

# MAGELLAN POWER

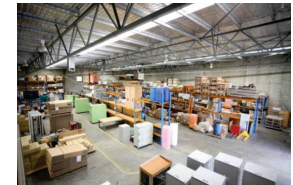
Australian Technology

## Energy Storage Case Study

By Masoud Abshar - Managing Director

## ABOUT MAGELLAN POWER

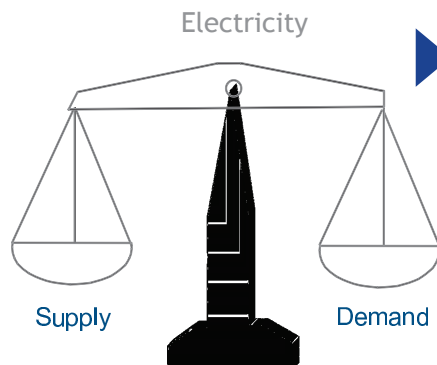
- Australian Designer and Manufacturer
- Established in 1991
- ISO9001-2008
- Industrial AC and DC Power Systems
- Energy Storage Systems
- Customised Power Solutions
- More than 10,000 power systems supplied
- Own IP in all sectors



## ENERGY STORAGE - INTRODUCTION

Fundamental principle and very important characteristic of electricity:

**'Electricity cannot be stored directly as electrical energy unless converted into another form'**



### Severe Cost Implications

- Excess Generation Capacity for Peak Loads
- Reserve Generation Capacity to account for changes in the load or unplanned loss of a generator etc.
- One possible solution is

**ENERGY STORAGE**



## WHAT IS ENERGY STORAGE?

Energy storage is accomplished by devices or physical media that store energy to perform useful processes at a later time.

Storing energy allows balance between the supply and demand of energy.

Energy storage systems in commercial use can be broadly categorised as mechanical, electrical, chemical, biological and thermal.



## WHAT IS ENERGY STORAGE?

Energy is stored to use it at a different time than when it was generated.

The process of converting the energy to storable form means that some energy is lost.

Additional energy is lost when the energy is released or recovered.

Renewable energy, however, is often intermittent (like wind and sun), and storage allows use at a convenient time.



## GRID ENERGY STORAGE

Grid energy storage (or large-scale energy storage) lets energy producers and distributors of energy send excess electricity over the electricity transmission grid to temporary storage sites that subsequently become energy suppliers when electricity demand is greater. Grid energy storage is particularly important in matching supply and demand over a 24-hour period of time.

The 150 MW Andasol solar power station is a commercial solar thermal power plant, located in Spain. The Andasol plant uses tanks of molten salt to store solar energy so that it can continue generating electricity even when the sun isn't shining.



## WHAT IS ENERGY STORAGE?

Many renewable energy sources produce intermittent power. Wherever intermittent power sources reach high levels of grid penetration, energy storage becomes one option to provide reliable energy supplies.

Individual energy storage projects augment electrical grids by capturing excess electrical energy during periods of low demand and storing it in other forms until needed on an electrical grid. The energy is later converted back to its electrical form and returned to the grid as needed.



## RENEWABLE ENERGY STORAGE

Common forms of renewable energy storage include hydroelectric dams including pumped-storage hydroelectricity, which has long maintained the largest total capacity of stored energy worldwide, as well as rechargeable battery systems, thermal energy storage including molten salts which can efficiently store and release very large quantities of heat energy, and compressed air energy storage.

Less common, specialized forms of storage include flywheel energy storage systems, the use of cryogenic stored energy, and even superconducting magnetic coils.



## BATTERY ENERGY STORAGE

Another early solution to storing energy was the development of the battery as an electrochemical storage device.

Batteries have previously been of limited use in electric power systems due to their small capacity and high cost.

However, newer battery technologies have been developed that can now provide significant utility scale load-levelling and frequency regulation capabilities.

As of 2013 some of the newer battery chemistries have shown promise of being competitive with alternate energy storage methods.



## TYPES OF ENERGY STORAGE

Possible large-scale methods of commercial energy storage include

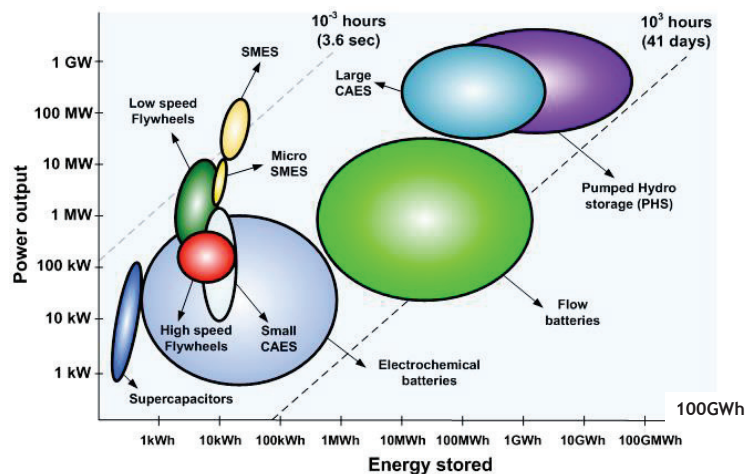
- Flywheel
- Compressed Air Energy Storage
- Hydrogen Storage
- Thermal Energy Storage
- Power to Gas

