COMPANY AND TECHNOLOGY INFORMATION SHEET

V-Fuel Pty Ltd

Summary

Energy storage has become the critical issue for the world's future energy supply and redox flow cells offer the best combination of energy efficiency, capital cost and life cycle costs compared with other technologies. The UNSW Vanadium Redox Flow Battery has been internationally acclaimed as the most promising technology currently available for new energy storage applications in the range from several kilowatts to several megawatts range where storage times up to several hours are required. With V-Fuel's recent advances in the development of a low cost stack technology for the VRB, the financial viability of the system can now be achieved so that energy storage products can be produced for a broad market. This emerging business opportunity has the potential to generate millions of dollars in export earnings, while also helping to alleviate serious global energy supply and environmental problems.

V-Fuel Pty Ltd was established in January 2005 with the support of the Victorian Government funded Centre for Energy and Greenhouse Technologies Pty Ltd to commercialise the Vanadium Redox Flow Battery developed at the University of New South Wales in Sydney. Its principal shareholder, Magnam Technologies Pty Ltd is the initial Start-up company that was formed in 2003 by two of the original inventors of the Vanadium Redox Battery Technology (VRB), Professor Maria Skyllas-Kazacos of the School of Chemical Engineering and Industrial Chemistry, UNSW and Mr Michael Kazacos. V-Fuel has developed new proprietary technology for the proven G1 VRB and has successfully secured an exclusive world-wide license for the new Generation 2 Vanadium Bromide Redox Battery (G2 V/Br) from the University of NSW commercial arm, NS Innovation Pty Ltd.

With almost twice the energy density compared with the original VRB (G1), the G2 V/Br battery will allow V-Fuel to enter markets and applications where the battery weight or footprint area restrictions would preclude use of the G1 VRB. Having the same electrolyte in both half-cells, the V/Br system has no problems of cross-contamination and combines the best features of the G1 VRB system with a high energy density and wider temperature capability.

A recent market analysis conducted from survey responses from a range of companies that have contacted V-Fuel to purchase redox batteries, has identified 2 primary stack products that will be developed and manufactured by V-Fuel. These are a 5 kW stack for use in small-scale systems with up to 50 kW power requirements, and a 50 kW stack for use in large-scale applications of 50 kW to several MW in size. V-Fuel is now ready to begin manufacture of 1-5 kW stacks for application in small to medium size energy storage systems and with its new low cost, high performance proprietary membrane, expects to be able to supply products at close to half the price as its current competitors.

1 INTRODUCTION

The world demand for efficient energy storage systems has been growing steadily in the last 20 years as concerns over Global Warming and urban pollution have led to pressure from environmental groups around the world for increased use of renewable energy technologies. In combination with renewable resources, energy storage can increase the value of photovoltaic (PV) and wind-generated electricity, making supply coincident with periods of peak consumer demand. Energy storage systems can also be used to follow load, stabilize voltage & frequency, manage peak loads, improve power quality, defer upgrade investments and provide uninterruptible power for many industrial and commercial applications. Batteries are ideal for storing electrical energy since they allow high energy conversion efficiencies to be achieved (over 80%) and long storage times.

The world market for batteries is estimated at about US $15 billion each year. The Energy Storage Association, USA (ESA), estimates that industrial batteries, as might be used in uninterruptible power supplies, power quality applications, standby and reserve batteries amount to US $5 billion each year. The Energy Storage Association also has compared the performance parameters of different types of energy storage systems ranging from flywheels, pumped hydro, capacitors and different battery technologies, and redox flow batteries are shown to have many technical benefits over other energy storage systems as well as an excellent combination of energy efficiency, capital cost and life cycle costs compared with other technologies (Ref: http://www.electricitystorage.org/tech/technologies_comparisons.htm).

Figure 1 shows a cost comparison of the redox flow battery against other battery technologies and a clear advantage is seen for the redox systems.

