

Vanadium Redox Flow battery - Key Features

General Information

The University of New South Wales, researched and produced an all-vanadium redox flow battery with unique features and the real potential for low cost stationary applications. The University reached a level of design enabling them to licence Mitsubishi the technology for large-scale stationary applications in Japan in 1989. Mitsubishi and others since has proven the basic chemistry for large-scale load levelling, storage and similar mains utility applications in the order of 200MW.

A redox battery resembles a fuel cell, except that a liquid oxidant is used instead of air to oxidise the fuel. Redox battery technology therefore comprises two storage tanks for the fuel and oxidant, a fuel cell where the reactants combine electrochemically to give electricity, and two storage tanks for the spent reactants. The electrochemical energy conversion is similar to a fuel cell in requiring a membrane to separate the fuel and oxidant while allowing completion of the electrical circuit via ionic conduction. Another important difference is that unlike a conventional fuel cell, the redox battery is able to regenerate the original reactants by operating the fuel cell in reverse, or electrolysis, mode. The advantage over a conventional rechargeable battery is that the energy stored depends on the tank size and is therefore independent of size of the electrochemical energy converter.

The vanadium redox flow battery is unique because both reactants are derived from the same elements, albeit in different oxidation states, and are dissolved in the same electrolyte, sulphuric acid. Therefore, the consequences of cross-contamination are far less serious. This advantage has contributed to a proven track record of indifference to deep cycling and very high charge and discharge rates, it has a long operational life greater than 15 years.

Vanadium redox does not give rise to fire, explosion or health risks and very has little environmental impact. The industrial processes involved are quiet, energy efficient, very clean with no known hazards to personnel or the environment and the product can and will be recycled.

The Vanadium Redox Battery has several unique technical advantages over most of its rivals in addition to the potential low installed cost and recharge per unit kilowatt costs. These features can be summarised in the list below:

1 Potential very low whole-of-life costs

Low purchase costs AND low operational costs per installed kilowatt. The Vanadium electrolyte can be housed in tanks of any reasonable shape and does not have to be housed within a building thereby allowing for greater design and infrastructure flexibility (and lower building costs) in comparison with "black box" type battery systems.

2 Robust

Rugged indifference to rapid charge and discharge rates.
The "stack" is a vibration proof rugged assembly with permanently connected plumbing.

3 Potential long life

The battery's reactive agents remain in liquid form at all times and the electrodes, membranes, are made of conductive plastic which does not take part in the electrochemical reaction. There is therefore no corrosion or shedding of the active material, a life limiting factor in most conventional batteries. The power module has an eight to ten thousand hour (ten year) design life, with an unlimited electrolyte life.

4 Convenience with three to five (3-5) minute refuel-ability

The handling of the vanadium electrolyte is somewhat similar to that of pumped diesel except that it can be either conventionally recharged from the electrical supply in situ or should the need arise, rapidly changed for "new" electrolyte in which case the replaced electrolyte can be recharged at a dedicated electrical charge point elsewhere.

5 Flexible

Ability to charge at one voltage and discharge at another

The voltage system may discharge at one voltage and recharge at another. This allows for maximizing overall system efficiency and can reduce infrastructure costs.

6 Self cooling and ambient temperature operation.

Vanadium REDOX does not operate at high temperature and does not present a fire threat. The circulation of the electrolyte allows for automatic self cooling.

7 Low self discharge

Both the positive and negatively charged electrolyte are the same Vanadium based chemical mixture but with a charge valance differential. Therefore there is not the degradation of electrolyte as with most other battery systems. Clearly, this also reduces self discharge.

8 Positive environmental impact

Vanadium does not present a toxic threat.

9 Ability to charge at one voltage and discharge at another

The system output voltage may be at one voltage and the recharging system voltage can be at another. This allows for maximizing overall system efficiency and can reduce infrastructure costs

What is Vanadium?