Smaller scale commercial application-specific storage methods include

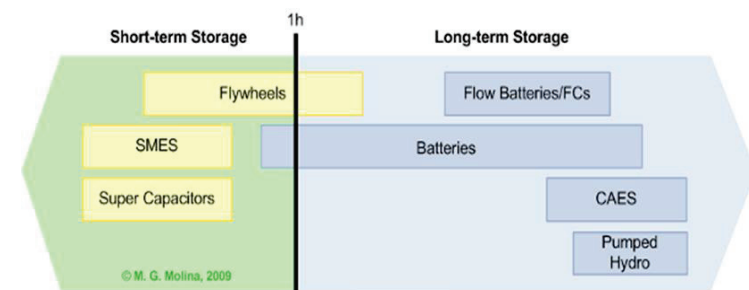
- Flywheels
- Battery Energy Storage
- Capacitors
- Super Capacitors



## TYPES OF ENERGY STORAGE

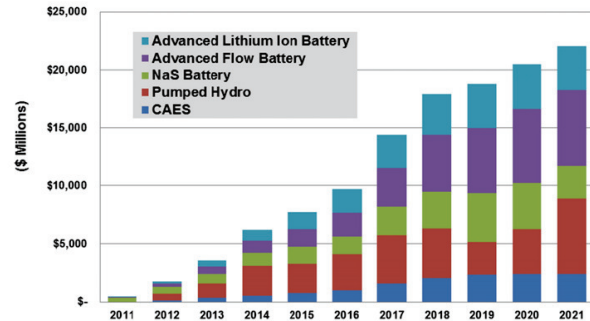


## TYPES OF ENERGY STORAGE



## TYPES OF ENERGY STORAGE

Chart 1.1 Installed Revenue by ESG Technology, World Markets: 2011-2021



(Source: Pike Research)



## COMPRESSED AIR ENERGY STORAGE

This is a way to store energy generated at one time for use at another time using compressed air. At utility scale, energy generated during periods of low energy demand (off-peak) can be released to meet higher demand peak load periods.

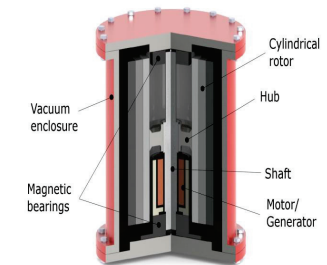
Small scale systems have long been used in such applications as propulsion of mine locomotives. Large scale applications must conserve the heat energy associated with compressing air; dissipating heat lowers the energy efficiency of the storage system.



## FLYWHEEL ENERGY STORAGE (FES)

Flywheel energy storage (FES) works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy.

When energy is extracted from the system, the flywheel's rotational speed is reduced as a consequence of the principle of conservation of energy; adding energy to the system correspondingly results in an increase in the speed of the flywheel.



## COMPRESSED AIR ENERGY STORAGE

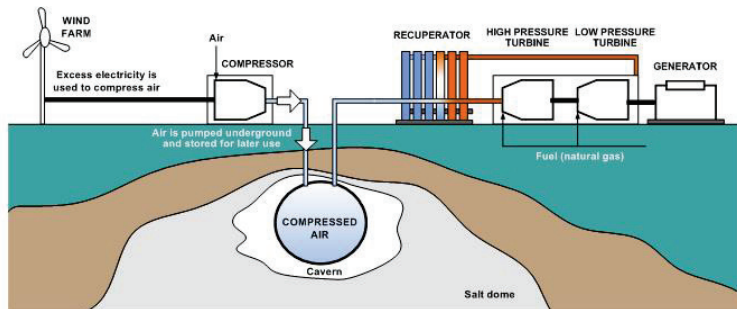
Compressed air energy storage (CAES) is a way to store energy generated at one time for use at another time using compressed air. At utility scale, energy generated during periods of low energy demand (off-peak) can be released to meet higher demand (peak load) periods.

Small scale systems have long been used in such applications as propulsion of mine locomotives. Large scale applications must conserve the heat energy associated with compressing air; dissipating heat lowers the energy efficiency of the storage system.





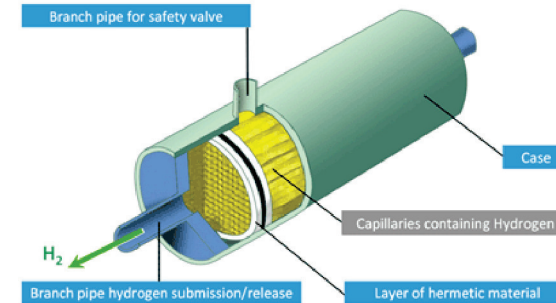
## COMPRESSED AIR ENERGY STORAGE



## HYDROGEN ENERGY STORAGE

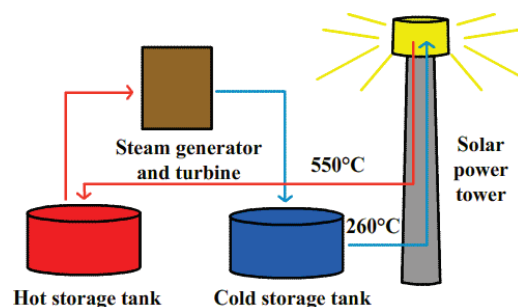
Methods of **hydrogen storage** for subsequent use span many approaches, including high pressures, cryogenics, and chemical compounds that reversibly release  $H_2$  upon heating.

Underground hydrogen storage is useful to provide grid energy storage for intermittent energy sources, like wind power, as well as providing fuel for transportation, particularly for ships and airplanes.



