


Storage for the Dairy Industry

Report for Dairy Australia


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Prepared for Dairy Australia

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1.0 Introduction

With costs falling and take-up rising of solar and other renewable energy systems, businesses are increasingly interested in storing the energy they produce to maximise its benefit and reduce their bills.

Renewable energy's main challenge is that its use is restricted to when the renewable resource is available (e.g. when the sun shines or the wind blows). Storage allows more of that renewable energy to be retained so it can be used on-site at a later time – and further reduce electricity consumption from the mains power grid.

How does this work? What should a Dairy Business consider when thinking about installing renewable energy systems coupled with storage?

1.1 The Value of Storage for Dairies

There are two main economic benefits of using storage in conjunction with renewable energy to reduce electricity bills.

Firstly, storage allows a business to purchase more of its electricity from the grid during cheaper off-peak times, or directly from an on-site solar PV system, and store it for later use during peak times – when the electricity tariff is higher. That means avoiding paying some or all of the higher peak charges.

Secondly, many large businesses like dairies are charged not only for the energy they consume (in kilowatt hours or kWh), but also for their 'demand' on the electricity network (in kilowatts [kW] or megawatts [MW]). The higher the power demand the business places on the network, the higher the demand charge will be. This is something that is typically charged on a monthly basis.

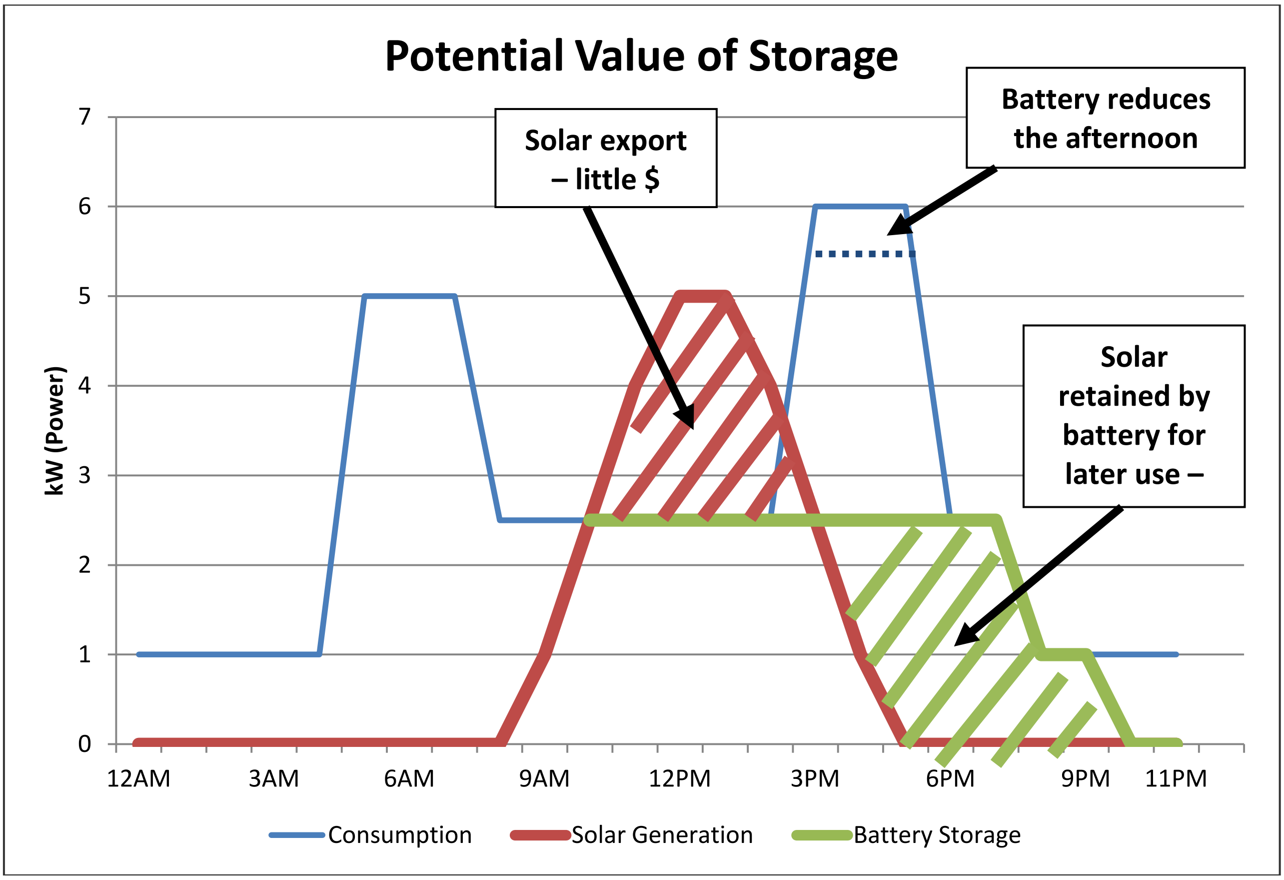
In this context, storage can also provide a portion of a dairy's peak demand – thereby lowering its demand from the electricity network and reducing its demand charge.

