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Why Electrochemical Energy Storage?

- Involve direct conversion of chemical energy into electrical energy
- Eliminate mechanical and thermal steps associated with other methods of generation and storage
- Allow high conversion efficiencies - over 80% possible.
Redox Flow Batteries – use solutions to store energy
examples V-V, V-Br, S/Br, Fe/Cr

VRB Concept

Vanadium + Half Cell Storage Tank
Energy storage (kilowatts hours)

Cell Stack
Energy conversion (kilowatts)

Vanadium - Half Cell Storage Tank
Energy storage (kilowatt hours)

The UNSW Vanadium Redox Flow Cell
Rating comparisons

www.electricitystorage.org
Per cycle cost comparisons

Possible reduction due to life extension by partial refurbishment

Carrying charges, O&M and replacement costs are not included

www.electricitystorage.org
The UNSW Vanadium Redox Battery
UNSW Vanadium Redox Battery

Uses solutions to store energy:
- V(II)/V(III) couple in negative half-cell
- V(IV)/V(V) couple in positive half-cell
VRB Technical Benefits

VANADIUM SOLUTION IN BOTH HALF-CELLS.

• Cross-mixing of electrolytes across membrane does not lead to contamination of electrolytes.
• Solutions have indefinite life so replacement costs are low (only battery stacks need replacement at end of life).
• Indefinite life of solution means they can be continuously recycled so no waste disposal problems.
• Vanadium readily available and relatively low cost, so that manufacturing or capital costs are low.
ENERGY STORED IN TANKS, SEPARATE FROM CELL STACK.

- Capacity increased simply by adding more solution.
- Land space can be saved by building underground electrolyte storage tanks.
- Instant recharge possible by exchanging solutions.
- Cost per kWh decreases as storage capacity increases.
VRB Demonstration Projects at UNSW

Emergency Back-up Battery for Submarines

UNSW vanadium battery powered golf-cart

Vanadium Battery Powered Solar House in Thailand
UNSW VRB Commercialisation

• Invented by Skyllas-Kazacos and coworkers in 1985 and first patent on all-vanadium redox battery filed by UNSW in 1986
• 1993, licence issued to Thai company for South-East Asian region
• 1993, licence to Mitsubishi Chemicals and Kashima-Kita Electric Power Corporation for load levelling and PV applications
• 1998 UNSW patents sold to Australian company Pinnacle VRB
• 1999 licence granted by Pinnacle to Sumitomo Electric Industries
• 2002 Kashima-Kita transferred the technology of VRB to Sumitomo Electric Industries
• 2005 Pinnacle and VRB Power separation with Australian patents retained by Pinnacle
• 2005 VRB Power acquires SEI technology for VRB
• 2006 Basic VRB patents expired and new developers enter market
While Generation 1 VRB employs solution of Vanadium Sulphate in Sulphuric Acid in both half-cells, the Vanadium Bromide Redox Fuel Cell employs the VBr$_2$/VBr$_3$ couple in the negative half-cell electrolyte and the Br$^-$/ClBr$_2^-$ or Cl$^-$/BrCl$_2^-$ couples in the positive half-cell.

Higher solubility of vanadium bromide allows energy density to be almost doubled (to around 50 Wh/kg).

Higher solubility of vanadium bromide also allows lower temperature operation of Generation 2 V/Br system.

New start-up company (V-Fuel Pty Ltd) established to commercialise VBr technology.
<table>
<thead>
<tr>
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<th>G1</th>
<th>G2</th>
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<tbody>
<tr>
<td><strong>Electrolyte</strong></td>
<td>V/Sulphate in both Half-cells</td>
<td>V/Br in both half-cells</td>
</tr>
<tr>
<td><strong>Negative couple</strong></td>
<td>V$^{3+}$/V$^{2+}$</td>
<td>V$^{3+}$/V$^{2+}$</td>
</tr>
<tr>
<td><strong>Positive couple</strong></td>
<td>V(IV)/V(V)</td>
<td>Br$^{-}$/Br$_3$ $^-$</td>
</tr>
<tr>
<td><strong>Specific Energy</strong></td>
<td>15-25 Wh/kg</td>
<td>25-50 Wh/kg</td>
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<tr>
<td><strong>Energy density</strong></td>
<td>20-33 Wh/l</td>
<td>35-70 Wh/l</td>
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Renewable Energy Storage
Applications for Vanadium Redox Batteries
Storage allows power output to meet peak summer or winter loads.

**VRB Advantages**:

- Easily upgraded by changing tanks and volumes of electrolyte.
- Tapped cells allow control of 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.
- Cost/kWh decreases as capacity increases (as low as US$150 / kWh).
REMOTE AREA POWER SUPPLY SYSTEM (RAPSS) APPLICATIONS

• Most RAPSS systems employ diesel generator with or without solar panels or wind generator and battery for storage. Due to poor deep-discharge performance of lead-acid battery, heavy dependence on diesel generator for power.
• With low cost, efficient battery, however, considerable diesel fuel reduction or complete replacement of diesel generator could be possible.

