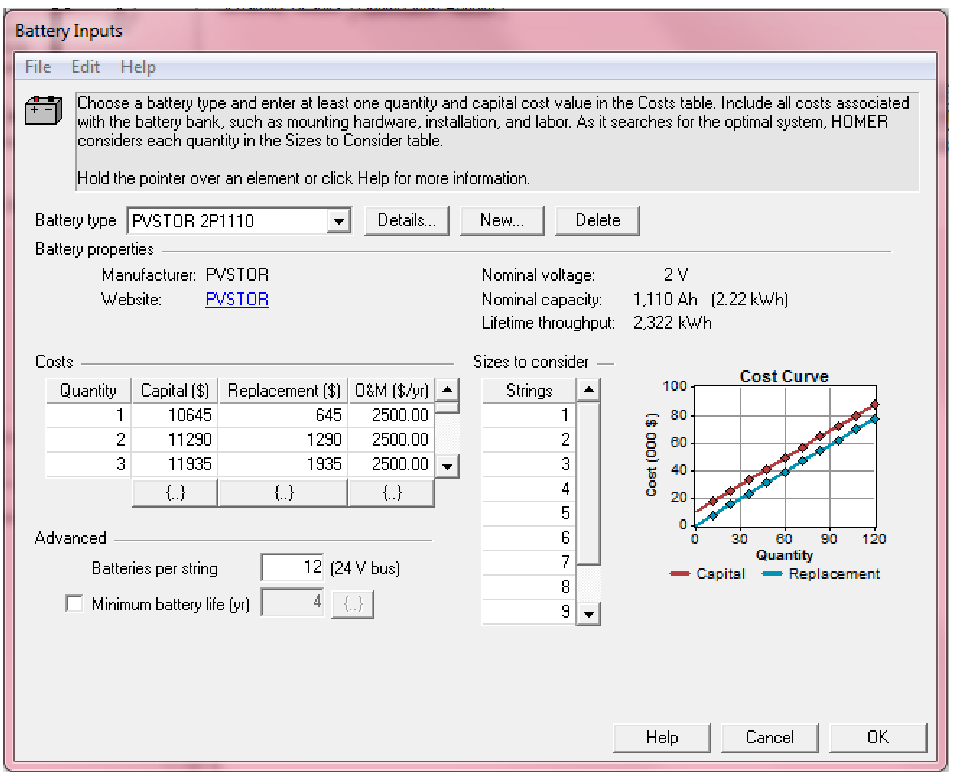

Figure 17: Lead acid battery HOMER Screenshot (HOMER program). (Note that sizes varied for simulations and the above is only an example)

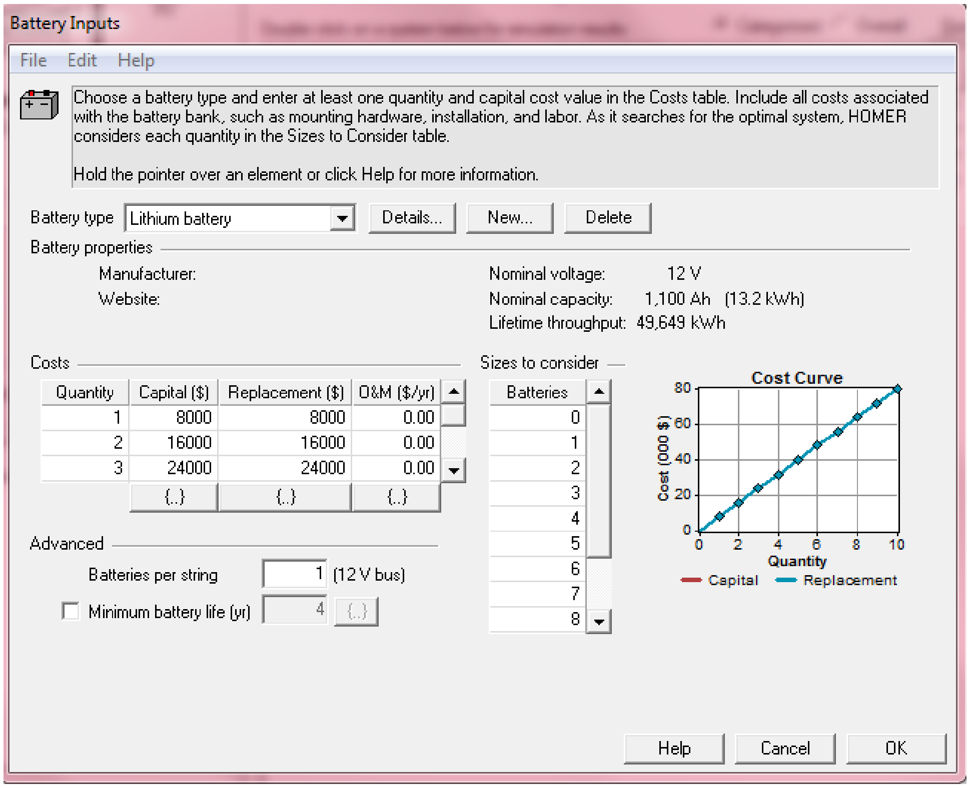

Figure 18: Lithium HOMER Screenshot (HOMER program). (Note that sizes varied for simulations and the above is only an example)

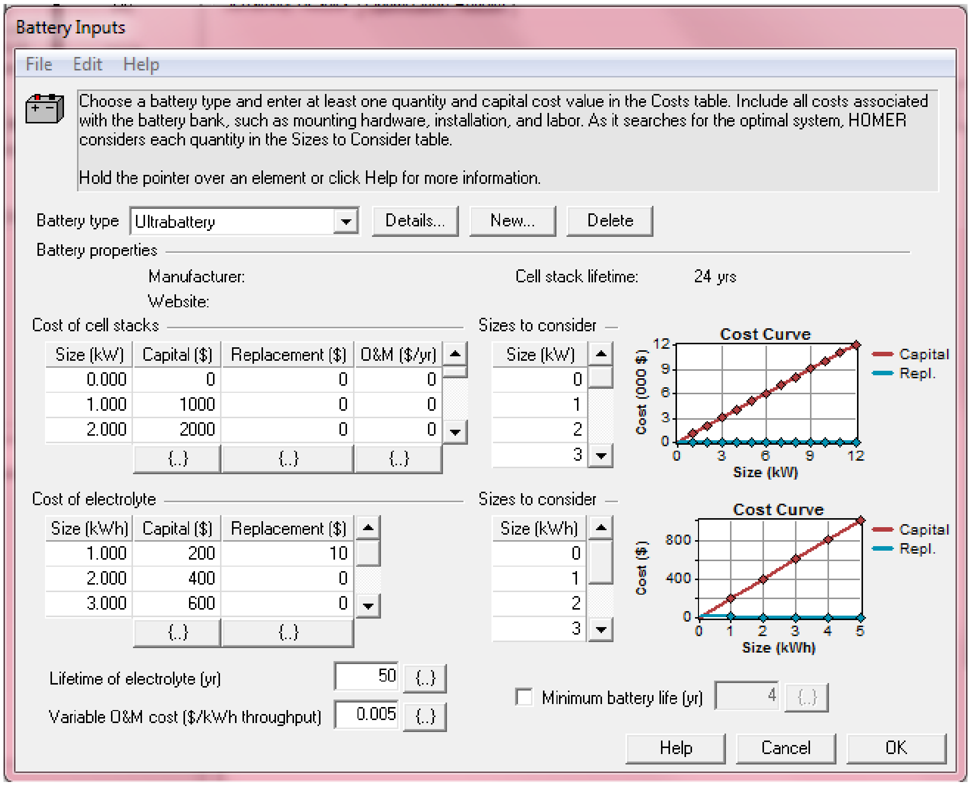

Figure 19: Ultrabattery HOMER Screenshot (HOMER program). (Note that sizes varied for simulations and the above is only an example)