There is of course the separate environmental benefit that storage can allow more renewable energy to be utilised on-site, furthering lowering a Dairy Business' carbon footprint.

The key questions to ask regarding the economic benefits of energy storage are:

- Does the value of the avoided peak and demand charges outweigh the up-front and operational costs of installing storage in the first place?
- Can I get a reasonable return on investment from a storage project?

Figure 1.1: The Potential Value of Storage



2.0 The Economics of Small Scale Storage

In order to understand the economic value of storage over time, a metric must be used that can effectively be compared across different battery chemistries.

Storage costs are typically presented in dollars per kilowatt hour ($/kWh). Whilst somewhat useful, this metric is limited in comparing the relative costs and value to the end user of different battery chemistries. This is because different battery chemistries contain different properties with regards to 'useable' energy capacity.

In the same way that the end user is interested in the 'life-cycle' costs and value of demand-side energy technologies such as solar photovoltaic (PV), it is life-cycle costs and value that must be properly analysed when considering the utilisation of storage in either a hybrid (grid-connect) or off-grid scenario.

The relative costs and value of storage to the end user are a function of:

- capital cost;
- any required maintenance costs;
- the 'useable' energy capacity – largely determined by the optimal depth of discharge employed in ongoing operation;
- the battery capacity at a given charge/discharge rate – known as the 'C-rate'; and
- asset life (which is typically a function of the number of cycles at a given depth of discharge).

The discharge rate measures the time it takes to discharge a battery before it needs recharging. The capacity of some batteries (specifically lead acid-based technologies) is reduced if the battery is discharged over a shorter period (e.g. one hour).

The amp hour capacity is reduced as well as the amount of lifetime cycles. This is an important consideration for households or businesses who may wish to access the energy stored in a battery relatively quickly (e.g. a daytime or evening peak).

Where the battery is discharged at a constant rate of current over a number of hours, this is referred to as the 'C' rate[1].

Newer lithium-based technologies do not suffer from these charge/discharge constraints in the same way – improving their effective operation.

The following table provides qualitative guidance as to the strengths and weaknesses of different battery chemistries in relation to the five properties listed above:

[1] As an example, many small batteries are rated at the 'C20' rate – meaning they will deliver their amp hour capacity if discharged over 20 hours. The types of batteries in large stand alone power systems are rated at the 'C100' rate which means that they are designed to be discharged over 100 hours or 4 days. This will give you a life span typically of about 15 years.

Table 1.1: Strengths & Weaknesses of Different Battery Chemistries

	Flooded Lead Acid	Gel	AGM	Lithium
Capital Cost	Low	Medium	Medium	Medium-High
Maintenance Costs	High	Low	Low	Very Low
Useable Energy Capacity	Low	Low - Medium	Low - Medium	High
Lifetime Cycles at High DoD	Very Low	Low	Low	High
Capacity at High Discharge Rate	Low	Low	Low	High

A specific example of the correct economic valuation of two different battery chemistries is presented below – that of conventional lead acid (e.g. absorbed glass mat [AGM] or sealed gel) versus lithium-iron phosphate (LiFePO4).

These numbers are indicative only and it should be noted they do not take account of the additional potential charge/discharge constraint on the conventional lead-acid batteries:

Table 1.2: Relevant Economics for Comparing Battery Chemistries

	AGM/Gel	LiFePO4
Amp-hours	260	300
Voltage	12	3.2
kWh – 'Nameplate' Capacity (per Cycle)	3.12	0.96
Capital Cost	$459	$540
Maintenance Cost (per annum)	-	-
$/kWh – 'Nameplate' Capacity	$147	$563
Cycles (10 Years)	3650	3650
Recommended Depth of Discharge for 3650 Cycles (10 years)	15%	70%
kWh – 'Useable' Capacity (per Cycle)	0.468	0.67
$/kWh – 'Useable' Capacity	$981	$804
$/kWh/Cycle – 'Useable' Capacity, 10 year basis	$0.27	$0.22

2.1 Existing Renewable Energy

An important factor when thinking about a storage system is whether renewable energy is already installed.

Over the past 10 years, many dairies across Australia have begun to install solar. A few may already have a small wind turbine or micro-hydro system on-site. For these businesses, their existing renewable energy system may be of sufficient size that they only need consider the costs of adding batteries and their related components.

Compared to a dairy without an existing renewable energy system, this may reduce the cost of any new storage project by 10%-30%.

For dairies without renewable energy in place, a solar PV and storage system, or even grid-connected storage on its own (i.e. without renewable energy) would be the most cost-effective system type.

The Winner is still Solar:
There are a variety of renewable technologies that can help a Dairy Business to reduce its bills – including small wind turbines, micro-hydro systems and solar photovoltaic (PV) systems.

As of 2015, solar PV is the stand-out for cost effectiveness. Solar has much lower installed costs and does not have significant ongoing maintenance costs. A good-quality solar system will not need most of its components replaced for 25-30 years[1].