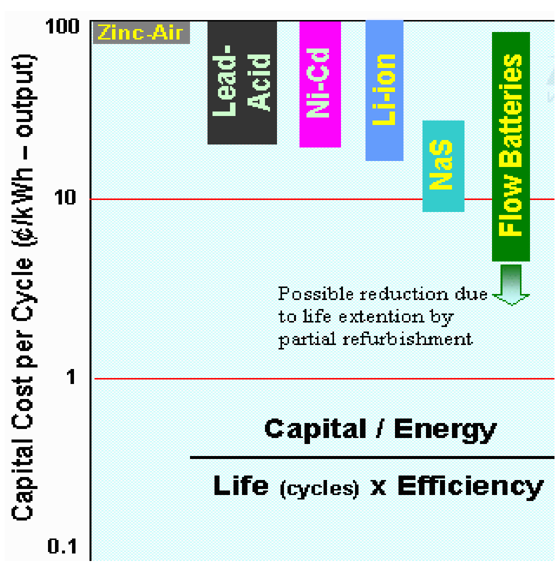

Figure 1. Cost per cycle comparisons of energy storage technologies (Ref: http://www.electricitystorage.org/tech/technologies_comparisons_percyclecost.htm)

The Redox Flow Cell is an electrochemical system which allows energy to be stored in two solutions containing different redox couples with electrochemical potentials sufficiently separated from each other to provide an electromotive force to drive the oxidation-reduction reactions needed to charge and discharge the cell. Unlike conventional batteries, the redox flow cell stores energy in the solutions, so that the capacity of the system is determined by the size of the electrolyte tanks, while the system power is determined by the size of the cell stacks. The redox flow cell is therefore more like a rechargeable fuel cell than a battery (see Figure 2).

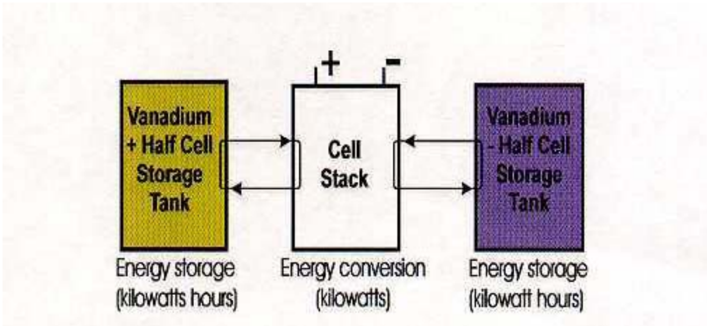

Figure 2: Redox flow cell concept with separate energy conversion and energy storage components

While the Redox Flow Cell concept has been around for close to 30 years with several systems evaluated by various groups around the world, only the Vanadium Redox battery pioneered at UNSW (1 - 42) has reached commercial fruition.

2. THE UNSW GENERATION 1 VANADIUM REDOX BATTERY (VRB).

Of the redox flow cells developed to date, the vanadium redox flow battery, or G1 VRB system, pioneered at the University of New South Wales, Australia, has shown the greatest potential with high energy efficiencies of over 80% in large installations and long cycle life. As illustrated in Figure 2 above, the Vanadium Redox Flow Battery employs the V(III)/V(II) and V(V)/V(IV) redox couples in sulphuric acid as the negative and positive half-cell electrolytes respectively. The charge-discharge reaction occurring in the vanadium redox cell are:

At the negative electrode:

$$V^{3+} + e^{-} \underset{\text{discharge}}{\overset{\text{charge}}{\longleftrightarrow}} V^{2+} \qquad E° = -0.26\ V$$

At the positive electrode:

$$VO_2^{+} + 2H^{+} + e \underset{\text{charge}}{\overset{\text{discharge}}{\longleftrightarrow}} VO^{2+} + H_2O \qquad E° = 1.00V$$

The standard cell potential E° (cell) is 1.26 Volts at concentrations of 1 mole per litre and at 25°C. Under actual cell conditions, however, the open-circuit cell voltage is 1.4 Volts at 50% state-of-charge and 1.6 Volts at 100% SOC. The electrolyte for the vanadium battery is typically 2 M vanadium sulphate in 2.5 M H_2SO_4, the vanadium sulphate (initially 1 M V (III) + 1 M V (IV)) being prepared by chemical reduction or electrolytic dissolution of V_2O_5 powder. The basic components of the redox cell are illustrated in Figure 3.