## THERMAL ENERGY STORAGE

Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. TES systems are used particularly in buildings and industrial processes.



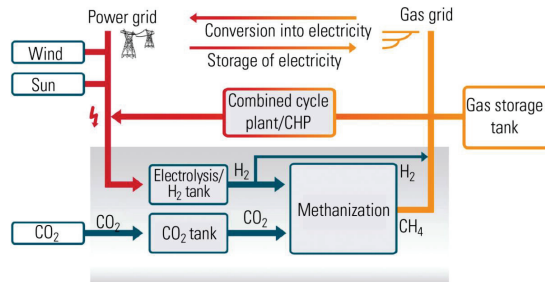
## SUPERCAPACITOR

A **Supercapacitor** is a high-capacity electrochemical capacitor with capacitance values greater than 1,000 farads at 1.2 volt that bridge the gap between electrolytic capacitors and rechargeable batteries. They store 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerate many more charge and discharge cycles than rechargeable batteries. They are however 10 times larger than conventional batteries for a given charge.

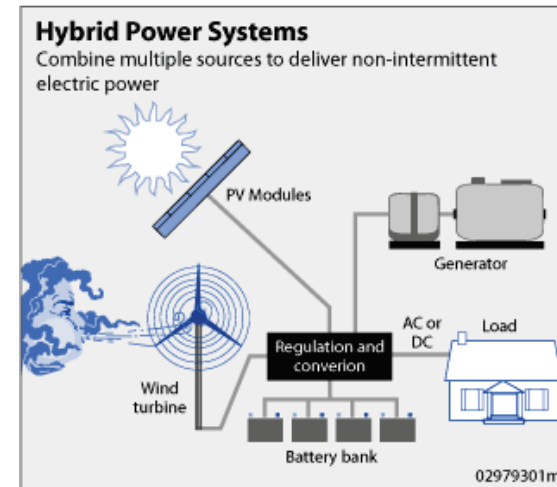


## POWER TO GAS ENERGY STORAGE

Power to gas (often abbreviated P2G) is a technology that converts electrical power to a gas fuel. There are currently three methods in use; all use electricity to split water into hydrogen and oxygen by means of electrolysis.

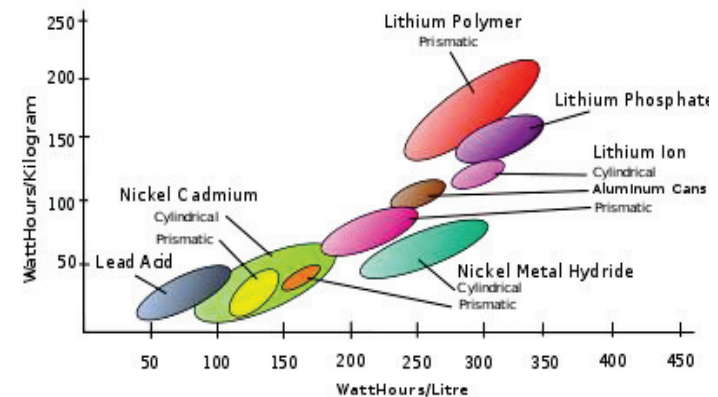


## BATTERY ENERGY STORAGE



## BATTERY TYPES

- The lead-acid battery
- The nickel-cadmium battery
- The lithium-ion battery
- Lithium-ion polymer batteries



## IMPORTANT BATTERY CHARACTERISTICS

- Size
  - Physical
  - Energy density (watts per kg or cm<sup>3</sup>)
- Longevity
  - Capacity (Ah, for drain of C/10 at 20°C)
  - Number of recharge cycles
- Discharge characteristics
- Cost



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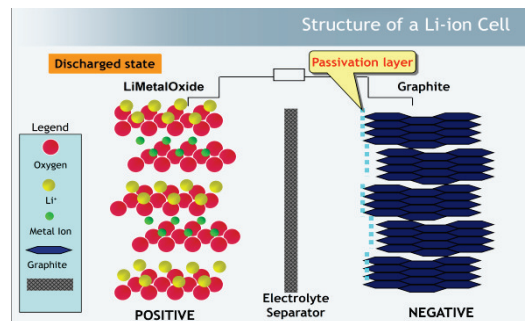
## IMPORTANT BATTERY CHARACTERISTICS

- Operational factors
  - Temperature range (storage, operation)
  - Self discharge
- Environmental factors
  - Leakage, gassing, toxicity



## WHAT IS A LITHIUM ION BATTERY?

- A lithium-ion battery is a member of a family of rechargeable battery types in which lithium ions move from the anode to the cathode during discharge and back when charging.



## WHAT IS A LITHIUM ION BATTERY?

The three primary functional components of a lithium-ion battery are the anode, cathode and electrolyte. Generally, the anode of a conventional lithium-ion cell is made from carbon. The cathode is a metal oxide, and the electrolyte is a lithium salt in an organic solvent.

The most commercially popular anode is graphite. The cathode is generally one of three materials: a layered oxide (such as lithium cobalt oxide), a polyamine (such as lithium iron phosphate) or a spinel (such as lithium manganese oxide).



## WHY LITHIUM ION?

### Lithium-ion batteries have:

3-5 times the cyclic lifespan of lead acid batteries.

1/3 the weight and size of lead acid batteries.

Not harmful to the environment.

Rechargeable lithium-ion batteries, when used appropriately with a Battery Management system are safer than many other forms of energy storage.