Vanadium was discovered twice. In 1801, Andres Manuel del Rio named it erythronium, but then decided he merely had found an impure form of chromium and later in 1830 Nils Gabriel Sefstrom found it separately, and named it after the Scandinavian goddess of beauty and youth the metal's compounds provide beautiful colours in solution. Henry Enfield Roscoe first isolated the metal in 1867, from vanadium dichloride, however it wasn't until 1925 that relatively pure vanadium was obtained by reducing vanadium pentoxide with calcium metal.

Vanadium is a natural element in the earth it has the chemical symbol V and is number 23 in the Table of Elements. Vanadium as a compound occurs in nature as a white-to-grey metal, and is often found as crystals. It usually combines with other elements such as oxygen, sodium, sulphur or chloride. Vanadium and vanadium compounds can be found in the earth's crust and in rocks, some iron ores, and in crude petroleum deposits, pure vanadium has no smell.

Vanadium is mostly combined with other metals to make special metal mixtures called alloys. Vanadium in the form of vanadium oxide is a component in special kinds of steel that is used for automobile parts, springs, and ball bearings. Most of the vanadium used in the world is used to make steel. Vanadium oxide is a yellow-orange powder, dark-grey flakes, or yellow crystals. Vanadium is also mixed with iron to make important parts for aircraft engines.

Small amounts of vanadium are used in making rubber, plastics, ceramics, and other chemicals.



Vanadium Pentoxide

Vanadium pentoxide is a yellowish-red powder, it forms when cooled from the molten state to form long red needles as a dust it is also odourless. This substance is therefore considered to have inadequate odour warning properties. It is slightly soluble in water.

Vanadium pentoxide is the most common state in which vanadium is found.

Vanadium is relatively abundant in the earth's crust (it is the 22nd most abundant element), however economic deposits are available in Western Australia but otherwise somewhat rare. Currently, South Africa produces 40% of the world's vanadium, with the remaining 60% split among Russia, the Far East (mostly China), the USA and elsewhere.

Sources and Production

Vanadium is traditionally obtained in the production of iron. Titaniferous magnetite ore is partially reduced with coal, and then melted. The resulting product includes a slag, containing titanium, and pig iron, containing vanadium pentoxide. The pig iron is then blown with oxygen, and a new slag rich in vanadium pentoxide is obtained. This can be further processed to obtain forms of the compound in various purities. Uranium production also provides vanadium pentoxide as a byproduct. A leachate is obtained in the early stage of production of uranium and vanadium from carnotite, which is then fed into a solvent, yielding a uranium compound and a separate raffinate containing the vanadium. A second solvent process and a soda ash solution with ammonium sulfate eventually yield vanadium pentoxide.

Other vanadium-bearing ores also yield significant amounts of the compound. Each of these traditional methods can yield a compound of somewhat better than 99.8% purity, but significantly better purity can only be obtained by atomically produced combinations.

The Market for Vanadium

Vanadium is used in producing rust resistant and high speed tools steels. About 80% of the Vanadium now produced is used as ferrovanadium or as a steel additive. Vanadium (added in amounts between 0.1 and 5.0 percent) has two effects upon steel: it refines the grain of the steel matrix, and with the carbon present it forms carbides. Thus, vanadium steel is especially strong and hard, with improved resistance to shock.

Vanadium foil is used as a bonding agent in cladding titanium to steel and generally by the aerospace industry in Titanium alloys. Medical implants often contain Vanadium alloys which contribute to their long life.

Vanadium has catalytic properties that make it useful in many industrial application. Vanadium Pentoxide is used as a catalyst in the production of Sulphuric acid where Sulphur dioxide is passed over a V_2O_5 catalyst bed and oxidized to Sulphur trioxide. Another important catalytic use is in the manufacture of maleic anhydride a chemical needed to make polyester resins and fibreglass.

Vanadium plays an important role in battery technology where it is used as an additive in the manufacture of Lithium Ion batteries. The Vanadium Redox battery is a recent development intended for large scale load levelling applications. It is also used to produce a super conductive magnet with a field of 175,000 gauss.