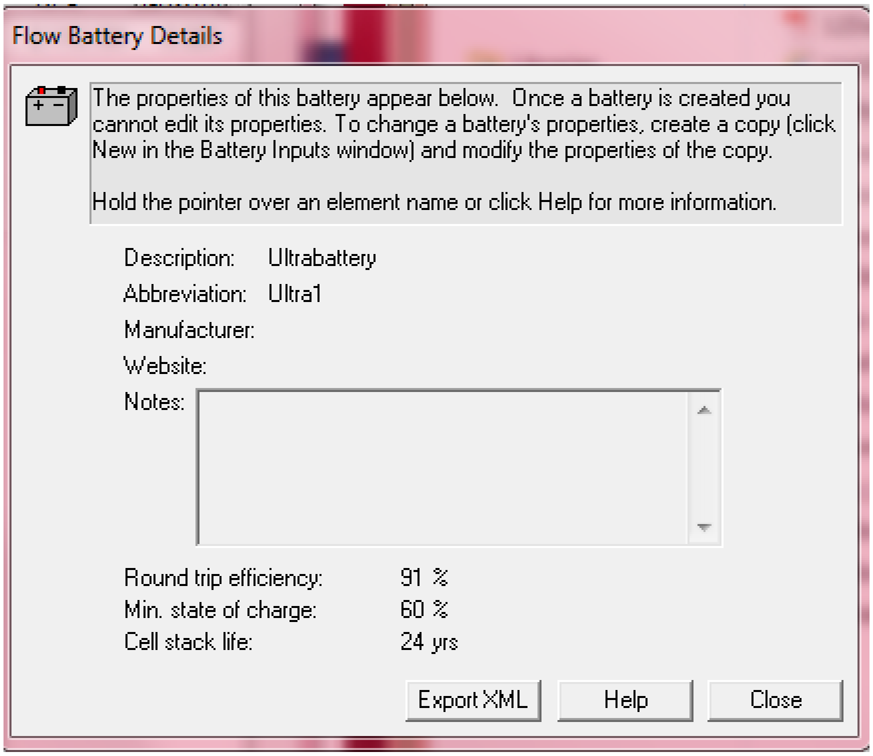

Figure 20: Battery inputs acid battery (HOMER program).

HOMER

HOMER was used for simulation using available battery models. Modelling was done for the three battery types as shown in Figures 18 to 23. Costs for electricity effecting payback, rising costs and the costs of heatwaves was also analyzed briefly for sensitivity from 27 cents/kWh to 40 cents/kWh.

Lead acid battery:

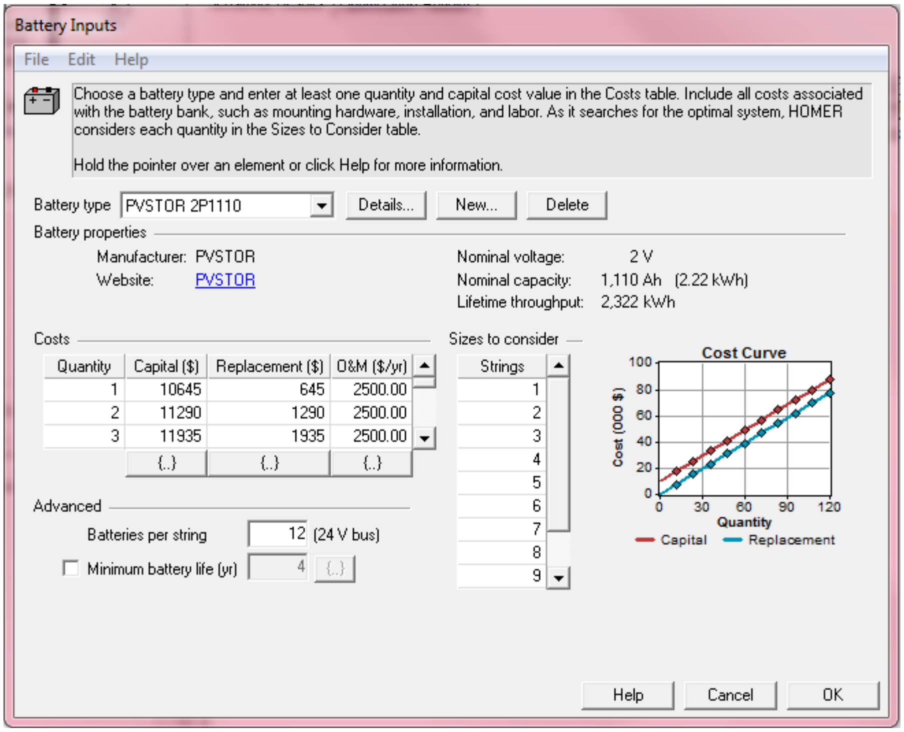

Figure 21: Lead acid costs (HOMER program).

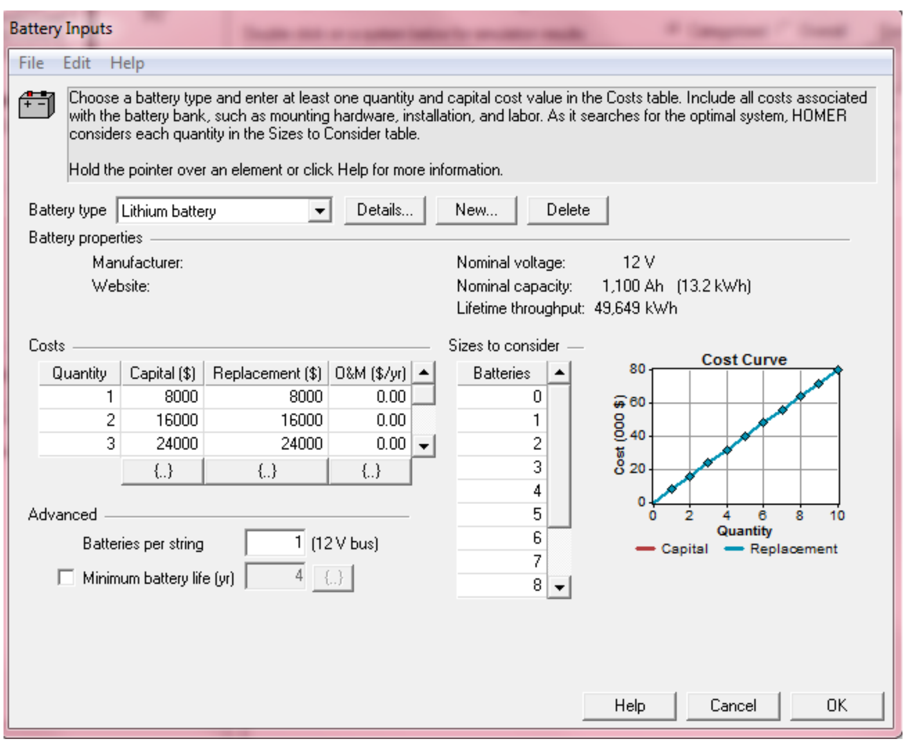

Figure 22: Lithium battery costs (HOMER program).

Ultrabattery: For the Ultrabattery simulation there had to be some assumptions since the HOMER program uses certain assumptions and there is not a prescribed Ultrabattery model. From the HOMER simulations the results of the battery types show lead acid batteries have a higher upfront cost due to pallet however Ultrabattery may be cheaper in the long run over Lithium as seen in figures 20 to 23.

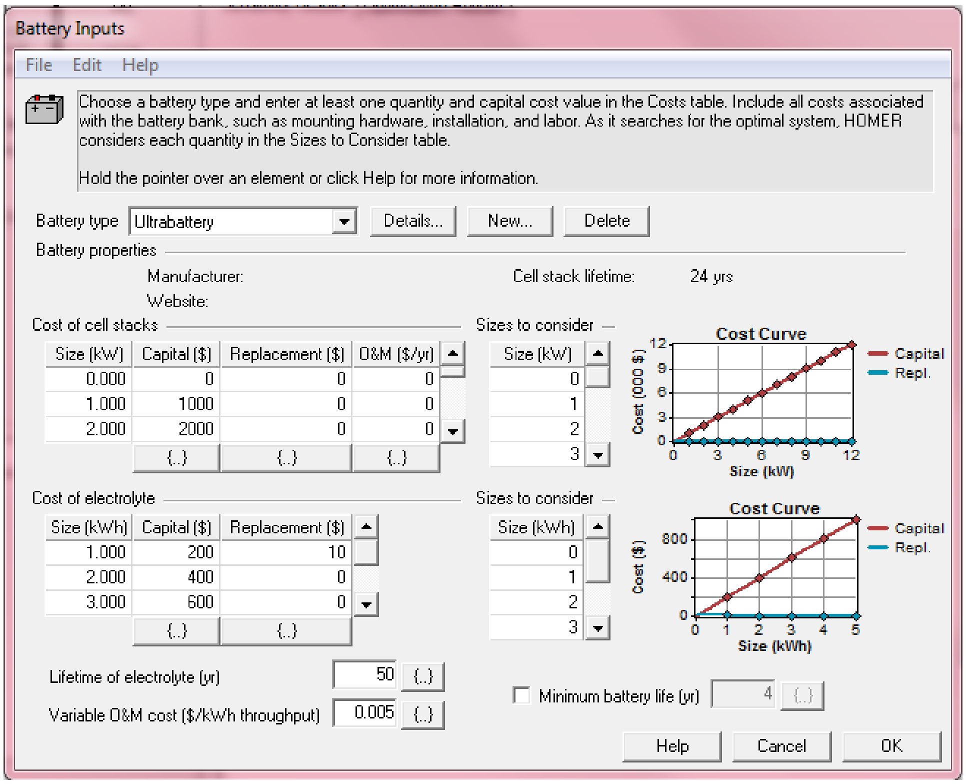

Figure 23: Battery Inputs screenshot of cost (HOMER program).