Consumer-level lithium-ion batteries are much more likely to have problems than those used in commercial and industrial applications because of the numerous safety precautions provided by BMS's.

Higher power but more volatile lithium-cobalt formulas are not generally used for vehicles or other applications like Energy Storage.



## BATTERY COMPARISON WITH OTHERS

Type	Cycle Life	Charge time	Discharge per month	Energy Density (Wh/Kg)	Power Density (W/Kg)	Cost (\$/kWh)	Voltage	Optimal Drain
Lead acid	200-1500	8-16h	5%	35	180	269	2	0.1C
NiCd	700-1500	2-5h	20%	40-60	150	280	1.25	1C
Li-ion (Typical)	2000-7000	2-4h	2-3%	120	1800	300-800	3.2-3.7	< 1C



## LITHIUM ION BATTERIES

### Strengths:

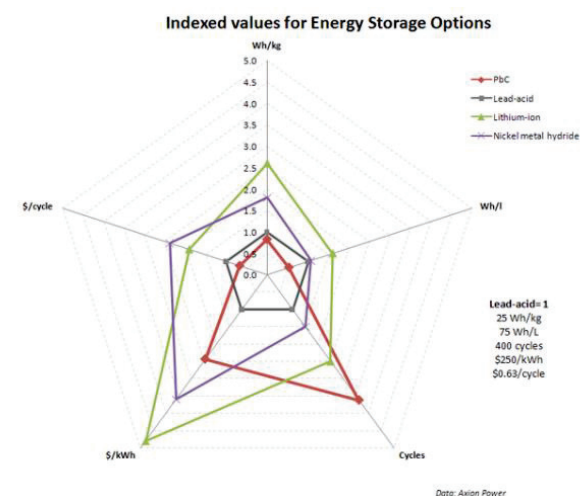
- The best specific energy
- (up to 230 Wh/kg in energy cell for consumer application)
- Good volumetric energy
- Excellent cycle life
- Good calendar life
- Very high power density (up to 12 kW/kg impulses)
- Excellent charging and discharging efficiency

### Weaknesses:

- Global cost of technology
- Complex electronic management compulsory
- High power chargeability to improve, especially at low
- temperature (ability to charge and discharge at the same rate)



## LITHIUM COMPARISON WITH OTHERS



## BATTERY MANAGEMENT SYSTEM

Without balancing, the cell of smallest capacity is a “weak point”, it can be easily overcharged or over-discharged while cells with higher capacity undergo only partial cycle. For the higher capacity cells to undergo full charge/discharge cycle of the largest amplitude, balancer should “protect” the weaker cells; so that in a balanced battery, the cell with the largest capacity can be filled without overcharging any other (i. e. weaker, smaller) cell, and it can be emptied without over-discharging any other cell. Battery balancing is done by transferring energy from or to individual cells, until the SOC of the cell with the lowest capacity is equal to the battery's SOC.



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## MAGELLAN'S EXPERIENCE WITH BMS

### Monitor

A BMS monitors the state of the battery as represented by various items, such as:

**Voltage:** total voltage, voltages of individual cells, minimum and maximum cell voltage or voltage of periodic taps

**Temperature:** average temperature

State of charge (SOC) or depth of discharge (DOD): to indicate the charge level of the battery

**Current:** current in or out of the battery



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## BATTERY MANAGEMENT SYSTEM

Balancing can be **active** or **passive**. The term *battery regulator* typically refers only to devices that perform passive balancing.

In passive balancing, energy is drawn from the most charged cell and is wasted as heat, usually through resistors.

In active balancing, energy is drawn from the most charged cell and transferred to the least charged cells, usually through DC-DC converters.



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## MAGELLAN'S EXPERIENCE WITH BMS

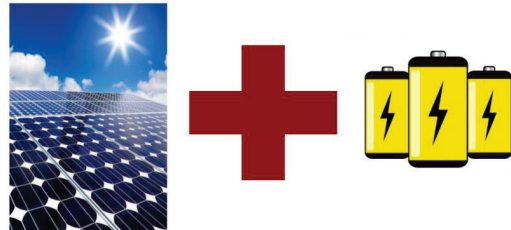
- *Protection*
- A Magellan-BMS protects its battery by preventing it from operating outside its safe operating area, such as:
- Over-current (may be different in charging and discharging modes)
- Over-voltage (during charging)
- Under-voltage (during discharging)
- Over-temperature



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## BENEFITS OF BATTERY ENERGY STORAGE



**Integrated power electronics + battery architecture**  
= more energy for less capital

Makes energy storage with solar PV commercially viable "today"  
so we can all use the sun's energy "day and night"

## STEADY STATE BENEFITS OF BATTERY ENERGY STORAGE

A Battery Energy Storage System (BESS) will enable you to capture more energy from the sun and allow you to use this energy in the evenings or when you need it most.

With Battery Energy Storage System (BESS), you can control your own power. This will help you save on electricity costs by allowing you to charge the batteries in cheaper off-peak periods and then utilise this stored power during peak periods (Time Of Use customers only).



## STEADY STATE BENEFITS OF BATTERY ENERGY STORAGE

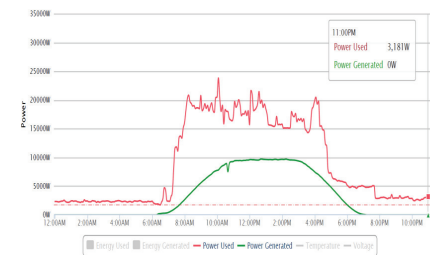
For solar customers on a net-meter, instead of sending your free solar energy back to the energy companies, you can divert this excess solar power into the BESS, allowing you to maximise your solar benefit and reduce your energy bills even further.