Environmental Impact

The environmental impact of both vanadium redox and lead-acid batteries for use in stationary applications has been assessed using a life-cycle assessment approach. (Source: Offer by Federation Resources for Pinnacle - BIDDER'S STATEMENT October 2000)

The assessment indicates that the Vanadium Redox Battery (VRB) contributes between 7-25% of emissions of lead-acid batteries in the key environmental pollutants namely:

carbon dioxide	CO ₂
sulphur dioxide	SO ₂
carbon monoxide	CO
methane	CH ₄
nitrous oxides	NO _x
dinitrous oxide	N ₂ O

during the whole-of-life cycle.

Everyone is exposed to low levels of vanadium in air, water and food; however, most people are exposed mainly from food. Breathing high levels of vanadium may cause lung irritation, chest pain, coughing, and other effects. This chemical has been found in at least 385 of 1,416 National Priorities List sites identified by the US Federal Environmental Protection Agency.

Vanadium in Air and Water

The most likely way for vanadium to pollute the air is by burning organic fuel, also, when rock and soil containing vanadium are broken down the resultant dust can be wind borne. Further such action including natural erosion of rock by rain, vanadium can combine with ground and surface water and soil.

Vanadium does not dissolve easily in water but can be carried by water as particulates. Generally, the following comments apply when vanadium enters the environment:

- vanadium enters the environment from natural erosion of rocks and soil and also from the burning of fuel oils
- vanadium stays in the air, water and soil as particles for a long time
- vanadium does not readily dissolve in water
- vanadium naturally combines with other elements
- vanadium sticks to soil particles
- low levels of vanadium are found in plants and thereby eaten by animals
- vanadium is unlikely to build up in animal tissue

No known authenticated levels of the annual release of vanadium into the environment are available, the best estimates from US industrial sources vary from ten to thirty thousand tonnes per annum. It is believed that the released vanadium is derived from the burning of organic fuels and is in the form of airborne particles which are simple or complex oxides.

The estimated residence of these particles vary due to particle size, fine particles are thought to have a residence time of one day.

Despite the fact that some seventy per cent of all atmospheric releases of vanadium are of anthropogenic origin corresponding releases to inland waters, soil and marine environments are considered very low when compared with natural sources.

Risk factors for exposure to vanadium compounds in the environment are considered very low. On entering aquatic environments vanadium is likely to form a more soluble pentavalent state. In which state the vanadium is absorbed by organic compounds and hence becomes incorporated in sediment systems. In sea water vanadium is continuously precipitated by the presence of ferric hydroxides or other organic matter and is deposited as seabed sediment.

Flammability

There is no National Fire Protection Association (US) fire hazard rating for vanadium pentoxide dust; this substance is not combustible.

Flash point	Not applicable
Auto-ignition temperature	Not applicable
Flammable limits in air	Not applicable
Extinguishant	Use an extinguishant that is suitable for the materials involved in the surrounding fire

Firefighters should wear a full set of protective clothing, including a self-contained breathing apparatus, when fighting fires involving vanadium pentoxide dust.

Health and Safety

Natural Exposure to Vanadium

Natural exposure to vanadium at very low levels which are not considered harmful occur in air, water and food.

The health effects in people ingesting significant quantities of vanadium are unknown since no cases are known to be reported. Animals that ingested very large doses have died. Lower, but still high levels of vanadium in the water of pregnant animals resulted in minor birth defects. Some animals that breathed or ingested vanadium over a long term had minor kidney and liver changes.

The amounts of vanadium given in these animal studies that resulted in harmful effects are much higher than those likely to occur in the environment.

Slightly higher levels but generally safe levels occur under the following circumstances:

- certain foods
- polluted air near the burning of organic fuels
- working with vanadium or near it in large quantities

Exposure to vanadium pentoxide dust can occur via inhalation and eye or skin contact, however, vanadium is not readily absorbed by the body either by ingestion or skin contact.