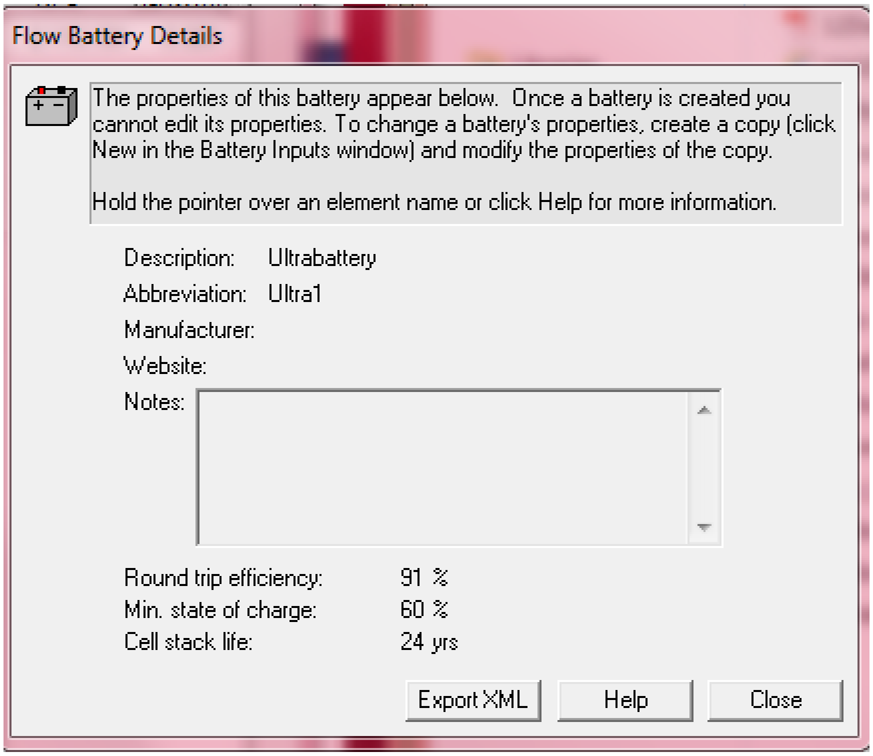

Figure 24: Screenshot of Ultrabattery (HOMER program).

As can be seen in the above, print screens Figures 17 to 24, there is a limit to data input however HOMER can also compare multiple systems together allowing for some comparison of costs and feasibility study for sizes of batteries and PV systems.

4.3 Comparing battery types

Lead acid – Modelling results

- Lead acid batteries have a payback period of 10 to 15 years
- This means that for most houses the payback is often not worth it as well as the space needed for lead acid batteries.

Lithium

- Lithium batteries payback will be as low as to 7.5 years for W.A.
- This does make the payback acceptable.

Ultrabattery

- Ultrabatteries has shorter payback periods than Lead acid batteries of 5 years this is just using one simulated size and cost which was from company claimed prices.
- Ultrabatteries could be used as a combination with other types of panels and inverters which may help to lower overall system costs.
- Modelling hybrid batteries was done within what was possible for lead acid batteries and modeling in the program.

Table 1: Operating parameters of advanced and conventional lead-acid batteries (CSIRO 2015).

Parameter → Technology ↓	Typical life time Years (cycles)	Power density Wkg^{-1} $/kWm^{-3}$	Energy density $Whkg^{-1}$ $/kWhm^{-3}$	Typical discharge time	Recharge time	Response time	Operating temperature °C	Self-discharge %/day	Critical voltage/cell V
Lead-acid battery	3–15 (2000)	75–300/90–700	30–50/75	min– h	8–16 h	5–10 ms	−10 to 40	0.1–0.3	1.75
Advanced lead-acid battery	3–15 (3000)	75–300/90–700	30–50/75	min–h	8–16 h	5 ms	−10 to 40	0.1–0.3	2

Table 2: Advantages and disadvantages of advanced lead-acid batteries (CSIRO 2015).

Advantages	Disadvantages
• Low cost • Low self-discharge • Rapid response • Has one of the highest recycling rates compared to other batteries	• Relatively low specific energy density • Need to be kept at charged state • Uses toxic lead and corrosive acid • Shorter cycle life at higher temperatures

Table 3: Characteristics of different energy storage technologies (CSIRO 2015).

Parameter → / Technology ↓	Typical life time Years (cycles)	Power density Wkg⁻¹ /kWm⁻³	Energy density Whkg⁻¹ /kWhm⁻³	Typical discharge time	Recharge time	Response time	Operating temperature °C	Self-discharge %/day	Critical voltage/cell V
Lead-acid battery	3–15 (2000)	75–300/90–700	30–50/75	min– h	8–16 h	5–10 ms	−10 to 40	0.1–0.3	1.75
Advanced lead-acid battery	3–15 (3000)	75–300/90–700	30–50/75	min–h	8–16 h	5 ms	−10 to 40	0.1–0.3	2
Nickel-cadmium battery	15–20 (2500)	150–300/75–700	45–80/<200	s–h	1 h	ms	−40 to 45	0.2–0.6	1
Lithium-ion battery	8–15 (500-6000)	230–340/1300–10000	100–250/250–620	min–h	min–h	20 ms–s	−10 to 50	0.1–0.3	3

Importantly, some of the technologies listed in Table 3 are more mature than others, and thus are suitable for immediate deployment for grid applications. Examples of existing larger-scale deployments include advanced lead-acid batteries that have been demonstrated in the “Hampton Wind Park, New South Wales, and Li-ion batteries installed on Mackerel Island, Western Australia” (CSIRO 2015).

4.4 Payback periods and cost analysis

- Sizes used for the analysis were:

  For pure solar systems– 2,5 and 6.5 kW.

  For Lithium battery systems – 2,5 and 6.5 kW.

  For Lead acid battery systems – 2,5 and 6.5 kW.

  For Ultrabattery systems – 2,5 and 6.5 kW.

From the results from the simulation:

- Ultra-battery can pay back in shorter time than Lithium batteries.

- W.A. has a lower payback period for standard Lithium batteries than other states.
- Ultra-batteries are cheapest for the capacity and abilities it has.

4.5 Results

As can be seen from the modelling results and literature review:

- As power prices in W.A. increase pure solar systems continue to grow and is popular.
- W.A. has some of the best solar resources and along with some of the highest electricity prices has meant that battery and solar systems have shorter payback periods.
- Of the three batteries simulated with the assumptions stated the Ultrabattery is either on par or has a shorter payback period than existing Lithium batteries.
- Growth of solar systems is steady however the growth of solar and battery is much smaller due to the costs of batteries and BMS and has longer payback periods as seen in simulations.

Impact of FiT and battery prices on payback periods

- FiT had less effect than the battery prices.

Impact of electricity prices on payback of PV/battery systems on Ultrabattery

- Electricity prices do have a greater effect on the viability and lower payback of these systems.

4.6 Analysis and interpretation of results

The results from the modeling and literature review show that existing modeling methods can be used and payback for the Ultrabattery and Lithium models have a payback from 5 to 7.5 years. Further modeling will need to be done in 5 years as electricity prices go up and the different models for PV and battery systems are implemented as well as when the final pricing for the Ultrabattery is known.

4.7 The significance of the results

1. The significance of solar and batteries for consumers, companies, government and the community are that batteries allow more flexibility, cost savings and additional utility such as trading spare power or charging an electric car.
2. The significance of a battery like the Ultrabattery is that is it tested in multiple applications, cheaper than Lithium and easier to use than Lead-acid.
3. The significance for residential solar and renewable energy in W.A. is the cheaper and more standardized energy storage systems will become more popular in states with higher electricity prices it could be assumed.

The limitations of the results

Modelling assumptions and literature assumptions define the limits:

1. Data source assumptions – limit simulations ability to predict payback.
2. Modelling the batteries – the programs themselves limit what can be simulated to an extent.

Dissertation assumptions and limitations include that the scale has been limited and does not cover larger micro-grid systems.