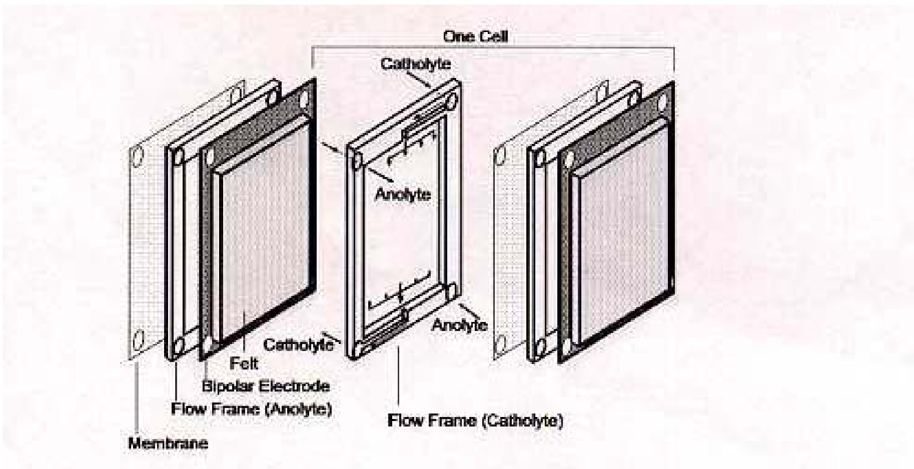

Figure 3: Basic Components of VRB cell stack

2.1 Features and Advantages of the VRB:

Most of the advantages of the vanadium battery are thus due to the use of the same element in both half-cells which avoids problems of cross-contamination of the two half-cell electrolytes during long-term use. This means that the electrolytes have an indefinite life so that waste disposal issues are minimised.

Other advantages of the VRB include:

- Low cost for large storage capacities. Cost per kWh decreases as energy storage capacity increases, typical projected battery costs for 8 or more hours of storage being as low as US$150 per kWh.
- Existing systems can be readily upgraded and additional storage capacity can be easily installed by changing the tanks and volumes of electrolyte.
- High energy efficiencies between 80 and 90% in large installations.
- Capacity and state-of-charge of the system can be easily monitored by employing an open-circuit cell.
- Negligible hydrogen evolution during charging
- Can be fully discharged without harm to the battery

- All cells fed with same solutions and therefore are at the same state-of-charge
- No problems of cross-contamination therefore solutions have indefinite life.
- Long cycle life
- Easy maintenance.
- Can be both electrically recharged and mechanically refueled

2.2 UNSW Vanadium Battery Research, Development and Demonstration Projects

The Vanadium Redox Battery (VRB) was taken from the initial concept stage by Skyllas-Kazacos and co-workers at UNSW in 1984 through the development and demonstration of several 1-4 kW prototypes in stationary and electric vehicle applications over a 15 year period at UNSW. UNSW also led the world in the construction and demonstration of VRB systems in field trials, including design and installation of the first ever VRB used in a demonstration Solar House in Thailand (Figure 4 and ref 40), an emergency back-up system for submarines (Figure 5) and the world's first vanadium battery powered electric golf cart (Figure 6 and ref 41).

Figure 4: Vanadium Battery powered Solar Demonstration House in Thailand

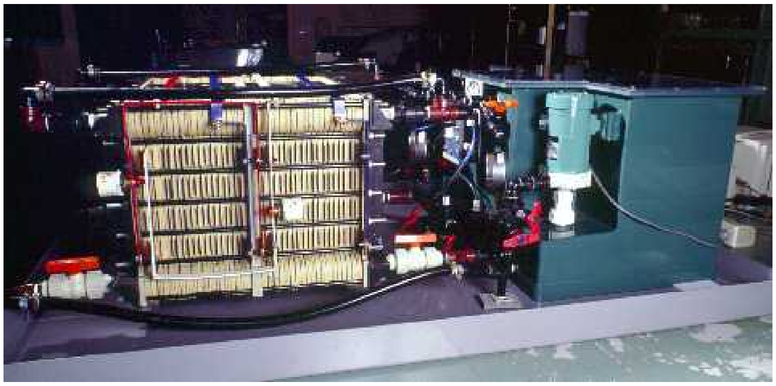

Figure 5: Emergency Back-up Battery for Submarines (sponsored by Australian Dept of Defence)