The up-front cost of solar PV has fallen in recent years to such an extent that in most parts of Australia, the cost of electricity generated by solar over its lifetime (e.g. cents per kilowatt hour) matches roughly the price of an off-peak tariff.

However, solar doesn't produce electricity when the sun doesn't shine – and when many businesses may have demand for energy. Battery storage can help to extend the use of solar power into other parts of the day.

2.2 Electricity Consumption & Tariffs

In most parts of Australia, the total amount of electricity consumed by a business has a significant impact on the types of electricity tariffs the business is charged.

Medium-sized businesses that consume up to about 100 megawatt hours (MWh) of electricity per year[2] are typically charged for peak and off-peak (and sometimes 'shoulder') energy, with the bills being 'bundled' into these tariff arrangements.

The tariffs paid by medium-sized businesses resemble more closely the tariffs paid by residential customers. In addition, they are not usually charged for the peak demand (i.e. per kW or MW) they place on the electricity network.

[2] In Victoria, this threshold is 160 MWh per annum.

The electricity bills of large businesses that consume hundreds or thousands of MWh per year are typically ‘unbundled’ – meaning they pay for each part of the electricity supply chain separately. This can include charges for peak and off-peak use, as well as network charges, retailer charges, Renewable Energy Target charges, market fees and most importantly, a separate demand charge.

Energy storage offers large businesses the potential to avoid both peak and demand charges. Larger dairies are therefore more likely to achieve a cost-effective storage project than a medium-scale dairy.

2.3 Tesla

The US electric vehicle manufacturer, Tesla, recently caused quite a stir in the global energy storage market. Their new ‘PowerWall’ and ‘PowerPack’ products set a new standard for storage costs; and in the way battery technology can be simplified and packaged.

The PowerWall is aimed at household energy management systems – designed with a useable storage of 7kWh or 10kWh capacity.

The PowerPack is a larger format battery providing 100kWh for utility-scale storage. As of May 2015, Tesla announced that these would be available in the US for around US$250/kWh[3]. This is just for the storage system itself – and would still require related components including inverters, potentially solar and installation.

Assuming the PowerPack (or similar large-scale storage) were available in Australia and the US prices translated directly into Australia dollars, this would set a new benchmark for storage prices locally.

Figure 2.1: Tesla’s New PowerWall (left) and PowerPack (right)

[3] http://en.wikipedia.org/wiki/Powerwall_%28Tesla%29

3.0 Case Studies

To try and understand whether storage may be economically viable for the dairy industry in Australia, ATA analysed the electricity bills of two specific dairies in different parts of Australia and modelled the energy flows and economics of different solar-battery system sizes.

One (Dairy A) was a medium-sized electricity customer whilst the other (Dairy B) was a large customer. In carrying out the modelling, ATA used its in-house solar simulation model called the 'Sunulator' – a powerful economic analysis tool for grid-connected solar-battery systems.

Sunulator estimates solar generation at a specific location drawing on 19 years (1991-2010) of solar irradiance data from the Bureau of Meteorology. This dataset exists across five-kilometre grids for all of Australia.

Regarding consumption, Sunulator has the capability to directly accommodate interval meter data files of any time period; or allows the user to build a detailed consumption profile based on relevant input data regarding load patterns (daily, weekly and seasonal variations) and taking into account other variables such as public and private holidays, weekends and standby loads. ATA built specific consumption profiles as part of this exercise.

Regarding storage, Sunulator has the ability to analyse the energy flows and economic outcomes of different storage chemistries with the ability to input specific battery charge/discharge rates and efficiencies, as well as a variety of tariff types.

Economic and energy results are based on netting off generation versus consumption data, specific to that location and user profile, for each 30 minute interval over a full year. This takes account of climate variability and gives the most accurate picture of how much solar generation will be consumed on-site (and when); versus how much will be stored and discharged from the batteries (and when); versus exported. System design and configuration can then be optimised to maximise the value of solar generation and minimise the cost of consumption from the grid.

Based on electricity tariff information, Sunulator then calculates the impact on a consumer's electricity bills (annually) and projects the savings over a 30-year time frame. Financial results include simple and discounted payback, net present value and project internal rate of return.

ATA maintains both an in-house version of Sunulator, as well as a free public download version from the ATA website. Dairy Australia members can download the free public version in order to become familiar with the model, or peruse the comprehensive user guide[4].

[4] It should be noted that the public version does not currently have storage analysis capability – however ATA's in-house, storage-enabled version will be available on the ATA website in the coming months. The in-house version is well-tested and proven on feasibility projects.

3.1.1 Dairy A

Dairy A was located in a decent part of Australia with regard to solar radiation and consumed just less than 100MWh per year.

Due to its consumption, Dairy A's bill was 'bundled' – i.e. it paid one specific tariff for peak energy; and a separate (and lower) tariff for off-peak energy. Dairy A did not pay a demand (i.e. per kW) charge.

The difference between Dairy A's peak and off-peak tariff was only about 6 cents per kWh. This is not large enough to allow the upfront investment in solar and batteries to be re-couped within 20 years.