The extent to which the aims of the research were achieved:

The project's aim and research objectives were:

The aim of a is to look at the technical, economic and cost benefit analysis for Ultrabatteries in comparison to other current battery systems in the market and only solar PV systems. This analysis was completed using software and literature review. The project looked at Lithium, Sodium, Vanadium and Zinc-Bromine or flow battery technologies shortening it to the three mentioned in this project. In this project, my objectives were to increase knowledge and understanding in this field to prevent blackouts and brownouts by showing the potential of batteries, develop the battery storage industry further and increase knowledge available more publicly for these technologies. This part was not covered as much due to time constraints and because it was thought that comparing three technologies would be sufficient.

4.8 Discussion

From these results, here it appears if the Ultrabattery does indeed fulfill the manufacturers claims it will have a successful niche in the W.A. Market. Further research and analysis will have to be done in a few years' time when the literature and trends suggest that battery prices will lower and there will be more competition in the market. Market forces may also be more favorable. Also, it appears that costs and policy will have determining factors as well as availability. Technical issues in modeling may also be present.

General points

- Background – The W.A. market has unique conditions compared to other states and locations.
- What the results seem to indicate - that the Ultrabattery will have a market niche assuming assumptions given previously.

5.0 Conclusion

The Ultrabattery, lithium batteries and W.A.

The Ultrabattery would seem to have a growing market considering recent changes in the price of solar systems and beneficial economic factors. If Ecoult's cost numbers can be realised it would be a competitor with the popular and more common Lithium home batteries. The lead acid hybrid battery (Ultrabattery) uses a more tried technology with a better price point. Lithium batteries lose capacity due to having a BMS to control thermal runaway and still have a higher price point. Australians expect home storage to become normal and W.A. is a growing solar home PV sector in Australia.

Lithium batteries are currently the market leader and solar PV; however, even in residential uses it still has a small proportion of the renewable energy generated. The SWIS continues to need to develop to use the solar PV available and these technical issues still remain to be worked on.

W.A.'s unique position of not being connected to the NEM and world class resources should be capitalised on and using an Australian made and designed battery would be one way to capitalise on this. Lithium batteries are constrained by the relative rarity of Lithium as well as its current use in other types of battery. The Ultrabattery is made of more commonly available materials which are also cheaper to source.

Modelling results and analysis findings

From the modelling results we see that Ultrabattery Ultrapods may be able to pay themselves in 5 to 8 years depending on the size of the system using average load profiles. The Lithium batteries currently have 7 to 8 years for payback with higher payback times for premium lithium batteries such as the Tesla Powerwall 2. Currently the most price efficient system is a pure solar system with batteries expected to be more common in 5 to 10 years as prices drop from market increase and improvements in manufacturing. The market sector may not need a subsidy, the more it is encouraged in the marketplace and the removal of barriers will help the markets growth. Currently the Ultrabattery needs to be trialed in more residential applications and battery standards must be kept consistent.

The deep cycle lead acid battery is the longest in use solar battery in Australia. It has been used for decades in remote applications and is a proven technology in the Australian environment. The Ultrabattery provides more capacity and power as well as reliability to a residential market which is looking for better payback periods and is uncertain about recyclability of batteries. Here in W.A. the long record of the lead acid battery in Australia is a benefit and should be a benefit to the expansion of the market for the Ultrabattery.

Different Australian states and the Ultrabattery

Western Australia does have specific benefits for Ultrabatteries compared to other states including many solar retailers, availability and incentive for batteries as well as a battery standard. While SA may have incentives for batteries and Queensland may have more of a battery market there is definitely an opportunity for growth of the Ultrabattery in W.A. There are a decent amount of owner occupiers and subsidies for the PV systems themselves. A sign of the growth of PV systems could be seen in the fact that Synergy now sells such systems and is currently having an ad program to promote PV/battery systems.

The federal government has discussed about dispatchable power and each of the different states have Renewable energy targets and lowering emissions targets. Ultrabatteries and home storage will clearly play a role in these targets and in Australian homes. The different competing technologies need favourable economics and customer/ retailer familiarity for their growth in market share. In this environment the Ultrabattery has notable advantages in being a dependable technology with none of the disadvantages of the lithium batteries and may of its advantages for each state.

Micro-grids, PV/battery systems and residential decentralised grids

The future growth of PV/battery systems cannot be fully known. While prices continue to decrease for such systems and factors continue to be positive for storage the form it may appear in is yet to be seen. Currently peer-to-peer trading is still being trialed as are residential micro-grids and is an exciting area for growth of PV and battery systems. The decentralised energy market is also being proposed which may give further incentive for home storage systems so that anyone may sell their power to their neighbor. The policy and technical challenges of such systems still remain to be solved. The technical challenges for the Ultrabattery is fewer compared to Lithium ion batteries which have already been used successfully in micro-grid trials and in home systems. Western Australia appears to be near to a tipping point in regards to our electricity supply and the Ultrabattery will be able to take advantage of the current electricity market public discussion.

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APPENDIX

Battery ban off the table after industry roundtable "consensus"

"Australia's energy storage industry looks to have notched up a quiet win earlier this week, with the news that Standards Australia appears likely to scrap draft guidelines that could have effectively banned the installation of lithium-ion battery systems in Australian homes and garages" (Vorrath 2017).

ACT tips another $4m into home battery subsidy scheme

"The Australian Capital Territory government will extend its subsidised roll-out of battery storage to Canberra homes and businesses, after announcing on Wednesday that it would allocate another $4 million to support the scheme" (Vorrath 2017).

Thousands of Canberra homes to receive subsidised battery storage

"Thousands of homes and businesses in the Australian Capital Territory will be equipped with battery storage in coming years in the largest subsidised roll-out of battery storage outside of Germany. More than 5,000 homes and households will get discounted battery storage under the latest round of capacity auctions for large scale renewables in the ACT. Around $25 million will be raised from the auctions for the specific purpose of subsidising battery storage installations in the national capital" (Vorrath 2017).

"Perth:

Under Stage 1 of the Perth Solar City project it is proposed to:

- install 6,000 smart meters and 2,514 smart meters with monitors
- distribute and install 6,300 Perth Solar City energy efficiency packs
- have 20 schools install a 1 kW photovoltaic system and in-class monitors.
- install 663 1 kW PV systems and 695 solar hot water systems."

(Solar Cities in Australia 2017)

"Victoria is putting $25 million towards its tender for 100MW of storage, while South Australia is putting up to $15 to $20 million, and may also write contracts to provide "firm" output at critical points" (Parkinson 2016).

Western Australia

"Western Australia's largest solar power farm, the Greenough River Solar farm, is at Walkaway, 70 km SE of Geraldton. It was opened in October 2012. The 10MW field has 150,000 solar panels."

Solar cities program

Main article: Solar Cities in Australia

Solar Cities is a demonstration program designed to promote solar power, smart meters, and energy conservation in urban locations throughout Australia. One such location is Townsville, Queensland.

Renewable Energy Master Plan 2030

The Council of Sydney is attempting to make the city run 100% on renewable energy by 2030. This plan was announced earlier in 2014 with the blueprints made public on their website. This ambitious plan was recently awarded the 2014 Eurosolar prize in the category of "Towns/municipalities, council districts and public utilities".”