Figure 6: UNSW Vanadium Fuel Cell Powered Electric Golf Cart

Thus, a unique feature of the VRB is its ability to be recharged both conventionally or with mechanical refueling by exchanging spent solutions at suitable refueling stations as illustrated in Figure 7. This concept has attracted enormous interest and enthusiasm from the community and from government and industry groups over the years and a world-first vanadium battery powered electric golf cart, sponsored by Pacific Power was commissioned and field tested by UNSW in 1995/96.

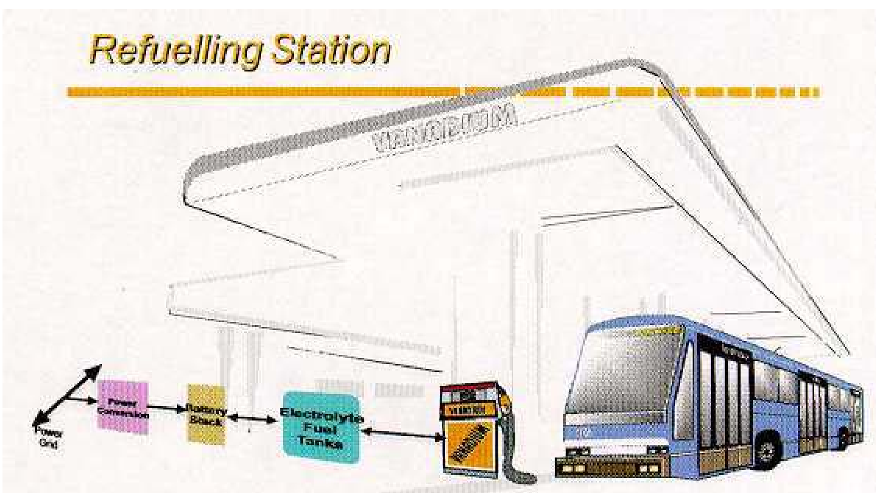

Figure 7: VRB refuelling station

2.3 Commercialisation of the VRB

The UNSW Vanadium Redox Battery technology is currently being successfully commercialised in a range of stationary applications such as wind, solar and load-levelling installations around the world and the demand for these systems is growing rapidly in North America, Japan, Europe and Australia.

In 1993 licences for the VRB were issued by UNSW to Thai Gypsum Products in Thailand for Solar House applications, as well as to Mitsubishi Chemicals and Kashima-Kita Electric Power Corporation in Japan where a 200kW/800kWh load-levelling demonstration system was installed in 1997 (44). In 1998, the UNSW VRB technology was sold to the Australia listed company Pinnacle VRB. In 1999, Pinnacle VRB entered into a new licence agreement with Sumitomo Electric Industries (SEI) who built a 450 kW/ 1 MWh vanadium redox battery load levelling demonstration system at the Kansai Electric Power Plant in Japan (Figure 8), as well as several other VRB systems for wind energy storage and other stationary applications (45, 46).

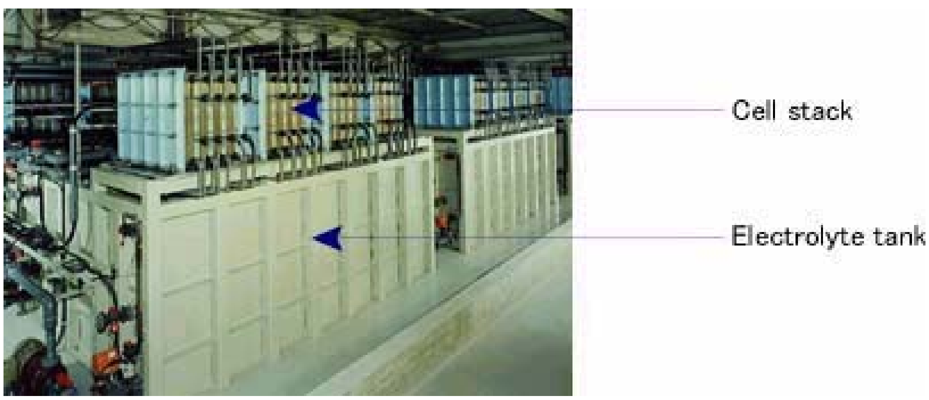

Figure 8: SEI Substation Demonstration System Load leveling DC 450kW x 2h (Ref: http://www.sei.co.jp/sn/0105/p1.html)