3.1.2 Dairy B

Dairy B was a larger energy customer – consuming almost 1,000 MWh per year and situated in a good part of Australia for solar radiation. Given its size, the business' electricity bills were 'unbundled', with the overall tariffs and charges being as follows:

Table 3.1: Electricity Tariffs, Dairy B

	$	Unit
Peak energy	0.16	$/kWh
Off-peak energy	0.04	$/kWh
Demand Charge	18.33	$/kW
Fixed (Supply) Charge	$50	per month

ATA modelled a solar-battery system designed to allow Dairy B to purchase and store more of its electricity at off-peak times, as well as charging the batteries directly from a solar PV system. ATA assumed that the solar PV system had already been installed at Dairy B. The system size, configuration and costs modelled were as follows:

Table 3.2: Modelled Inputs & Outputs, Dairy B

	Size	Unit	$	Comments
Solar PV	99	kW	-	50% system East facing; 50% west - to maximise morning and late afternoon generation. North facing, 30 degree tilt. 80% panel to socket efficiency.
Lithium (LiFeP04) Batteries	200	kWh	150,000	Useable energy storage. Charging efficiency 95%. Discharging efficiency 95%. Maximum state of charge 98%. Replace in 15 years. Includes Balance of System costs.
Discount Rate	10	%		Potential value of capital investment to Dairy B.
Annual Electricity Bill			134,000	Before the solar + batteries were installed.
Annual Bill Saving			17,500	

As can be seen, Dairy B needed to spend in the order of $150,000 upfront to install the batteries and related components. (This cost estimate took into account the latest price estimates announced by Tesla in May, 2015, but should be noted are not currently available in Australia).

The potential bill savings per year were just under $20,000. Discounted at 7%, this means that Dairy B would get its capital investment back in around 14 years.

The challenge with storage however is the lifetime of the batteries themselves. Most conventional battery technologies, including lithium, cannot be assumed to last much longer than 10 years. It is possible to make them last a few years longer if they are not cycled deeply during their working life.

The challenge for Dairy B (and any dairy) is therefore whether they can achieve full payback of the money invested before it becomes time to replace the batteries, inverters and related system components.

Given the current costs of energy storage, it is unlikely that many dairies across Australia would be able to achieve an attractive economic return on a renewable energy/storage project in 2015.

However just as solar technology costs fell rapidly from about 2008, storage costs are predicted to decline significantly over the coming decade – with some technology analysts forecasting that prices will fall by 50% by 2020 and 70% by 2025.

Should these cost reductions materialise, it will be worth re-visiting the value of storage for dairy and other businesses in the coming years.

3.2 Where to from here?

Unfortunately, given the complexity of renewable energy and storage technology, there is no easy or quick way to answer the question of “how much storage do I need at my site and what will it cost?”

The only way to properly answer this question, which maximises the chance of implementing a cost-effective project at any given site, is to undertake a feasibility analysis – taking into account that site’s specific consumption patterns, electricity tariffs and solar resource.

Please Note:

That both renewable energy and storage technologies continue to evolve – with storage prices predicted to drop dramatically in the coming decade. Make sure you consult an expert about your individual business to see whether renewables + storage is a viable option for your farm.

4.0 Appendix A: Energy Storage Technologies

There are many different types of energy storage technology available in Australia today. Let's examine the main types.

4.1 Lead Acid

The most common technology used in household and commercial applications is the lead-acid battery. This has been in existence for more than a century and works well provided the appropriate size and type is selected and used and maintained appropriately.

In years past, the most common lead-acid battery used flooded cells. More recently, the trend towards prioritising lower maintenance has resulted in sealed lead-acid – with no need to check cell levels or monitor corrosion. Sealed lead-acid batteries come in two main designs—AGM (absorbent glass mat) and gel cell.

The main cause of failure in lead-acid batteries is corrosion, usually from high temperatures. Lead-acid batteries are also constrained by the capacity of the rate at which the energy is discharged. As the rate increases, the battery's available capacity decreases.

This is a significant limitation for people who want to use a large proportion of a battery's capacity in a relatively short time (e.g. during an afternoon or evening peak).

Figure 4.1: Large Format (left) & Small Format (right) Sealed Lead-Acid Batteries

While a small format battery contains multiple cells grouped together ready to use, large format batteries require cells of the same size to be connected together once installed, allowing batteries of any voltage and capacity to be assembled.

4.2 Ultra-Batteries

New 'ultra-batteries' are essentially a lead-acid battery with capacitors added to the electrolyte for enhanced performance.

Like all lead-acids, ultra-batteries remain susceptible to corrosion and must be periodically charged to 100% to maintain their capacity (e.g. once a month). This requirement comes at a cost to the user as the battery will not be available for a portion of the time.

Ultra-batteries do not have the same limitations on discharge rate as conventional lead-acid. According to the CSIRO, the capacity of ultra-batteries is not reduced by the discharge rate, as long as they are only cycled between 50% and 80% state of charge. In practice, this is still a minor limitation on battery functionality.