A BESS provides you with backup power to essential appliances in the event of blackouts.

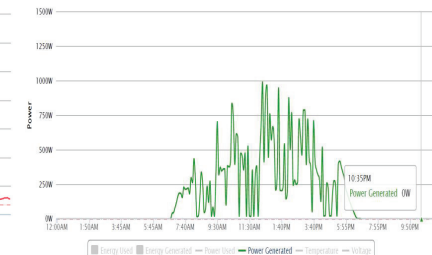


## DYNAMIC BENEFITS OF BATTERY ENERGY STORAGE

Energy generated by renewable sources for commercial areas has many advantages over conventional supplies, but a negative aspect is that the supply that it is stochastic in nature and consequently difficult to control.



For a Sunny Day

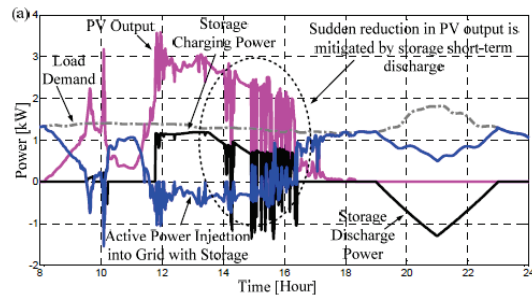


For a Cloudy Day



# DYNAMIC BENEFITS OF BATTERY ENERGY STORAGE

Battery energy storage could be a good solution for commercial projects because of its technical maturity and wide availability.



# ENERGY STORAGE APPLICATIONS

Other key applications include:

## Spinning Reserve:

- Stored energy to compensate for unexpected loss of resources
- Refers to stored energy that can be made available (i.e. very fast response time)

## Off-grid:

- Off-grid consumers use fossil or RE for their electricity
- Since these are variable in nature they need to be complemented with storage solutions to fill gaps between supply and demand

## Others:

- Power factor correction
- Voltage support.
- Frequency Control.



# ENERGY STORAGE APPLICATIONS

A wide variety of potential storage applications exist and depending on the application an appropriate technology needs to be chosen. *Some key applications include -*

## Load Shifting:

- Refers to usage of energy stored during periods of low demand for periods with high demand (production constant). During peak demand hours, stored energy is discharged to augment generation output or T&D capacity.

## Mitigating Transmission Congestion:

- Holding onto the generated capacity until transmission lines clear up (especially in cases where the generation is far from population centers)

## Renewables Time Shifting:

- RE generation and demand do not match and typically occur in different periods during day / year
- Wind and solar depend on weather conditions
- Similar to load shifting



## How renewable energy generation benefits from BESS Reduce variability

### Challenge:

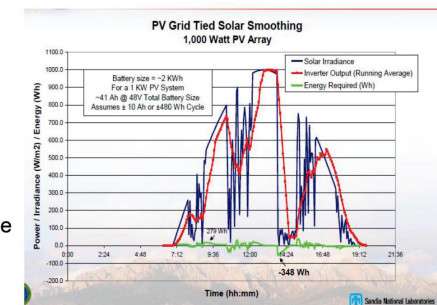
- Variations in wind speed and/or shading of the sun occur through the day

### Objective:

- BESS "fills in" dips so that the combined output from the renewable generation plus storage is close to constant

### Benefit:

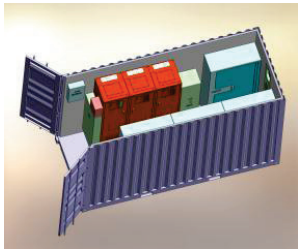
- Maintain higher forecasted levels of generation => higher revenue
- Increase amount of CO2 free generation



" Courtesy of Sandia National Lab"