More recently, a 4 MW/6 MWh VRB was installed by Sumitomo on the Japanese Island of Hokkaido to store wind power and stabilize the output shift of wind generation. The advantage of the VRB for wind power output stabilisation is the very high cycle life of the VRB compared with other battery systems. In fact, SEI have reported more than 12,000 charge-discharge cycles with a 25 kW VRB stack, or up to 8 years projected life. After 8 years, it is possible to replace the membrane and extend the life of the system even further. This means that the replacement costs of the VRB would be significantly lower than other types of batteries.

In 2004, a 250 kW/1 MWh installation was constructed and commissioned by Pinnacle VRB on King Island in Tasmania to provide storage energy for a wind generator for diesel fuel displacement. This project was funded by the Australian Greenhouse Office and the customer was Tasmania Hydro. The stacks for this system were supplied by SEI, Japan, electrolyte was supplied by Highveld, South Africa, with other components being sourced from elsewhere.

With more than 20 installations around the world totalling over 20 MWh installed capacity, the G1 VRB is now regarded as a proven technology. Achieving the necessary cost structure for each of the identified markets, however, will determine its widespread consumer take-up in the years ahead.

In April, 2006, the basic G1 VRB patent expired, thereby allowing V-Fuel to commercialise G1 VRB systems around the world using its proprietary new low cost stack technology. Figure 9 that show V-Fuel's new 1-2 kW/6 kWh G1 VRB prototype that is now ready for production in stack sizes up to 5-10 kW.

Figure 9: 1-2 kW/6 kWh VRB incorporating V-Fuel's low cost stack design.

A 25-50 kW module is soon to be developed by V-Fuel for application in large MW sized installations for load-leveling, power arbitrage and large-scale renewable energy storage.

3. SPECIFIC BENEFITS OF THE VANADIUM BATTERY IN DIFFERENT STATIONARY APPLICATIONS.

A. Remote area power supply system (RAPPS) applications

Australia's large land mass and great distances between major urban centres, makes it particularly dependent on stand-alone power systems for remote communities, mining towns and isolated homesteads and tourist locations. Its heavy dependence on diesel fuel for diesel grids and smaller stand-alone systems is a great cost to the community, both financially and environmentally. Most RAPSS systems employ a diesel generator with or without solar panels or wind generator and a lead-acid battery for storage. Due to the poor performance and short cycle life of the lead-acid battery under deep discharge cycling, there is a heavy dependence on the diesel generator for power.

The cost of diesel-fired power generation is comparatively high, typically in the range of AUD 0.14 – 0.60 per kWh. For small remote diesel generating sets in the range 1 – 15 kW_e, the cost can be as high as AUD 2.50 per kWh

With a low cost, efficient battery, however, considerable reduction or complete replacement of the diesel generator could be possible. The important features of the vanadium battery for this application are:

- low capital and generation cost per kWh for large storage capacities
- easy maintenance
- flexibility
- long life

B. Large-scale photovoltaic applications

VRB Advantages :

- Capacity easily upgraded by changing tanks and volumes of electrolyte.
- Battery voltage chosen by tapped cells - allows change of operating condition according to variations in solar insulation & load to achieve greater efficiency.
- Appropriate voltage chosen to control solar array performance at optimum conditions - provides low cost, high efficiency maximum power point tracker, allows battery to operate as DC transformer.
- Capacity & SOC monitored, by open-circuit cell.
- Target cost/kWh decreases as capacity increases (as low as US$150 / kWh.)