4.3 Lithium

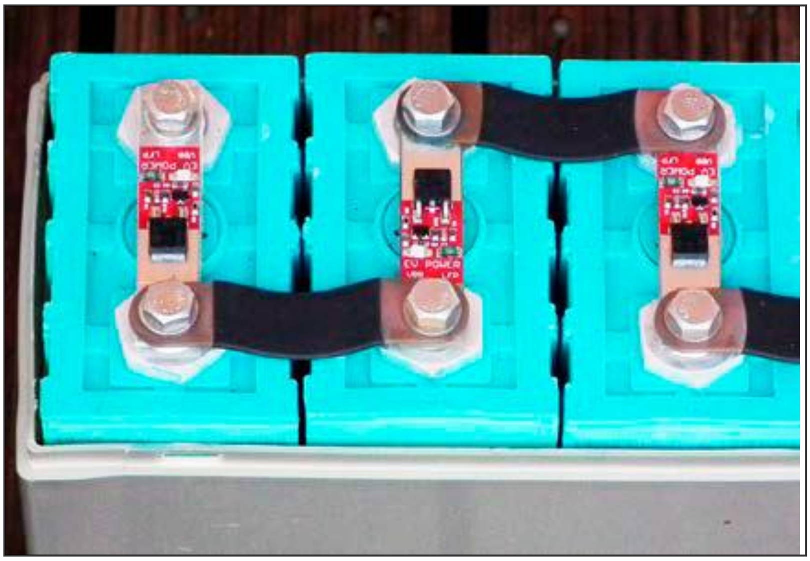
As demand for more advanced energy storage grows, there is an increasing focus on lithium-based batteries. These are typically lithium iron phosphate (often called $LiFePO_4$ or just LFP), with considerable advances in recent years and a steady decrease in cost as manufacturing scale has increased.

Lithium offers some important advantages over traditional lead-acid: – higher storage density (more energy can be stored in a battery of a given volume), greater power density (smaller batteries can produce greater instantaneous power outputs), much better charging efficiency and longer life spans.

Lithium batteries are currently more expensive than lead-acid but have lower lifetime costs – with more useable energy capacity provided over time. This is likely to improve as the global push for lower-cost batteries for electric vehicles continues.

Lithium cells require some form of Battery Management System (BMS) across each cell to protect from overcharging.

Figure 4.2: Battery Management System for Lithium Cells



Lithium batteries are also not constrained by the rate at which their energy is discharged. According to the CSIRO, there is effectively no limit on discharge rate.

These benefits enable smaller-capacity lithium battery banks compared to lead-acid. Overall, when the costs and energy value of different battery types are considered over time (e.g. 10 years), lithium is currently (and likely to continue to be for some time) the most cost-effective storage technology for renewable energy systems.

4.4 Nickel

Nickel-cadmium batteries were used for a while in stand-alone power systems. However, their high cost and relatively high toxicity means they have all but disappeared. Nickel-iron batteries are related but much safer.

Nickel-iron is an old storage technology and also one of the most robust. Tolerant of over-charging, over-discharging and short circuiting, nickel-iron batteries can have a very long life even when treated badly.

The main drawbacks of nickel-iron are lower charging efficiency and higher self-discharge compared to other technologies. Although their active materials are common and relatively low-cost, nickel-iron cells are quite expensive to purchase due to their small market in Australia.

4.5 Flow Technology

A newer technology is the flow battery, usually based on vanadium or bromine, such as the zinc bromide flow battery. Unlike most batteries which store their energy in metal-based plates, flow batteries use two liquids – the anolyte and catholyte – to store energy. The liquids flow through a cell which contains a membrane that allows current to travel across it.

Because energy is stored in the liquids, flow batteries have the advantage of being recharged by replacing the liquids, although most flow batteries are simply recharged like other batteries. To increase the battery storage capacity, more storage tanks of anolyte and catholyte are added.

The primary disadvantage of flow batteries are their high up-front cost, which means they are used only in very large commercial applications.

Figure 4.4: Flow Battery

4.6 Flywheels

Flywheel batteries use relatively small flywheels (usually weighing a few kilograms) spinning at high speeds inside an evacuated enclosure to store energy. The flywheel is connected to an electric generator that also acts as a motor.

When charging, the motor/generator uses the electricity to increase the flywheel's speed. When discharging, the flywheel spins the generator to produce electricity.

The main advantage to these devices is that they have no chemical energy storage – it's purely mechanical – so they theoretically have an extremely long life span. Their main disadvantage is complexity and cost. Some flywheel units are used for commercial short-term energy supply.