The current Occupational Safety and Health Administration (OSHA) in the US permissible exposure limit (PEL) for vanadium pentoxide dust is 0.05 milligram per cubic metre of air as an eight (8) hour time-weighted average concentration [29 CFR 1910.1000, Table Z-1-A].

The National Institute for Occupational Safety and Health (NIOSH) in the US recommended exposure limit (REL) for vanadium compounds (measured as vanadium) is 0.05 mg/m³ as a fifteen (15) minute ceiling [National Institute for Occupational Safety and Health Recommendations, 1988].

The American Conference of Governmental Industrial Hygienists (ACGIH) has assigned vanadium compounds (measured as vanadium) a threshold limit value of 0.05 mg/cubic metre as a 15-minute ceiling [American Conference of Governmental Industrial Hygienists, Handbook 1989, page 42].

The OSHA and ACGIH limits are based on the risk of irritation, pulmonary, and systemic effects associated with exposure to vanadium pentoxide dust, and the NIOSH limit is based on the risk of eye, skin, and lung effects associated with exposure to this substance.

Heavy Exposure to Vanadium

Exposure to high levels of vanadium can cause harmful health effects. The major effects from breathing high levels of vanadium are on the lungs, throat, and eyes. Workers who breathed it for short and long periods sometimes had the following effects:

- short and long lung irritation
- coughing and wheezing
- chest pains
- runny nose
- sore throat

Similar effects have been observed in animal studies. No other significant health effects of vanadium have been found in people.

The effects are known to stop when non-contaminated air become available, however no other significant health effects have been found in people. Similar effects have been observed in animals.

A human study showed no changes in serum glutamic, oxaloacetic transferases, cholesterol, triglyceride or phospholipid levels or any haematological abnormalities following significant oral exposure to vanadium. Vanadium does not appear to effect enzyme activity or bilirubin levels.

Vanadium is not classed as a carcinogenic, however, no human studies are available on the carcinogenicity of vanadium. No increase in tumors was noted in a long-term animal study where the animals were exposed to vanadium in the drinking water.

No human death (or a recorded one of an animal) has been recorded as a result of heavy exposure to vanadium.

Summary of toxicology

Effects on Animals:

Vanadium pentoxide dust irritates the eyes, mucous membranes and respiratory tract and may cause nervous system, gastrointestinal tract, liver, and kidney damage in laboratory animals.

The oral LD(50) for rats is ten (10) mg/kg; the lowest lethal concentration by inhalation in the same species is seventy (70) mg/m³ for two (2) hours [source *RTECS 1989*].

Acutely poisoned animals develop nose bleeds, labored respiration, diarrhea, hind limb paralysis, and seizures [source: *Gosselin, Smith, and Hodge 1984, p. II-148*]. At autopsy, the pathologic lesions seen in these animals included desquamative enteritis; vascular congestion of the liver, kidneys, lungs, adrenal glands, brain, spinal cord, and bone marrow; and fatty degeneration of the liver and kidneys [source: *Gosselin, Smith, and Hodge 1984, p. II-149*].

Eye irritation properties.

No quantitative data are available on the eye irritation threshold for vanadium pentoxide dust; however, exposure to a concentration of 0.018 mg/m³ vanadium pentoxide is known to have caused eye irritation.

Spills and Leaks.

In the event of a spill or leak of vanadium, it is highly recommended that persons should wear protective equipment and clothing in contaminated areas until cleanup has been completed.

NIOSH / OSHA Health Guideline.

Summarizes pertinent information about for workers and employers as well as for physicians, industrial hygienists, and other occupational safety and health professionals who may need such information to conduct effective occupational safety and health programs.

Workers who may be exposed to chemical hazards should be monitored in a systematic program of medical surveillance that is intended to prevent occupational injury and disease. The program should include education of employers and workers about work-related hazards, placement of workers in jobs that do not jeopardize their safety or health, early detection of adverse health effects, and referral of workers for diagnosis and treatment.