C. Large-scale wind energy storage.

Wind Energy is now emerging as the most promising renewable energy source for short term commercialization. However, wind generators suffer from output power instability and as with all renewable energy technologies, the energy production cannot match the demand. A VRB wind installation by SEI in Japan has demonstrated output power stabilization that is only feasible due to large cycle life of the VRB. More than 12,000 cycles have been demonstrated with 20 kW stacks and with suitable materials selection, achieving more than 1.5million cycles is expected for the VRB. The life of the VRB is measured in years rather than cycles, so theoretically an infinite number of cycles is possible over the life-time of the battery stacks. The life-time can further be extended by periodically replacing the membrane, so that replacement costs are also much lower than other battery technologies while waste materials are also minimized by the re-use of the electrolytes.

D. Load leveling and distributed power systems.

The use of energy storage allows for:

- more efficient use of energy
- deferral of capital investment in new power stations
- Battery energy storage systems built in 1-2 years vs 10 years for power station
- No emissions or noise so can be installed in urban areas to meet peak demands
- Can defer investment in new transmission lines by installing battery plants at load centre
- Battery modules can be added as demand increases

In addition to the above, the most important benefit of the VRB in such applications is the high energy efficiency (over 80% overall energy efficiency has been demonstrated in large demonstration scale VRB systems), long cycle life and low cost per kWh.

E. Emergency back-up power and uninterruptible power systems (UPS)

Many UPS systems employ lead-acid batteries with or without a diesel generator. Due to the poor performance and short cycle life of the lead-acid battery under deep discharge cycling, there is a heavy dependence on the diesel generator for longer term power generation in the event of power failure. With a low cost, efficient VRB, however, considerable reduction or complete replacement of the diesel generator would be possible.

While both the VRB and Generation 2 V/Br system share many features in common, it is expected that the potentially higher vanadium bromide solubility over a wider range of temperatures will make the V/Br a superior choice in these applications that require a small footprint area and higher energy density.

Uninterruptible power for telecommunications is an enormous potential application for the G2 V/Br, and following the power failures in the United States during 2003, USA telcom providers are moving towards fully stand-alone back-up power systems that will secure their systems against loss of communication during power failures. A VRB or V/Br system can inject large quantities of power and energy into the grid within milliseconds, aiding in the recovery from blackouts, or stabilizing the grid before failures cascade through the system. The VRB and V/Br can either be deployed at large scale (tens of megawatt hours from each unit) or through a distributed network of smaller scale facilities.

5. G1 VRB COST PROJECTIONS AS A FUNCTION OF STORAGE TIME.

5.1 Capital costs as a function of storage time

In the case of redox flow cells, the independent sizing of the system power and energy, means that the cost per kWh of the entire battery is a function of the energy storage capacity. The total system cost was calculated on the basis of a projected stack cost of approximately $ 420 per kW and an electrolyte system cost of $230 per kWh (including electrolyte, tanks, pumps, controller etc) and the data is presented in Figure 10.

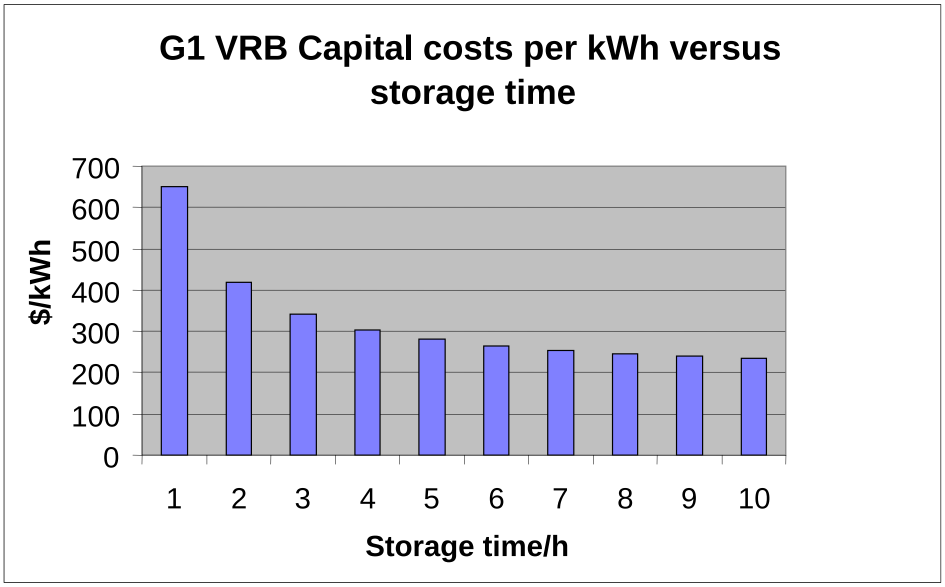

Figure 10: Total battery costs per kWh versus storage time for electrolyte system cost of $230 per kWh and assumed stack cost of $420/kW