Important features of VRB for stand-alone applications are:
- low cost for large storage capacities
- long cycle life
- easy maintenance
- flexibility.
Wind Energy Storage

Wind generators suffer from output power instability

- VRB wind installation by SEI in Japan has demonstrated output power stabilisation - only feasible due to large cycle life of VRB - more than 16,000 cycles demonstrated with 20 kW stacks

- 200 kW/ 800 kWh VRB recently installed on King Island, Australia for wind energy storage and diesel fuel replacement
King Island... in the Roaring 40s
Average wind speed > 8 m/s
Population 1800(approx)

Original Windfarm
• Three Nordex 250kW wind turbines installed in 1998.
• Hydro Tasmania’s first wind turbines.
• 14,000 MWhrs total system load, ~2,200 MWhrs generated by wind ~16%
King Island Wind Farm
Expansion

- **Objectives**
  - 80% instantaneous wind penetration
  - 45 to 50% of island consumption from wind energy
  - Reduce diesel consumption by ~1 million litres and therefore CO₂ by a further 3000 tonnes/year

- **Main Components**
  - Two Vestas V52, 850kW wind turbines.
  - Total installed Rated Wind Energy of 2.45MW
  - 200kW Vanadium Redox Battery installed by Pinnacle VRB
  - Control System
  - Demand Side Management Study
Vanadium Redox Battery for King Island

Key Specification

- 200kW for 4 hours – energy storage capacity
- 300kW for 5 minutes – to comfortably allow time to start a diesel generator if required
- 400kW for 10 seconds - to support power system
King Island VRB Installation
Photos courtesy Hydro Tasmania

Battery Building

Electrolyte tanks

Cell Stacks
Electric Vehicles

- Redox Flow Batteries allow BOTH electrical recharge & “instant” mechanical refueling
- Spent solutions can be recharged with wind or solar energy during off-peak times
- Eliminates need for new power stations to meet increased load from electric cars
- Low energy density overcome by G2 V/Br
- V-Fuel established Jan 2005 to commercialise V/Br
V-Fuel Pty Ltd

- Incorporated on 5th January 2005 with seed funding from Victorian Government funded Centre for Energy and Greenhouse Technologies
- Business – development and commercialisation of G1 VRB and G2 V/Br redox flow cell technology
**Current Status**

### Improved Membrane

- Excellent membrane identified that performs well in both G1 VRB and G2 V/Br and less than half the cost of competitor’s membranes.
- International patents filed by V-Fuel
- Membrane treatment studies to increase power density and achieve stack cost of less than $AUD500/kW

**Voltage Efficiency - 90%**  
**Coulombic Efficiency - 90%**  
**Overall Energy Efficiency = 81%**
V-Fuel 1-2 kW/ 6 kWh VRB

- 1-2 kW stack laboratory testing completed with G1 VRB electrolyte
- 5 kW stack design verification completed
- Tooling up for 5 kW stack production
- Completion of 5 kW stack expected by end 2006
- 50 kW stack design underway
- Government and private funding sought to complete 50 kW stack development and manufacture
Current Stack and Electrolyte Costs

Total battery costs per kWh versus storage time for vanadium pentoxide prices of $US 10/ lb (Series 1) and $US 5/ lb (Series 2) respectively.
Assumed stack cost = ($1000/ kW)
Stack and Electrolyte Cost Targets

G1 VRB Capital costs per kWh versus storage time

Total battery costs per kWh versus storage time for stack cost of $AUD500/ kW and V2O5 price of $US5/ lb.
Cost of generated power as a function of storage time

**Assumptions:** 8% discount rate, $US5/lb V2O5, $500/kW stack cost, 24 year stack life, membrane replacement every 8 years.

**NOTE:** With further performance improvements, figures for 4 and 8 hours of storage expected to be below 6.0 and 5.0 cents per kWh respectively.
Summary

- The UNSW / V-Fuel Vanadium Redox Battery offers many advantages that make it suitable for wide range of applications:
  - high energy efficiency (>80% overall energy efficiency)
  - low cost per kWh for high storage times
  - simple maintenance (remix solutions to recover capacity)
  - long cycle life (> 16,000 cycles)
- G1 VRB currently being commercialised around the world in many stationary applications
- G2 V/Br offers up to double energy density but 2-3 years away from field testing
- V-Fuel’s improved membrane technology providing significant cost reductions for G1 VRB – patents pending
- V-Fuel’s 5 kW stacks modules to be available for G1 VRB field trials in 5-100 kW installations by mid 2007
- 50 kW stack modules to begin development in 2007 for large-scale MW size installations