Figure 4.5: Schematic Diagram of a Flywheel

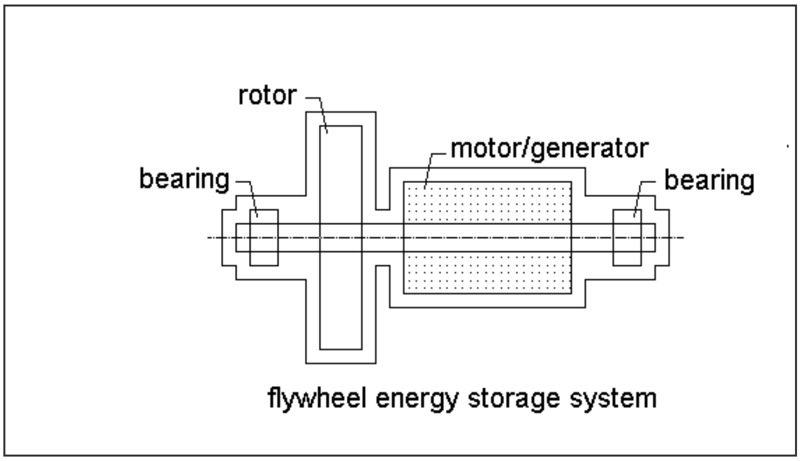
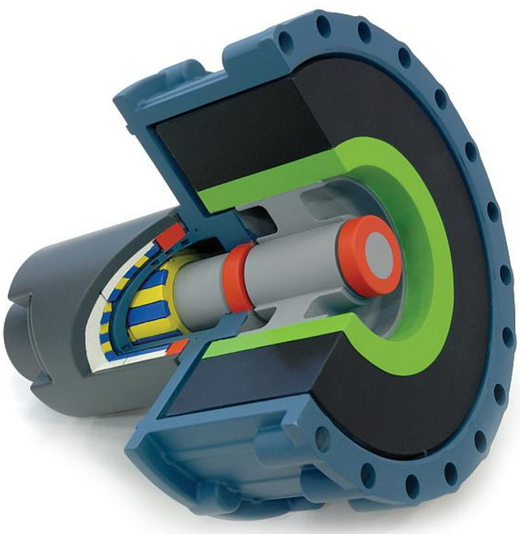


Figure 4.5: Cross-section of a Flywheel



4.7 Sodium

Aquion Energy, a new player in the energy storage field, is manufacturing sodium ion storage systems for solar and wind power systems based on benign materials such as manganese oxide, sodium sulphate, carbon and cotton.

The batteries are extremely simple internally and use salt water for the electrolyte. The batteries are manufactured in single 48-volt, 2.4-kWh stacks which are also available in a bank of 12 stacks as a 25.5-kWh battery.

Aquion batteries are aimed at the renewable energy storage market. They have relatively low discharge rates and low energy density—neither of which is really a problem for a suitably sized battery in a renewable energy system.

The main advantage of these batteries is the environmentally benign component materials, the ability to withstand 100% depth of discharge without damage and the rated cycle life of 5000 cycles. Disadvantages include current high cost, high weight per battery and their restriction to low output power applications.

Figure 4.6: Sodium Battery

4.8 Zinc-Air

Zinc-air batteries are a new technology that is expected to become commercially available in 2016. Normally found as single-use batteries in small devices such as hearing aids, they have been developed into rechargeable batteries in the US.

One manufacturer rates their zinc-air technology as capable of a 30-year life span. Relatively non-toxic and low-cost, zinc-air batteries are largely used for grid stabilisation. Smaller systems may be available in Australia in the near future.

Aluminium-air technology is also in the research and development phase, but the CSIRO predicts the commercialisation of this technology is more than 20 years away.

5.0 Appendix B: Relevant Storage Concepts

BATTERY CAPACITY

Battery capacity is a measure of how much energy a specific battery has available for use over time. The unit of battery capacity is the ampere-hour, or amp-hour (Ah). As energy is usually measured in watt-hours or kilowatt-hours, you have to convert between the two.

Energy is battery capacity in amp-hours multiplied by the nominal battery voltage. For example, a 1200 Ah, 24 V battery bank has a total energy storage capacity of 28,800 watt-hours, or 28.8 kWh.

For most chemistries, especially lead-acid, the actual capacity of the battery varies depending on the rate at which it is discharged. This is expressed as the 'C' rating – for example C100. In this instance, the battery is discharged over a period of 100 hours.

If you were to discharge the battery in 10 hours, the capacity would be reduced (this effect, which causes reduced capacity at greater discharge rates, is known as the Peukert effect). For stand-alone power systems, batteries are usually specified at the C100 rate, as this most closely represents the discharge rate experienced in these systems.

Lithium batteries tend to be specified at the C1 rate. Their capacity is pretty much the same, regardless of discharge rate.

BATTERY FORMATS

Batteries come in both small and large formats. Small format batteries consist of a group of cells encased together to form a battery, whereas large format batteries are sold as individual cells that you group together during installation to achieve the required battery voltage; each cell has the required amp-hours you need, ranging from less than 100 amp-hours up to several thousand.

Small format batteries can be simpler to set up than large format, but they are only suitable for smaller systems, up to 300 amp-hours or so for lead-acid and 100 amp-hours or so for lithium.

VOLTAGE

Voltage can be thought of as the electrical 'pressure' of the battery—the higher the voltage, the greater the ability of the battery to push current through a particular load. Battery voltage is usually 12 volts for small systems such as used in RVs and weekenders, 24 volts for small homes and homes with low energy demand and 48 or 120 volts for larger homes/businesses or those with higher energy demands.