The EPA requires discharges or spills of five hundred (500) kilograms or more of vanadium into the environment to be reported.

The Occupational Safety and Health Administration (OSHA) has set an exposure limit of 0.05 milligrams per cubic metre for vanadium pentoxide dust and 0.1 mg per cubic metre for vanadium pentoxide fumes in workplace air for an eight (8) hour workday, forty (40) hour work-week.

The American Conference of Governmental Industrial Hygienists (ACGIH) has recommended an occupational exposure limit of 0.05 mg/m³ for vanadium pentoxide.

The National Institute for Occupational Safety and Health (NIOSH) has recommended that 35 mg/m³ of vanadium be considered immediately dangerous to life and health. This is the exposure level of a chemical that is likely to cause permanent health problems or death.

Vanadium Battery the HILTech Connection

HILTech Developments has an ongoing research program in both the electro-chemistry and core materials technology relating to vanadium redox flow batteries.

Vanadium Battery the Marketplace

Global market by application in US\$Billion at constant 2000 prices		
Application	2000	2005
Automotive batteries	17.00	17.80
Motive Power (Traction batteries for golf cycles and other electric vehicles)	2.30	2.40
Communications (telephones multiplex etc.)	0.95	1.00
Portable Electronics (computers, camcorders etc.)	0.65	0.67
Toys	0.30	0.31
Tools	2.30	2.50
Stand-by Power (UPS, telecoms etc.)	1.95	2.10
Power Conditioning (solar load levelling etc)	0.18	0.19
Signalling	0.16	0.17
Medical	0.45	0.50
Military / Aerospace	0.62	0.68
TOTAL MARKET	26.86	28.32

Source: HILTech Developments 2000 estimated 2005 projected

The role for vanadium redox is high level power storage.

Power storage can be used for:

- Stand-by power for a wide range of applications
- Combined heat and power
- Load levelling (meeting peak demand)
- Emergency Power / Alarms
- Uninterruptible Power Supplies - UPS
- Renewable Energy Market

Some applications are for utility supply energy levels which can be as high as 350MW and more. The HILTech focus, however is on industrial energy storage level typically of no more than 500kWhours. Industrial energy storage can be assessed at two levels namely,

industrial level	say from 100kWhours to typically 1MWhours and above for commercial / hospital / bank internal distribution usually as an on-site back-up facility.
light industry level	say from 20kWhrs to no more than 100kWhr for local computer network, instrumentation, emergency commercial etc.

These market segments are dominated by lead-acid batteries and nickel-cadmium batteries with sodium-nickel-chloride and zinc- bromide redox very slowly winning market share. These alternatives to lead acid have a higher capital cost but generally benefit in terms of maintenance and / or convenience.

Generally speaking the following summary highlights the current position

Item	Lead acid	Nickel Cadmium	Other current batteries
Purchase cost	low	high	high
Maintenance profile / cost	high	reduced	low
Operational life in years (typical)	5 / 6 years	7 / 8 years	7 / 8 years
Operational problems - chemical memory etc.	none	yes	none
Robust - prone to operational damage	some risk	little risk	little risk
Corrosion issues	yes	no	no
Fire and other risks	some risks	little risks	yes with some
recycle-ability	yes	yes	yes

Depending upon the application the alternative means for stationary power to vanadium redox come from various sources. All of which are well established however, vanadium redox does promise outstanding technical and commercial advantage over many of these. A matrix of the typical alternative to vanadium redox is given below.

	Diesel engine - generator	Micro-turbine generator	Fuel cell	Battery
Alarms	no	no	yes with battery	yes
Emergency Power	yes with battery	yes with battery	possible	yes
Stand-by Power	yes with battery	yes with battery	yes with battery	yes
UPS system	yes with battery	yes with battery	possible with battery	yes
Load levelling	no	no	no	yes
Renewables	yes with battery	yes with battery	not likely	yes
State-of-the-art	combined heat and power		rankine cycle heat exchanger	UPS systems

The foregoing table clearly shows that a battery is necessary in almost all stationary applications even if only needed to start the diesel generator. In most of the above systems the battery provides instant power upon demand. Up until now however, when battery storage is too expensive to cope for potentially long periods of demand or where very significant power is required generator sets have been used.