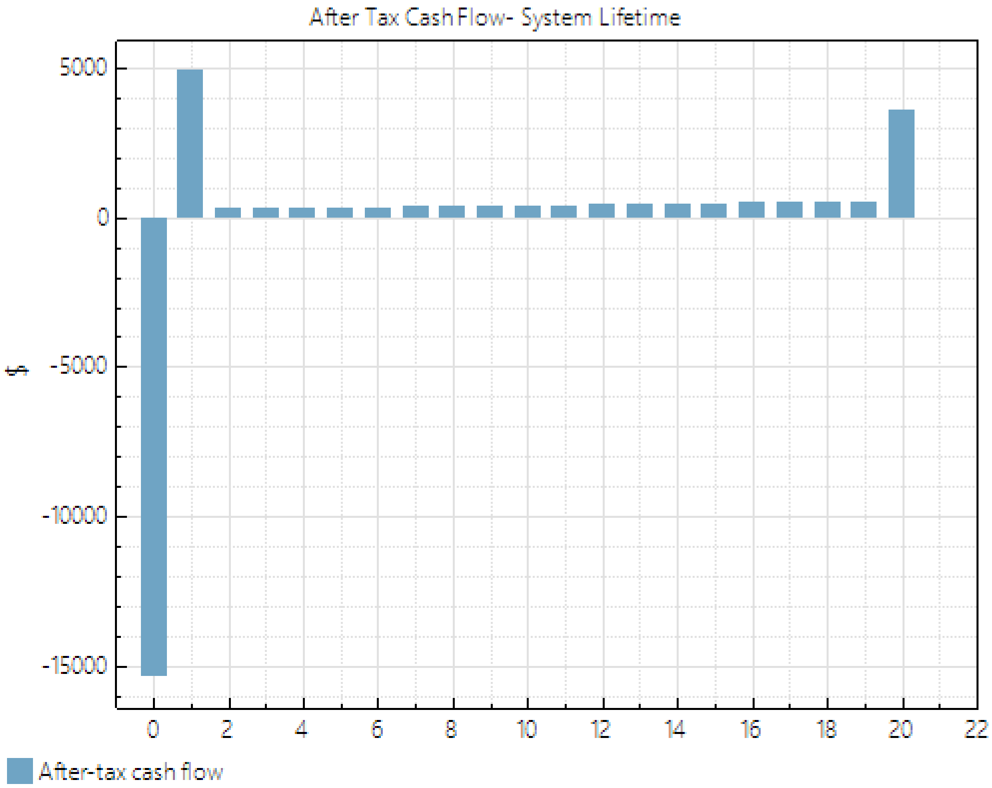
SAM Screenshots

Table and Graphs comparing system types:

SAM Model for Lithium battery

Table 1: SAM simulation values for the Lithium battery simulation

Metric	Value
Annual energy (year 1)	6,193 kWh
Capacity factor (year 1)	14.1%
Energy yield (year 1)	1,239 kWh/kW
Battery efficiency	82.08%
Levelized COE (nominal)	26.26 ¢/kWh
Levelized COE (real)	21.43 ¢/kWh
Electricity bill without system (year 1)	$973
Electricity bill with system (year 1)	$304
Net savings with system (year 1)	$669
Net present value	$-6,835
Payback period	19.9 years



Graph 1: After Tax CashFlow for the system lifetime for the Lithium battery simulation

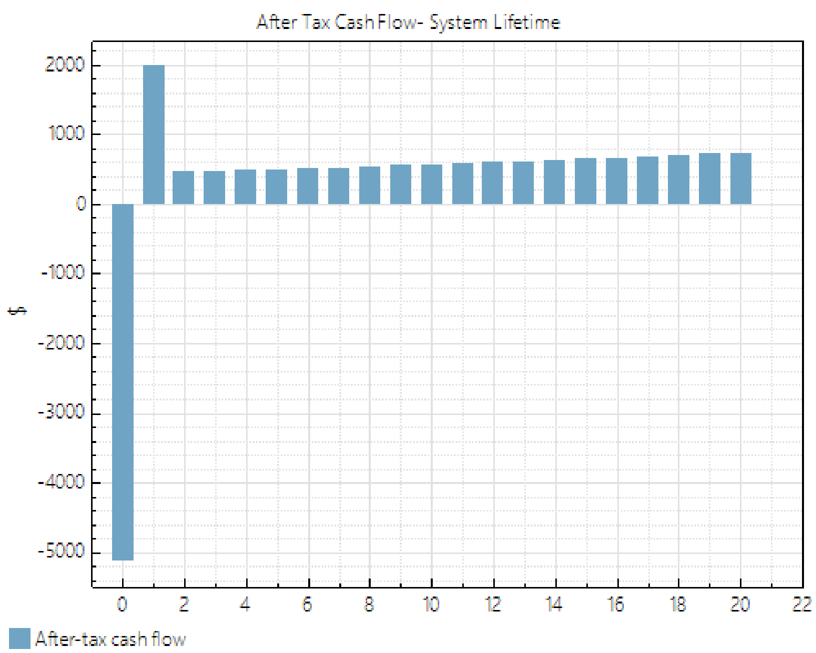
Table 2: Production, savings and operating expenses from the SAM simulation for the Lithium battery simulation

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PRODUCTION																					
Energy (kWh)	0	5,894	5,865	5,836	5,806	5,777	5,749	5,720	5,691	5,663	5,634	5,606	5,578	5,550	5,523	5,495	5,468	5,440	5,413	5,386	5,359
SAVINGS																					
Value of electricity savings ($)	0	669	684	700	716	733	750	768	786	804	823	842	861	881	901	922	944	966	988	1,011	1,034
OPERATING EXPENSES																					
O&M fixed expense ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M production-based expense ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M capacity-based expense ($)	0	100	103	105	108	110	113	116	119	122	125	128	131	134	138	141	145	148	152	156	160
Property tax expense ($)	0	307	307	307	307	307	307	307	307	307	307	307	307	307	307	307	307	307	307	307	307
Insurance expense ($)	0	77	79	81	83	85	87	89	91	94	96	98	101	103	106	109	111	114	117	120	123
Net salvage value ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,075
Total operating expense ($)	0	484	489	493	498	503	508	513	518	523	528	534	540	545	551	557	564	570	577	583	-2,485

SAM Model for Ultrabattery graphs

Table 3: SAM simulation values for the Ultrabattery simulation

Metric	Value
Annual energy (year 1)	6,193 kWh
Capacity factor (year 1)	14.1%
Energy yield (year 1)	1,239 kWh/kW
Battery efficiency	54.65%
Levelized COE (nominal)	11.40 ¢/kWh
Levelized COE (real)	9.31 ¢/kWh
Electricity bill without system (year 1)	$973
Electricity bill with system (year 1)	$301
Net savings with system (year 1)	$672
Net present value	$1,561
Payback period	7.4 years
Discounted payback period	10.1 years
Net capital cost	$5,140
Equity	$5,140
Debt	$0



Graph 2: After Tax CashFlow System Lifetime for the Ultrabattery simulation

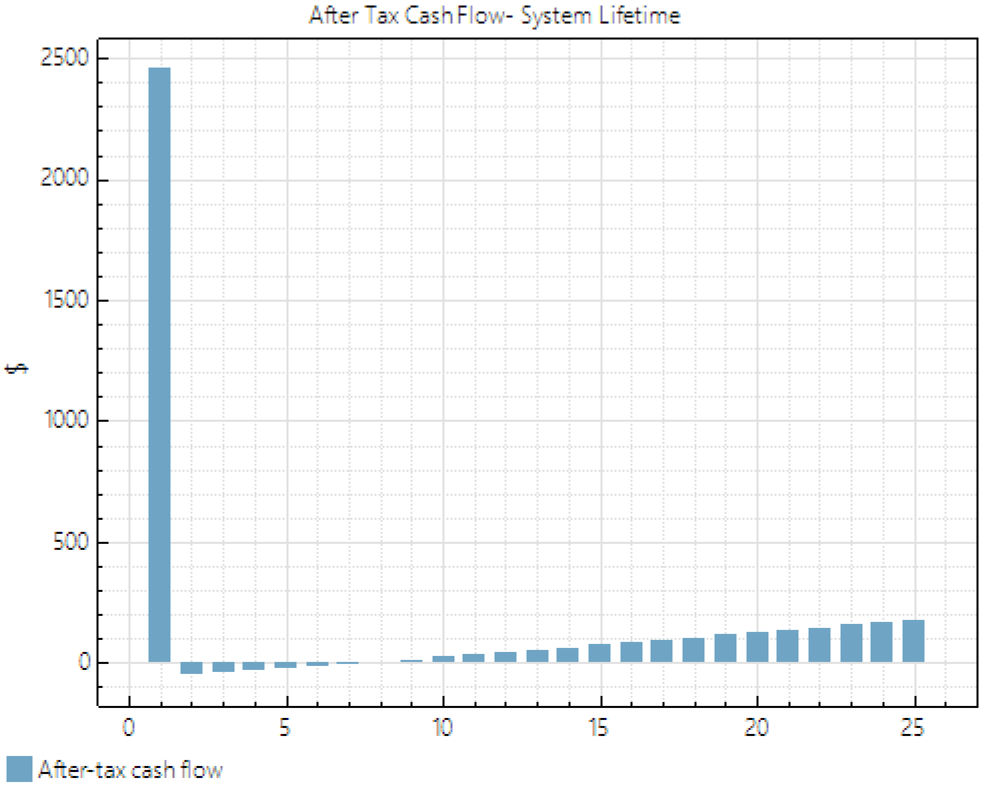
Table 4: Production, savings and operating expenses from the SAM simulation for the Ultrabattery simulation