This figure shows that for storage times of 2 hours, a total battery cost of just over $400 per kWh can be achieved, this dropping to less than $300 per kWh for storage times above 4 hours.

5.2 Cost of generated power as a function of storage time

Another way of evaluating the cost competitiveness of the V-Fuel battery is to calculate the cost per kWh of generated energy over the life of the battery installation. This involves input data for:

1. cost per kW of the stack
2. cost per kWh of electrolyte
3. life of membrane – with periodic replacement of membrane over an assumed total system life of 20 years
4. cost of replacement membrane

5. annual maintenance cost per kWh installed capacity.

Cost comparisons were also made between the VRB and the Lead-acid battery. The Sungel range, 2SG4500 battery was selected as base battery for building the battery bank with 5 kW nominal power output for different storage times and the annualised costs assuming a 9.7 year lifetime and a discount rate of 8% p.a. are presented below.

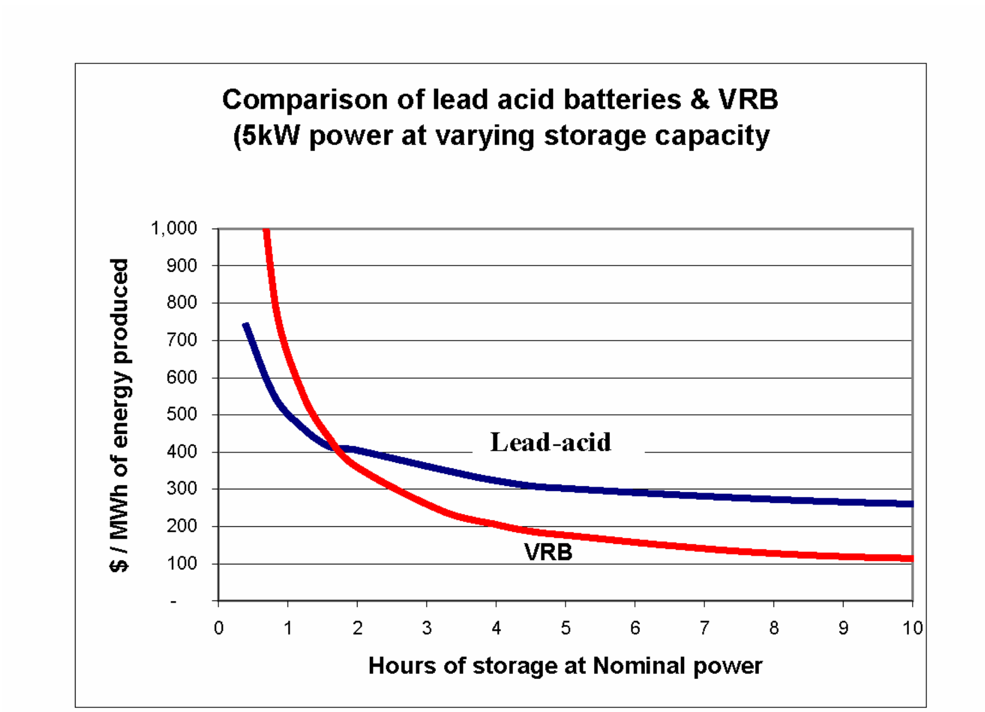

Figure 11: Cost of generated power per kWh as a function of storage time for VRB and Lead-acid battery.

The important feature of this graph is that the cost of each kWh generated by the VRB over its life, is considerably lower than that provided by lead-acid batteries for storage times in excess of 1.5 hours. This confirms the significant cost benefit of the VRB in applications that require long storage times, for example, renewable energy storage and remote area power systems for residential, industrial and sustainable tourism applications

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