Battery voltage is fairly self-explanatory for small format batteries. They are supplied in common voltages such as 6 or 12 volts—you normally buy them in the voltage that you are going to use for your system, commonly 12 volts, although for higher voltage systems you connect batteries together in series to achieve the desired voltage.

Large format cells each have a voltage of their standard cell chemistry—2 volts (technically 2.2 V) for lead-acid, 3.2 volts for lithium iron phosphate and 1.2 volts for nickel -iron. You just buy as many cells (each sized with your required amp-hours) as is required to achieve the required battery voltage.

BATTERY CHARGING EFFICIENCY

There is always some energy loss when charging batteries. The less-than-perfect efficiency means that you have to put more charge back into the battery than you took out, to get back to the same level.

For new lead-acid cells, battery charging efficiencies of 90% to 95% can be expected; however, efficiency will decrease with age due to sulphation and stratification.

Sulphation in lead-acid cells occurs when the battery is discharged. During the battery's discharge phase the active materials on both plates are converted to lead sulphate (PbSO4). The sulphate deposit on the positive plate is normally dissolved during recharge. However, if the battery is left for a period without being fully recharged, the lead sulphate can crystallise and become insoluble, resulting in reduced battery capacity.

Stratification occurs when flooded cells get little or no cycling. The electrolyte tends to settle into layers of different densities (with higher specific gravity at the bottom), which can reduce the life of the battery by accelerating plate corrosion. This potential problem is solved by regular boost charging (gassing) of the cells. This also helps to equalise the state of charge of the individual cells as non-uniform charging can occur due to inevitable differences in characteristics of individual cells.

In lead-acid cells in particular, temperature has a direct bearing on the battery's state of charge. The lower the ambient temperature the more charge needed to replace that taken out. The reverse applies for higher temperatures. Battery specifications assume an ambient temperature of 25°C and battery manufacturers provide correction tables and graphs so you can determine precise specific gravity (the density) of the electrolyte, which is a good indicator of the state of charge with lead-acid batteries.

Lithium cells are more efficient chargers, with charging efficiencies of over 95%. They also do not suffer from sulphation, but other forms of degradation (such as the loss of accessible lithium due to chemical changes at the solid electrolyte interface layer or cell degradation due to temperature) mean that their lifespan is not infinite either. With lithium cells, temperature doesn't have a noticeable effect on charging efficiency.

BATTERY LIFE

Battery life is measured in cycles rather than years. Battery manufacturers usually specify the lifespan of deep-cycle batteries by the number of cycles they can withstand to a particular depth of discharge (DOD) while retaining a particular level of capacity.

Some manufacturers will only supply figures for one particular DOD, while others will supply data for a number of different discharge levels.

A cycle, in simple terms, is when the battery is discharged to a certain level and then recharged fully. The more deeply the battery is discharged before recharging, the lower the number of cycles it will last. The depth of discharge of a battery is expressed as a percentage. A 30% depth of discharge (DOD) means that 30% of the energy is taken from the battery before it is recharged.

This effect means it is important to specify a battery bank that will be cycled as shallowly as possible, unless you want to be replacing batteries every few years.

Lead-acid batteries should never be completely flattened as this will severely reduce their life expectancy. For stand-alone power systems, the usual DOD is between 10% and 15% per day. At this rate, most large-format lead-acid batteries will provide around 10 years of service.

Normally a system would be designed so that the maximum discharge won't exceed 50%. For example, if you aim for 10% per day then you have five days of capacity before the batteries need to be recharged.

Discharges may be done at different rates, such as C10, C100 or C120 (the number refers to the number of hours the discharge to that level takes; so, for example, an 80% DOD at C100 means the battery was discharged 80% over the course of 100 hours).

For off-grid renewable energy systems that must supply energy for several days, the C100 or C120 discharge rate data is the most appropriate guidance.

For on-grid systems that are more likely to be used for a single day's storage, a C10 or C20 rate may be more appropriate. Note that for lithium batteries, the discharge rate has little effect on capacity and may be done at rates as high as C1.

The cycle lifespan of lithium batteries also declines as the depth of discharge per cycle increases. However, they tend to get a greater number of cycles compared to lead-acid batteries for the same DOD. As a result, they can be sized somewhat smaller than a lead-acid battery bank, reducing initial costs. However, for maximum lifespan, like lead-acid batteries, the larger the battery and the smaller the depth of discharge, the better.