## MAGELLAN'S EXPERIENCE WITH ENERGY STORAGE SYSTEMS



## MAGELLAN'S EXPERIENCE WITH ENERGY STORAGE SYSTEMS

### Renewable Energy GPSS

Grid Power Support System for  
SWER transmission system

30kVA/120kWh

- Power Quality
- Power Demand management



### I Demand Project - Transgrid

<http://idemand.transgrid.com.au/LiveMonitor>

100kVA-400kWh solution

- Power Demand Management
- Solar Power Storage
- Voltage Regulation



## RESIDENTIAL ENERGY STORAGE

1 Phase 10kW/9.2kWh

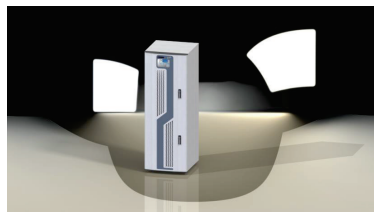
3 Phase 30kW/13.8kWh

Retrofit to existing solar installations or  
new installation

Programmable peak/time shifting

UPS function

Solar Smoother



## COMMERCIAL SCALE ENERGY STORAGE

50kW-100kW/50kWh-500Wh

Retrofit or new solar installations

Programmable time/peak shifting

Solar Smoothing

Power factor correction



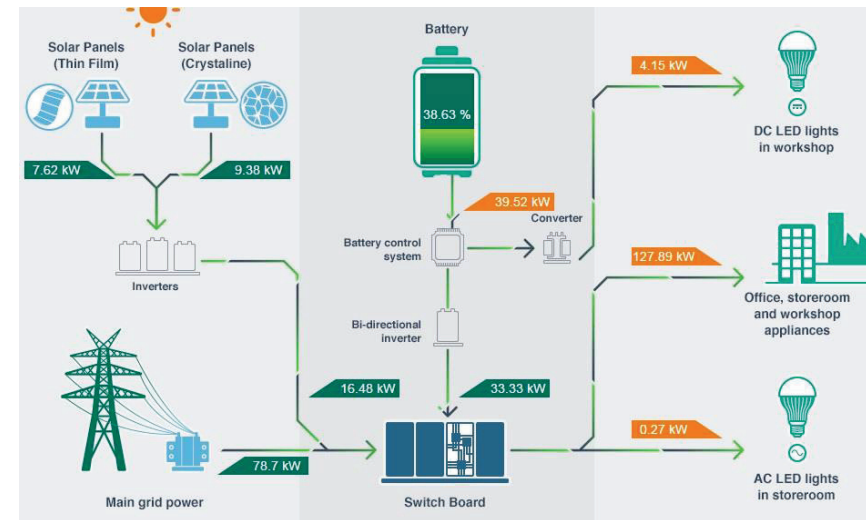


## UTILITY SCALE ENERGY STORAGE



## TRANSGRID IDEMAND PROJECT

<http://idemand.transgrid.com.au/LiveMonitor>



## UTILITY SCALE ENERGY STORAGE

### GPSS - SWR

Grid Power Support System for  
Single Wire Earth Return transmission  
Made for Ergon Energy 2010  
25kVA/ 100kWh



### GPSS - SP

Grid Power Support System for  
Standard grid  
Made for Ergon Energy 2011/12  
Units deployed to Townsville  
Residential Energy Storage  
6kVA/20kWh(Continuous Rating)

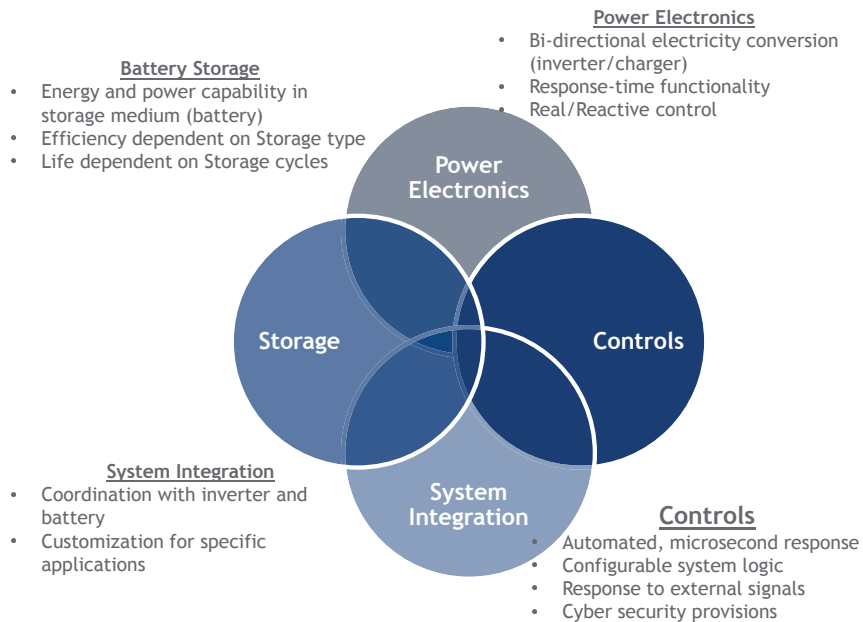


## CASE STUDY

Exploring viability of a 27kW-Battery Energy Storage System (BESS) and Solar power for commercial applications.



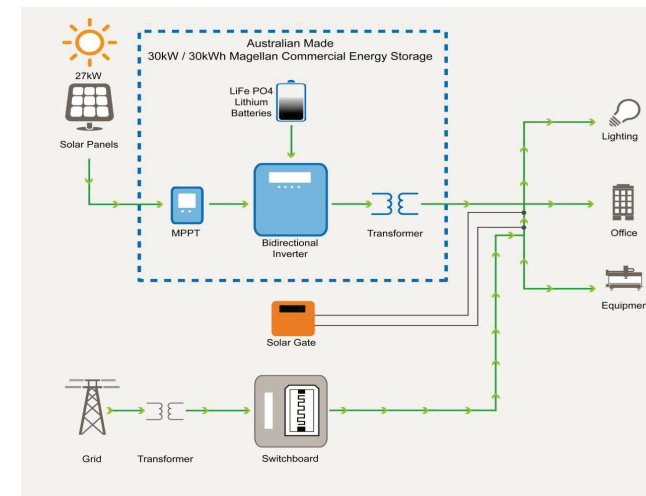
# WHAT IS REQUIRED IN ENERGY STORAGE?



