Submission No: 21

Status of Energy Storage Technologies as Enabling Systems for Renewable Energy from the Sun, Wind, Waves and Tides

Submission to

House of Representatives Standing Committee on Industry and Resources

Case Study into Renewable Energy in Australia

by

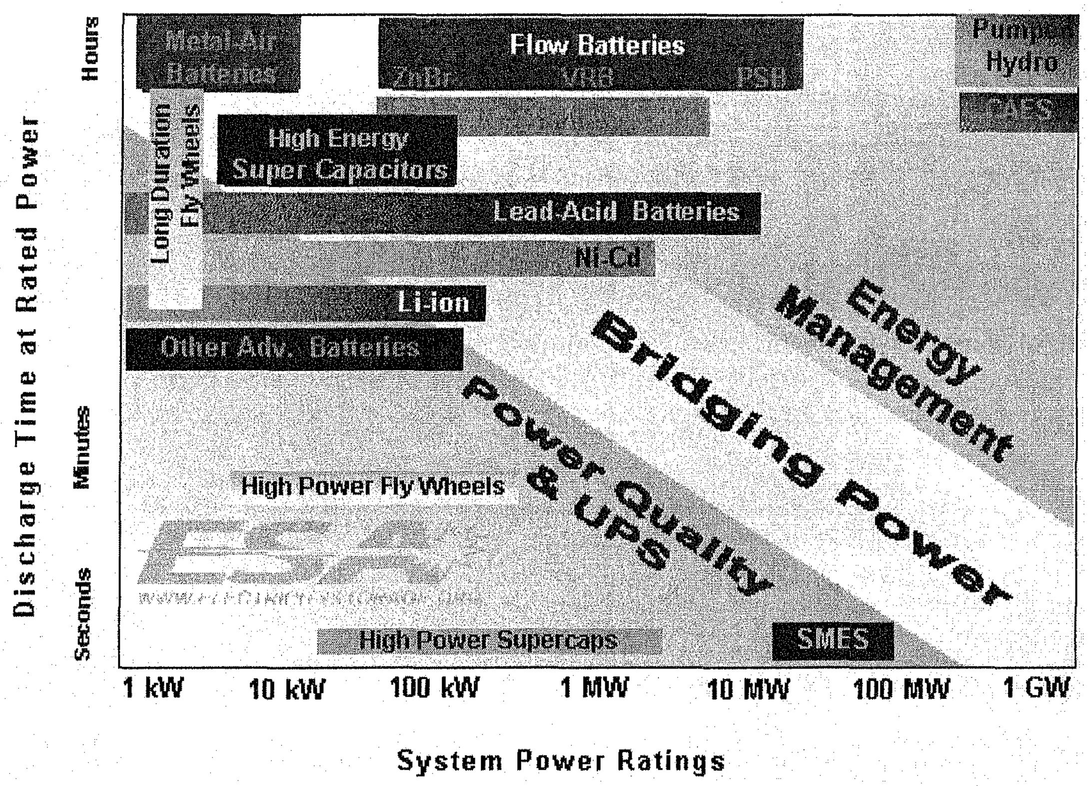
V-Fuel Pty Ltd,

Sydney, Australia

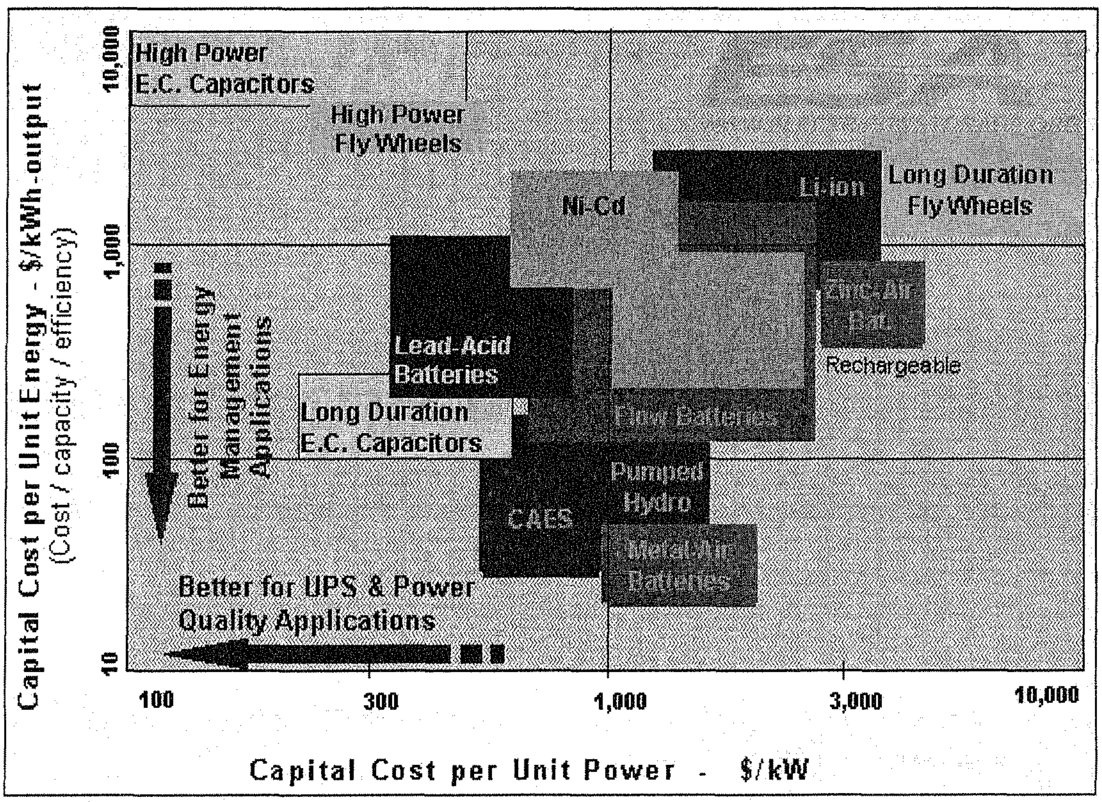
The greatest problem associated with renewable forms of energy, such as wind, solar, wave and tidal, is that of variability of supply. As such, electricity derived from these sources cannot be matched to consumption at peak daily times, so must be 'balanced' by some other form of generation, usually coal-fired or nuclear, to maintain a stable network. Of equal concern is that if energy output from the renewable source is higher than predicted and there is no available balancing output that is able to be ramped down, then a percentage of the electricity from the renewable source must be constrained, and therefore lost. To overcome these issues, a safe and efficient means of storing renewable energy is needed so that all available energy from the renewable source can be captured and supplied to the grid or user when it is needed. The development of energy storage systems has received considerable attention in the last 2 years and a number of technologies have now emerged that can address the problem of renewable energy storage, enabling renewable energy systems to match supply with demand. Energy storage is therefore often referred to as the key to unlocking the door of renewable energy.

The US-based Electricity Storage Association describes the different energy storage technologies that are currently available around the world and compares them in terms of their applicability to different storage time needs, capital costs and life-cycle costs (Ref: http://electricitystorage.org/index.html). These technology comparisons are presented below:

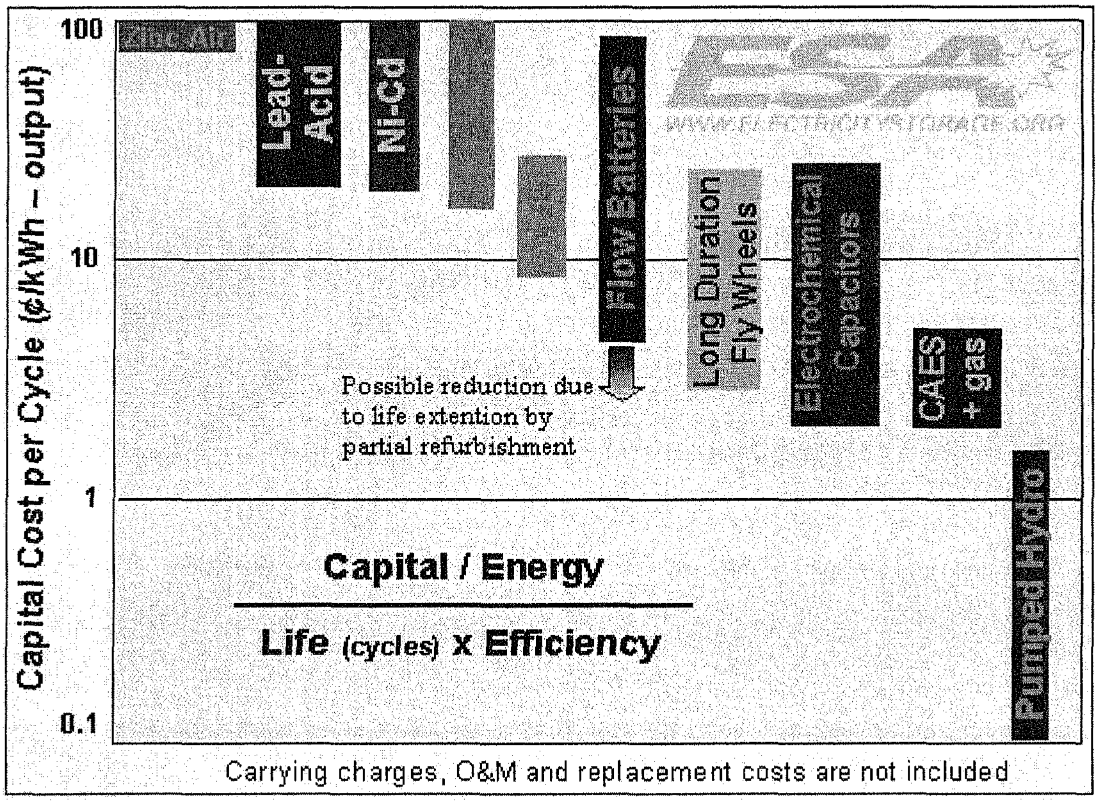
Storage Technologies	Main Advantages (relative)	Disadvantages (Relative)	Power Application	Energy Application
Pumped Storage	High Capacity, Low Cost	Special Site Requirement		●
CAES	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel		●
Flow Batteries: PSB VRB ZnBr	High Capacity, Independent Power and Energy Ratings	Low Energy Density	◐	●
Metal-Air	Very High Energy Density	Electric Charging is Difficult		●
NaS	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns (addressed in design)	●	●
Li-ion	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit	●	○
Ni-Cd	High Power & Energy Densities, Efficiency		●	◐
Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost	●	○
Lead-Acid	Low Capital Cost	Limited Cycle Life when Deeply Discharged	●	○
Flywheels	High Power	Low Energy density	●	○
SMES, DSMES	High Power	Low Energy Density, High Production Cost	●	
E.C. Capacitors	Long Cycle Life, High Efficiency	Low Energy Density	●	◐



Metal-Air Batteries
Flow Batteries
ZnBr
VRB
PSB
Pumped Hydro
CAES
Long Duration Fly Wheels
High Energy Super Capacitors
Lead-Acid Batteries
Ni-Cd
Li-ion
Other Adv. Batteries
Energy Management
Bridging Power
Power Quality & UPS
High Power Fly Wheels
High Power Supercaps
SMES
Hours
Minutes
Seconds
Discharge Time at Rated Power
1 kW
10 kW
100 kW
1 MW
10 MW
100 MW
1 GW
System Power Ratings



High Power E.C. Capacitors
High Power Fly Wheels
Li-ion
Long Duration Fly Wheels
Ni-Cd
Zinc-Air Bat.
Rechargeable
Lead-Acid Batteries
Flow Batteries
Long Duration E.C. Capacitors
Better for Energy Management Applications
Pumped Hydro
CAES
Metal-Air Batteries
Better for UPS & Power Quality Applications
10,000
1,000
100
10
Capital Cost per Unit Energy - $/kWh-output
(Cost / capacity / efficiency)
100
300
1,000
3,000
10,000
Capital Cost per Unit Power - $/kW



Technology comparisons

Electrochemical Capacitors or Supercapacitors.

Supercapacitors represent a high-power-density energy-storage that is able to bridge the gap in energy density between batteries and the common capacitor. Supercapacitors exhibit very high energy-storage efficiencies (>95%) and can be cycled hundreds of thousands of times without appreciable loss of energy-storage capacity. Supercapacitors therefore represent an energy-storage solution with a very high cycle life. Supercapacitors are, however, susceptible to self-discharge and are most suitable for . use in hybrid energy-storage systems to complement batteries and to offer periods of pulsed power which would otherwise be difficult to engineer. It is therefore essential to note that supercapacitors do not offer an alternative to batteries, but provide a synergy for many contemporary energy storage/high power delivery systems.