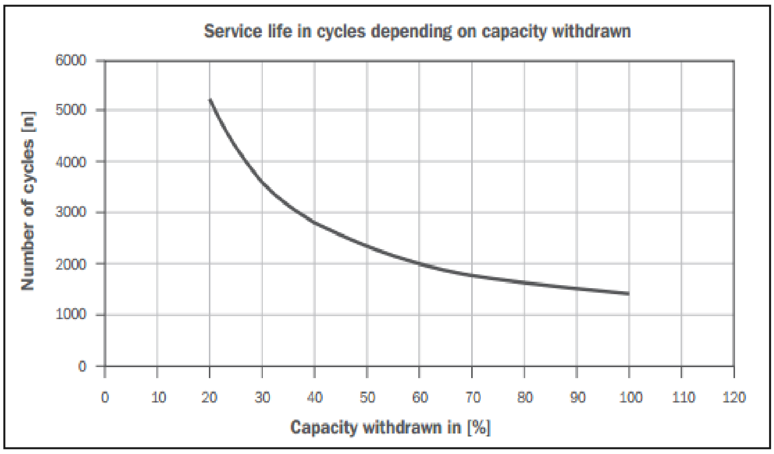
Another factor that affects cycle life is ambient (and hence battery) temperature. For lead-acid batteries, battery temperature should be kept below 38 °C as positive plate corrosion (the primary method of degradation) increases above this temperature.

For lithium cells, temperature can have a varying effect depending on the actual chemistry used and the manufacturer's specifications, so make sure to check the datasheet.

It should be noted that there are a number of different testing standards used around the world, and manufacturers may consider different levels of capacity loss to be the end-of-life point. For example, one manufacturer might consider a battery to have reached the end of its life when it can only hold 80% of its original capacity, whereas another manufacturer might use a different figure.

This can make it difficult to compare batteries, so it is important to get the latest technical datasheet from each manufacturer for the batteries you are considering.

Figure 6.1: Cycle Life versus Depth of Discharge, Typical Lead-Acid Battery



SIZING FOR SAPS

For a stand-alone power system, one needs to know how many days of autonomy is required—i.e. how many days your battery bank needs to provide energy with little or no charging, as can happen during a string of very overcast days.

A commonly used figure is five days of autonomy, although with the greatly reduced cost of solar panels, it is common to install an oversized PV array that can cope better with poor weather. This means fewer days of autonomy may be required, and three days can become a realistic figure.

The maximum depth of discharge you want the battery to receive also must be considered. For lead-acid batteries this is usually 50%, meaning that after five days, the battery must still retain 50% of capacity. You can opt for another figure, and some battery manufacturers allow deeper discharges. This is especially the case for lithium batteries, where figures of 80% are typically used.

As an example, a particular house might be expected to use 5 kilowatt-hours (kWh) per day. However, this is not the whole story, as there are losses in the inverter.
If we assume an average 10% losses, then the actual energy taken from the battery bank is 5/0.9 or 5.56 kWh per day, or 5560 watt-hours. If the house is using a 48 volt battery bank then the battery capacity required per day is 5560/48=115.8 amp-hours. Rounding this up to 120 makes sense, as usage can vary. You might also want to allow an extra 10% to 20 % for future energy use growth, which gives 144 Ah per day, assuming 20% growth.

Once you have the daily requirement then you can calculate the total battery bank capacity simply by multiplying the daily energy required by the number of days reserve capacity required, divided by the maximum total DOD, expressed as a decimal. For our example, the calculation would be: (144 x 5)/0.5 = 1440 Ah.

Obviously, battery banks can become quite large and expensive, but there are ways to reduce this. Installation of more energy generation capacity, usually in the form of more PV panels, can reduce the required storage. This is particularly so if a considerable proportion of the household's energy use occurs while it is being generated, i.e. during the day. In such cases, battery banks can also be reduced in size as they only need store the energy to be used outside of generation hours.

With lithium batteries it is possible to use a smaller, cheaper battery bank and cycle it more deeply, provided, of course, you also have extra generation capacity to cover days of low energy production, such as cloudy periods.

Generally, sizing a battery bank requires experience and needs to be considered carefully in light of average daily energy requirements, peak energy requirements and energy generation capacity, and is not to be taken lightly. Such systems are best designed by people with appropriate experience such as renewable energy system installers/ designers.

If the system is grid-connected, sizing depends on what the storage is to be used for—load shifting, backup in case of power outages, or running the whole house.

MAINTENANCE
Most manufacturers supply ancillary kits with their battery sets. These kits include such items as hydrometers (for flooded cells), thermometers, stainless steel or brass nuts and bolts, terminal covers, terminal spray, log books, installation manuals, safety signs and more.

Flooded-cell lead-acids need the most maintenance, including regular checking of electrolyte levels, removal of any corrosion on terminals and around filling vents, and the tightness of terminal clamp bolts. Acid corrosion is usually removed using a mix of calcium carbonate dissolved in water (the ratio isn't critical).

For sealed lead-acid batteries and lithium batteries, maintenance usually consists of a monthly visual check, checking clamp bolts for tightness, and checking individual cell (or cell group) voltages for consistency. All voltages should be within 10 to 20 millivolts of each other.

Checking cell voltages requires the use of a reasonable quality voltmeter or multimeter (a meter that can measure voltage, current and other parameters). A good basic multimeter costs as little as $20 and is an invaluable tool for any power system owner.

For maximum battery life you should ensure that batteries and battery terminals are kept clean and corrosion-free, that battery temperatures are kept within manufacturer's specifications, and that batteries are placed on thermally insulating surfaces, not directly onto concrete floors, as the latter can cause stratification of electrolyte due to the colder concrete temperature compared to ambient temperature.