Clearly, in the case of vanadium redox the amount of energy required is a function of the size of the electrolyte tanks not the size of the battery stack. This opens up an entirely new opportunities for the vanadium redox battery to compete with gensets. Where local generation schemes involve combined heat and power then clearly it is unlikely that a vanadium battery will be applicable.

The following table shows a comparison of three current competitive energy storage systems.

Comparative energy storage systems				
Characteristic		Lead Acid	Vanadium Redox	Flywheel
Storage medium		chemical	chemical	mechanical
Energy density	Whr per dm ³	105	30	300
	Whr per kg	37	20	
Efficiency of overall system	per cent	75-80	ca 85	ca 95
Service life	years	< 8	15-20 ^a	>20
Technology maturity		mature	developmental	immature
System packaging		unitary	modular	modular
Control of system		electronic	electronic	electro-mechanical
Cost (lead-acid base)	capital	1	ca 1.3	3
	operational	1	ca 0.7	Ca 0.5
User issues		corrosion / handling	electrolyte handling	system containment / safety

^a Not determined. Shelf life is very high but at current state of development, maintenance includes replacement of membrane approximately every 5 years

The above matrix shows the comparative potential features of vanadium redox, subject the support of the appropriate control electronics which would allow vanadium redox to compete against some alternative stationary power storage devices. The table shows that subject to adequate capacity tanks vanadium promises to dispense with generator sets even where stand-by equipment should remain in service beyond two hours. In this case the economics could be very favourable with added UPS and alarm-security implications and further system sophistication.

Purchase Criteria

Considering the standby power battery market, the choice of battery is decided on the basis of the following key criteria:

Total Cost	including any system degradation due to life cycling or temperature or other issues
Reliability	there is no point in expensive stand-by energy storage if its not available immediately and reliably upon demand
Serviceability	ease of maintenance preferably ultra-low maintenance
Space	accommodating large conventional batteries can be expensive in building costs

Regulatory and Advisory Bodies

Body	Address
Agency for Toxic Substances and Disease Registry	The US Public Health Service Division of Toxicology 1600 Clifton Road E - 29 Atlanta Georgia 30333 tele 1-800-447-1544 fax; 404-639-6315
Air Occupational Safety and Health Administration	U.S. Department of Labor Occupational Safety and Health Administration 200 Constitution Avenue, N.W. Washington, D.C. 20210
Environmental Protection Agency	Building 53 P.O. Box 25227 DFC Denver Colorado 80225 tele (303) 236-5111
National Institute for Occupational Safety and Health	NIOSH Publications 4676 Columbia Parkway Mail Stop C-13 Cincinnati OH 45226-1998 tele 1-800-356-4674
US Department of Health and Human Services	The U.S. Department of Health and Human Services 200 Independence Avenue, S.W. Washington, D.C. 20201 (202) 619-0257 Toll Free: 1-877-696-6775
US Department of Mines	Department of Mines, Minerals and Energy, Office of Information Services, P.O. Drawer 900, Big Stone Gap, VA 24219, tele 540 523-8146
World Health Organisation	WHO Headquarters Office in Geneva Avenue Appia 20 1211 Geneva 27 Switzerland telephone: (+00 41 22) 791 21 11 facsimile (fax): (+00 41 22) 791 3111

Commercial Enterprises

Chemical Suppliers of Vanadium

Atlantic Equipment Engineers
British (UK) Vanadium Suppliers
Crucible Materials
E & C Trading
GFS Chemicals
Oremet - Wah Chang
Shree Babaji Chemicals
Specialty Steel & Forge
Stanford Materials
Treibacher Industrie AG - (Austria)