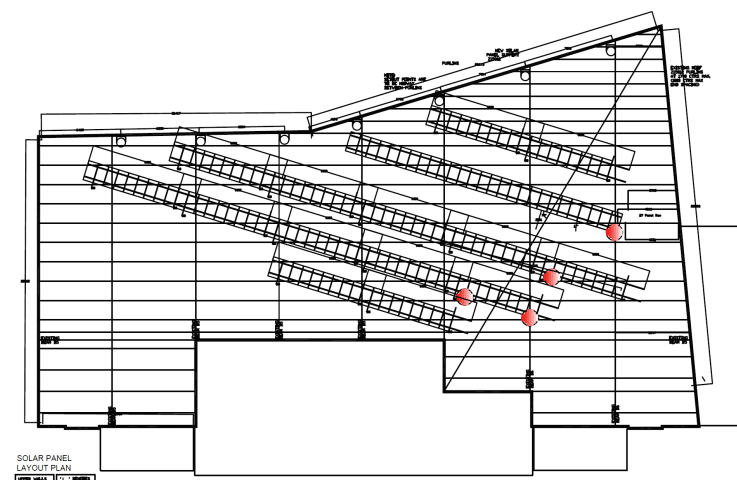
## SOLAR PANELS



# COMMERCIAL ENERGY STORAGE - SLD



## BUILDING LAYOUT





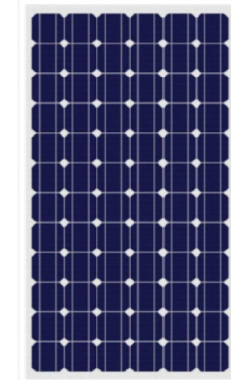
## SOLAR PANELS

- 135 Monocrystalline panels on the roof, connected in strings of 9 panels each assembled at 32° and 4° to the North.
- Strings in parallel in various combinations to make four feeds down. In details, the first string only has one string with 9 panels. The second one has 6 strings (6×9=54 Panels), and the others have 4 strings (4×9=36 Panels).
- Based on the open circuit voltage of panels, the system open circuit voltage is  $43.2V \times 9 = 388.8V$ .



## SOLAR PANELS

Cell Size(mm)	125×125mm
Cell Efficiency (%)	>17%
Type of Cell	Monocrystalline silicon
Cell Configuration	72(6x12)
Size of module	1580×808×50mm
(mm) Weight per piece (Kg)	19.3Kg
Maximum power (Wp)	200W
Maximum power voltage (V)	34.9V
Maximum power current (A)	5.73A
Tolerance of Pmax	0/+5%
Open circuit voltage (V)	43.2V
Short circuit current (A)	6.30A



## MAGELLAN COMMERCIAL ENERGY STORAGE



## SYSTEM DETAILS

Battery Efficiency	96%	
Charger Efficiency	93%	
Inverter Efficiency	95%	
Solar Charger Efficiency	97%	
Solar Array "Nameplate" Size	27	kWp
Solar Array Practical Derating	85%	
Daylight hours	10	hrs / day
Solar Peak Output	22.95	kW
Solar Generated (No limiting)	120	kWh/Day
Solar Generated (Zero export limited)	95	kWh/Day
Average Factory Power during Day	18	kW
Average Factory Power during Night	3	kW
Factory Load during Day	170	kWh/Day
Factory Load total	210	kWh/Day



## INVERTER TECHNOLOGY

Four quadrant Inverter together with Lithium batteries and battery management system (BMS)

- Power Factor correction and voltage regulation.
- Demand/Peak Demand management.
- Solar Energy Storage.



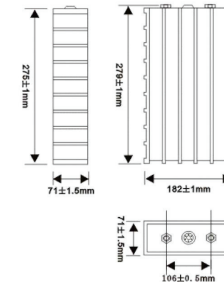
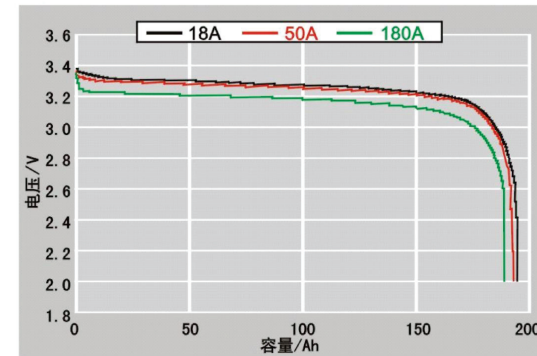
## Battery Specs

Nominal Capacity (Ah)	180	
Nominal Voltage(v)	3.2	
Internal Impedance(1kHz AC ,mΩ)	≤0.6	
Charging Cut-off Voltage(CCCV Model,V)	3.6	
Discharging Cut-off Voltage(v)	2.5	
Recommend Charging-Discharging Current (0.3C,A)	54	
Maximum short-time Discharging Current (periods10s,A)	1000	
Life Cycle(0.3C Charging-discharging,80%DDC)	2000	
Operating Thermal Ambient	Charging	0℃~45℃
	Discharging	-20℃~55℃
Storage Thermal Ambient	-20℃~45℃	
Weight(kg)	5.6±0.1kg	
Shell Material	Plastic	



## Battery Specs

Discharge Curve:



## BATTERY MANAGEMENT SYSTEM (BMS)

Lithium Ion battery chemistries cannot be overcharged without damaging active materials. The electrolyte breakdown voltage is precariously close to the fully charged terminal voltage, typically in the range of 3 to 3.8 volts/cell.