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PRODUCTION																					
Energy (kWh)	0	5,773	5,744	5,715	5,687	5,658	5,630	5,602	5,574	5,546	5,518	5,491	5,463	5,436	5,409	5,382	5,355	5,328	5,301	5,275	5,249
SAVINGS																					
Value of electricity savings ($)	0	672	688	704	720	737	754	772	790	808	827	847	866	887	907	928	950	972	995	1,018	1,042
OPERATING EXPENSES																					
O&M fixed expense ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M production-based expense ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M capacity-based expense ($)	0	100	103	105	108	110	113	116	119	122	125	128	131	134	138	141	145	148	152	156	160
Property tax expense ($)	0	103	103	103	103	103	103	103	103	103	103	103	103	103	103	103	103	103	103	103	103
Insurance expense ($)	0	26	26	27	28	28	29	30	31	31	32	33	34	35	35	36	37	38	39	40	41
Net salvage value ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total operating expense ($)	0	229	232	235	238	242	245	249	252	256	260	264	268	272	276	280	285	289	294	299	304

Lead acid battery tables and graph for SAM

Table 5: SAM simulation values for the Lead Acid battery simulation

Metric	Value
Annual energy (year 1)	6,193 kWh
Capacity factor (year 1)	14.1%
Energy yield (year 1)	1,239 kWh/kW
Battery efficiency	62.53%
Levelized COE (nominal)	10.32 ¢/kWh
Levelized COE (real)	8.16 ¢/kWh
Electricity bill without system (year 1)	$973
Electricity bill with system (year 1)	$323
Net savings with system (year 1)	$650
Net present value	$2,504
Payback period	12.5 years
Discounted payback period	NaN
Net capital cost	$8,389
Equity	$0
Debt	$8,389



Graph 3: After Tax CashFlow System Lifetime for the Lead Acid battery simulation

Table 6: Production, savings and operating expenses from the SAM simulation for the Lead Acid battery simulation

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PRODUCTION																					
Energy (kWh)	0	5,630	5,602	5,574	5,546	5,518	5,490	5,463	5,436	5,409	5,381	5,355	5,328	5,301	5,275	5,248	5,222	5,196	5,170	5,144	5,118
SAVINGS																					
Value of electricity savings ($)	0	650	666	681	697	713	730	747	765	783	801	820	839	859	879	899	920	942	964	987	1,010
OPERATING EXPENSES																					
O&M fixed expense ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M production-based expense ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M capacity-based expense ($)	0	100	103	105	108	110	113	116	119	122	125	128	131	134	138	141	145	148	152	156	160
Property tax expense ($)	0	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168
Insurance expense ($)	0	42	43	44	45	46	47	49	50	51	52	54	55	56	58	59	61	62	64	65	67
Net salvage value ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total operating expense ($)	0	310	313	317	321	324	328	332	337	341	345	349	354	359	363	368	373	379	384	389	395

Graphs showing $/kWh for each battery type

Table 7: System costs for equipment (DiOrio, Dobos and Janzou 2015)

Variable	Value
Module cost	0.71 $/Wdc
Inverter cost	0.21 $/Wdc
Battery cost	$300/kWh Lithium Ion $255/kWh Lead Acid
Balance of system equipment	0.57 $/Wdc
Installation labor	0.15 $/Wdc
Installer margin and overhead	0.75 $/Wdc
Permitting	0.06 $/Wdc
Operation and Maintenance	20 $/kW-yr

Table 8: Typical values for comparison of the three types of batteries Lead acid, lithium and hybrid/advanced lead acid batteries (A. A. Franco 2015; Mckeon, Furukawa and Fenstermacher 2014; Energy Networks Australia 2017; Summer et al. 2012)

Typical values	Lead acid battery (flooded, AGM or Gel)	Lithium batteries	Hybrid/Advanced lead acid (Ultrabattery)
Energy Density	90-160 Wh/kg	130-200 Wh/kg	3 times conventional lead acid batteries.
Cost	$100-300 /kWh	$400-600 /kWh	CSIRO, claims “The UltraBattery is about 70 per cent cheaper to make than batteries with comparable performance and can be made using existing manufacturing facilities”
Cycle Life	800-5600	1200 - 2600	UltraBattery will last about three to four times longer than a conventional VRLA battery.
Specific Energy	180 Wh/kg	100-265 Wh/kg	80 Wh/kg
Charge/discharge efficiency	50–95%	80-90%	DC–DC efficiency of 93–95%
Lifecycle	10-20 years	2-7 years	UltraBattery will last about three to four times longer than a conventional VRLA battery.
storage temperature	25°C	-40-50°C	25°C

Table 9: Financial parameters (DiOrio et al 2015)

Variable	Value
Analysis period	25 years
Debt percent	100%
Loan term	25 years
Loan rate	7.5% per year
Inflation rate	2.5%
Real discount rate	5.5%
Nominal discount rate	8.14%
Depreciation	5-yr MACRS
Federal income tax	28% per year
State income tax	7% per year

Table 10: Advantages and disadvantages of advanced lead-acid batteries (CSIRO 2015)

Advantages	Disadvantages
• Low cost • Low self-discharge • Rapid response • Has one of the highest recycling rates compared to other batteries	• Relatively low specific energy density • Need to be kept at charged state • Uses toxic lead and corrosive acid • Shorter cycle life at higher temperatures

Table 11: Characteristics of different energy storage technologies (CSIRO 2015)

Parameter → Technology ↓	Typical life time Years (cycles)	Power density Wkg^{-1} $/kWm^{-3}$	Energy density $Whkg^{-1}$ $/kWhm^{-3}$	Typical discharge time	Recharge time	Response time	Operating temperature °C	Self-discharge %/day	Critical voltage/cell V
Lead-acid battery	3–15 (2000)	75–300/90–700	30–50/75	min– h	8–16 h	5–10 ms	−10 to 40	0.1–0.3	1.75
Advanced lead-acid battery	3–15 (3000)	75–300/90–700	30–50/75	min–h	8–16 h	5 ms	−10 to 40	0.1–0.3	2
Nickel-cadmium battery	15–20 (2500)	150–300/75–700	45–80/<200	s–h	1 h	ms	−40 to 45	0.2–0.6	1
Lithium-ion battery	8–15 (500-6000)	230–340/1300–10000	100–250/250–620	min–h	min–h	20 ms–s	−10 to 50	0.1–0.3	3

Graph showing payback for Ultrabatteries

Payback period for Ultrabatteries assuming a cost of $200 to 300 /kWh can be from 4 to 7 years according to the size of the system. It can be estimated that the solar system can save up to 80% of a bill which was around 400 dollars per quarter (1200 dollars a year) in our example. If a typical system costs around

	PV (kW)		Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	6.5		5	5000	$ 1,570	3,262	$ 66,810	0.160	0.38	0.00
	6.5	24	4	5000	$ 6,160	3,453	$ 75,211	0.180	0.38	0.00
				5000	$ 0	6,093	$ 121,858	0.292	0.00	0.00
		24	1	5000	$ 5,010	6,262	$ 130,248	0.312	0.00	0.00

Figure 1: HOMER simulation results for the Ultrabattery simulation

Then a payback graph would be:

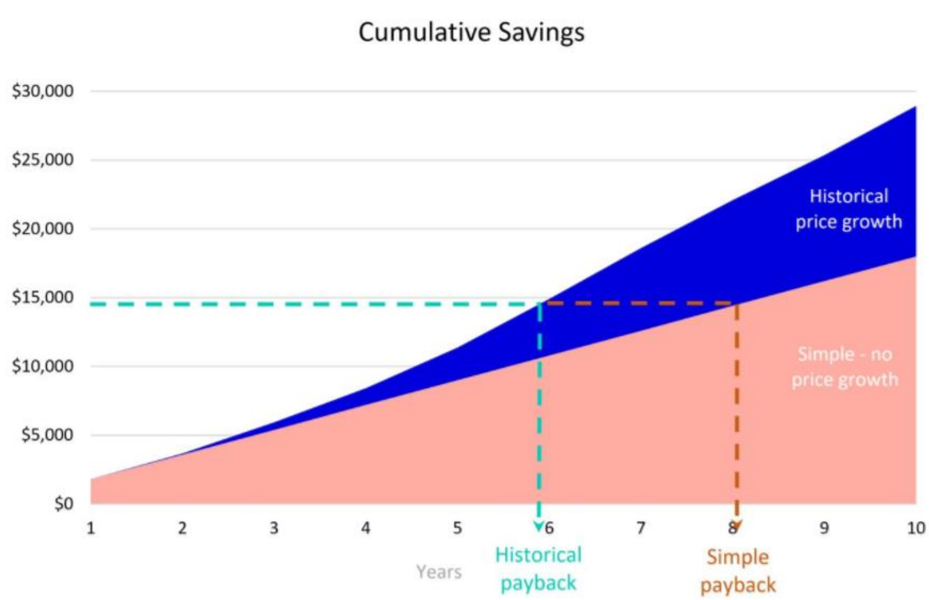
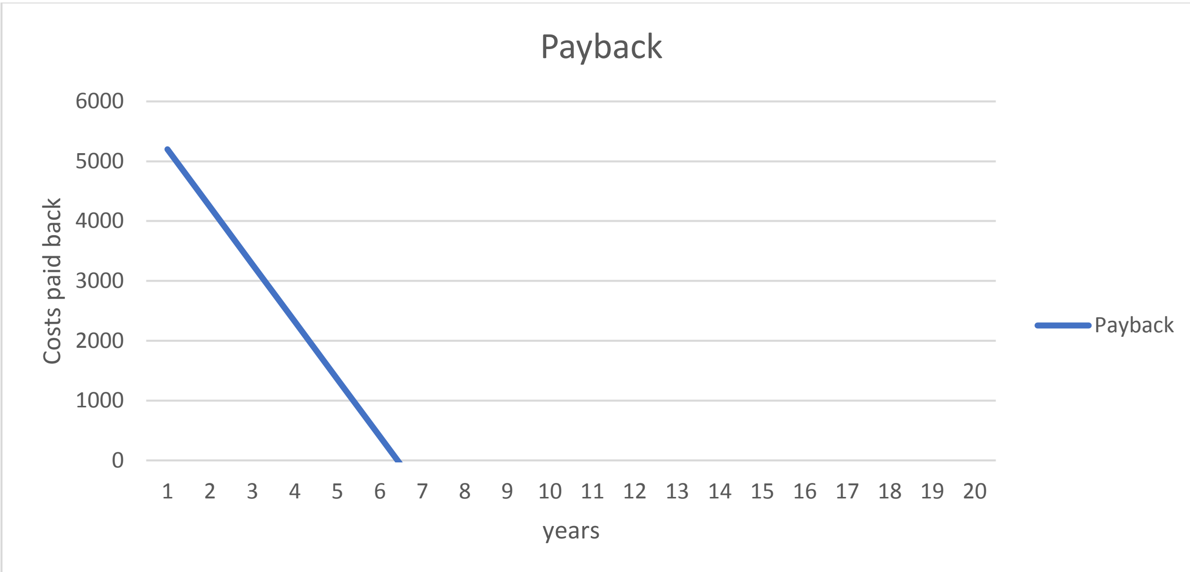
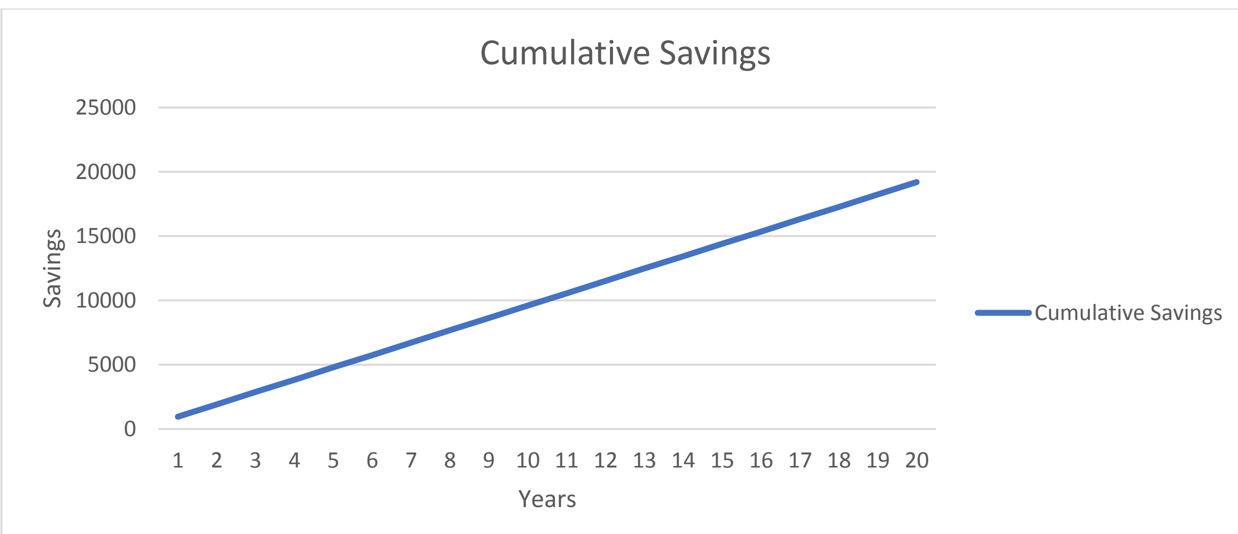


Figure 2: An example Cumulative savings comparison for Lithium batteries

(https://www.evergen.com.au/news/payback/)



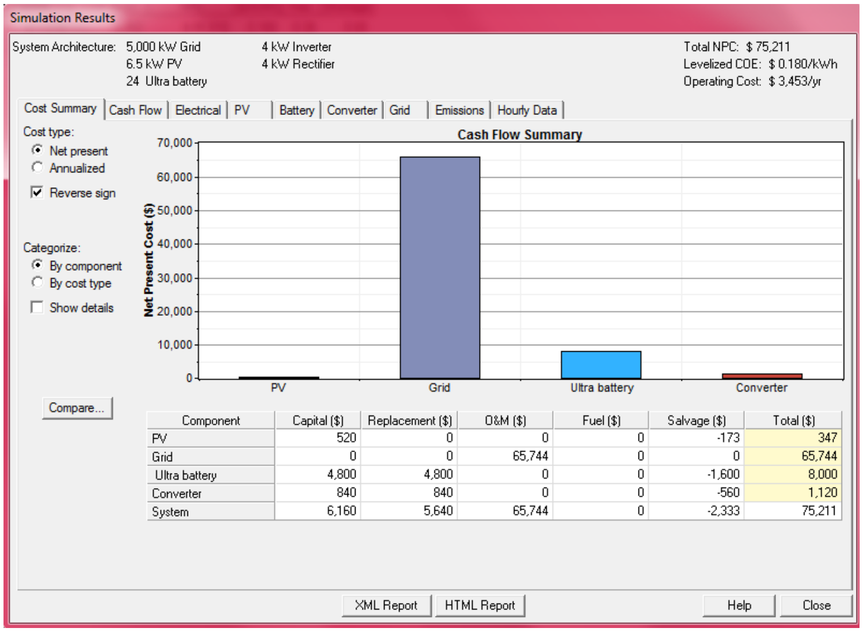
Graph 4: Payback for the Lithium battery simulation



Graph 5: Cumulative savings from the Lithium battery simulation

HOMER

Graphs comparing system types:



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	520	0	0	0	-173	347
Grid	0	0	65,744	0	0	65,744
Ultra battery	4,800	4,800	0	0	-1,600	8,000
Converter	840	840	0	0	-560	1,120
System	6,160	5,640	65,744	0	-2,333	75,211

Figure 2: HOMER Graph showing Component cash flow

In the simulation results above the costs of the Ultrabattery compared to system savings could be compared.

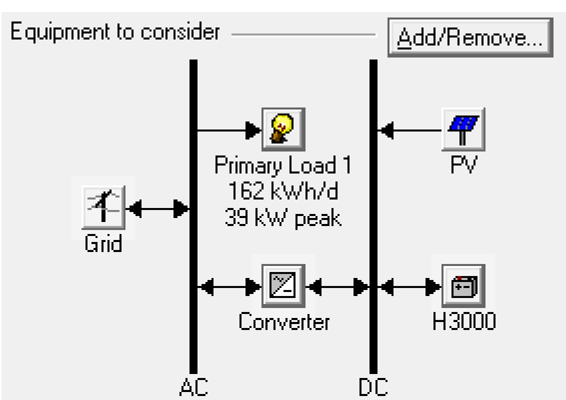


Figure 3: HOMER Screenshot

Quotes and industry information/ wholesaler information

INFINITE ENERGY Quote

Solar PV Quotation

	System Size	Average Daily Production		Estimated Annual Production
1	6.48 kW	Summer 36.7 kWh	Winter 22.8 kWh	11,258 kWh
2	6.54 kW	Summer 37.0 kWh	Winter 23.0 kWh	11,362 kWh
3	6.60 kW	Summer 37.4 kWh	Winter 23.3 kWh	11,466 kWh

The performance estimates are for a generic system and assume a north facing roof with a 30 degree pitch. If you require a production estimate specific to your roof please contact us.