Metallurgical and Analytical services

Ammtec Ltd
Lakefield Oretest

Mining Companies & Vanadium Producers

Chengde Xinghua Vanadium Chemical Co
Highveld Steel and Vanadium
Gulf Chemical & Metallurgical Corporation
Precious Metals Australia
Stratcor
Vanadium Australia
Xstrata

Mineral and Resource Exploration

Mackenzie Bay International
Osisko Exploration Ltd
Vanadium International Inc

Researchers in vanadium battery technology

Funktionswerkstoffe GmbH, Austria
HILTech Developments Limited, United Kingdom
Magnam Technologies Pty Ltd, Australia

Additional Sources of Information and Related Bodies

CADDET Centre for renewable energy ETSU	International organisation for dissemination in the efficient use of energy resources	
Energieonderzoek Centrum Netherlands, ECN, Petten, formerly Netherlands Energy Research Foundation	Renewable energy and fuel cell research	
Journal Electrochemical Society	C.Létourneau, M. Gauthier, A.Béalnger, D. Kuller, J. Hoffman,	Several papers are published on the lithium-ion and other new battery technologies
Journal Power Sources	Journals	
Journal Solid State Electronics		
Intermediate Technology Consultants Rugby UK	Consultants in intermediate technologies to Third world countries	
9 th International Meeting on Lithium Batteries	M. Gauthier, M. Armand, A. Bélanger, M. Simoneau and R. Atanasoki Edinburgh July 12-17 1998	
EV14 Symposium	Orlando, USA, Dec 12-17 1997	
Solid polymer electrolytes: fundamentals and technological applications	VCH Cambridge 1991	Gray, F.M.
Royal Society	Phil. Trans. 1996, 354, 1529	Rand D. A. J.
Philips Resources Report	1970, pages 133, 25	van Vucht, J.H.N., Kuijpers, F.A. Bruning, H.C.A.M.
Journal Battery Materials Resources	Bull. 1983, 18, 461	Thackeray M. M. David, W. I. F. Bruce, P. G. Goodenough
Journal Electrochemical Society	1967, 114, 323	Horwood, 1991 Gutmann, F., Hermann, A., Rembaum, A.
Journal Chemical Society	Chemical Communications 1974	Whittingham, M. S.

Glossary of Terms

Blackout	An American UPS term to convey total loss of power.
Carcinogenicity:	Ability to cause cancer.
Distributed power	Any technology that produces power or stores power. These include all the above with the addition of batteries, flywheels, super-capacitors, regenerative fuel cells and superconducting magnetic energy storage.
Distributed energy resources	Any technology that is included distributed generation or distributed power (as defined above) plus demand-side measures.
Distributed generation	Any technology that produces power outside the mains utility grid. These include: fuel cells, gas turbines, micro turbines, hydro, micro-hydro, thermal engines, photovoltaics, wind energy, solar energy, waste and biomass, etc.
Ingesting:	Taking food or drink into the body
Long-term:	Lasting one year or longer.
Milligram (mg):	One thousandth of a gram
Redox flow	The reduction and oxidation through the circulation of electrolytes.
Redox	The term comes from reduction and oxidation
Redox flow battery	The battery's energy storage principle is based on changing electrical energy into electrolyte-based ion energy in the cell portion of the battery. The electrolyte is stored in two electrolyte tanks, one for positive and the other negative electrolyte
Sag (or Brownout)	An American, UPS term to convey a decrease in voltage levels which can last for periods ranging from fractions of a second to hours. Can be caused by the utility company coping with increased demand or by heavy equipment being switched on causing the supply voltage to dip.
Spike	An instantaneous increase in the voltage level usually lasting for periods of microseconds to milliseconds. Very low total power. Can be responsible for permanent electronic component damage or malfunction. Usually caused by high frequency harmonics or lightning strike.
Surge	A substantial increase in voltage lasting from milliseconds to seconds. Can be of significant overall power. Usually caused when heavy equipment is shut down or significant generation capacity is added to utility supply.