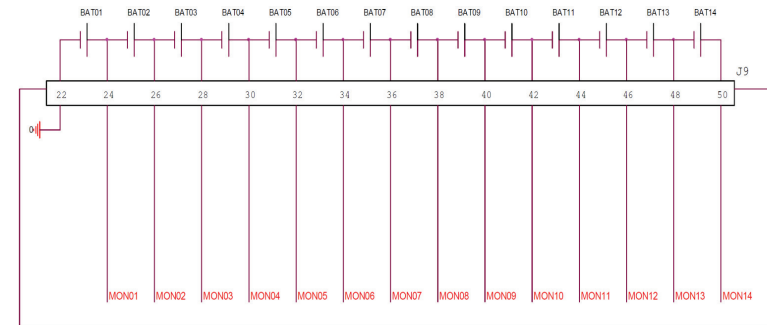
Therefore, careful monitoring and controls must be implemented to avoid any single cell from experiencing an overvoltage due to excessive charging.



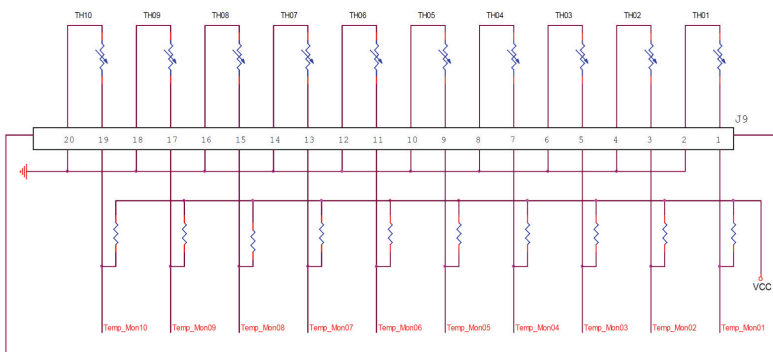
## BATTERY MANAGEMENT SYSTEM (BMS)



## BATTERY MANAGEMENT SYSTEM (BMS)



## BMS FUNCTIONALITY TEMP MEASUREMENT



## MODES OF OPERATION

- **Charging Mode** - The system is connected to the grid or PV and is charging the energy storage or waiting to charge the energy storage.
- **Islanding Mode** - The system is isolated from grid, running off the stored energy and supplying the locally connected load.
- **Manual Grid Support Mode** - The system is supplying or supplementing the locally connected load and grid network with stored energy.
- **Automatic Grid Support Mode** - the system is supporting the grid network by utilising a four-quadrant injection/absorption algorithm. Support is based on the grid voltage.

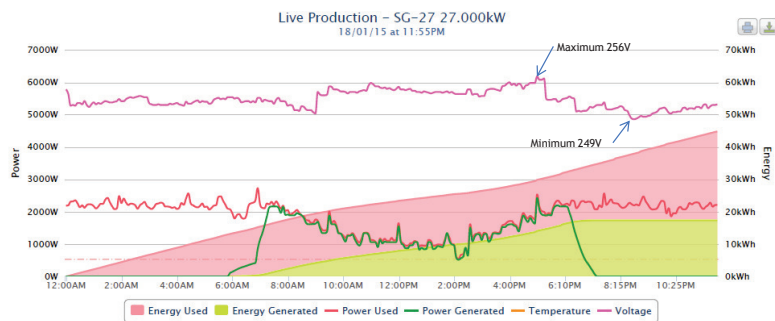


## Functions

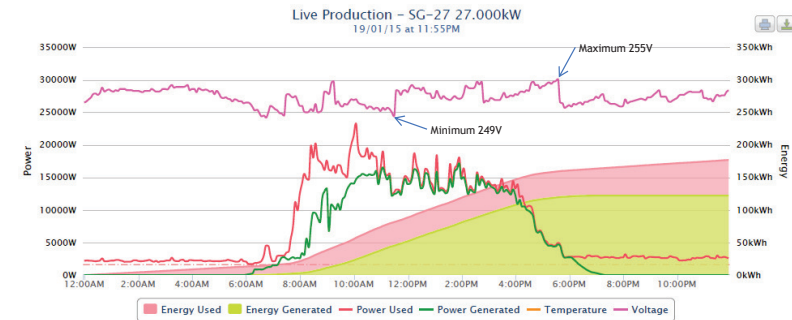
- Grid Control
- Highly configurable charging system
- Programmable grid fault response.
- Remote monitoring and control allowing operational and Engineering access.
- Data logging of all operational parameters



## LOAD/ GENERATION VARIATION FOR A TYPICAL WEEKEND



## LOAD/ GENERATION VARIATION FOR A TYPICAL WEEKDAY



## Payback and Financials Using Tariff L1

Synergy Tariff - L1	
Supply Charge: Cents Per Day	44.77
Electricity Charge: Cents Per Unit	25.60
Total Annual Cost of Electricity Without Energy Storage and Solar	\$19,208

Installing Energy Storage and Solar				
Total Initial Cost of Installation	PV Size (kW)	BESS Size (kWh)	Savings Per Year	
\$59,770	27	30	\$9,427	6.34



## Payback and Financials Using Tariff R1

Synergy Tariff - R1	
Supply Charge: Cents Per Day.	183.56
Electricity Charge: Cents Per Unit for Peak Hours.	32.22
Electricity Charge: Cents Per Unit for Off-Peak Hours.	9.93
Total Annual Cost of Electricity Without Energy Storage and Solar	\$21,279

Installing Energy Storage and Solar				
Total Initial Cost of Installation	PV Size (kW)	BESS Size (kWh)	Savings Per Year	Payback Period (Years)
\$59,770	27	30	\$14,445	4.13



## Conclusions

The above case study shows that installing solar power and energy storage equipment in a commercial building is a very effective way of reducing the cost of electricity and provides an excellent return on investment (not including plant depreciation).



# Thank you.

## Questions?