Lithium-ion (Li-ion), sodium sulphur (NaS) and related zebra battery (Na-$NiCl_2$), nickel cadmium (Ni-Cd) and related nickel metal hydride (Ni-MH), and lead acid (Pb acid) batteries.

Although NiCd, Ni-MH and Pb-acid can supply excellent pulsed power (due to their low equivalent series resistance), they are large and heavy compared to Li-ion. Nickel cadmium and lead acid also contain toxic heavy metals, which are undesirable. Nickel metal hydride suffers from severe self-discharge (up to 25% per month), which would lead to a loss of valuable stored energy (long-term). Ni-Cd and NiMH batteries must be fully discharged before recharge. NaS batteries operate at 300°C and suffer safety problems of potential release of molten sodium and sulphurous/sulphide vapours. Although they have an energy efficiency of around 85%, they require constant heat input to maintain the molten states of the electrolytes. The same applies to the zebra battery. Li-ion batteries offer the highest energy density and need to increase the power density for some applications as well as an energy-storage efficiency close to 100%. The small size and low weight of the Li-ion system make it ideally suited to portable applications, but potential safety issues would need to be addressed in large-scale installations. The main drawbacks Li-ion technology are its high cost and the detrimental effect of deep discharging on its cycle life.

Kinetic energy storage: flywheels

The basic principle of flywheel technology is that of kinetic energy stored in rotating cylinders supported by magnetic bearings and operating in a vacuum to eliminate frictional losses. They have the potential to simultaneously be both high-energy and power-density devices. Although flywheels with a long working lifetime (>20 years) are already available, there are no commercial applications for flywheels in power management, the technology still being at the demonstration stage. However, large arrays of flywheels have been shown to be successful in frequency management and there has been some modest success in transport applications. Research is taking place into improved bearings, using superconducting magnets and also into producing new high-tensile-strength composites capable of withstanding extremely high angular velocities. The main limitation with regard to the widespread use of flywheels is still the high cost due to the precision engineering needed.

Flow batteries

Flow batteries consists of two electrolyte reservoirs from which the electrolytes are circulated through an electrochemical cell comprising a cathode, an anode and a membrane separator. The energy storage capacity of such systems is solely dependent on the volume of the electrolyte stored in the reservoirs. Power density depends on the rates of the anode and cathode reactions in the cell.

To date, the three leading designs of flow battery have been:

- polysulphide bromide (PSB)
- vanadium redox (VRB)
- zinc bromine (ZnBr).

Flow batteries such as these offer energy storage/delivery efficiencies of 75–85% with potential differences across individual cells, of 1.4–1.8V. By combining cells in series and parallel combinations, high-current and high-voltage solutions may be designed. Self-discharge of flow batteries is mitigated by the isolated storage of the charged electrolytes in the separate reservoirs.

From the above comparisons, flow batteries are seen to offer high efficiency storage for a lower capital and per cycle cost than other technologies, offering storage capabilities in the range of 1 hour to multiple hours in applications from 1 kilowatt to tens of Megawatts.

Of all the flow-cell technologies currently available, the Vanadium Redox Battery (VRB) developed at the University of New South Wales, has shown the greatest commercial promise with more than 20 MWh of installed capacity in a range of applications in Japan, Australia, USA and Italy. The very high energy storage capacity of the VRB would allow green energy to be produced sporadically, but distributed in a constant, reliable way that can meet peak demands. In this way, the **VRB makes it truly possible for renewable energy production to stand alone from coal-fired electricity production, thereby enabling large-scale future reductions in greenhouse gases.** Since 1994 there have been more than 20 VRB installations commissioned in a range of energy storage application around the world, starting with a 15 kWh VRB system built and installed by UNSW in a demonstration Solar House in Thailand. Other larger installations include:

1. 200 kW / 800 kWh VRB installed by Mitsubishi Chemicals in 1996 at Kashima- Kita Electric Power station in Japan for load-levelling.
2. 450 kW / 900 kWh VRB installed in 1996 by Sumitomo Electric Industries (SEI) at Tasumi Sub-Station, Kansai Electric Power, Japan, for peak shaving.
3. 100 kW / 800 kWh VRB installed by SEI in 2000 in the Urban Ace Awaza Building, Japan for office building peak shaving.
4. 200 kW / 1.6 MWh VRB installed by SEI in 2000 at Kansai Electric Power, Japan for peak shaving.
5. 170 / 1 MW VRB installed by SEI in 2001 at Hokkaido Electric Power Wind farm, Japan for wind turbine output power stabilisation.
6. 30 kW/240 kWh VRB installed by SEI in 2001 at Obayashi Corporation Dunlop Golf Course Japan for solar energy storage in a PV-hybrid system.
7. 1.5 MW / 1.5 MWh VRB installed by SEI in 2001 at Tottori Sanyo Electric, Japan for peak shaving and emergency back-up power.
8. 250 kW / 500 kWh VRB installed by VRB Power in 2001 at Stellenbosch University for ESKOM Power Corporation, South Africa for peak shaving and UPS back-up power
9. 500 kW / 5 MWh VRB installed by SEI in 2001 at Gwansei Gakuin University Japan for peak shaving.
10. 42 kW / 90 kWh VRB installed by SEI in 2001 at CESI, Milan, Italy for R&D into distributed power systems.
11. 100 kW / 100 kWh VRB installed by SEI in 2003 at Utility company in Japan for peak shaving.
12. 120 kW / 960 kWh VRB installed by SEI in Office Building in Japan for UPS/peak shaving.
13. 500 kW / 2 MWh VRB installed by SEI in 2003 in High-Tech factory in Japan for UPS/peak shaving.
14. 250 kW / 1 MWh VRB installed by Pinnacle VRB in 2003 for Hydro Tasmania on King Island for wind energy storage and diesel fuel replacement.
15. 250 kW / 2 MWh VRB installed for PacificCorp by VRB Power in 2004 in Moab, Utah, USA for voltage support, rural feeder augmentation.

16. 4 MW / 6 MWh VRB installed by SEI in 2005 for J Power at Subaru Wind Farm, Tomahae, Hokkaido, Japan for wind energy storage and wind power stabilisation.

More recently, an order for a 6 MW VRB was placed by the Irish Sustainable Energy Association (SEA) for energy storage at the Sorne Hill wind farm in Ireland. The system is expected to be delivered by *VRB Power, Canada* by the end of 2007. After successful demonstration of the VRB in this wind farm, SEA anticipates expansion of VRB systems to allow Ireland to achieve 20% renewables penetration by 2020, making a reduction in carbon dioxide emissions of 7.2 million tonnes per annum.

Furthermore, the VRB has been independently characterised as having the lowest ecological impact of all energy storage technologies. Combined with its cycle life capability of more than 10,000 cycles and low cycle cost, it is currently unmatched in its performance, cost and sustainability, offering the best solution for achieving dispatchable renewable energy and reducing greenhouse gas emissions.

Barriers to Implementation

As with all new technologies, widespread commercial implementation of renewable energy storage technologies must be preceded by appropriate cost structures that can only be met with large-scale mass production. In the early stages of commercial supply, therefore, government support in the form of renewable energy subsidies and rebates (that extend to the storage system as well as the renewable power generator) will be essential for consumer acceptance.

Furthermore, under the current electricity industry structure, energy storage is regarded as a generation system and as such, cannot be installed by electricity distributors to handle variations in electricity supply and demand within their network. A regulatory change that would permit electricity distributors to install energy storage devices within their distribution system will thus facilitate the installation of renewable energy storage systems closest to where system fluctuations and instability could best be managed.

Increasing mandatory renewable energy targets, while essential for the on-going support and promotion of renewable energy technologies in Australia, may have little impact on encouraging efficient renewable energy systems that offer dispatchable power to the consumer, unless energy storage is included as a mandatory feature of all new wind and solar farms. To allow developers to offset increased capital costs associated with the energy storage component of their wind or solar farms, however, appropriate rebates that account for the improved reliability of the renewable energy source would be essential in the short to medium term until costs can be reduced with increased production volumes.

With a number of proven energy storage technologies now available, it is no longer appropriate to classify renewable energy as intermittent and unreliable. Electricity can be efficiently stored for use when required, so there should no longer be any technical barriers to the widespread use and implementation of renewable energy systems to off-set coal-fired power generation in Australia. This would enable Australia to dramatically reduce carbon dioxide emissions to acceptable international levels and to set realistic greenhouse gas reduction targets for the future.