3 System Size — 5.23 kW

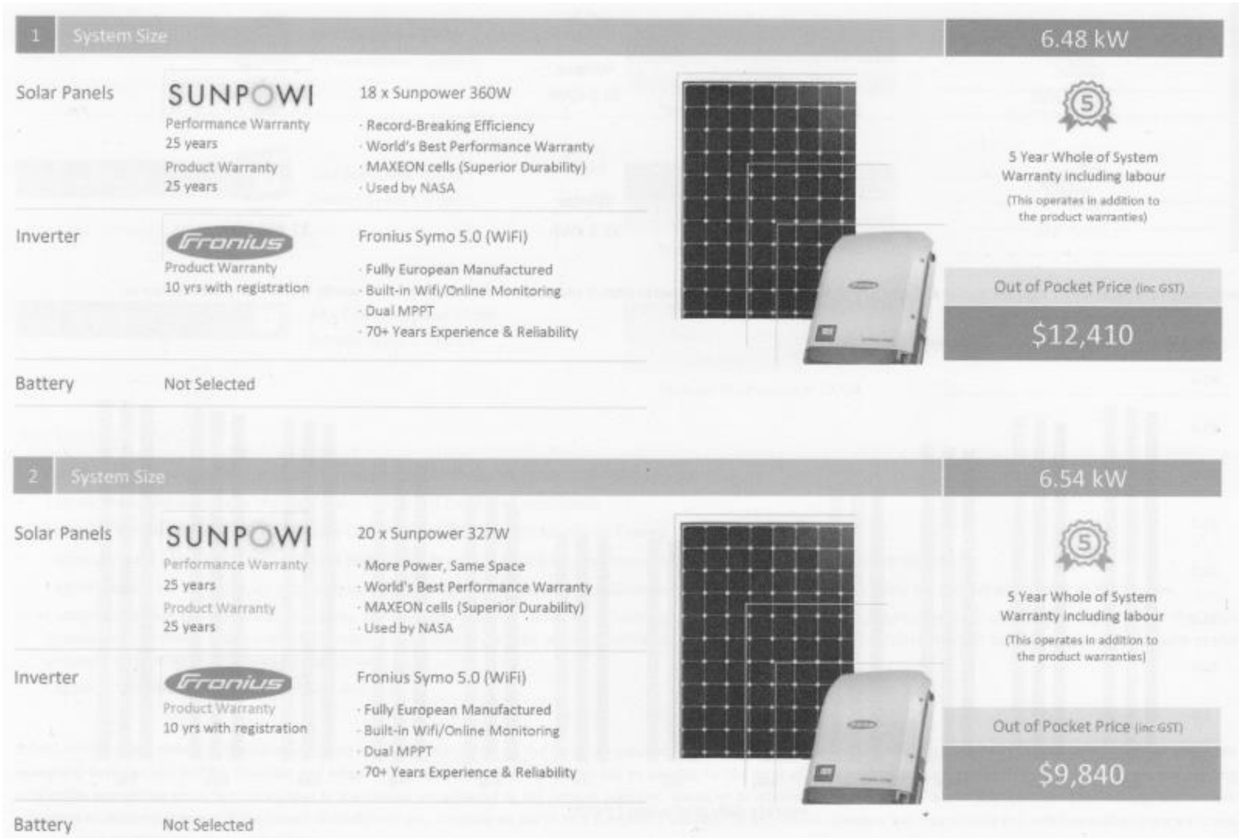
Solar Panels	CanadianSolar QUINTEC Performance Warranty 25 years Product Warranty 10 years	19 x Canadian Solar 275W · World's 2nd Largest Manufacturer · 8 Manufacturing Plants World Wide · New 5 bus-bar cells · Genuine MC4 connectors
Inverter	solaredge Product Warranty 12 years	SolarEdge HD Wave 5.0kW · Longest Inverter Warranty · Record-breaking efficiency (99%) · Panel Level Monitoring · Battery Ready with Storedge
Battery	Not Selected	

5 Year Whole of System Warranty including labour

(This operates in addition to the product warranties)

Out of Pocket Price (inc GST)

$4,990



1 System Size — 6.48 kW

Solar Panels	SUNPOWI Performance Warranty 25 years Product Warranty 25 years	18 x Sunpower 360W · Record-Breaking Efficiency · World's Best Performance Warranty · MAXEON cells (Superior Durability) · Used by NASA	5 Year Whole of System Warranty including labour (This operates in addition to the product warranties)
Inverter	Fronius Product Warranty 10 yrs with registration	Fronius Symo 5.0 (WiFi) · Fully European Manufactured · Built-in Wifi/Online Monitoring · Dual MPPT · 70+ Years Experience & Reliability	Out of Pocket Price (inc GST) $12,410
Battery	Not Selected		

2 System Size — 6.54 kW

Solar Panels	SUNPOWI Performance Warranty 25 years Product Warranty 25 years	20 x Sunpower 327W · More Power, Same Space · World's Best Performance Warranty · MAXEON cells (Superior Durability) · Used by NASA	5 Year Whole of System Warranty including labour (This operates in addition to the product warranties)
Inverter	Fronius Product Warranty 10 yrs with registration	Fronius Symo 5.0 (WiFi) · Fully European Manufactured · Built-in Wifi/Online Monitoring · Dual MPPT · 70+ Years Experience & Reliability	Out of Pocket Price (inc GST) $9,840
Battery	Not Selected		

REGEN **POWER Quote**

System Size	Solar Panels	No of panels	Inverter	METER	Discounted Price
5.83kW	RISEN (Global Tier 1 Panel)	22	JFY / Goodwe / Zeversolar (chinese inverters)	Single	**$2,890**
5.83kW	RISEN (Global Tier 1 Panel)	22	Sungrow (worlds 2nd largest manufacturer)	Single	**$3,090**
5.83kW	RISEN (Global Tier 1 Panel)	22	Fronius (European)	Single	**$3,790**
5.83kW	RISEN (Global Tier 1 Panel)	22	SMA(German)	Single	**$3,790**

-
Upgrade to 6.62kW system (25 panels) . add 3 panels more at just $200 extra cost

5.4kW solar system fully installed as below (inclusive of wifi monitoring system)

-

System Size	Solar Panels	No of panels	Inverter	METER	Discounted Price
5.4kW	Jinko 270watt (Tier 1)	20	JFY / Goodwe / Zeversolar (chinese inverters)	Single	**$2,990**
5.4kW	Jinko 270watt (Tier 1)	20	Sungrow (worlds 2nd largest manufacturer)	Single	**$3,190**
5.4kW	Jinko 270watt (Tier 1)	20	Fronius (European)	Single	**$3,890**
5.4kW	Jinko 270watt (Tier 1)	20	SMA(German)	Single	**$3,890**

-
Upgrade to 6.48kW system (24 panels) . add 4 panels more at just $300 extra cost

5.4kW solar system fully installed as below (inclusive of wifi monitoring system)

-

System Size	Solar Panels	No of panels	Inverter	METER	Discounted Price
5.4kW	Canadian 270watt(Tier 1)	20	JFY / Goodwe / Zeversolar (chinese inverters)	Single	**$3,090**
5.4kW	Canadian 270watt(Tier 1)	20	Sungrow (worlds 2nd largest manufacturer)	Single	**$3,290**
5.4kW	Canadian 270watt(Tier 1)	20	Fronius (European)	Single	**$3,990**
5.4kW	Canadian 270watt(Tier 1)	20	SMA(German)	Single	**$3,990**

-
Upgrade to 6.48kW system (24 panels) . add 4 panels more at just $300 extra cost

SOLARLUNA Quote

Array Size: 5.22 kW

SOLAR PANELS

Brand: REC
Size: 18 Panels x 290 Watt
Warranty: 25 Year Performance Warranty
Description: Made in Singapore

INVERTER

Brand: Fronius
Model: Fronius Symo 5.0-3-M
Capacity: 1 x 5.0 kW
Warranty: 10 year warranty
Description: Made in Austria; world's second largest inverter manufacturer; Wifi monitoring

RAILINGS AND FIXINGS

Brand: Radiant
Model: PV-RoofTopRac System
Warranty: 15 year warranty
Description: Innovative Australian company

ISOLATORS

Brand: ABB
Model: According to current rating
Description: Swedish-Swiss multinational; largest switching manufacturer in the world

Date:	1/07/2017
Gross Price:	$9,140
STC Credit:	$3,550
Total to Pay (inc. GST):	**$5,590**

PV PERFORMANCE ESTIMATE